Moya, Bernardo Llamas (Ed.); Storch de Gracia, María Dolores (Ed.); Mazadiego, Luis Felipe (Ed.)

Book

Case study of innovative projects : successful real cases

Provided in Cooperation with:
IntechOpen, London

Reference: (2017). Case study of innovative projects : successful real cases. Rijeka, Croatia : InTech.
doi:10.5772/67183.

Chapter 1

The New Panama Canal

Ana Belén Berrocal Menarguez and

Juan Pous de la Flor

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.69605

Abstract

The canal of Panama is one of the most emblematic constructions in the world, for that reason, for Sacyr, the construction of the Third Set of Locks has been a great challenge and huge pride. The chapter details the technical specifications and innovative breakthroughs that have been used in the work. Detailing the hydraulic filling and drainage system, gate system, control systems, and auxiliary systems. The final result shows the innovation capacity of the technicians who have participated in this work, who have been one of the keys to be able to overcome the challenge that Sacyr committed to Panama and the rest of the world.

Keywords: canal, panama, locks, innovation

1. Introduction

The Panama Canal is one of the most emblematic works of construction in the history of the humanity. For this reason, for Sacyr, to lead the consortium responsible for the construction of its most representative and complex feature, the Third Set of Locks, is a matter of enormous satisfaction and great pride.

Sacyr's broad experience and success in the field of construction and services speaks for itself: today, the company is listed on the IBEX 35, the blue chip stock index of the Spanish stock market.

Founded in 1986, Sacyr's commitment to work quality and customer satisfaction, along with its determination to grow, has been the keys to its success. Sacyr is now a diversified company with a presence in more than 20 countries on 5 continents through its subsidiaries [1].

Sacyr maintains the "GLOBAL INNOVATION" motto, the result of which is that it currently has the hallmark of "Excellence in Innovation" in its gold form, certified by Germany's TÜV Rheinland group.

On the other hand, in R&D activities, SACYR has approved and works under an R&D Management System certified by AENOR since 2006. In the last 10 years, we have 14 companies of the Sacyr group certified in R&D, among them all participated in 193 projects with national and international external recognition, adding among all these projects a total budget in R+D+i activities amounting to €220, 593, and 332.

The Panama adventure began in the middle of the international financial crisis. Nonetheless, Sacyr structured a technically and economically solid proposal and reached agreements with key partners that allowed it, at the last moment and in a fully sobering investment climate, to win the concession of the most important public works program of this century. The construction project of the Third Set of Locks has acted as an absolute reinforcement of Sacyr's management and determination to remain in the forefront of the sector [**5**].

The Panama Canal has had an undeniable success in international transport logistics since it has allowed the transit of more than 700,000 ships since its inauguration in the 1914. As a consequence of this success and with the need to expand their capacity, Panamanian citizens decided in the referendum of October 22, 2006, to construct the Third Set of Locks of the Panama Canal. This decision has involved an investment of more than US$5250 million and aims to capture the estimated demand until beyond 2025 building a Third Set of Locks with capacity to double the tons that in total transit annually through the channel. In this way, and considering the diversity of possible ships, total annual traffic could approach 20,000 vessels.

The dimensions of the chambers of the new locks were established on the basis of those of the vessels Neopanamax, with a length of 366 m, a sleeve of 49 m, and a maximum draft of 15 m. EastDesign vessel was considered as the target capacity and routine use size in trade routes. Its maximum capacity is 14,500 TEUs (unit equivalent to a container 20 ft long, 8 ft wide, and 8.5 ft high), 3 times capacity of the largest admissible vessels to date, the Panamax, which with 294 m of length, 32 m of sleeve, and 12 m of draft, can transport 4500 TEUs. The dimensions of the new locks may also receive vessels of solid bulk and liquid type Capesize and Suezmax, respectively, with loading capacities in excess of 160,000 dwt (tons of Deadweight), LPG and LNG gas transport vessels with volumes exceeding 135,000 m^3, Cruisers, and car carriers with transport capacity of more than 8500 vehicles.

The new set of locks has required the excavation of the corresponding approach channels from both oceans. On the Pacific side, 6.1 km has been excavated as an approach channel, parallel to Lake Miraflores, to connect with the waterway upstream of the locks of Pedro Miguel. In addition, it has been necessary to deepen and widen the internal channels of Culebra Cut on the Pacific side and Gatun Lake in the Atlantic, together with the 45 cm increase in the maximum operational level in Gatun Lake. **Figure 1** shows a plan view of the expanded Panama Canal with the actions that has been necessary to undertake.

1.1. Remarks

1. Deepening and widening of the access channel in the Pacific and Atlantic.
2. Deepening and widening of the internal canal in Culebra Cut and construction of the new bypass channel of Pedro Miguel.
3. Construction of the new locks and water saving basins (WSB) (Atlantic-Pacific).
4. Deepening and widening of the internal navigation channel to Lake Gatún.

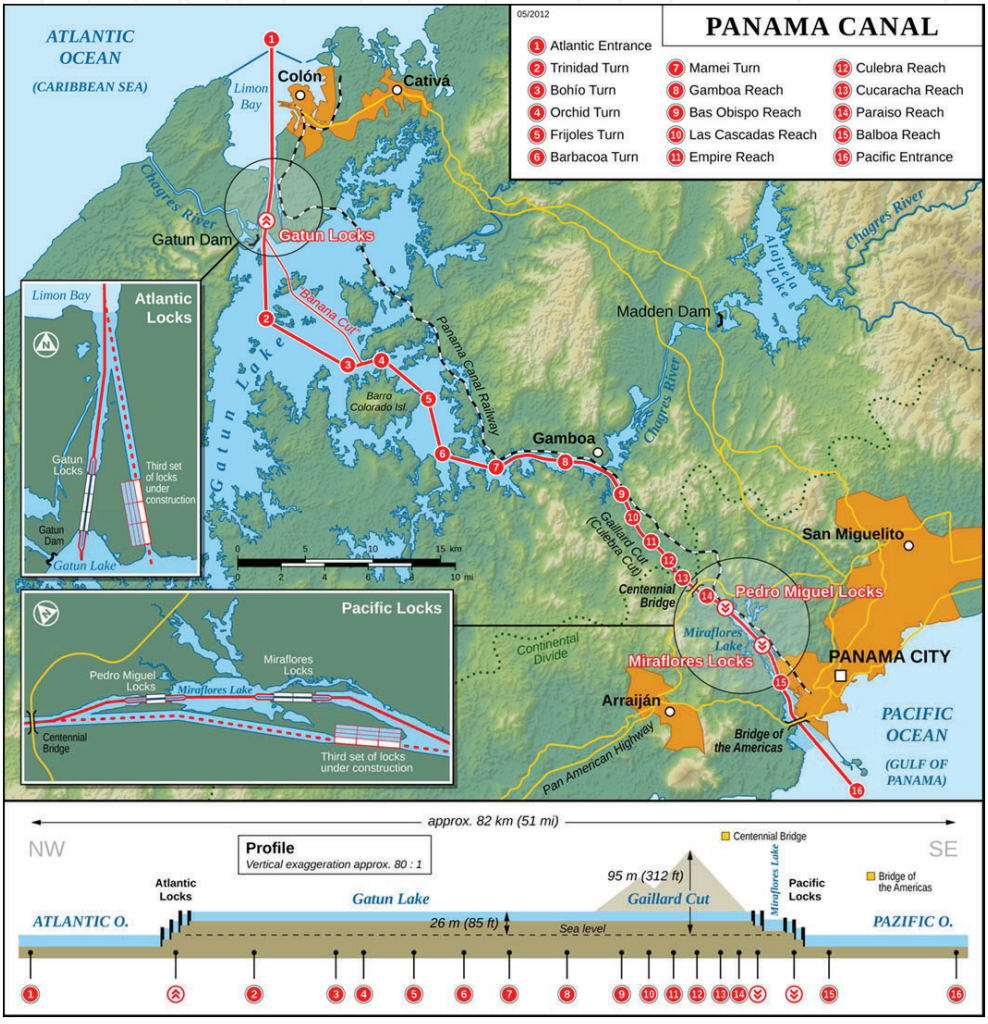

Figure 1. General map of the Panama Canal and its enlargement. Below, longitudinal cut of the navigable route.

The bidding process for the Third Set of Locks began on December 21, 2007 with the issuance of the request for proposals by the Panama Canal Authority (ACP) for the project. On July 15, 2009, these works were awarded to the consortium Grupo Unidos por el Canal (GUPC), which obtained the best technical and economic score (base budget of US$3119 million), with Sacyr being the leader company of the Consortium.

2. Description of the Third Set of Locks

The original locking system was based on the concept of creating an elevated artificial lake (present Lake Gatun) with a depth that would allow the ships to cross Panama from ocean to ocean and the construction of locks at each end of the way to allow the descent of the ships from the lake to the ocean or vice versa, ascending from the ocean to the lake. The operations of ascent or descent of the ship are obtained by the movement by gravity of the water coming from the lake and accumulated annually in the periods of rain that registers Panama.

The original locks of the Panama Canal have two parallel lanes, called games, which allow both sides of the road both on the Pacific side and on the Atlantic side (**Figure 1**). The general functioning of the Third Set of Locks is similar to that built by France and the United States 100 years ago, although it has significant differences in the equipment used. Like the original system, the Third Set of Locks saves the approximately 27 m gap between the zero bound of the Atlantic and Pacific oceans and the level of Gatun Lake. To do this, it uses three jumps of about 9 m each, communicated by gates. The complex of locks of the Pacific side has been called Cocolí and the one of Atlantic Clara Water, following the name of the rivers in each zone. Unlike the mitering of the original gates, the new gates are rolling, being collected in concrete side niches. All the essential elements of the Third Set of Locks are duplicated, ensuring the operation of the system even during the failure of any of them so that there are eight floodgates in each complex, four couples on the Atlantic coast, and four couples in the Pacific [**6**].

The filling and emptying of the chambers is done through a system of galleries—main and secondary ducts—operated by valves and operating completely by gravity. These galleries run longitudinally along the sidewalls of concrete and communicate with the chambers by ducts arranged horizontally at the height of the hearth, unlike the original channel, in which the entrance of water to the chambers is realized vertically in the hearth. The Third Set of Locks also has a complementary water reuse system. This system consists of a battery of water saving basins (WSB) arranged in parallel to the chambers, which are capable of reusing up to 60% of the water required in a complete locking manoeuvre. Each chamber has three basins, arranged in three levels, which are emptied and filled by gravity and are also managed by valves.

It should also be noted that the original Panama Canal has a unique vessel positioning system. A set of towing locomotives guides the boats from the locks to the locks, allowing them to move in the fully centered chambers. In the new channel, tugs are used inside the cameras to achieve the same objective.

The works of the expansion were concentrated in an area of 2300 m by 350 m where the three chambers that house two gates at each of its ends and the pools of water saving are located, as shown in the **Figures 2** and **3**.

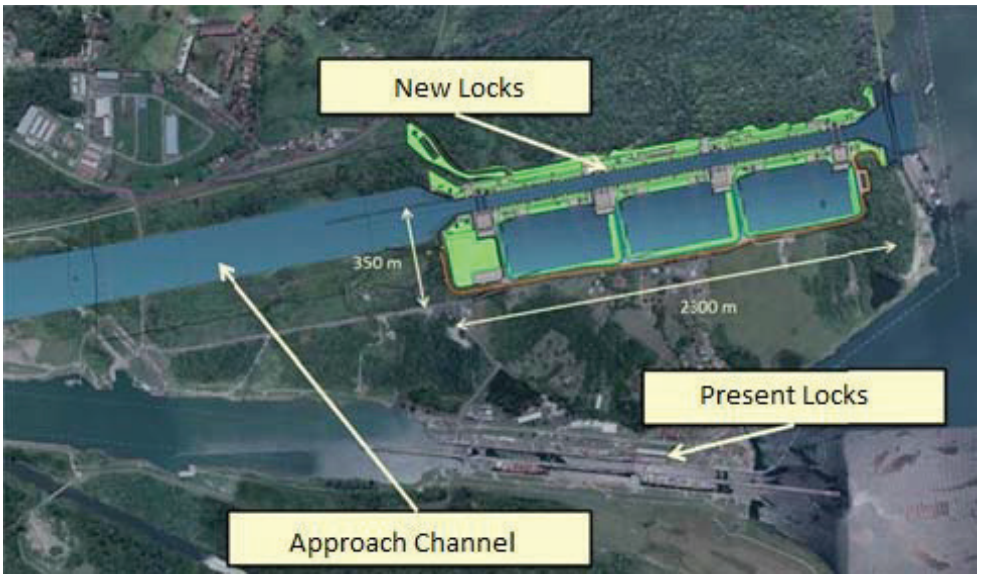

Figure 2. Overview of the project.

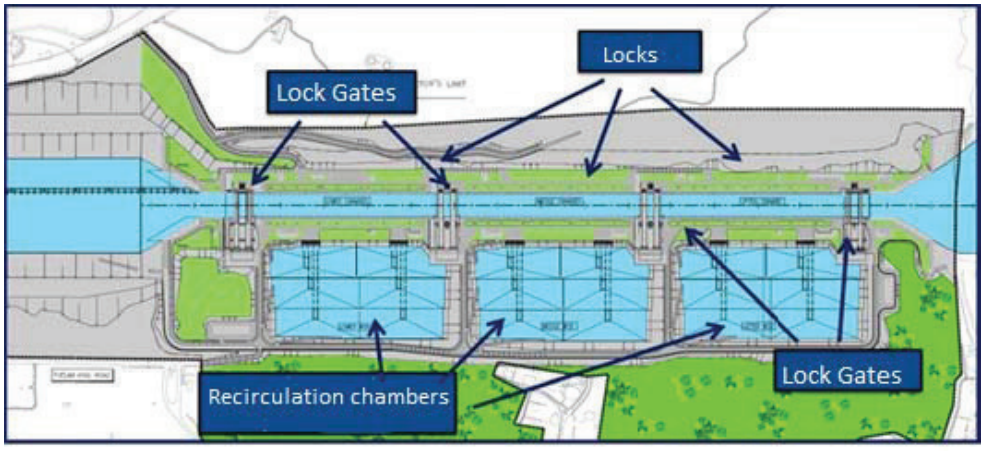

Figure 3. Main elements of the project (Atlantic side).

Apart from the locks, the Atlantic side also includes canal approach dredging and the north-east approach structure, whose function is to orient the ship and align it at the entrance to the first lock. This approach dock has a length of 500 m and has been built in pile—board type prefabricating the beams in the same work. On the Pacific side, the access channel has also been dredged and two approach structures have been arranged, one at each end of the locks, built using the same typology as in the Atlantic sector.

Current chanel overview [2]	
Canal length	77 km
Gap between oceans and lake	27 m (Although variable according to the tides and lake water level)
Dimensions of the chambers	304.8 × 33.5 × 12.8 m
Characteristics of the largest vessels allowed	289.6 × 32.3 × 12 m
Volume of water discharged by locks	96,300 m^3
Current share of world maritime trade (without expansion)	5%
Capacity annual tons in transit (without expansion)	330 millions of tons CP/SUAB
Annual transits	Almost 14,000
General information on the Third Set of Locks	
Duration of works	6 years
Maintenance period included in Contract	3 years
Volume of construction work	112 million man hours
Volume of design works	3 million man hours
Operating manuals delivered to ACP	300 manuals
Civil work	
Excavation volume (structures and quarries)	68 millions m^3
Volume of landfills (structures, dams, and landfills)	50 millions m^3
Structural concrete volume	5 millions m^3
Volume of dredged material	6 millions m^3
Arming steel weight	269,000 tons
Borinquen dams of loose materials	Nearly 3 km of total length, 37 m of height, and 30 m of width of the upper berm.
Primary crushing plant capacity	3300 tons/h (Pacific)
Capacity of secondary and tertiary crushing plants	1300 tons/h (Pacific and Atlantic)
Performance achieved in the manufacture of concrete	540 m^3/h
Performance achieved in concrete pouring on site	5000 m^3 daily
Transit tip trucks on the Pacific side	2000 daily trucks
Buildings (96 units)	47,000 m^2
Electromechanical systems	
Total number of valves	158
Total weight of steel in valves and their accessories	20,000 tons
Average throughput during locking	550 m^3/s
Total number of gates	16
Total weight of steel in gates	51,000 tons

Dimensions of the largest gate	57.6 × 10 × 33.04 m
Steel weight of the largest gate	3900 tons
Total number of medium voltage cabins (12 kV)	32
Power installed in transformation for each complex	26 MVA In each of the two redundant rings
Installed capacity in batteries for critical loads (4 h)	20,000 Ah
Total length of installed electrical cables	2000 km
Total length of Fiber Optic cables installed	400 km
Management of the control system for each complex	100,000 signals 34 servers 74 work stations 500 PLC
New locks in service	
Reliability (% operating time)	99.6%
Maximum capacity with basins	15 vessels/day
Maximum capacity without basins	17–18 vessels/day
Capacity of annual tons in transit	300 millions of tons CP-SUAB
Unloaded water volume with basins	90,000 m^3/lockage
Unloaded water volume without basins	230,000 m^3/lockage
Dimensions of the chambers	427 × 55 × 18.3 m
Characteristics of the largest vessels allowed	Neopanamax (12,500 TEUs, 366 × 49 × 15.2 m)
Concrete design life	100 years
Design life of the gates	50 years
Human factor	
Number of workers	40,000 people
Proceedings	79 Different nationalities
Beneficiaries of training courses	21,800 people
Peak period workers	14,000 people
Work team in January 2016	790 People expatriate staff 931 people Panamanian staff 3460 workers
ACP operators trained by the contractor for the operation and maintenance of the Project	160 people
Environment	
Number of rescued animals	More than 4.500
Reforested area	2.800 ha
Number of trees planted	5.8 millions
Estimated CO_2 balance by reduction of transits	160 millions CO_2 yearly

Table 1. Significant magnitudes of the project.

Table 1 summarizes the most significant magnitudes of the executed project.

As comparisons with familiar elements, we could expand the table above with the following information:

The locks are 427 m long, equivalent to four football fields.

For the expansion of the Panama Canal, 220,000 tons of steel have been used, equivalent to 22 Eiffel Towers.

In addition, 2100 km of wiring have been used, the distance between Miami and New York.

3. Hydraulic filling and emptying system

The hydraulic system of the new locks differs from the original canal in two main elements: The Borinquen dam, which communicates the set of locks on the Pacific side, as detailed in the introduction, and the implementation of Water Saving Basins, WSB. This solution allows to handle ships with 2–3 times more load, but using 7% less water than the original channel [**4**].

The new locks should be understood in their conception, like a great hydraulic machine conceived to pass enormous volumes of water in few minutes. The design of the filling and emptying system required studies with supercomputers and physical models to ensure compliance with the requirements of the contract. In fact, the challenges were not only limited to the time needed to balance the adjacent chambers, but also their durability (vibration control, cavitation, and air intake) and safety (the water surface must be kept as horizontal as possible to avoid excessive movements in the vessels that generate high efforts in their moorings). Let us see in detail how the system works and the challenges we face will become evident.

The locks work thanks to the principle of communicating vessels. Each chamber is a water container that, with the use of valves, communicates with the adjacent one. In this way, the water of the chamber at higher height goes down to the one of smaller height until they reach the same elevation. The water is never pumped up, the water always goes down from one chamber to the next by gravity. If the boat is in the chamber to be emptied, it will go down along with the water level. If it is in the one that is more empty, then it will rise. This is the theory, now it has to be put into practice. If we limit ourselves to the three chambers, without taking into account the WSB, this communication is done with the valves of the main ducts ("Culvert Valves").

The main hydraulic lines communicate with the three chambers, passing under the gates in the area of the garages (**Figure 4**). They are located inside the boxes of the chambers of the Third Set of Locks that are formed by concrete walls. The tellers are monoliths built in reinforced concrete of high resistance, low permeability, and high durability (100 years). The walls of the chambers present two types of concrete, one in mass that solidifies the core of the monoliths (Internal Mass Concrete), and another structural, of high resistance to marine means and very low permeability (Structural Marine Concrete) that covers all the surface of the structure. The walls have an approximate height of 30 m on foundations and a width in

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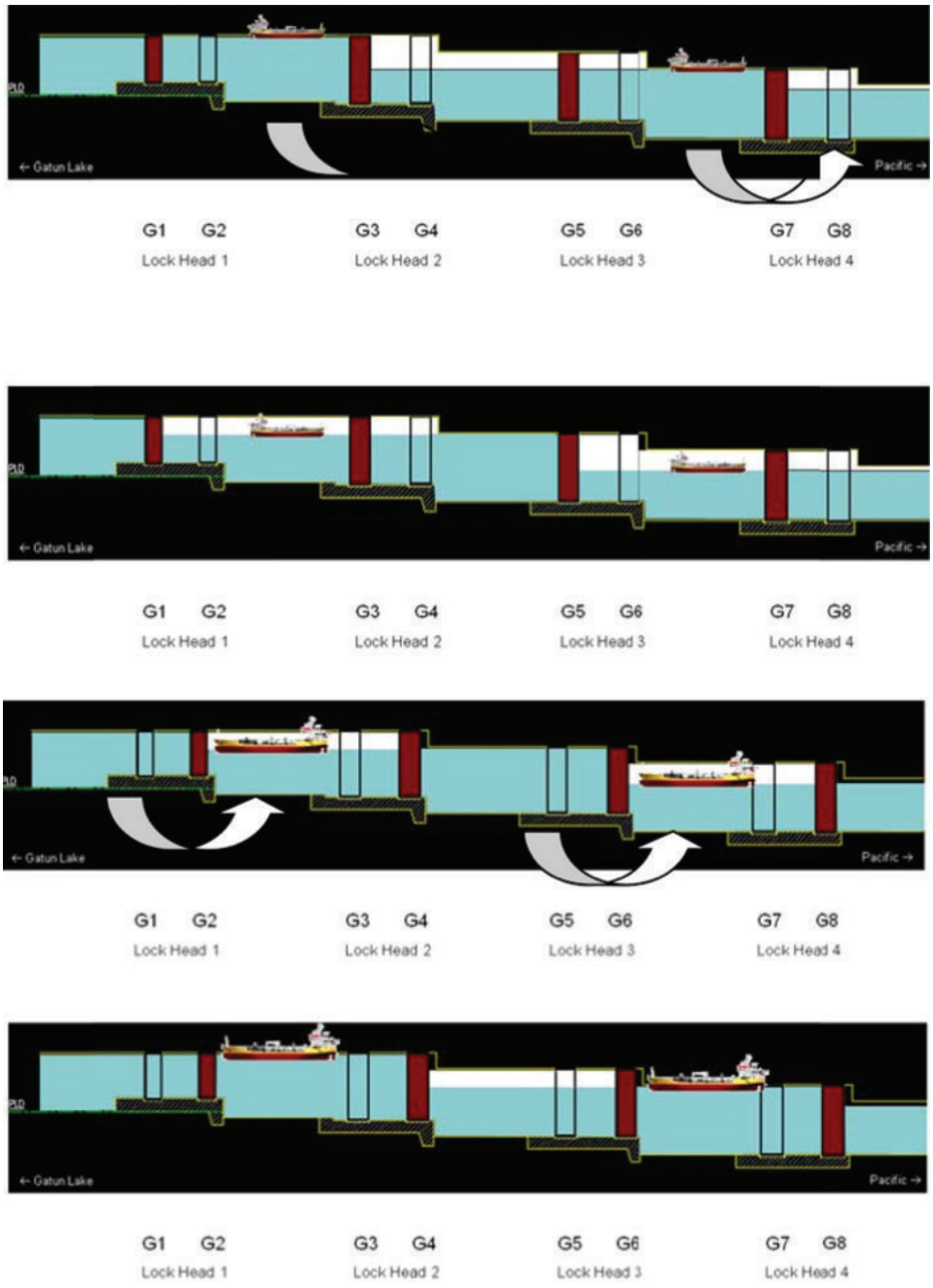

Figure 4. Principle of operation of the cameras as communicating vessels.

the base of about 27 m. Its triangular profile resembles that of a dam, but in this case, they have a prominent core at the base, which houses the hydraulic conductors, as indicated above. The back of the wall is in contact with a selected soil filling until crowning. **Figure 6** shows a cross-section of said wall with the mentioned hydraulic lines.

During this operation, the water used does not depend on the size of the boat, since the volume required depends on the area of the chambers and the difference in level between the two. If the area of the chambers cannot be modified, the level difference can be reduced by using the water saving basins (WSB). These chambers are not very different from the main ones, but placed at intermediate elevations allow us to reduce the water expense. Each time the level of a camera is lowered, the lateral tubs are used, filling their three levels in a decreasing way. Whenever it is necessary to refill the chamber, it will communicate with the three water saving tubs in increasing order and these will return the necessary water. Before the ship can pass, a final equalization between camera and camera will be executed, but at much more similar hydraulic levels and with much lower water expenditure. This manoeuvre will have saved 60% of the water needed for the locking (**Figures 5–7**).

We could say that the system of filling and emptying is the channel of Panama, the pulsating heart of the work. The efforts dedicated to the development of this system were immense. If something had not worked as expected, very little could have been done to solve it. However, this system is extremely particular. The amount of water handled in each operation is unrivalled in the world, and the time available for each extremely short operation. The main elements are similar to other channels with recovery tanks, but none brings to the limit the existing technology as the Third Set of Locks. Grupo Unidos por el Canal and all the companies involved soon realized that what was learned in similar applications here was not enough.

Numerical models and physical models were of vital importance to the success of the project. Each solution was investigated in a simplified 1D model, then entered data into 3D models at specific points. The level of detail and the complexity of the phenomenon, prevent the models from analyzing the flow throughout the system (**Figure 8**). Available supercomputers

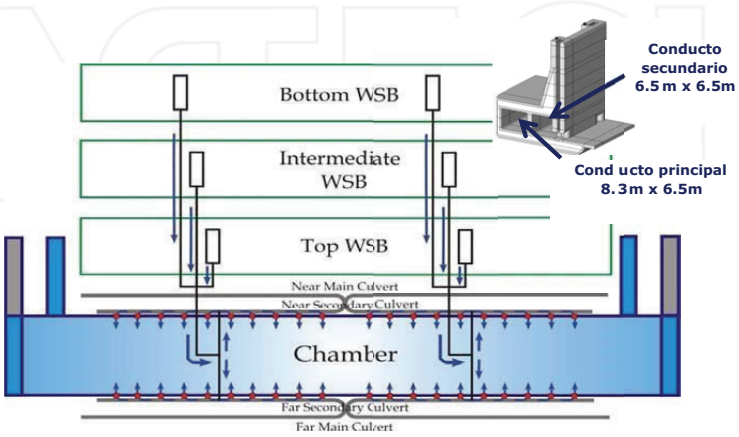

Figure 5. Bottom view of the main conduits (culvert) and water saving basins (WSB).

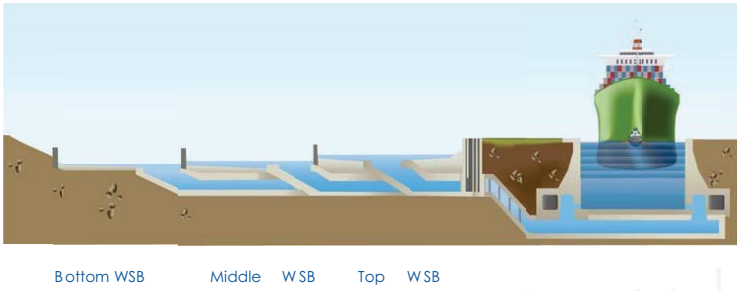

Figure 6. Cross-section of the water saving basins (WSB).

Figure 7. Aerial image of the water saving basins (WSB).

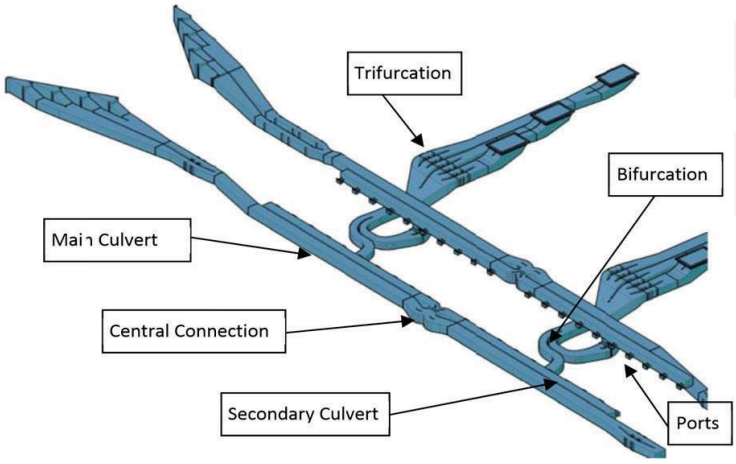

Figure 8. Schematic representation of the ducts in the upper chamber.

took days in solving the equations describing the flow of water. Obviously, each solution was tested in a physical model built in Lyon (France) in scale 1/30. The model was a lock in itself. This model not only allowed to validate hydraulic solutions well before the construction, but also to estimate effects very difficult to assess with numerical methods, such as the currents of salinity that form in the ocean or the influence of the approach structure in this flow. The physical model was monitored with more than 100 sensors providing data on water levels, velocities, pressures, differences in elevation in the chamber, and forces exerted on the vessel during the locking process and optimum position of the valves. The correlations obtained between the physical and numerical models were very high, so that the distribution of flows in each critical section of the model was very well controlled.

4. System of gates

The gates of the Third Set of Locks are of the "sliding" type. They are moved using an upper carriage and a lower carriage with wheels on rails located in said zones (**Figure 9**).

This type of gate has several advantages over the hinged doors of the original channel. One of them is the use of the niche where they are located in open position like dry dock to give maintenance to the floodgate without having impact in the operations.

Figure 9. Overview of a gate in operation.

Figure 10. Overview of the structure where the two gates are located at each end of the chamber.

Each lock has three chambers so that the jump of approximately 27 m from the sea to the lake is divided into three steps of 9 m each (**Figure 10**). This requires four of these structures located at the end of each chamber, space in which each pair of gates is placed. The gates go in pairs precisely for reasons of redundancy and maintenance. If one of the two is in the niche and cannot be used, then the sister allows the operations to continue without problems. There are also safety reasons and, for this reason, when the ship is in motion there are always two gates closed to the front.

The entrance from either of the two oceans finds its first pair of gates—the 7 and the 8—at the beginning of the first camera, the inferior one—Power Chamber. These gates make the system independent of the oceanic tide races, very pronounced in the Pacific, where they reach 6 m of difference, and more moderate in Atlantic, with 1 m of unevenness approximately. The next pair of gates—5 and 6—is about 9 m above the previous ones, at the beginning of the chambers—Middle Chambers. The third pair—3 and 4—identical to the previous ones, is at the beginning of the upper chamber—Upper Chamber, which rises again about 9 m from the intermediate one. The last pair of gates—1 and 2—separates the Gatun Lake locks system, whose water level under ordinary conditions is about 27 m above the reference level of both oceans.

The gates present different dimensions and weights depending on the contour conditions that determine their buoyancy. In effect, the gates are orthogonal parallelepipeds, which have hollow and watertight chambers, arranged in each case at the necessary height and with the precise dimensions to reduce dead weights and allow their buoyancy. These watertight chambers work like the hull of a boat, reducing the operating weight of the gates up to 85% of their dry weight to be able to slide them. In this way, the total vertical force that the gates of the gates must support does not exceed 600 tons in total.

The manufacturing and transport operations of the floodgates have been, due to their complexity and spectacularity, one of the images that more media monitoring has had in the execution of this work. For these operations, the use of self-propelled heavy cargo transport trolleys (SPMT), barges with dozens of pumps capable of compensating the transfer of cargo and with two ocean-going heavy cargo ships adapted to the present project (**Figure 11**).

Each gate is supported by two wagons. One moves along the niche in the concrete structure, in the highest part, and by this is defined as upper wagon. This car is responsible for transmitting the movement to the gate through a beam where the pulleys are located, as we will see later. At the other end of the gate, the carriage is located in the lower part of the gate and rolls on a rail placed at the bottom of the chamber (**Figure 12**). To facilitate its maintenance, the connection point between the lower wagon and the gate is located at the top of the gate, outside the water, and the gate is supported by a column. This eliminates the need for complicated dives in the channel for the extraction of the wagon provided every 5 years.

In the case of the Panama Canal, the watertightness and durability requirements are extremely demanding. The seals have to guarantee a leak of less than 5 L/min/m and a life of 15 years or 135,000 cycles, operating more than 20 times a day. Almost all floodgates of this type in the world work with the tides, 2–4 times a day. A fairly common solution is a wooden support with a thickness of plastic mounted on the gate and a support of smooth concrete or natural stone in which it is supported and sealed. This solution could not guarantee the required benefits and it was necessary to analyze other alternatives. The one that was finally adopted consists of a rubber stamp in the

Figure 11. Unloading of the gates on the quay side Atlantic.

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Figure 12. Conceptual diagram of the operation of the gates.

form of a musical note ("J-seal"), independent of other functions, that activates with the hydraulic differential and is deactivated when the equilibrium is reached. This solution is more common in valves of dams or dry docks. Several tests were necessary to ensure that the rigidity of the profile was correct. A too rigid profile would not be activated in time, while too soft one could be activated with differences in water levels sufficient to move the damper, with the risk of damaging it.

5. Control system

The power control system (PCS) is designed to operate safely, reliably, and functionally the Third Set of Locks. It is divided into two major sub-systems:

1. The lock machinery control system (LMCS): This system is in charge of operating, monitoring and controlling valves, gates, and auxiliary systems.
2. The electrical distribution control system (EDCS): This system is in charge of operating, monitoring and controlling the control centers of motors, transformers, direct current equipment, and other electrical equipment.

The control system was designed in order that the lock could be operated in the most reliable, safe, and easy way for the lock operator. Today, a single operator in each lock is able to operate the control system to achieve the passage of ships through the channel.

There are three operating consoles in both locks, which are distributed as follows: two consoles are located in the control tower (CB) and a console is located in the back-up building (BCB) of the lock. The operator can operate in any of the three existing consoles, which were designed in order to have a redundant system, either within the same control tower or inside the backup building in case something happened to the tower of control.

6. Auxiliary systems

The auxiliary systems correspond to those complementary functions necessary for the operation of the Third Set of Locks, such as the systems necessary to guarantee the physical security of the Canal, to manage the traffic in an efficient and safe way above the floodgates, to detect and to extinguish a Fire or monitor the area with thermal cameras.

7. Conclusions

The expansion of the Canal has been cataloged in several publications as the most important work of recent years worldwide. There is no doubt that the strategic importance of the Panama Canal and its original epic construction, with all the difficulties suffered by Ferdinand de Lesseps in the first instance and the American government in its final stage, have influenced this consideration. However, there are other elements that have contributed to the media interest aroused throughout the planet during its construction. Among these technical elements are the enormous volumes of work, the dimensions of the floodgates, the water-saving pools, and the singularity of the project itself, which are discussed below:

7.1. The volumes of work

In the previous chapters, we have detailed the magnitudes that make the new Canal an enormous work. These volumes require a special logistics both for procurement and for execution of work. The small industrial fabric present in Panama complicates much more this logistics. Detailed planning has therefore been necessary to resolve this point.

7.2. The dimensions of the gates

The 16 steel gates have focused the technical interest of the work during its final phase. The transport of these 16 structures has been complex, not only because of its weight (almost 4000 tons in the worst case) but also because of its size (58 m in length, 10 m in width, and 33 m in height). The equipment and experience in transport processes and installation of heavy load have been carried to their maximum capacity.

7.3. Water saving basins

The main engine of the channel as we have already mentioned is the water coming from the rain. One of the requirements of the project was to save water used in the operation of the Canal. The side pools of water saving have been an innovative measure that has worked perfectly and has managed to reuse on average 60% of the water used in each lock.

7.4. The singularity of the project

The new locks have undoubtedly been a unique project that has required the development of unprecedented solutions; Prototypes never used previously. It is here that innovation has played a key role in the technical success of the project. Among the innovations of the most

significant electromechanical elements, we must highlight those relating to materials and construction procedures and also those that refer directly to the execution. In the dosing of concrete, it has also been necessary to implement innovative measures that have already been the subject of technical articles in this regard, as discussed below:

7.5. Innovations in materials and construction procedures

The locks, as well as other hydraulic works, combine two technologies that are constructed in a different way: the part of civil work with concrete implementation with centimetric precisions and mechanics that require millimetric precisions. In the installation of valves (guide rails) and gates (guiding, support, and sealing elements), it has been necessary to solve complex problems in order to make civil works and mechanical elements compatible. The final solution has been given through the installation of adjusting elements (embedded in first and second stages of concreting) and the selection of materials, such as high density polyethylene which enabled the machining in the shop or *in situ* to achieve precisions of the order of magnitude of 1 mm.

In parallel, the specifications of the ACP reference document included compliance with water leakage values through the seals of the unusual gates, in this type of infrastructure. Solutions known for that point of contact using stainless steel, polished stone, special woods, or other materials used in similar locks in Holland or Belgium were not suitable. That is why GUPC together with its designers and subcontractors began an investigation to develop a solution that combined a rubber seal with steel sheets on prestressed panels of high-density polyethylene. After several tests at the CIMOLAI facilities, the University of Udine (Italy), the 1:1 test facilities at MARIN (The Netherlands), fatigue tests at several European laboratories and on-site adjustment tests, the expected result, and meeting customer requirements.

The functionality of the auxiliary systems described above has also required the use of the most innovative equipment on the market, sometimes requiring a tailor-made adaptation for the application in the Panama Canal.

7.6. Innovations in execution

It is difficult to segregate those aspects that have stood out for their innovation in the constructive process. The points mentioned above, work volumes, transport, and installation of floodgates, have in themselves generated the need to implement unusual sequences and procedures on site. There is, however, a characteristic of this work that makes it unique in front of many others: it combines a civil work of great volumes with elements of an industrial work also of great magnitude and of high complexity. For example, during the commissioning phase, more than 200 calibration locks have been carried out, requiring more than 33 million m^3 of water, more than 2000 integration tests of the different systems present and should be carried out under supervision of ACP the 14 tests with 36 different hydraulic scenarios to verify the requirements of the project. These activities were carried out while the rest of civil, mechanical, electrical, and control activities were completed. This simultaneity of activities can only be managed through proper preparation (planning) and with a practical and effective control system.

The first point regarding the execution of the start-up phase was overcome with detailed and detailed planning. This process was prepared for over a year and a half. The thousands

of planned activities were analyzed to finally elaborate a sequence that allowed adjustments according to the degree of progress of the work and the unforeseen that could appear. With the procedure already developed, the start-up sequence could be completed in 7 months, reducing in almost 2 months the initially planned time.

The second point was related to the control system that would allow overlapping of the hundreds of simultaneous and concurrent activities in the same space that were given on a daily basis. It required a simple methodology that would ensure the possibility of progressing on all these fronts but minimizing the possibility of accidents. If there is simultaneous electrical work, testing of mobile equipment and civil activities (painting, concreting, and finishing in buildings) by program requirement, the risk of accident increased significantly. The solution was the implementation of a system of work permits by zones, controlled by LO-TO procedure ("Lockout-tagout"), and supervised by a team of dispatchers. This system, although habitual in works in industrial plants, has been novel in a work of thousands of people with simultaneity of activities of so many different disciplines [3].

7.7. Final reflexion

As a final conclusion to highlight that the ability to innovate of the technicians who have participated in this work has been one of the keys to be able to overcome the challenge that SACYR committed to Panama and the rest of the world.

The acquired know-how must allow to face works of great importance and of high technical complexity in which the Spanish companies are in the international avant-garde (**Figure 13**).

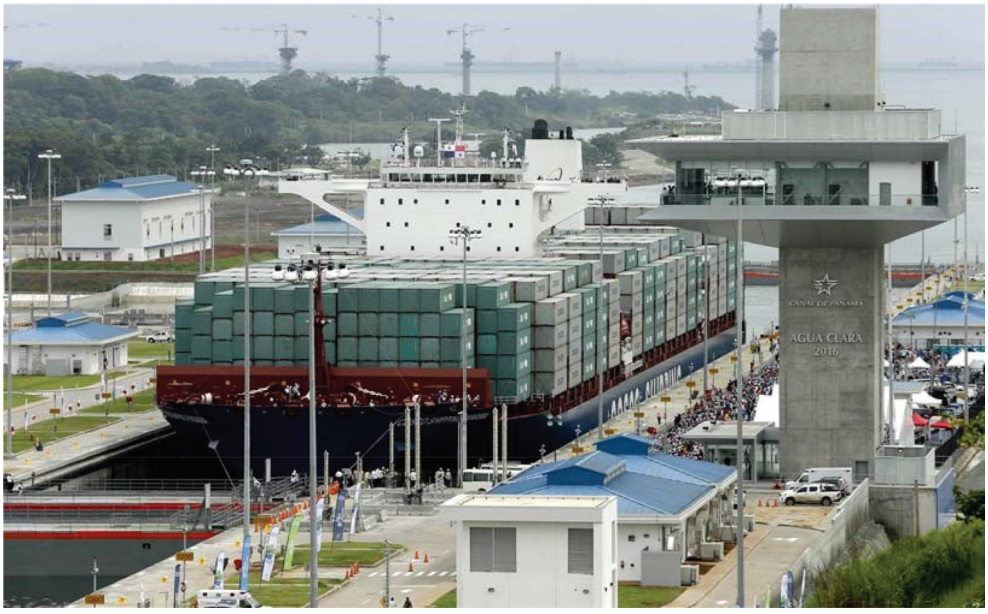

Figure 13. Passing of the ship Cosco Shipping Panama with 10,000 TEUs during the inauguration of last June 26, 2016.

Author details

Ana Belén Berrocal Menarguez and Juan Pous de la Flor*

*Address all correspondence to: jpousf@sacyr.com

Universidad Politécnica de Madrid, Madrid, España

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Chapter 2

Innovation Management in Iberdrola

Agustín Delgado Martín

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/67770

Abstract

Innovation is Iberdrola's main tool to guarantee its sustainability, efficiency and competitiveness. The model in Iberdrola is decentralised because the process is carried out independently in each Business Unit with support and coordination from the Innovation Department and open innovation because it seeks to involve Group technology suppliers such as universities, technology centres and equipment manufacturers in the innovation process. Research, Development and Innovation efforts comprise three main components: Efficiency: optimising operations, managing the life of facilities and equipment, bringing down operating and maintenance costs and reducing the environmental impact. New products and services to meet customer needs through digitalisation, automation and tailored solutions. Disruptive technologies and business models to tackle future energy challenges. The Company has organised its R&D Management System so that the Innovation Department can provide the Business Units with a global model, since we believe that there should be a single, standard and systematic innovation process for the entire organisation. Thanks to the commitment with Innovation, Iberdrola has positioned as a world leader in the offshore area, where it develops the most advanced and innovative projects. Wikinger Offshore wind farm is an emblematic project for Iberdrola, the symbol of Iberdrola's commitment to innovation, sustainability and internationalisation.

Keywords: open innovation, smart grids, offshore, R&D, technology, management system, digitalisation

1. Summary

In anticipation of the energy transition, Iberdrola has committed to sustainable solutions that require greater electrification of the global economy: more clean energy, more storage capacity, more backup power, more and smarter grids, and more digitization, being innovation a strategic variable that constitutes the main tool for guaranteeing the sustainability, efficiency and competitiveness of the company.

The innovation model in Iberdrola is decentralised because the process is carried out independently in each business unit with and open because it seeks to involve group technology suppliers such as universities, technology centres and equipment manufacturers in the innovation process. The R&D&i (research, development and innovation) efforts comprise three main components:

- Efficiency: continuously optimising operations, managing the life of facilities and equipment, reducing operating and maintenance costs and the environmental impact.
- New products and services to meet customer needs through digitalisation, automation and tailored solutions.
- Disruptive technologies and business models to tackle future energy challenges.

Thanks to the commitment with Innovation, sustainability and internationalisation, Iberdrola has positioned as a world-wide leader in the offshore area, where it develops the most advanced and innovative projects.

The Wikinger offshore wind farm is an emblematic project for Iberdrola. This project has materialised in a fusion of the company's resolute dedication to renewable energies with technological innovation, internationalisation and a contribution to the economic development with job creation in regions where the group is present. Moreover, through our international expansion, Iberdrola opens the door for its suppliers and service providers to new markets and business.

2. Introduction

Boasting a track record that spans over 170 years, currently Iberdrola is a multinational group leading the energy sector: the company produces and supplies electricity to some 100 million people in the countries in which it operates. Furthermore, the company has become the leader in clean energy—Iberdrola is the first renewable producer among European utilities and the cleanest power company in the USA, with almost zero emissions—, it is pioneering the rollout of smart grids and has an energy storage capacity in excess of 4 GW.

Iberdrola reached its current position as a result of the transformation undertaken by the company over the past 15 years and thanks to a corporate advantage point capable of anticipating sector trends: acknowledgement that the intensely growing world energy demand cannot be satisfied with an inefficient and unsustainable model for the environment based on fossil fuels. On the contrary, the shift towards a gradual decarbonisation of the economy, increase in the importance of electricity in the universal energy balance and growth of clean energies was relentless and irreversible.

In anticipation of the energy transition, Iberdrola has committed to sustainable solutions that require greater electrification of the global economy: more clean energy, more storage capacity, more backup power, more and smarter grids and more digitisation.

Iberdrola is tackling the outlook for the immediate future in a scenario characterised by a sharp growth in the global energy demand from efficient, clean sources to cut global emissions and combat climate change [1].

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As a result of our permanent commitment to human, economic and management-centred innovation, Iberdrola has been recognised as the most innovative power utility in Spain and third in Europe according to the European Commission's ranking [2].

3. Innovation strategy

3.1. R&D&i Management System

At Iberdrola, we strongly believe that the current paradigm can continue advancing and we can move forward towards the far-reaching transformation envisioned for the energy section by continuously improvement and attaining greater efficiency in our processes and operations. Now, more than ever, we need to bolster innovation to turn it into the main implement in our search for the new opportunities that will enable us to progress towards a flexible, cheaper, balanced, more sustainable and less polluting energy model, while also creating jobs.

Innovation is a strategic variable that constitutes the main tool for guaranteeing the sustainability, efficiency and competitiveness of the company. Our efforts in R&D&i aim to optimise operating conditions, improve safety and reduce the environmental impact of our activities.

Iberdrola is aware that innovation requires planning to ensure that all the R&D&i activities of all the businesses in the Group are coordinated and structured. For this reason, an R&D&i Management System was implemented in mid-2007 thus providing systematised and standardised criteria for R&D&i activities that can be implemented globally and efficiently.

Iberdrola has structured its R&D&i Management System so that the Innovation Division can provide business units (Generation, Networks, Renewables, IT and Engineering) with a global model, since we believe that there should be a single, standard and systematic innovation process for the entire organisation. The development of a specific structure for this management, such as R&D&i committees, has been fundamental for managing the innovative process from a perspective that is closer to them. Each business or company has an R&D coordinator and an R&D manager [1] (see **Figure 1**).

- **R&D Coordinators Committee**, which is carried out annually and is presided by the Innovation Director and attended by the R&D coordinators of each Business.
- **Business R&D Committee**, which is held twice a year for each Business and coordinated by the Business R&D Coordinator, including the Innovation Director, the Business Innovation Manager, as well as experts depending on the issues (i.e. project managers) and the R&D Management System Coordinator if it is necessary.

In short, the R&D&i Management System enables us to view innovation as a basic activity of a consistently and effectively managed organisation, according to a set of well-defined and well-documented processes with owners assigned to the various activities and a proper allocation of resources. The chart below shows the international process map for R&D&i management across the Iberdrola Group [1] (see **Figure 2**).

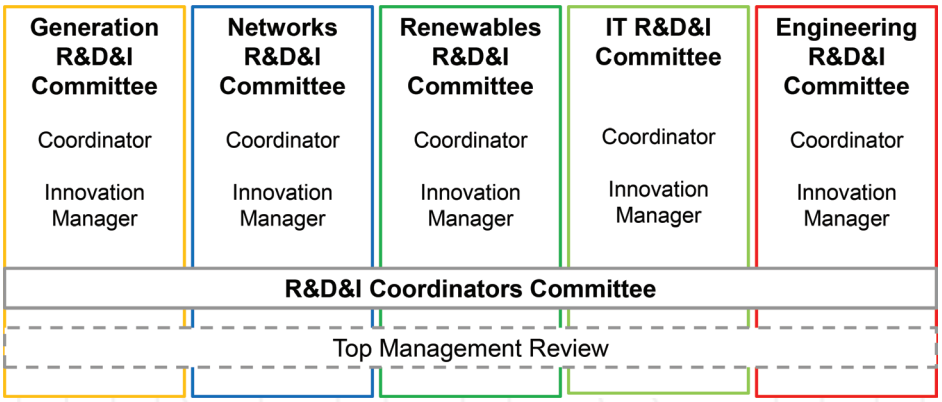

Figure 1. R&D organisation model.

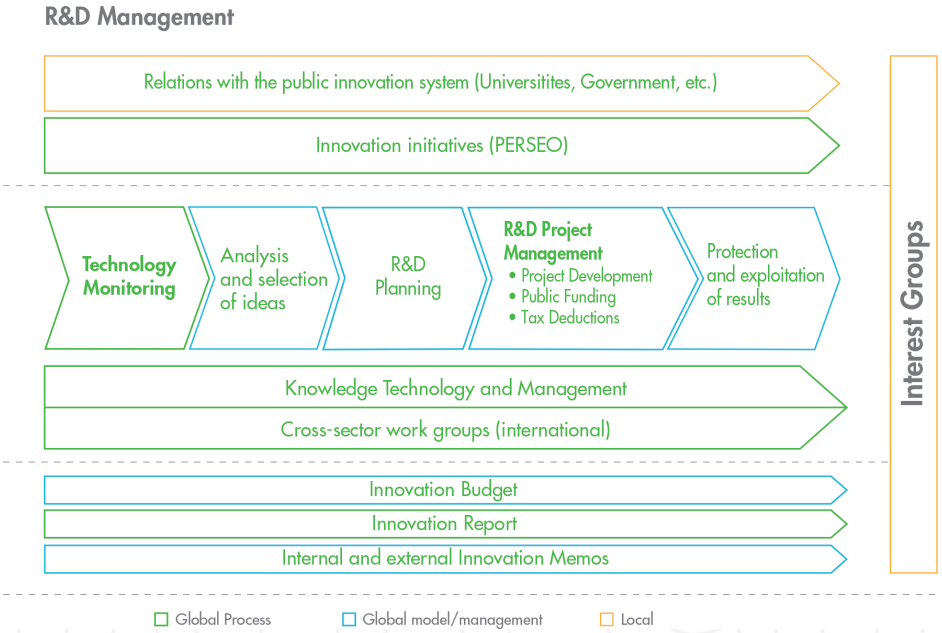

Figure 2. R&D&i Management System.

Iberdrola understands innovation as a decentralised and open process:

- *Decentralised*, because the process is carried out independently in each business unit with the support and coordination of the Innovation Division.
- *Open*, because Iberdrola prides itself on being a technology-driven company and, as such, seeks to involve Group technology suppliers, such as universities, technology centres and equipment manufacturers in the innovation process.

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The chart below shows the different internal and external agents that form part of Innovation at Iberdrola on a day-to-day basis [1] (see **Figure 3**):

- *The innovation division*: Rigorously and efficiently managing the Iberdrola Group's innovation capabilities, providing the Group with the tools, resources and structures necessary for creating a suitable environment for cultivating innovation.
- *R&D&i coordinator committee*: Responsible for innovation at the Iberdrola Business Units, sharing best practices at an executive level and monitoring compliance with the R&D&i Plan.
- *Business units*: As a fundamental part of the decentralised innovation model, business units conduct R&D&i activities and projects. The Innovation Committees have been set up as a support and management structure. The work of our Innovation Coordinators is highly relevant at a management level, while the Innovation Manager provides support to all R&D&i promotion activities.
- *Support for innovation*: Internal areas at Iberdrola for fostering innovation.
- *Special initiatives*: Iberdrola Corporate University, Spanish Iberdrola Foundation and Iberdrola Ventures-PERSEO (corporate venture capital programme).
- *Value chain*: The company's stakeholders, clients, manufacturers and external partners.
- *R&D&i system*: Universities and technological centres, government agencies.

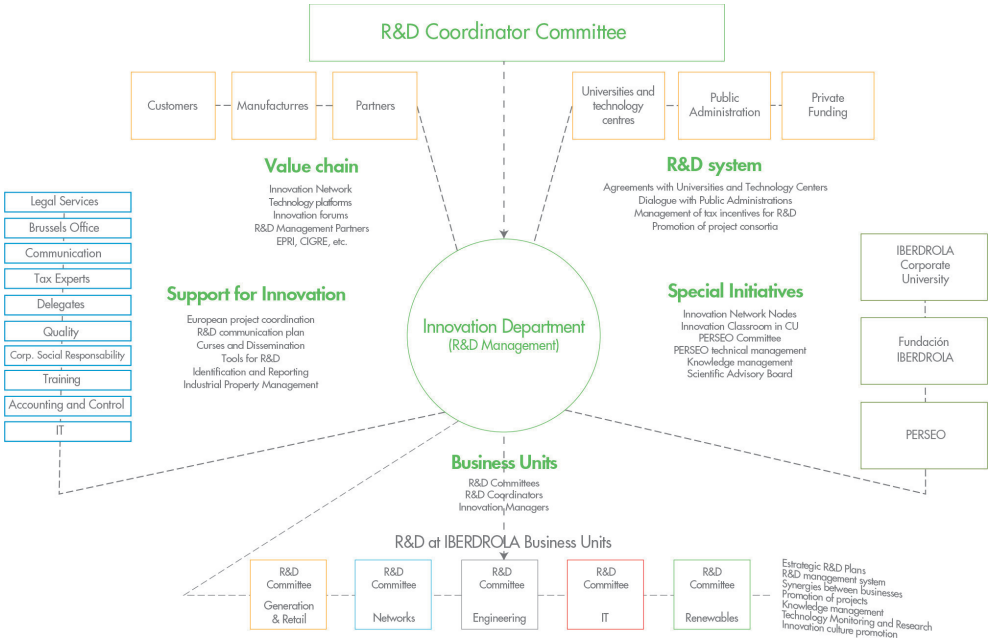

Figure 3. Internal and external agents.

3.2. Open innovation

Open innovation represents the management of collaboration contributing to maintain and renew structures for innovation and is essential for large collaborative groups as is the case of Iberdrola, with 30,000 employees in 40 countries. This management provides a forum for communication with the Group and the right tools to ensure that collaboration is successful and objectives are met.

This open innovation model entails partnerships with companies, universities, technology centres, industrial organisations and public institutions through different programmes and agreements.

In this line, Iberdrola launched its **Supplier Innovation Programme** for promoting and accelerating the development of new products and services that provide solutions to the future needs of the company while responding to the challenges facing the sector.

The programme revolves around three central axes: facilitating access to financing mechanisms, fostering the joint creation of companies (spin-offs with suppliers) and favouring innovative acquisitions from small and medium-sized enterprises.

The Ministry of the Economy and Competitiveness and Iberdrola will share good practices in innovative acquisition procedures, fostering innovation from the demand side and opportunities for co-investments within the framework of the INNVIERTE programme, which aims to promote innovation in entrepreneurships through support to the venture capital investment in innovative technology-based entrepreneurs [2].

This initiative will boost the pull effect that IBERDROLA exerts on the business sector in the areas where it has operations.

In addition, Iberdrola has launched a new initiative, **IBERDROLA Universitas**, to boost special partnerships with the world of academia and science in order to:

- Promoting University-Business technology transfer.
- Establishing a framework for collaboration for the launch of R&D&i projects and training initiatives in common areas of interest.
- Promoting specialised training in the fields of greatest interest to Iberdrola.
- Materialising social commitment.

3.3. Iberdrola innovation plan

The deployment of innovative strategy both in management and technology has converted Iberdrola into the world leader and benchmark in R&D&i, as a result of the successful implementation of a common model for all geographic and technological areas, collaboration with technology providers and the fostering of a culture of innovation.

The Iberdrola R&D&i Plan consolidates the research, development and innovation plans of the different Business Units during this period. In line with the Group's outlook, the Plan reinforces the commitment to sustainable development, promotion of renewable energy sources and emerging technologies along three lines of action [1–3]:

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- *Efficiency*, focused on continuous optimisation of our operations, facilities and materials management, operations and maintenance cost reductions and reduction in environmental impact. Thanks to the participation of all employees in Iberdrola Group, there are more than 200 R&D projects that are developing with an impact on the business in the short- and medium-term.
- *New products and services* that respond to the needs of customers in a market that is increasingly global and competitive. These are projects that employing existing technology become business models which offer the most efficient and environmentally respectful supply of electricity, equipment and technologies. These include projects highlighting electrical efficiency, electric vehicles, digitisation, smart grids and distributed generation resources.

Figure 4. R&D&i in generation.

- *Disruptive technologies and business models* that allow us to face the energy challenges of the future. Through PERSEO, Iberdrola's corporate venture capital programme, we invest in disruptive technologies and new businesses that ensure the sustainability of the energy model.

The project portfolio for Research, Development and Innovation (R&D&i) at Iberdrola comprises activities in four main areas, reflecting the company's strong commitment to sustainable development and the promotion of emerging technologies [1]:

- *Sustainable generation and retail:* The efforts in the generation and retail area focus on flexibility and operating efficiency, with respect to the environment and the improvement of facility safety based on two main areas: clean generation and energy efficiency (see **Figure 4**).
- *Networks for the future:* Smart grid is a technological evolution of the energy distribution system that combines traditional facilities with modern monitoring technologies, and information and telecommunication systems. Iberdrola hones its efforts in innovation on

Figure 5. R&D&i in networks.

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the grids area to offer a broader range of services to customers, improve supply quality, respond to society's future demand for electricity and achieve optimal power distribution management (see **Figure 5**).

- *Renewable energy sources:* Innovation activities in the area of renewables have mostly focused on improving the efficiency of operational assets, the integration of renewable energies and the development of new designs or processes for projects in the pipeline or future projects mainly associated with offshore wind power and other renewable technologies (see **Figure 6**).
- *Cross-sector technologies:* These activities are related to information and communications technologies (ICT), digitisation, engineering and other cross-cutting areas such as electric vehicles, energy storage, environmental performance and energy efficiency, security, etc.

Figure 6. R&D&i in renewables.

4. Example of success: Wikinger offshore wind farm project

The Company has become a global benchmark in the offshore sector, where it carries out the most cutting edge and innovative projects. Innovation in offshore wind power projects is fundamental in order to reduce costs and limit the risks in projects in the pipeline and future projects [4].

Wikinger offshore wind farm is an emblematic project for Iberdrola, the symbol of Iberdrola's commitment to innovation, sustainability and internationalisation.

This project has materialised in a fusion of the company's resolute dedication to renewable energies with technological innovation, internationalisation and a contribution to the economic development with job creation in regions where the group is present. Moreover, through our international expansion, Iberdrola opens the door for its suppliers and service providers to new markets and business.

The construction of this offshore wind farm in the Baltic Sea, where the water is between 37 and 43 m deep, requires an investment of €1400 million. The site covers a surface area of about 34 square kilometres (km^2), where the company plans to install 70 wind turbines, each with a unit capacity of 5 MW [5].

Iberdrola is taking part in this initiative alongside the main offshore wind farm developers in order to reduce the costs of producing offshore wind power. Projects in this respect are being carried out throughout the supply chain. Work lines include production estimating, foundations, efficiency improvements in electricity transmission infrastructure and accessibility to perform maintenance tasks.

The offshore substation christened as 'Andalucía', now installed at its final location, will be the power core of the renewable energy facility. This electricity distribution infrastructure, which weighs some 8500 tonnes, will handle all electricity generated by the wind turbines operating in the open sea (see **Figure 7**).

By the time it is connected to the grid in late 2017, Wikinger's 350 MW capacity will produce enough energy to meet the electricity needs of over 350,000 German households, avoiding the emission of some 600,000 tonnes of CO_2 into the atmosphere each year [2] (see **Figure 8**).

With this general approach, we should highlight some of the innovation activities carried out in the Wikinger project [3]:

- Development of a numerical weather forecasting tool for planning installation work and operations.
- Implementation of an on-site pile test campaign at Wikinger wind farm aimed at validating (and optimising) the design of the jacket foundation piling (tasked with securing the foundations to the ground) due to the special characteristics of the seabed, with major improvements being achieved. In addition to validating the design, the project also seeks to develop new offshore testing procedures that can be applied to any terrain of

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Figure 7. Substation 'Andalucia'.

Figure 8. Wikinger main project data.

uncertain characteristics by conducting a series of tests on calcareous ground. The conclusions drawn from the tests will be carried across to the development of new, more reliable design procedures.

- Design of a four-leg jacket foundation for the Wikinger project. The design of the foundation has been adapted to the site, and it has been optimised to simplify the fabrication process (see **Figure 9**).
- Innovative design of the offshore substation for the Wikinger wind farm that involves building it in two parts due to weight and size restrictions for transportation, along with its foundations on a six-leg jacket structure (see **Figure 10**).

Figure 9. 3D design of the Wikinger wind farm.

Figure 10. Wikinger wind farm pile test campaign.

Author details

Agustín Delgado Martín

Address all correspondence to: adelgadom@iberdrola.es

Iberdrola, Spain

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Chapter 3

Composite Solutions for Construction Sector

Pilar Górriz, Anurag Bansal, Carlo Paulotto,
Stefano Primi and Ignacio Calvo

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68964

Abstract

FRP composite materials have been successfully used for several decades in the aerospace industry, while their use in Civil Engineering is relatively recent and generally in the form of sheets and strips employed to strengthen existing reinforced concrete structures. Since the construction of the first all-FRP-composite bridge in 1982, in Miyun, China, FRP composites have been gradually gaining acceptance as a new construction material for bridges and footbridges with some notable applications in Spain. Their use offers a number of advantages with respect to traditional materials:

(i) Since FRP composite members are lighter than those built using concrete and steel, they need less powerful equipment for their transport and installation;

(ii) Their lightweight fosters prefabrication, speeding up construction processes, thus helping in the reduction of the impact of worksites on their surrounding areas;

(iii) FRP composites can curb maintenance cost of infrastructures since they do not suffer from galvanic corrosion.

In this chapter, the successful ACCIONA FRP composite structures are going to be described, demonstrating that the use of these materials is a feasible solution in infrastructure sector.

Keywords: composite materials, civil works, bridges, footbridges, lighthouse, carbon fiber, glass fiber

1. Introduction

The development of humanity as we know it today has been closely associated with the development of infrastructures. The first civilizations that lived between the valleys of the Tigris

and Euphrates performed diversions of water to be able to cultivate land. Nobody can imagine the Roman Empire without the "roman via" that linked all the points of the Empire spanning thousands of miles (Omnes Viae Roman Ducunt) [1]. Currently, the population of big cities grows around 200,000 people per day, which requires the creation of new, more efficient and sustainable infrastructure to serve this growing population in urban areas [2].

The global construction industry has grown from US$7.4 trillion in 2010 to US$8.5 trillion in 2015 and is projected to grow up to US$10.3 trillion in 2020, when measured at constant 2010 prices and exchange rates (real 2010 US$).The global construction industry has regained growth momentum, with the pace of expansion accelerating from an annual average of 2.7% a year in real terms in 2011–2013 to 3.1% in 2014. In 2015, a further rise to 3.8% in 2015 was forecasted and then an average annual increase of 3.9% over 2016–2020 [3].The construction industry represents around 6% of global GDP and still growing. In developing countries such as India, this industry generates about 8% of GDP, being also one of the highest single-consuming industries (consumption of 50% of the world steel production) causing between 25 and 40% of carbon emissions to the atmosphere [4].

The construction sector has historically adapted technologies and innovations slower than other sectors which avidly welcome them [4]. That has translated into less productivity in relation to other sectors [5].

Recently, some companies have begun to incorporate new ways of performing both design and execution of work processes The outcome of this effort is, for example, the implementation of the BIM methodology in companies like ACCIONA, which means not only a transformation of the processes and the incorporation of new softwares in the workplace but also a new definition of the roles in the company [6]. Further progress is being made with the incorporation of scanning lasers, drones and other information systems in the worksites not only in ACCIONA but also in other construction companies [7–9].

In the field of new materials, the construction sector has made a significant research effort in recent years. There is an extensive bibliography on incorporation of nanoparticles to the concrete to provide greater durability or to improve mechanical properties, and self-healing materials have been developed to use them in roads or buildings [10–12]. Currently, there are coatings in the market with different properties depending on the application in which they are to be used (multifunctional coatings) for instance with photocatalytic properties for reduction of environmental pollutants [12, 13].

There has been significant progress in the use of composite materials for the manufacture of structural elements in the construction sector. A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone [14].

In the construction sector, composite materials are considered those formed among others by polymeric resins combined with fibers (fiber reinforced polymer composites (FRP)). The resin matrix mainly acts protecting and distributing loads among the fibers which in turn provide strength and stiffness to the composite material. Selecting a specific orientation for the fibers, it is possible to tailor the mechanical properties of the composite material in the different directions of the space in order to match the mechanical requirements placed in each specific direction by the acting loads. The excellent properties against corrosion in chemical environments, electromagnetic transparency, and the reduction of up to 10 times the weight of the structures in relation

to those made with traditional materials such as steel or concrete allow to consider composite materials a viable solution for the infrastructure sector. What is especially appealing of these materials is the fact that they do not suffer for electrochemical corrosion which instead affects steel used in civil and industrial structures commonly in the form of profiles and bars. It is worth noting that steel corrosion is the main cause of damage and losses for infrastructure. Corrosion problems are exacerbated by high temperature, humidity and the presence of salts. For these reasons, reinforced concrete and steel structures located close to or in the sea, in water treatment or in chemical plants, and bridges located in cold regions where deicing salts are massively used are exposed to severe corrosion phenomena [15–17].

Another characteristic of composite materials that is very attractive for construction activities is their lightweight since it enormously simplifies transportation and installations of structural elements, fostering structure prefabrication. Lightweight and high prefabrication heavily contribute in accelerating the construction process, in reducing the need for high capacity cranes, and in improving safety at worksite. Accelerating the construction process offers great advantages in densely populated urban areas where it allows reducing disruption times and the consequent indirect losses [18, 19].

We should not ignore that the use of these materials also presents a challenge with its performance against fire and automation in manufacturing. In the first case, intumescent coatings and resins with improved fire resistance and reaction times that significantly reduce the associated problems have been developed. With respect to automation in the manufacture of these structures, it depends on the type of resin to be used, as well as on the design of the final structure, so it is a field under research [18, 19].

ACCIONA, a pioneer in the application of these materials within the construction sector, has designed, manufactured and installed three vehicular and two foot bridges, a lighthouse, spiral staircase, and couple of other innovative solutions using composites during the last decade. A recent innovative application developed by Acciona is the composite plate, an alternative to steel and concrete in the construction of high-speed railway tunnel infrastructure (**Figure 1**).

Figure 1. Left: construction plates' detail, Right: tunnel with construction plates solution.

In this chapter, we have described in detail three successful cases that demonstrate the use of the composite materials in the construction industry with emphasis on the technological challenges and the benefits provided by the composite materials.

2. First CFRP vehicular bridge designed, manufactured and installed in Spain

2.1. Introduction

This project consists of carbon fiber girder and concrete slab. Carbon fiber girders, the main element of this bridge, were manufactured off-site followed by quick transportation and easy installation at site using inexpensive easily available standard cranes, thanks to the lightweight properties of composite. Apart from lightweight, these materials also provide long life with almost negligible maintenance [20–23] (**Figure 2**).

The bridge is straight, with a 2% slope. It consists of four spans: two middle spans of 13.0 m and two end spans of 10.0 m, resulting in a total length of 46.0 m. The deck overall width is 8.0 m and has been constructed of three continuous beams of carbon fiber and a reinforced

Figure 2. Composite bridge in Asturias (Spain).

concrete slab. The deck is supported by 6.50, 6.62 and 6.75 m high columns. The bridge is composed of the following structural elements:

- The deck slab consists of a glass fiber preslab that supports a 20.0 cm thick reinforced concrete slab, with upper and lower rod mats, constructed of rods with a diameter of 16.0 mm, placed at 20.0 cm intervals.
- Three box girders have a trapezoidal cross section with: 1.2 m top, 0.8 m bottom, and 0.8 m web. The entire section of the bridge girder is a thin-walled carbon fiber laminated with 9 mm thickness at web, 7 mm at the top and 17 mm at the bottom. The core of the thin-walled beam is filled with polyurethane.

The reinforced concrete piers have a 2.0 m with 0.6 m cross section and are joined at the top by 8.0 m with 0.6 m rectangular capital, which supports the beams. This capital is the only support for the beams. The abutments have been constructed of traditional reinforced concrete, capable of accommodating the loads transmitted by the deck.

The girder-slab cross section, shown in **Figure 3**, consists of layers of low-modulus (140 Gpa), high-strength (~1.5% strain to failure) carbon fiber fabrics preimpregnated with epoxy resin.

The carbon fiber–reinforced polymer (CFRP) girder is manufactured by wrapping preimpregnated carbon fiber fabrics over the polyurethane mold, followed by application of vacuum for removing the air entrapped between the carbon fiber fabrics and finally application of hot air for curing the laminate. The cure cycle is adjusted in such a way that the final laminate exhibits a glass transition temperature (Tg) of more than 120°C.

To manufacture the top and bottom flange of the girder, precalculated layers of nonwoven carbon fiber fabrics were laminated along the principal girder axis (0° direction), and for the webs, nonwoven, unidirectional fibers alternately aligned at ±45° were wrapped over the polyurethane mold. The individual lamination layers laminated at 0° had a finished thickness

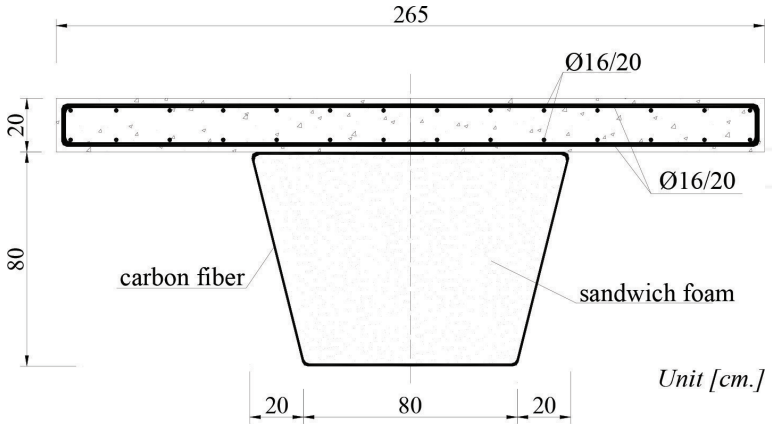

Figure 3. Section through the specimen at midspan.

of 0.59 mm, whereas the combined ±45° layers had 1.58 mm. For the top flange of the box beam, the layup is $[(0, \pm45, 0)]_2$, for the lower flange it is $[(0_5, \pm45, 0_2)]_2$, and $[\pm45_7]$ for the webs, and the layup order given is from the perimeter into the core. In addition to these, all four corners of the beam cross-section have 220 mm transition zones from the webs to the flanges: in the top flange, the configuration is $[(\pm45,0, \pm45, 0)]_2$, whereas at the bottom flange corners, it is $[(0_2, \pm45,0_3, \pm45, 0_2)]_2$. The bottom flange contains the highest percentage of unidirectional fibers (0°) in order to provide maximum strength in tension. The percentage of carbon fiber used in the top flange is lower as compared to the bottom flange as the concrete slab will carry the compression load.

An ambitious research, design, manufacturing, and testing process was followed in order to demonstrate the technical viability and cost-competitiveness of composites bridges. An integrated monitoring system was set up on the bridge for real-time strain and temperature data acquisition.

2.2. Experimental

2.2.1. Preliminary design and structural behavior test

2.2.1.1. Materials

In order to select the optimum material for the manufacturing of the bridge elements, laminates made with different materials and configuration were tested for mechanical, chemical, and physical properties. The test values obtained were later compared, and the optimum values were used in the design calculations. These tests were conducted at different government approved laboratories.

2.2.1.2. Connectors

For the bridge to perform well under load, it is inevitable to have a good connection between the CFRP girder and the concrete slab. Ten different types of connectors were tested using the pullout test, and these tests were performed using different connector design and the bonding system. Based on the test results, an Alkali resistance glass fiber pultruded profile was chosen as the connector. These pultruded connectors are easy to manufacture off-site and quick to install on site. This concept of connecting the concrete slab with CFRP girder is a technological innovation in itself being the first structural application.

2.2.1.3. Joining of bridge girders

The bridge was designed using long continuous girder to give it the total length of 46 m. For the ease of transportation from the manufacturing facility to the installation site, girders were manufactured in 10 and 13 m lengths, which means, in order to get a single long continuous girder of 46 m, two girders of 10 and 13 m need to be joined on site. A joining protocol was made, which consists of following steps: (i) preliminary treatment of the surface and (ii) placement of dry glass fiber fabrics over the CFRP girder, where they were impregnated with the resin. The joints were given precalculated taper in order to ensure gradual distribution of the

stress along the joint. Of a preliminary treatment of the surface, the use of an impregnation system with two different types of resin and the application of dry laminates were impregnated as they were placed on the beam. To complete the procedure, the joints were made with tapered laminates to ensure a gradual stress distribution in the joint. To better understand the joint behavior under the designed load, a series of tests were conducted. The test consisted in applying a pulling force to a specimen formed by the joining of two plates. After completing the pulling tests on joined laminates and knowing their behavior, a further flexotension test was conducted, on a reduced scale specimen (with a scale factor f = 3). In this test, another layer of laminate was added to the joint and was accepted as a final solution during the construction of the bridge.

2.2.1.4. Buckling tests

Two different buckling tests were carried out on the laminates, to ascertain their behavior, verify the current theories about the stability of orthotropic plates and quantify the effect of the polyurethane core.

In order to accommodate the two different types of tests, a device was developed to simulate the desired contour and the required load conditions. The first test was a uniaxial compression test, in which the load is applied to the top and bottom edges, while the unloaded edges of the specimen are constrained by knife-edge supports, constraining the out-of-plane displacement and rotation about the horizontal axis.

The second test consisted in applying a force along the plate's edge, thus simulating an instability caused by shear stress. The load is applied to a profile secured to the plate right edge. This load is applied until the plate becomes unstable. In this case, the plate is bolted to the edge profiles

2.2.2. Reduced scale test

Deflection, strength, and buckling are equally important aspects in the design of composite girders. As mentioned in the preliminary design, the deflection of a composite girder has two components, bending and shear, $\delta = \delta b + \delta S$. The bending deflection δb is controlled by the bending stiffness *(EI)* and the shear deflection δS by the shear stiffness *(GA)*. Shear deformations are neglected for metallic girders because the shear modulus of metals is high ($G \approx E/2.5$), but shear deformations are important for composites, because the shear modulus is low (about E/10 or less). The significance of the shear deflection δS with respect to the bending deflection varies with the span; the larger the span, the lesser the influence of shear (compared with bending).

In preliminary design, an average modulus of elasticity Ex can be easily obtained. Then, the geometry can be designed to achieve the required bending stiffness. Selecting laminates with high values of 0° layers yields the highest modulus Ex, but such laminate may have low shear modulus Gxy, which may result in unacceptable values of shear deflection. Also, a laminate with high values of 0° layers will have low shear strength Fxy which may be inadequate to carry the shear loads. The shear deflection is computed after the geometry has been finalized.

If the shear deflection is excessive, the laminate or the geometry will have to be changed. The shear deflection is controlled by the shear stiffness (GA) of the section. Selecting a laminate with higher values of ± 45-degree layers yields higher values of Gxy. The webs and flanges can be made with different laminates, like in the case of box-beam sections for bridge girders, trying to maximize EX on the flanges and Gxy in the webs. During the test, two-point loads were applied to a continuous beam, which simulates one half of a girder of the bridge. The load was applied by two 500.0 KN jacks, located in the middle sections of the girder spans. The test girders were 7.7 m long and had a trapezoidal cross section, with 26.6 cm edges, a 26.6-cm bottom base, and a 40.0-cm top base. This deck was a 6.6-cm thick and a 66.6-cm wide concrete slab. The concrete compressive strength was evaluated at 25.0 MPa.

The three test girders have the same geometry, but different fabric patterns, namely:

- The first girder has been constructed of a hybrid fabric: glass fiber and carbon
- The second girder has been constructed only of a carbon fiber fabric.
- The third girder has been designed as the second one but included a joining element to assess the structural behavior of the bridge beam joints.

After reviewing the results obtained from reduced scale test, the following conclusions were drawn:

The ultimate load transmitted to the girder does not result in a design constraint, as the bearing capacity of both the hybrid and the carbon girders exceeds the load requirements laid down by the design standard.

Deflection represents most important constraint. The hybrid girder is less rigid than the one constructed of carbon fiber only.

In the plane of the loads imposed, the carbon beam offers an excellent structural response and, from both the resistance and deformation points of view, meets the requirements laid down by the applicable standards.

The connectors placed between the girders and the concrete slab behaved as expected, with the box upper fiber and the concrete slab experiencing a similar strain. The joint provided by the connectors ensures a perfect transfer of stresses between the carbon fiber beam and the reinforced concrete slab.

Both fabrication systems for the scale girders (layup and preimpregnation systems) offer big fabrication advantages, but greater fabrication accuracy and higher quality levels are obtained through the use of the preimpregnation and curing process with controlled temperature and pressure, which have proved more cost-effective.

2.2.3. Final test

The purpose was to check, using real dimensions, the behavior of the assembly made up of the concrete slab and the polymer girder reinforced with carbon fiber.

The final test was carried out in a loading rig that was devised to generate both positive and negative bending moments varying along the bridge length in accordance with the loading

protocol and design specifications in order to meet the requirements of the Spanish building codes as prescribed by the Ministerio de Fomento, which were RPX 1995 (design recommendations for composite-action highway bridges), IAP 1998 (prescriptions for loading protocols of highway bridges), and EHE 1998 (prescriptions for structural concrete).

The composite structure consists of the concrete slab and the thin-walled carbon fiber laminated girder. The reinforced concrete slab is 20.0 cm thick and 2.70 m wide. The concrete compressive strength is 25.0 MPa. The slab reinforcement is provided by bars with a diameter of 16.0 mm, placed at 20.0 cm intervals. The thin-walled laminated girder was laminated by hand layup on a polyurethane mold. This mold offers greater stability to sides and flanges and represents the so-called lost formwork. Similarly, provision has been made for a vertical diaphragm on the supports, to help transmit the shear loads to the support. In order to prevent any eventual buckling, the bottom flange has been provided with horizontal, sandwich type, stiffeners around the compression areas. In order to assess girder behavior, measurements of strain were taken along three sections of the girder using sensors and measurements of deflections by means of vertical clamps.

2.3. Conclusions

On the basis of the results obtained from the test, through the use of extension-meters and gauges, transducers and inclinometers, the following conclusions are drawn:

The girder meets the rigidity requirements (l/600 = 22.0 mm.), because during the test and under working loads, the displacement measured was 14.0 mm.

The joints between girders meet the design load requirements, because, due to the typology of the test, the joint section was subjected to the maximum positive moment, with an accompanying shear load greater than the maximum to be withstood by the structure. Given the fact that the strains at the joints are considerably smaller than the ones tested, an excellent behavior of the joints is guaranteed.

The strains experienced during the tests are 15% below theoretical values.

The stresses generated within the structure were 1.6 times greater than the increased design loads, offering an overall safety coefficient of 2.4.

As a consequence of the positive results achieved in this bridge, ACCIONA has built two more bridges in the recent years. All these cases demonstrate that the use of FRP girders for this type of bridges results to be competitive in comparison with the traditional steel/concrete solutions.

Of the other two bridges, the first one (twin bridges) situated in Madrid, and built in 2007, is characterized by three simple supported spans of 10, 14 and 10 m and a 20.40-m-wide box-girder deck. The deck girder is manufactured with a reverse "Ω"-shape cross section). Each of the girder is then made close connecting its top flange to a sandwich panel for the whole length of the girder. The sandwich has a polyurethane core and glass-fiber skins (**Figure 4**). The bottom flanges of the girder are made by hybrid glass-carbon fiber laminates with the considerable amount of the fibers oriented along the girder axis. The girder webs are made of sandwich panels with polyurethane core and glass fiber skins. Since the webs must essentially

Figure 4. M111 bridge (Madrid, Spain).

sustain external shear forces, the great amount of the fibers is placed so as to form angles equal to ±45° with the girder longitudinal axis. In order to increase the torsional rigidity of the girder beams, a number of transversal diaphragms are placed along the girder beams. These diaphragms also have a sandwich structure.

In the year 2013, Acciona Construction designed and manufactured a Fiber Reinforced Plastic road bridge which was installed in Gabon (Africa) in 2014. The bridge girders, originally designed in steel reinforced concrete, were redesigned, employing FRPs to take advantage of the lightweight of these materials and the ease of off-site prefabrication.

The bridge deck, with a span of 17.00 m and a width of 6.00 m, is formed by two simply supported FRP girders with an overlying 0.25-m-thick concrete slab reinforced longitudinally and transversal with FRP bars. The FRP girder has a U-shape cross section with a maximum width of 2600 mm and a depth of 1150 mm. The top flanges are 450 mm wide, and the bottom flange is 1200 mm wide. The top flanges and the webs have a thickness of 37 mm, while the bottom flange is 35 mm thick. A sandwich panel is adhesively connected to the top flanges of the girder to be used as a formwork during the concrete slab casting. To increase the torsional stiffness of the girder and prevent shear-bending buckling of its webs, six transverse stiffeners are placed along the length of the girder. The girder is connected to the top reinforced concrete slab through FRP shear connectors (**Figure 5**).

Figure 5. Iboundji bridge (Gabon, Africa).

As general conclusions, these composite bridges offer more design freedom. Compared with a concrete girder, which requires 28 days just for curing, the composite girder was ready for shipping in 15 days. No painting is required on these FRP girders. They are easy to transport, quick and easy to install on sites where high-capability cranes are not available. They provide better corrosion resistance than concrete and steel in coastal areas and require less maintenance.

3. First stress-ribbon pedestrian bridge in Spain

3.1. Introduction

In 2011, ACCIONA construction was involved in the design and construction of a stress-ribbon pedestrian bridge [23–26]. "Stress-ribbon bridge" is the term that has been coined to describe structures formed by directly walked prestressed concrete decks that have the shape of a catenary [26]. Their resisting structures consist of slightly sagging tensioned cables normally embedded in a concrete slab, which provides them a certain amount of bending stiffness, guaranteeing the distribution of local loads and the stability of the overall shape. The cables, which

are normally made by steel, for the present bridge, were manufactured using a carbon fiber reinforced polymer material. Thanks to their low-specific weight (1.6 g/cm^3), these cables can easily be pulled from one abutment to the other and, since they do not suffer from galvanic corrosion, they are expected to be more durable than steel cables.

The pedestrian bridge, with a total length of 216 m, has three continuous spans of 72 m each. A 0.25-m-thick reinforced-concrete slab, supported by 16 CFRP cables, forms its cross section. After the construction of the abutments and piers of the bridge, the CFRP cables were pulled from one abutment to the other, using a set of guide wires, and anchored to the abutments. The cables were then tensioned one by one, using a hydraulic jack, until reaching an axial load level of 700kN. A series of prefabricated reinforced concrete slabs were then positioned side by side on top of them to form the bridge deck and loaded with big bags full of sand. With the cables tensioned by the weights of the big bags, concrete was poured in the joints between adjacent slabs. Once the concrete had hardened in the joints, the sand bags were removed unloading the cables that, trying to change their configuration, induced compressive stress in the concrete deck. In this way, it was possible to prestress the deck without embedding the cables in it.

The CFRP cables employed in the construction of the pedestrian bridge, with a diameter of 42 mm and fish-eye terminations at both their ends, are covered by an aramid sleeve to protect them from possible damage induced by accidental collisions with sharp-edge objects during their installation.

These cables were manufactured fixing two stainless steel rings at a relative distance equal to the final length of the cable and wounding preimpregnated carbon fiber tow around these two rings, in a configuration similar to that of a belt and a pulley system. The whole bundle of preimpregnated carbon fiber filaments is wrapped with a thermo-shrinkable film, which is then heated up to consolidate the cable cross section and give it a circular shape. Eventually, the cables are placed in an oven to cure the epoxy resin. In proximity of their ends, the cables separate in two halves to go around the steel rings, which have an outer diameter of 108 mm. The angle formed between the two halves of the cables, equal to 18°, is fixed, during the manufacturing process, inserting a polyurethane wedge between the two halves and wounding preimpregnated carbon fiber tow around the cable just after the point at which the two halves separate, in order to prevent the splitting of the cable once, it has been loaded (**Figure 6**).

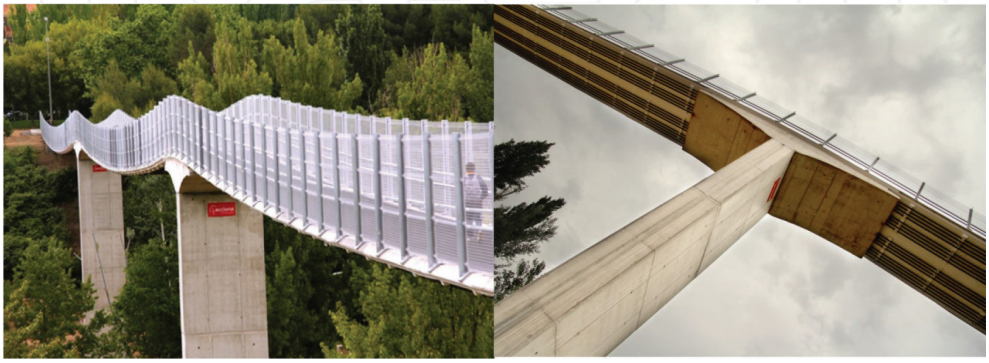

Figure 6. Left: Cuenca footbridge, Right: detail of the cables used.

The possibility of using them in a pedestrian bridge was considered a good chance to gain knowledge about their behavior in view of their future application in the construction of suspended and cable-stayed bridges. This type of composite material cables is nowadays popular in sailboats rigging. The cables used in the construction of the present pedestrian bridge have diameters much greater than those of the cables currently employed in sailboats, since the magnitudes of the loads the cables need to resist are sensibly different for these two applications. Due to the novelty of the use of this type of cables in bridge construction and the considerable difference existing between their diameters and those of the cables normally produced for sailboats, it was decided to carry out a series of tests to assess their mechanical behavior.

3.2. Experimental

3.2.1. Tensile tests on the cables

Three cables, named SP1, SP2 and SP3, were submitted to tensile tests to assess their axial rigidity, their strength and to investigate the mechanical behavior of the laminates used to wrap their ends.

3.2.1.1. Experimental setup

The tensile tests were carried out using a horizontal servo hydraulic machine. This machine, specifically designed for testing cables, has a maximum load capacity in tension of 3000 kN and can accept specimens with a length up to 6 m. The machine can only measure and record the load applied to the specimen and the displacement of its moving head. To evaluate the longitudinal strains induced in the cables, two electric strain gages were glued on each of them, at two diametrically opposed points of their midspan section. The strain gages were applied directly on the CFRP cable surface, after the removal of the aramid sleeve and the thermal-shrinking film. Four more strain gages were applied to one end of the cable SP3, two in the longitudinal direction of the specimen and two in the circumferential direction, to evaluate the mechanical behavior of the laminate wrapping the cable end. The signals coming from the strain gages were digitalized and recorded using two strain indicators and recorders.

All the tests were performed under force control with a constant loading rate of 3080 N/s. Cables SP1 and SP2 were submitted to three load cycles between zero and the cable service load, 900 kN, and three load cycles between zero and the expected ultimate load of the cables, 1600 kN. If after these six cycles the specimen had not failed, the load was monotonically increased until reaching the cable failure. Cable SP3 was submitted to monotonically increasing load up to failure.

For all the tested cables, the values obtained for their axial rigidity were close to 170 MN, and their failures were explosive and always started from one of their ends. It can be noticed that, initially, for values of the applied load lower than 500 kN, the cable core and the surrounding laminate act as a solid section: the tensioned cable core, due to the Poisson effect, tends to contract transversally inducing circumferential compression strains in the surrounding laminate. Then, as the applied load increases, the cable core partially detaches from the laminate as shown by the fact that the value registered by one of the circumferential strain gages suddenly goes to zero. In other words, the tensile strength of the resin layer existing between the cable

core and the surrounding laminate is locally overcome by the radial tensile stress acting in this region of the cable. As the load continues to increase, the surrounding laminate starts to be tensioned by cable core that tend to split.

3.2.2. Finite element model

A finite element (FE) model was implemented in ANSYS® to analyze the behavior of the CFRP cables. Only one half of the cable was modeled, since the cable specimen is symmetrical. Solid 3D elements (SOLID186) were employed to model the cable: orthotropic material properties were assigned to the elements which model the CFRP cable, while isotropic material properties were assigned to the elements which model the steel ring. CFRP material properties were estimated using the Micromechanics Theory moving from the properties of the basic materials, e.g., epoxy and carbon fiber, provided by the suppliers and the results of thermogravimetric tests carried out on specimen SP0. Special shell elements TARGE170 Y CONTA174 were used for modeling the surface contact between the CFRP cable and the steel ring. The polyurethane wedge was not modeled, since it does not have any structural function. It can be observed that at the points where the two halves of the cable touch the steel rings the longitudinal strains attain the maximum value of 1.55%, which is close to the ultimate strain value given for the carbon fiber by its supplier. For the same value of the applied load, the value given by the FE model for the longitudinal strains at the cable midspan is equal to 1.02%, which is close to the values registered experimentally in correspondence to the cable failure. These results agree with the experimental observation that the cables always failed at one of their terminations.

With the aim of reducing the difference between the values of the longitudinal strains at the cable termination and those at the cable mid span, the effect of increasing the outer diameter of the steel ring, keeping constant the distance between the center of the ring and the point at which the two halves of the cable separate, was analyzed through the implementation of other 2 FE model models. In these two models, the outer diameter of the ring was set equal to 152 and 196 mm, values that correspond to an angle between the two halves of the cables of 25 and 32°, respectively. In correspondence to an applied load of 1600 kN, the maximum longitudinal strains at the cable termination obtained from the numerical simulations were 1.48% and 1.50%, respectively. It is apparent that no improvement of the cable strength is obtained following this approach.

3.3. Conclusions

It could be concluded that the results of tensile tests carried out on three cable samples exhibited linear elastic behavior up to failure. In all the examined cases, the cable failure was explosive and happened at one of its ends.

The results in terms of longitudinal strains obtained through a FE model of the cable showed a good agreement with the experimental values.

The change in the longitudinal strains at the cable termination due the variation of the angle between the two cable halves was numerically investigated. The results indicate that the strain values are not very sensitive with respect to the variation of this angle.

Figure 7. Almuñecar footbridge.

Related with this kind of infrastructures, ACCIONA has designed and built Almuñécar footbridge in 2010 in Madrid to substitute an old reinforced concrete footbridge crossing the Manzanares river. It has a span of 44 m and a width of 3.5 m. The girder, completely made of carbon fiber, presents a series of longitudinal and transversal stiffeners to be able to accomplish with the challenging architectural and structural requirements: a girder with a depth not greater than 1.20 m and with its inner surface completely covered with prefabricated reinforced concrete slabs. The girder was fabricated in at a manufacturing facility on the outskirt of Madrid, transported to the worksite during the night, and installed in less than 1 h. Before the placement of the concrete slabs on its inner surface, both the girder's ends were enclosed in their respective abutments, restraining in this way their rotations and controlling their deflection at the middle (**Figure 7**).

4. First composite lighthouse in the world

4.1. Introduction

A lighthouse, 32 meters high and entirely made of fiber reinforced polymers, was designed and manufactured by ACCIONA and was installed in only 2 h in the north extension of Valencia Port (middle east of Spain), in February 2015 [19–24]. This five-story structure, which weighs 19 tons, is formed by eight-carbon FRP circular hollow columns made by pultrusion and positioned at the vertices of an octagon. The five storeys are glass FRP and polyurethane octagonal sandwich panels made by resin infusion. An FRP spiral staircase is placed in the center of the structure, going from its base to its top. To increase the lateral stiffness of the structure, between each couple of consecutive storeys, its carbon FRP columns are connected along the structure perimeter by horizontal glass FRP pipes which form in this way four octagonal rings.

The lighthouse **Figure 8** is a five-storey structure supported by eight carbon FRP circular hollow columns whose center lines, at the lower storey, pass through the vertices of an octagon inscribed in a circumference of 4.15 m diameter and, at the upper storey, through those of an octagon inscribed in a 3.75-m diameter circumference. These 32 m long columns, manufactured by pultrusion with epoxy resin, have an outer diameter of 250 mm and a wall thickness of 20 mm. The five storeys, manufactured by resin infusion with vinylester resin, are 200-mm thick sandwich panels with 10-mm thick glass FRP skins and a polyurethane core with a density of 70 kg/m^3. The storeys are placed every 6 m, and each one has a different octagonal geometry depending on its position in the structure. A spiral staircase is placed in the center of the structure, going from its base to its top. The steps are manufactured by RTM and have a sandwich structure made of glass FRP skins and a polyurethane core. Each step has a 200-mm rise and is formed by a ring with 500 mm inner diameter connected to a 900-mm-length trapezoidal platform, with a variable tread width. The step rings, vertically aligned along the lighthouse central axis, form a cylindrical space which is filled with reinforced concrete, providing a stiffening core to the structure. To increase the lateral stiffness of the structure, the carbon FRP columns are connected by four octagonal rings placed between each two consecutive storeys. Each of these rings is formed by eight glass FRP pipes placed along the structure perimeter. The glass FRP pipes, manufactured by pultrusion, have an outer diameter of 190 mm and a wall thickness of 20 mm. The connections between columns and the horizontal glass FRP pipes are made by FRP rhomboidal diaphragms having a thickness of 42 mm

Figure 8. The FRP lighthouse (Valencia, Spain): Left: lighthouse detail, Right: general view of the lighthouse in Port of Valencia.

The base of the lighthouse is a 4-m-high reinforced concrete box with an octagonal prismatic shape. The lower ends of the lighthouse columns are embedded in the 1.10 thick box's bottom slab. The 0.35-m reinforced concrete slab which forms the box ceiling is perforated to permit the eight carbon FRP columns and the central reinforced concrete core to pass through it. Neoprene bearing collars are placed between the FRP columns and this concrete slab to restrain the horizontal displacement of the columns at this level. Before the lighthouse was commissioned, final tests were conducted to ensure it met load and wind requirements.

In the marine environment, to minimize maintenance costs, the use of FRP materials for the construction of durable and lightweight civil structures is an attractive and promising alternative to traditional materials, such as steel or steel reinforced concrete. Because of the particular mechanical behavior of FRP structures and the increased interest on this technology, many experimental and numerical research projects have been carried out in the last years, most of them focused on the static response of FRP structures but very few in the field of dynamic response. In the case of the FRP lighthouse, the flexibilities of the connections between structural elements have an important influence on the flexural-torsional vibration response of the structure, so an adequate numerical model can be calibrated based on the experimental results from free vibration testing.

4.2. Experimental

Because of the particular mechanical behavior of FRP, a study of dynamic response of the lighthouse has been carried out. The flexibilities of the connections between structural elements have an important influence on the flexural-torsional vibration response of the structure, so an adequate numerical model can be calibrated based on the experimental results from free vibration testing [27].

4.2.1. Numerical simulation

A three-dimensional finite element model of the whole structure is developed using SAP-2000 v16.1.1. The carbon FRP columns, the glass FRP pipes, and the central core column are modeled with frame elements, while the storeys and the rhomboidal diaphragms are modeled with shell elements. Each column is fixed at its base, while its contact with the top slab of the concrete box is modeled with a set of linear elastic springs radially connected to the column frame elements and having a stiffness equivalent to that of the neoprene bearing collar. Although carbon FRP columns and glass FRP pipes are orthotropic materials, the transverse elastic modulus E_y is not used in the model since these parts are modeled with frame elements. The spiral staircase steps are not modeled since it is assumed they do not contribute to the stiffness of the structure. Nevertheless, their masses are considered adding them to the frame elements. The mechanical properties of each element are determined experimentally through static tests. A modal analysis of the numerical model of the structure is carried out to obtain the vibration modes and the corresponding frequencies, with the aim to compare them with those measured experimentally.

4.2.2. Experimental test

Three months after the installation of the lighthouse, wind-induced vibrations in the structure are recorded by a set of accelerometers strategically placed to determine its dynamic

response. Eight unidirectional *DeltaTron Accelerometers Type 4508* are used, connected to its corresponding data logger *Brüel&Kjær LAN-XI 51.2 kHz - Type 3050*. At each storey, but at the lowest one (S1), two unidirectional accelerometers are placed, one oriented along X-axis and the other oriented along Y-axis.

At storeys S3, S4, and S5, each pair of accelerometers was fixed to a 5-kg steel block placed on the storey top surface near one of the carbon FRP columns. At storey S2, the accelerometers are fixed to small L profiles bonded to the storey top surface near the center of the structure.

Different data records are registered in order to compare the results of each measurement to detect possible random differences between them. The experimental vibration frequencies are determined by the fast Fourier transform (FFT), which converts the accelerations recorded in the time domain to the frequency domain. The measurements are made with a sampling frequency of 100 Hz. The choice of this frequency for data processing is set after analyzing several measurements with a higher initial frequency and after the observation that there are no excited frequencies in the structure higher than 50 Hz. As an example, **Figure 5** shows the registered accelerations and the corresponding Fast Fourier Transform for the pair of measuring points (X-axis and Y-axis) in storey S2 during one of these data records. After processing all the data records, the first ten frequencies are almost the same in most measurements with very little differences between them, so it can be assumed that the first 10 global modes of vibration of the structure correspond to these excited frequencies.

4.2.3. Results of the test

The experimental analysis carried out based on acceleration measurements has proven to be a good technique to obtain useful information about the structural behavior of the lighthouse from the free vibration of the structure. The analysis of the wind-induced accelerations by FFT identifies the first five modes of vibration of the structure, and the corresponding experimental frequencies are 1.309, 2.979, 3.922, 6.178, and 9.307 Hz. The frequency analysis is completed with a finite element model, with frequencies very close to those obtained experimentally. This model allows identifying the experimental modal shapes, where the first mode corresponds to the first flexural mode and the second one to the first torsional mode, being the following modes the second, third, and fourth flexural modes, respectively.

4.3. Conclusions

The main benefits of using composite materials in this project were:

- Quicker completion of construction work: the total manufacturing and installation time of the lighthouse is 40% lower than with the traditional process.
- Lower impact on port operations: apart from the fact that the total time of building the lighthouse is shorter, the time the port is affected is also much less because the assembly of the structure was done in the factory. This also means a smaller surface area and a shorter occupation time in the port, and less waste and noise in comparison with the work normally involved in the construction of a lighthouse.

- Longer working life of the lighthouse: one of the main advantage of using fiber glass or carbon fiber composites in harsh environmental conditions is that they are not affected by corrosion. This makes them very attractive for use in damp or marine environments; lighthouses built with traditional materials usually suffer considerable degradation, which leads to a shorter working life.
- Reduction in construction and maintenance costs: the use of composites is more efficient in economic terms because the construction process is faster, and there is less need for the transport of materials. Furthermore, by resisting environmental conditions better, the lighthouse does not require investments in maintenance.
- A reduction of CO2 emissions in the construction process, due to fewer transfers of heavy materials and a lower level of extraction of aggregates. The environmental impact is believed to be 20% lower when using composites instead of traditional materials.

5. General conclusions

With all these successful cases and the respective outcomes, we conclude that composites (FRP) offer better performance as compared to traditional steel and concrete materials, especially in corrosive environments, in sites with limited access, in conditions requiring quick and fast installation and where aesthetic differentiations are required.

Acknowledgements

The authors wish to express their gratitude to the members of the Infrastructure Area at the ACCIONA Construction Technological Centre, for their contribution to the success of this chapter.

Author details

Pilar Górriz*, Anurag Bansal, Carlo Paulotto, Stefano Primi and Ignacio Calvo

*Address all correspondence to: mariapilar.gorriz.ramon@acciona.com

ACCIONA Construction Technological Center, Alcobendas, Madrid, Spain

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INTECH

Chapter 4

Importance and Ranking Evaluation of Cost Overrun Factors for Oil Transmission Pipeline Projects

Pooneh Saidi

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/67542

Abstract

Over the recent years, the cost escalation in oil pipeline projects in Iran has been inevitable due to the political and economic conditions. On the other hand, due to Iran's 20-year vision plan, several projects and plans have been defined by National Iranian Oil Company (NIOC); therefore, to achieve the vision plan's goal and deliver the projects on-budget, identification of the cost overrun causes is the first step. In this research, a list of important cost overrun factors in oil pipeline projects was extracted after a detailed literature review, study the executed projects document, semistructured interview, and a questionnaire survey among clients, consultants, and contractors who are involved in such projects. The results show that the political and economic sanctions, rise in the price of material, delay in payments, unrealistic price proposal to win the tender, inflation, change in orders/extra works, type of bidding award, delay by vendors/suppliers, slow speed in obtaining permits/massive bureaucracy, and unrealistic time and cost estimation are ranked in the top ten cost overrun factors.

Keywords: project management, project delay, cost overrun, oil transmission pipeline

1. Introduction

Being a member of the Organization of Petroleum Exporting Countries, Iran ranks fourth in the world's oil reserves with total oil reserves of 154 billion barrels which amount constitutes 10 percent of the world's oil reserves and over 12 percent of the existing oil reserves of the OPEC (Organization of the Petroleum Exporting Countries). Iran also has signed agreements in the format of Swap with Azerbaijan, Kazakhstan, and Turkmenistan since 1997 that in this case, transmission pipelines play an important role. These instances are indicative of the importance of the oil industry in the economic sector and hence the growth and development of Iran. According

to the twenty-year vision plan of the oil industry, Iran plans to keep the second rank of oil producer within the OPEC and supply over 12% of the world's oil production by the end of the 2025. The share of the increase in the domestic demands by the year 2025 should be considered [1]. Therefore, in order to achieve these goals, the National Iranian Oil Company (NIOC) has defined several projects and plans in which some have been completed, a number are at hand and some have not yet been commenced. But the point worthy of this is that based upon the existing reports (project progress reports, coordination minutes of meetings, and the NIOC publications), most of the projects are facing delay and cost overrun as compared to the amount forecasted. Project finishing on time and absence of cost overruns are considered the most critical factors in projects success. According to the PMBOK (Project Management Body of Knowledge) 5th edition [2], project is successful if it achieves the triple objective outcome of within time, scope, and quality. Also many researchers have been trying to discover which factors lead to project success, according to their research, most of them imply that cost, time, and quality have become inextricably linked with measuring the success of project [3–6]. Unfortunately, due to various reasons, many projects experience time and cost overrun. Delay of project in any type, such as excusable/concurrent/compensable and critical, leads to qualitative and quantitative cost escalation. The quantitative costs consist of such cost as the lost profit, escalation of costs, and the cost of the interest of the capital spent, which are easily calculable through principles as engineering economics; while qualitative costs are not visible and cover such instances as the loss of the company's creditworthiness, losing the competitive market and as well the loss caused due to the reduction in the government revenues. This is especially true in Iran due to the resistive economy policy that is proposed by the government. These are indicative of the importance of identification the factors having impacting effects on the time and cost at the early stages of the project.

2. Literature review

In the many studies conducted on causes of time and cost overrun in projects, both locally and internationally have been reviewed. Most of the researchers focused on construction projects, and few studies have been done in oil, gas, and petrochemical projects and also very few research in Iran. Some of the previous studies were presented below:

Kaliba et al. identified the most important causes and effects of cost escalation and schedule delays in road construction projects in Zambia. They concluded that bad weather and heavy rains which lead to floods was the number one cause for cost escalation, also scope of work changes, environmental protection and mitigation costs, schedule delays, strikes, local government pressures, technical challenges, and inflation were found to be next major contributors to cost escalation [7].

Fallahnejad extracted 10 major delay factors in Iran gas pipeline projects by investigation 24 executive gas pipeline projects, according to the result, the five major factors are as follow: low ability of contractor to import material, unrealistic project durations imposed by owner, slow delivery of material by owner, slow land expropriation due to resistance from occupants, change orders, and extra works [8]. Sepehri analyzed the time delay factors in Iran and emerging countries. He studied the south pars gas project in Iran and founded that the most important

http://dx.doi.org/10.5772/67542

causes of delay refer to planning phase [9]. Yang and Wei (2010) concluded that the most important cause of projects delay is "changes in owner's requirement" [10]. Lu et al. identified and analyzed the hidden transaction costs in project dispute resolutions. They identified the major variables of the hidden transaction costs and grouped them into five factors: reputation, cooperation/trust, emotion, time, and judgments. Based on the result, lack of future cooperation, contractors' reputation damage, and delayed recovery of money are the two most important variables, while for owners, project delay is the most severe hidden transaction cost [11]. Mansfield et al. studied the causes of time and cost overrun in Nigeria construction projects. Based on their research, the five main causes come from poor contract manager, financing and payment of completed works, changes in site conditions, shortage of materials, and improper materials and plant items [12]. A study to identify the factors influencing construction time and cost overruns on high-rise projects in Indonesia has been done by Kamin and Olomolaiye. Results of their study show that the main extra cost factors are raw materials costs, increase in inflation rate cost, inappropriate estimation of the required raw materials, and complexity of the project [13]. Assaf and Al-Hejji identified the causes of delays in construction in Eastern Province of Saudi Arabia. The results show that 70% of projects experience time overruns due to the various factors but the most common cause of delay identified by owner, consultant, and contractor is change order [14]. In building construction industry, based on Ahmed et al. research, consultants play a very important role in design-related delays and also delay in payments has effective impact on project completion times [15]. Sambasivan and Soon assessed the time over run in construction projects in Malaysia. The author presented ten most important causes of delay as follow: contractor's improper scheduling, poor site management, inadequate experience, delay in owner's finance and payments, problems with subcontractors, shortage in material, labor supply, failure of equipment, lack of communication between parties, and mistakes during the construction stage [16]. Faridi and El-Sayegh conducted a survey to evaluate the top-ten delay causes in the UAE construction industry, they point out that the major causes are related to preparation and approval of drawings, inadequate preplanning, and slow decision making by owners [17].

3. Methodology

In this study, five oil transmission pipeline projects, which have been executed by National Iranian Oil Company (NIOC) during 2000 to 2014, have been investigated. Based on project documents and also literature review, a comprehensive long list of cost overrun causes was prepared. The factors influenced cost overruns in projects were reviewed, modified, and finalized after semistructured interview and discussion by eight project team members who have more than 20 years' work experience, including one procurement manager from contractor, three project coordinators from owner, consultant and contractor, one contract engineer from consultant, and one financial manager from contractor. The final list of causes was reduced to 42 causes; these factors were categorized into five groups depending on their nature and mode of occurrence (See **Table 1**). Based on the final list that contained 42 cost overrun causes, a questionnaire was developed and sent to the respondents to evaluate the frequency of occurrence and severity of each identified causes.

Category	Factors
Client	KF01-Unrealistic time and cost estimation
	KF02-Delay in payments
	KT03-Poor feasibility study
	KT04-Change orders/extra work
	KT05-Incomplete design package during the tender
	KL06-Late land expropriation
	KP07-Delay in material delivering being client's obligation
	KP08-Slow decision making
	KP09-Change in management layer
	KH10-Lack of experts
	KC11-Ambiguity & conflict in contract
	KC12-Contract type
	KC13-Improper executive methods in contract
	KL14-Bidding method
	KL15-Slow speed in obtaining the permits/massive bureaucracy
	KR16-Poor coordination
	KR17-Poor communication
Contractor	PF01-Low technical capability/breakdown & shortage of equipment
	PF02-Delay in subcontractor's payment
	PF03-Propose unrealistic price to win the tender
	PF04-Contractor poor cash flow/financial problem
	PF05-Poor subcontractor performance
	PM06-Poor project management
	PM07-Project risk identifying
	PM08-Nonavailability of daily/weekly/monthly plan
	PM09-Weakness planning and scheduling
	PH10-HSE problems
	PH-11-Lack of expert labor/redundancy of works
	PH12-Change in material specification during the construction phase
Consultant	MT01-Weakness in design/slow in reviewing and approve the documents
	MM02-Poor supervision on schedule
	MM03-Delay in checking the contractor invoices
	MH04-Lack of skill on technical & contractual executive issues
	MH05-Poor management/lack of experts

http://dx.doi.org/10.5772/67542

Category	Factors
Vendor	VT01-Delay by vendors/suppliers
	VP02-Material shortage
External issues	SE01-Economic & political sanctions/low capability in procurement
	SE02-Rise in the price
	SE03-Weather condition/force majeure
	SE04-Change of government/priority of projects
	SE05-Inflation
	SE06-Change in low & regulations

Table 1. The factors influenced cost overruns in projects.

3.1. Questionnaire design and content validity

Four experts, whose characteristics are shown in **Table 2**, reviewed the preliminary questionnaire. The table shows extensive experience of the reviewer to modify and verify the questionnaire. Based on the result of the reviews, some modifications to general questionnaire format, text type, size, and wording of the paragraphs were suggested. Also some new items such as respondents' experience range and average of projects executed per year were added to the questionnaire. The questionnaire is divided into two sections: section I is related to general information about the companies, and section II includes the list of the identified causes of cost overrun. These causes are classified into five groups according to the source of problem: causes related to owner, contractor, consultant, and vendor/supplier and external issues. For each cause, two questions were asked: (1) what is the frequency of occurrence for this cause? and (2) what is the degree of severity of this cause on project cost overrun? Both parameters were scored on a five-point scale from 1 to 5; rating the factors with 1, representing the least condition, and 5, representing the highest condition (Likert Scale).

3.2. Research population

The population of the present research was categorized in three groups: the contractors, consultants, and owners in oil, gas, and petrochemical fields. The respondents of the owner were selected from the team members of four NIOC active projects. According to the Management

Position	Experience (years)	Organization
Assistant Professor	20	University
Chairman of the board/Engineering Manager	40	Consultants
Project Manager	36	Owner
Project Manager	30	Contractor
Procurement Manager	27	Contractor

Table 2. Characteristics of the questionnaire reviewed experts.

and Planning Organization of Iran (MPO), the contractor and consultant companies in Iran are classified into five and three classes, respectively, based on their performance in several fields: execution/experience record, company size, capital, assets, and qualifications of the technical staff. The authors considered contractors and consultant companies from class 1 (first class). The selected respondents for contractors were from among those companies being registered with the Association of Petroleum Industry Engineering and Construction companies (APEC), the consultant companies were those being members of the Iranian Society of Consulting Engineers and also both have cooperated with NIOC in pipeline projects. One hundred and seventy-five questionnaires were sent to the companies via email, fax, or post. One hundred and eleven questionnaires were returned by responses and after eliminating incomplete questionnaires; finally, 90 properly completed questionnaires were returned, yielding 51.4% responses. **Table 3** illustrates the statistic data of the questionnaire distribution and respondents' characteristics. The response rate for the questionnaire survey was 53.3%, 58.3%, and 47% for client, consultant, and contractor, respectively. As the response rate shows consultants had the maximum collaboration.

3.3. Ranking the causes

To calculate the ranking of cost overrun causes in terms of occurrence, severity, and importance from the view point of owner, consultant, and contractor, the method that was used by Le-Hoai et al. (2008), Alinaitwe et al. (2013), and Romuald-Kokou et al. (2013) has been followed [18–20]. The indices are obtained by the following formula:

Characteristics		Organization			
		Owner	Consultant	Contractor	Total
Sent	No.	15	60	100	175
	Percent	8.6%	34.3%	57.1%	100.0%
Received	No.	8	35	47	90
	Percent	8.9%	38.9%	52.2%	100.0%
Response rate	Percent	53.3%	58.3%	47.0%	51.4%
Gender	Male	15 (100%)	32 (91.4%)	100 (100%)	147 (98%)
	Female	0	3 (8.6%)	0	3 (2%)
Experience (years)	5–10	0	1 (2.9%)	7 (14.9%)	8 (8.9%)
	11–15	1 (12.5%)	8 (22.9%)	5 (10.6%)	14 (15.6%)
	16–20	2 (25.0%)	7 (20.0%)	18 (38.3%)	27 (30.0%)
	20+	5 (62.5%)	19 (54.3%)	17 (36.2%)	41 (45.6%)
Education	B.Sc.	6 (75.0%)	21 (60.0%)	41 (87.2%)	68 (75.6%)
	M.Sc.	1 (12.5%)	12 (34.3%)	4 (8.5%)	17 (18.9%)
	Ph.D	1 (12.5%)	2 (5.7%)	2 (4.3%)	5 (5.6%)

Table 3. Questionnaire statistics.

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Severity index is used to rank causes of cost overrun based on severity as indicated by the participants.

$$(\text{S.I.}) = \frac{\sum a_i s_i}{5N} (i \text{ from 1 to 5}) \quad (1)$$

a_i is the weight assigned to each response (ranges from 1 for not at all to 5 for extremely),

s_i is the severity of the impact,

N is the number of total respondents.

Severity index calculate through formula (1) for each factor and rank. The results are presented in **Table 4**.

Frequency index is used to rank causes of cost overrun based on frequency of occurrence as identified by the respondents.

$$(\text{F.I.}) = \frac{\sum a_i f_i}{5N} (i \text{ from 1 to 5}) \quad (2)$$

a_i is the weight assigned to each response (ranges from 1 for never to 5 for always),

f_i is the frequency of each response,

N is the number of total respondents.

Category	Factors	Client		Consultant		Contractor		Overall	
		S.I.	Rank	S.I.	Rank	S.I.	Rank	S.I.	Rank
Client	KF01	0.85	11	0.83	8	0.85	3	0.840	3
	KF02	0.78	18	0.84	6	0.91	1	0.87	2
	KT0	0.68	33	0.64	33	0.50	33	0.57	32
	KT04	0.75	23	0.74	22	0.74	15	0.74	16
	KT05	0.78	18	0.62	34	0.39	41	0.52	39
	KL06	0.80	15	0.69	29	0.77	10	0.74	17
	KP07	0.83	13	0.81	12	0.74	13	0.78	13
	KP08	0.80	15	0.79	14	0.70	20	0.74	14
	KP09	0.58	41	0.61	36	0.46	37	0.53	38
	KH10	0.70	32	0.69	28	0.57	29	0.63	28
	KC11	0.65	35	0.59	38	0.42	40	0.50	41
	KC12	0.73	28	0.57	40	0.49	35	0.54	36
	KC13	0.73	28	0.58	39	0.43	38	0.52	39
	KL14	0.90	4	0.85	5	0.75	11	0.80	9
	KL15	0.80	15	0.72	25	0.72	18	0.73	18
	KR16	0.65	35	0.71	26	0.73	17	0.72	20
	KR17	0.75	23	0.66	32	0.73	16	0.70	24

Category	Factors	Client		Consultant		Contractor		Overall	
		S.I.	Rank	S.I.	Rank	S.I.	Rank	S.I.	Rank
Contractor	PF01	0.90	4	0.79	15	0.68	21	0.74	15
	PF02	0.88	7	0.83	7	0.81	5	0.83	6
	PF03	0.93	2	0.86	3	0.81	6	0.838	5
	PF04	0.88	7	0.82	10	0.80	7	0.82	8
	PF05	0.73	28	0.76	19	0.66	23	0.71	23
	PM06	0.93	2	0.82	9	0.84	4	0.84	3
	PM07	0.58	41	0.71	27	0.43	39	0.55	35
	PM08	0.90	4	0.75	20	0.65	24	0.71	22
	PM09	0.75	23	0.78	16	0.58	27	0.67	26
	PH10	0.78	18	0.55	41	0.47	36	0.53	37
	PH-11	0.88	7	0.81	11	0.75	12	0.78	11
	PH12	0.65	35	0.67	31	0.59	26	0.63	28
Consultant	MT01	0.78	18	0.77	18	0.63	25	0.70	25
	MM02	0.85	11	0.74	23	0.57	28	0.66	27
	MM03	0.75	23	0.68	30	0.51	32	0.60	31
	MH04	0.75	23	0.73	24	0.71	19	0.72	19
	MH05	0.68	33	0.77	17	0.68	22	0.71	21
Vendor	VT01	0.78	18	0.80	13	0.77	9	0.78	12
	VP02	0.73	28	0.75	21	0.50	34	0.62	30
External issues	SE01	0.95	1	0.91	1	0.86	2	0.88	1
	SE02	0.88	7	0.85	4	0.79	8	0.82	7
	SE03	0.65	35	0.52	42	0.34	42	0.44	42
	SE04	0.63	39	0.62	35	0.51	31	0.56	33
	SE05	0.83	13	0.86	2	0.74	14	0.80	10
	SE06	0.60	40	0.60	37	0.53	30	0.56	33

Table 4. Severity index of cost overrun causes in oil transmission pipeline projects in Iran (S.I. and ranking).

Based on the above formula frequency index and rank of each factor has been calculated. **Table 5** shows the results.

Importance index calculated as a function of both frequency and severity indices to evaluate the ranking of each cause with respect to its impact on cost overrun from viewpoints of the three parties (client, contractor, and consultant).

$$(\text{IMP.I.}) = (\text{F.I.}) \times (\text{S.I.}) \tag{3}$$

The indices were calculated and ranked through the formulae (1)–(3), and the results are illustrated in **Table 6**.

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Category	Factors	Client		Consultant		Contractor		Overall	
		F.I.	Rank	F.I.	Rank	F.I.	Rank	F.I.	Rank
Client	KF01	0.43	34	0.75	12	0.73	11	0.71	12
	KF02	0.65	20	0.63	16	0.92	2	0.78	8
	KT0	0.53	29	0.51	24	0.53	30	0.52	30
	KT04	0.75	13	0.77	11	0.94	1	0.86	2
	KT05	0.35	40	0.37	42	0.50	32	0.44	38
	KL06	0.58	23	0.53	23	0.71	13	0.63	21
	KP07	0.58	23	0.46	33	0.66	16	0.58	22
	KP08	0.73	15	0.60	18	0.83	5	0.73	10
	KP09	0.40	37	0.38	41	0.42	38	0.40	42
	KH10	0.30	42	0.43	37	0.63	20	0.52	29
	KC11	0.45	33	0.54	22	0.41	39	0.46	36
	KC12	0.65	20	0.41	39	0.48	34	0.47	35
	KC13	0.40	37	0.45	35	0.50	33	0.47	34
	KL14	0.85	6	0.87	3	0.70	15	0.78	9
	KL15	0.93	1	0.85	4	0.80	9	0.83	4
	KR16	0.55	27	0.58	19	0.74	10	0.66	18
	KR17	0.48	31	0.55	21	0.61	24	0.58	22
Contractor	PF01	0.73	15	0.43	38	0.48	35	0.48	33
	PF02	0.700	17	0.82	10	0.62	23	0.70	15
	PF03	0.90	4	0.93	1	0.71	14	0.81	6
	PF04	0.750	13	0.65	15	0.66	17	0.66	19
	PF05	0.93	1	0.84	6	0.62	22	0.73	10
	PM06	0.70	17	0.49	29	0.55	29	0.54	28
	PM07	0.90	4	0.83	7	0.57	27	0.70	14
	PM08	0.78	11	0.83	8	0.56	28	0.68	16
	PM09	0.65	20	0.71	14	0.63	19	0.67	17
	PH10	0.55	27	0.44	36	0.41	40	0.43	39
	PH-11	0.68	19	0.47	31	0.59	26	0.55	26
	PH12	0.85	6	0.55	20	0.80	8	0.71	12
Consultant	MT01	0.80	9	0.51	25	0.73	12	0.65	20
	MM02	0.53	29	0.48	30	0.65	18	0.57	24
	MM03	0.38	39	0.47	32	0.52	31	0.49	32
	MH04	0.58	23	0.50	26	0.63	21	0.57	24
	MH05	0.48	31	0.50	27	0.60	25	0.55	27

Category	Factors	Client		Consultant		Contractor		Overall	
		F.I.	Rank	F.I.	Rank	F.I.	Rank	F.I.	Rank
Vendor	VT01	0.83	8	0.74	13	0.82	6	0.79	7
	VP02	0.43	34	0.62	17	0.43	37	0.50	31
External issues	SE01	0.93	1	0.89	2	0.84	4	0.86	1
	SE02	0.78	11	0.82	9	0.88	3	0.85	3
	SE03	0.35	40	0.46	34	0.40	41	0.42	41
	SE04	0.58	23	0.49	28	0.38	42	0.44	37
	SE05	0.80	9	0.85	5	0.81	7	0.82	5
	SE06	0.43	34	0.38	40	0.45	36	0.42	40

Table 5. Frequency index of cost overrun causes in oil transmission pipeline projects in Iran (F.I. and ranking).

Category	Factors	Client		Consultant		Contractor		Overall	
		IMP	Rank	IMP.I.	Rank	IMP.I.	Rank	IMP	Rank
Client	KF01	0.88	1	0.80	1	0.80	2	0.76	1
	KF02	0.68	6	0.70	5	0.69	4	0.70	2
	KT0	0.50	20	0.53	16	0.83	1	0.68	3
	KT04	0.83	2	0.80	2	0.57	10	0.68	4
	KT05	0.66	8	0.73	4	0.60	7	0.65	5
	KL06	0.56	17	0.57	13	0.70	3	0.64	6
	KP07	0.77	3	0.73	3	0.53	13	0.63	7
	KP08	12	0.47	0.59	11	0.63	5	0.62	8
	KP09	0.74	4	0.61	10	0.58	9	0.60	9
	KH10	0.36	28	0.62	9	0.62	6	0.60	10
	KC11	0.61	14	0.68	6	0.50	15	0.58	11
	KC12	0.58	16	0.48	17	0.58	8	0.55	12
	KC13	0.66	9	0.53	15	0.53	14	0.54	13
	KL14	0.67	7	0.64	7	0.41	23	0.52	14
	KL15	0.70	5	0.62	8	0.36	27	0.49	15
	KR16	0.36	30	0.42	19	0.54	12	0.48	16
	KR17	0.46	24	0.36	27	0.55	11	0.47	17

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Category	Factors	Client		Consultant		Contractor		Overall	
		IMP	Rank	IMP.I.	Rank	IMP.I.	Rank	IMP	Rank
Contractor	PF01	0.65	11	0.40	20	0.46	18	0.45	18
	PF02	0.62	13	0.39	21	0.46	19	0.45	19
	PF03	0.49	21	0.56	14	0.37	26	0.45	20
	PF04	0.55	18	0.37	24	0.48	17	0.45	21
	PF05	0.47	22	0.37	25	0.49	16	0.45	22
	PM06	0.59	15	0.38	22	0.44	22	0.43	23
	PM07	0.43	26	0.37	26	0.45	21	0.42	24
	PM08	0.36	31	0.36	28	0.45	20	0.41	25
	PM09	0.32	33	0.38	23	0.40	24	0.39	26
	PH10	0.52	19	0.59	12	0.24	32	0.39	27
	PH-11	0.45	25	0.56	14	0.37	25	0.38	28
	PH12	0.65	10	0.34	30	0.32	29	0.36	29
Consultant	MT01	0.21	42	0.30	35	0.36	28	0.33	30
	MM02	0.31	34	0.46	18	0.21	36	0.31	31
	MM03	0.35	32	0.33	31	0.26	31	0.30	32
	MH04	0.28	37	0.32	32	0.27	30	0.29	33
	MH05	0.47	23	0.23	42	0.23	34	0.25	34
Vendor	VT01	0.36	29	0.30	34	0.20	38	0.25	35
	VP02	0.29	36	0.26	36	0.21	35	0.24	36
External issues	SE01	0.26	39	0.23	41	0.24	33	0.24	37
	SE02	0.29	35	0.32	33	0.17	41	0.23	38
	SE03	0.43	27	0.24	37	0.19	39	0.23	39
	SE04	0.27	38	0.23	39	0.20	37	0.23	40
	SE05	0.23	40	0.23	40	0.19	40	0.21	41
	SE06	0.23	41	0.24	38	0.13	42	0.18	42

Table 6. Importance index of cost overrun causes in oil transmission pipeline projects in Iran (IMP.I. and ranking).

3.4. Spearman's rank correlation

There are two types of correlation test: parametric and nonparametric. In this research, Spearman's correlation test, which is a nonparametric test, is used to measure the correlation between two parties ranking. Nonparametric tests are referred to as distribution free tests.

These tests have the obvious advantage of requiring neither the assumption of normality nor the assumption of homogeneity of variance. The formula No. (4) represents the Spearman's rank Correlation Coefficient:

$$r_s = 1 - \frac{6\sum d^2}{N(N^2-1)} \tag{4}$$

r_s is Spearman's rank correlation coefficient between two parties,

d is the difference in ranking between two parties,

N is the number of variables (here 42).

4. Results and discussion

4.1. Analysis of results

By using the formula No. (1), (2) and (3), the frequency, severity and importance indices were calculated, and the results are presented in **Tables 4–6**, respectively. The final ranking of factors' importance from all parties' point of view is presented in **Table 6**. From statistical analysis, it was found that the political and economic sanctions (low capability of parties in supply the materials/equipment), rise in the price of materials, delay in payments, propose the unrealistic price with the aim of winning the tender, inflation, change orders/extra works, type of bidding award, delay by vendors/suppliers, slow speed in obtaining permits/massive bureaucracy, and unrealistic time and cost estimation are ranked in the top 10 cost overrun factors (**Figure 1**).

According to the results, the average of each group factors importance index (IMP.I.) represents the group ranking, and as a result, the ranking of all five groups is as follow: (1) external issues, (2) vendor/suppliers, (3) contractor, (4) client, and (5) consultant. It means that in the current condition in Iran, external issue–related problems have great degree of importance on cost overrun and most of these problems are uncontrollable; therefore, they could be surprisingly considered as the most significant origin of cost overrun in oil pipeline projects in Iran. The Spearman's correlation coefficients of the ranking have been calculated, and the results are presented in **Table 7**. The calculated data indicate that the important perception of the variables between the three groups (client, consultants, and contractor) is in acceptable agreement. The highest degree of agreement is between clients and consultants (0.806) while the lowest is between clients and contractors (0.657).

4.2. Comparison and discussion

The top five important cost overrun causes in eight projects are listed in **Table 8**. The results of current research are also added to the table for comparison and discussion. Based on the results, external issues–related problems have high significant effect on cost overrun and ranked at the top place. Also they are common in all the reviewed researches but differ in ranking. External issue is a main category and is divided into sub-groups. In this research, political and economic sanctions related problems are first in factor ranking. Generally in

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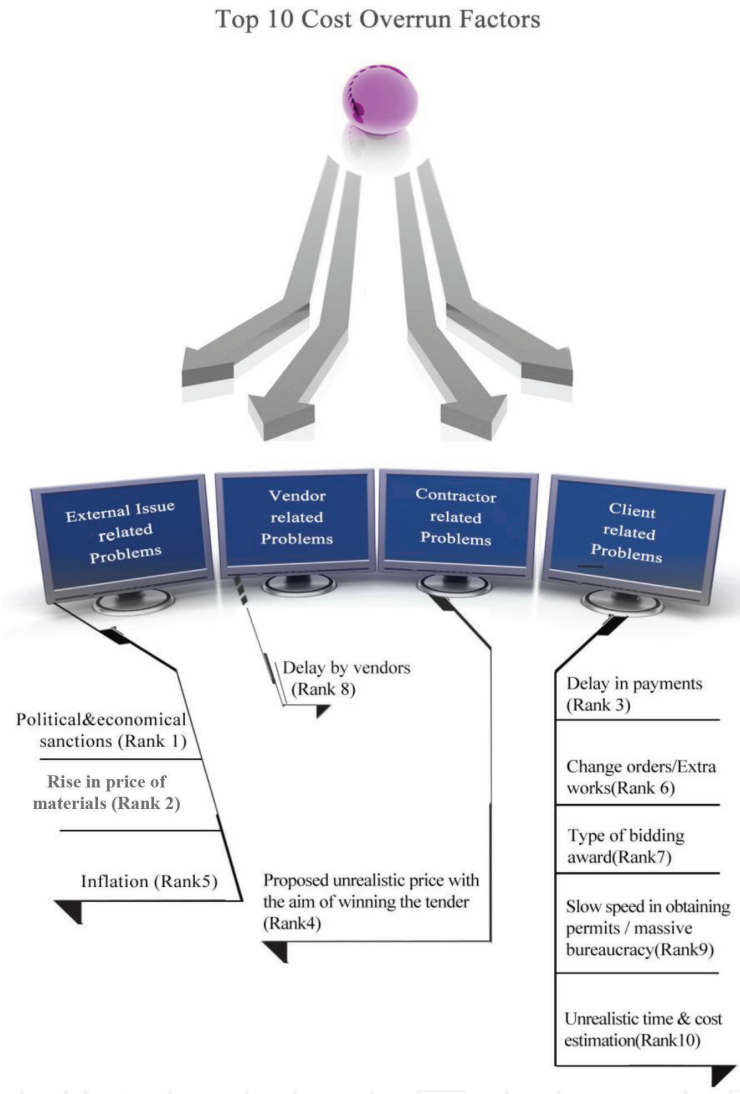

Figure 1. Ten major causes of cost overrun in oil transmission pipeline projects in Iran.

Organization	Correlation coefficient	Sig. (2-tailed)	No. of factors
Client-consultant	0.806	0.000	42
Client-contractor	0.657	0.000	42
Consultant-contractor	0.754	0.000	42

Table 7. Spearman correlation coefficient.

Reference no.	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
[12]	Poor contract management	Financing & payment of completed works	Changes in site conditions	Shortages of materials	Imported materials & plant items
[22]	Late payment	Poor cash flow, management	Insufficient financial resources	Financial market instability	—
[23]	Material problems	Financial problems	Organization deficiencies	Lack of qualified workers	Extra works
[21]	External risks	Inadequate financial strength (client)	Inadequate financial strength (contractor)	Failure in performing contractor's obligations	Dispute regarding contract interpretation
[8]	Low ability of contractor to provide imported material	Unrealistic contract durations imposed by client	Slow delivery of material	Slow land expropriation	Change orders
[7]	Bad weather	Inflation	Schedule delay	Scope changes	Local government pressures
[24]	Monthly payment difficulties	Poor contract management	Material procurement	Inflation	Contractor's financial difficulties
[25]	Unclear scope of work, cost control	Contract dispute	Fluctuation, the gap between plan and actual, material shortage	Time management	Practical experience
This study	Sanctions	Rise in the prices	Delay in payments	Propose the unrealistic price to win the tender	Inflation

Table 8. Comparison of the top five major time/cost overrun factors from literature reviewed.

Iran's oil, gas, and petrochemical projects, more than 70% of the whole project's weight is related to procurement phase, and due to the low ability of project's parties to purchase and import the materials/equipment, most of the projects are behind the schedule and have delay in project deliverables as well which leads to cost overrun. Fallahnejad and Hasheminasab et al., both presented the same problem for projects in Iran in their researches [8, 21]. But in the other researches related to other countries, the external issue problems are such bad weather, site condition, or government pressure, and none of them addressed to this factor in the series of the top 10 important causes. The other effects of sanctions are also noticeable and cannot be ignored. It can primarily be categorized as (a) refusal of reputable foreign companies to come or continue working in Iran and consequently slowing down the pace of transfer of knowledge of new construction methods and management, (b) lack of opportunities for ambitious and qualified managers which encourage them to leave Iran for opportunities in other countries (brain drain), (c) lack of chance for young graduates to train for up to date methods of construction which leading to lack of experts, and (d) lack of modern construction equipment which were prevented due to sanctions to bring in to Iran.

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Rise in the price of materials and inflation are the factors, which are addressed by five researchers from **Table 8**. Their ranking in current study is second and fifth, respectively. Unfortunately, the duration of oil pipeline project is quite long and due to the special economic and political condition in Iran, the cost overrun due to these problems is predictable for the projects. It should be noted that these factors are uncontrollable but consideration and identification them at early stages of the project would help project's participants to issue effective plan in case of occurrence.

Other material-related problems such as material monopoly by some vendors/suppliers and vendors delay in delivery of material are also common in most of the projects in different countries regardless of political, economic culture, and social conditions, that implementing an efficient quality control and assurance system by the third party and periodical vendors/suppliers assessment would be useful to mitigate negative impacts.

Client-related problems such as late payment, change orders/extra work, low speed in decision making, slow speed in obtaining the permits, type of bidding, and client cash flow are addressed in all the seven researches. According to the result of this study, the position of delay in payment factor is three in the series of top ten important factors. Due to the delay in payments, most of the projects are now delayed, so the project duration increased, and as a result, the cost escalated. The client, NIOC, is one of the major subsidiaries of the Ministry of Petroleum of Iran, has powerful financial background but the delay in payment problem could be the result of excessive bureaucracy in the government organization in Iran, especially in their financial management department due to their complex and time consuming financial processes. Project manager should prepare a financial plan and also assign required budget for the project before entering to the execution phase, this would allow client to ensure that required budget during the execution of project is available. It can be concluded the main source of this problem come from mismanagement of the project. Cooperation and investment of private sectors would be one of the solutions as well. Spending adequate time for feasibility study and preparing a complete and clear contract documents would decrease the quantity of change orders as well.

Contractor financial problem during the execution of projects is one of the major problems leading to time and cost overrun effectively. In Iran the source of this problem may come back to the uncompetitive bidding type. The process of evaluation of the proposals in Iran is of two stages, technical and financial evaluation, but due to the low impact of the quality criteria in final evaluation, proposed price would be the governing factor. Some contractors proposed unrealistic price just to win the tender. Not only this is not a fair competition (capable contractors will lose the chance of winning) but also the projects failing to meet budgetary, schedule, and desire quality because the potentially more qualified contractors who have followed the professional ethics in their proposal are not able to be awarded the contract. The source of this problem is not unprofessional or incomplete cost estimates. It is the contractor strategy to award the tender and after that they may try to find a way to compensate their financial deficit such as claims. Claims are always time consuming and leading cost overrun and delay in target completion date; therefore, in case of occurrence, this problem, the prompt reaction and sensitivity of clients on project duration, is necessary. On the other hand, as this kind of delay, as a result of claim, is

not an excusable delay, client should terminate the contract as per the contract's related clauses and retender the contract. But because of the very difficult and complex law, regulation and processes related to retender the contracts, clients in Iran are unlikely to terminate the contracts, and contractors are aware of this issue. Revising the bidding and contractor selection methods and also reviewing the termination laws would be useful to reduce probability of raising such a problem. In spite of the high rank of this factor (4th place) in the current research, it has low impact on cost overrun in the other researches reviewed by the authors.

5. Conclusion

According to the 20-year Vision Plan of Iran's oil industry, Iran mission is to increase the oil production capacity over 12% of the world's oil production by the end of the 2025, which needs to develop the existing projects and also define several new projects as well. Reviewing the existing documents for oil pipeline projects in Iran shows that these kinds of projects are facing time and cost overrun. Therefore, identification of the time and cost overrun factors is one of the most important activities to achieve the Vision Plan's goals. In the current research based on the previous project documents and also literature review, a list of 42 cost overrun causes was prepared. The top 10 causes then identified through a questionnaire survey which are as political and economic sanctions (low capability of parties in supply the materials/equipment), rise in the price of materials, delay in payments by client, propose the unrealistic price with the aim of winning the tender by contractor, inflation, change orders/extra works by client, type of bidding award by client, delay by vendors/suppliers, slow speed in obtaining permits/massive bureaucracy, and unrealistic time and cost estimation by client. Based on the responses, factors related to political condition in Iran are the major factors affecting cost overrun and, at the same time, are the most common factors. The results of this research could help participants of Iranian oil industry to have the strategic plan before getting involved in the projects. Future investigations could be done to identify the source of these causes and propose solutions to mitigate the negative impacts.

Acknowledgements

The author would like to acknowledge whoever cooperates for the interview and also to all clients, consultants, and contractors for their participation in questionnaire survey.

Author details

Pooneh Saidi

Address all correspondence to: poonehsaidi@gmail.com

Parsikan Iran Engineering & Management Consultants, Tehran, Iran

http://dx.doi.org/10.5772/67542

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Chapter 5

Alliances: An Innovative Management Model for Public and Private Investments

Fco. Javier Carrillo de Albornoz Portes

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68228

Abstract

Although Alliancing has been in use since the 1990s in Australia and New Zealand, this method of procuring and managing major capital assets and services has become more popular also in Europe in the past few years. Under an Alliance contract, a public or private entity contractually works collaboratively with the contractor to deliver the project under the principle of 'open books', that is, sharing gains and pains. This chapter will analyse the Alliance contracting model, which is characterised by three main features: It requires parties to work collaboratively, act with integrity and make best-for-project decisions. The project team, formed with members of the promoter and contractors, works as an integrated, collaborative team to deal with all project matters. In alliance contracts, risks are jointly managed by the parties together, except financial exposure, which lies mostly on the owner/promoter. Through the examples presented in the chapter, including the desalinations plants of Perth or Adelaide water supply system, in Australia, it will be concluded which kind of projects are more suitable for potential delivery as Alliances.

Keywords: Alliance, PPP, open books, mining, water, contract, management

1. Alliances for public and private investment management

In recent years, globalisation has meant that large infrastructures in any country are executed by international consortiums, formed by large multinationals (in many cases, Spanish) and by local companies. Examples of this are various water treatment plants in Australia (Melbourne, Perth, Adelaide, etc.), the expansion of the Panama Canal, the Heathrow terminal or the high-speed train from Medina to Mecca, among others (**Figure 1**).

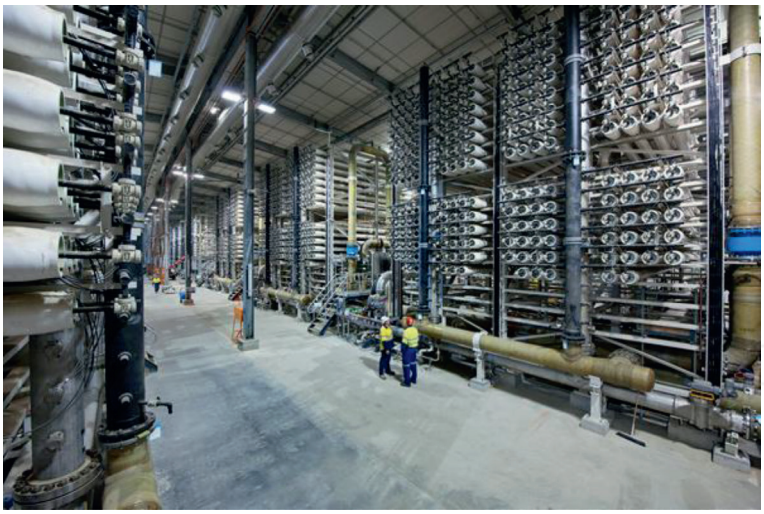

Figure 1. Desalination plant of Melbourne. 450,000 m^3/d. PPP built by SUEZ/Thiess.

In these megaprojects, to their intrinsic technical complexity, legal and financial aspects help to generate a climate of mutual mistrust between the promoters and the contractors, since the benefit of one part seems to be obtained to the detriment of the other.

In these circumstances, the quality of the project and its optimisation are relegated to a second order of priorities, both for contractors and for the promoters themselves, whose main focus may be on avoiding being deceived and enforcing the contract in force, even if the time elapsed between designing the solution and executing the state of the art would make significant changes that would improve the final result.

Given this situation, several countries, notably Australia and New Zealand, as well as some Nordic countries, such as Finland or England, have developed a form of recruitment that focuses on obtaining the best possible result of the project.

These are the contracts of Alliance.

In this type of contracting, the promoter and the contractor sign an agreement of Alianza by which they commit to work the project in equipment, under the philosophy of open books.

A multi-disciplinary team, made up of professionals from both the developer and the contractor, will develop the best possible technical and economic solution, both entities managing all available information, so that the decision-making is based on real data contributed and analysed by both entities.

In this model, the contractor and the developer agree on the benefit that the contractor will have over the costs of the project (direct costs plus own structure). If the project comes out better than expected and costs are reduced, this reduction will benefit both parties in the agreed proportion. If the project shows extracts in which it is agreed to incur, the developer will at

least be responsible for covering all direct and structural costs that the contractor has, which may not have a benefit, but is guaranteed to have no losses.

Let us see below the origin of these types of contracts, some of their most important characteristics, their advantages and disadvantages and some examples.

2. Origin of Alliances

Alliance model was the solution to the dissatisfaction within the oil industry for delays in project deliveries together with escalating costs. This led to litigations for years with their main contractors and induced their legal departments to account for every eventuality in increasingly long and complicated contracts, which were difficult to be accepted by any contractor.

The first project to be managed as an Alliance was promoted by Ampolex, an Australian oil company, which was acquired by the Mobil group. Ampolex opted for this model to carry out the construction of a tank to store crude oil and gas from the oil field Wandoo in 1996.

It was an investment of 100 million Australian dollars, which consisted of the construction of an 80,000 t reinforced concrete structure that was built in the port of Bunbury and transported 1700 km away to be sunk and weighted next to the marine reservoir.

In 1998, this Alliance won the second edition of the Australian construction achievement award (ACAA), the Australian construction industry's most prestigious award, in recognition of its innovation and the highest standard of work.

Since then, this hiring system has been widely used in Australia, where about 30% of infrastructure investments are contracted following this model [1]. And the percentage is higher if we consider only investments in water, roads and railways exclusively.

Another well-known example is the Alliance that was created in New Zealand for the recovery of areas devastated by the earthquakes of 2010 and 2011 (**Figure 2**). More than 1.6 million m^2 of roads were damaged and 1100 buildings had to be demolished. The Alliance, sponsored

Figure 2. Effects of earthquake in New Zealand.

by the Canterbury earthquake recovery authority (CERA), the New Zealand transport agency (NZTA) and the Christchurch city council, had 5 contractors who, in total, managed a budget close to 2000 million dollars.

In Europe, it is in the United Kingdom along with the Nordic countries where more implementation is having such agreements. The latest is the one announced on 13 July 2016 between Network rail and Northern rail operator to improve the rail system of the north of England, which serves 15 million people and manages around 2500 trains a day. Network rail started using the Alliances with the different rail operators in 2012 currently counting on seven Alliances with different railway operators. According to David Higgins, NR chief executive: '*Working more closely with the train operators will deliver a better service for passengers and freight users and at lower overall cost to the taxpayer'* [2].

'*Demand for our railway continues to grow and we need to work smarter with our rail industry partners if we are to continue with the improvements we have made to services over the last decade. Maintaining high levels of performance on an ever congested network, while investing billions of pounds and cutting costs, is a major challenge for all of us, a challenge that alliances will help to tackle'*.

But Alliances are not only for building huge infrastructures. The National Health Service (NHS) in England is also considering Alliances for their health and social care services contracts.

The King's fund [3, 4], probably the most important independent think tank in England working to improve health and care services in the country, emphasises that one of the most important characteristics of Alliances is that '*Commissioners and providers are legally bound together to deliver the specific contracted service, and to share risk and responsibility for meeting the agreed outcomes. As such, they should be incentivised to innovate and identify efficiencies across the system, rather than solely within their organisation'* [3].

In their paper published in November 2014 with the title: '*Contractual models for commissioning integrated care'* [3], they summarise the advantages and disadvantages of Alliancing contracting for the health and care services (**Table 1**).

Advantages of alliance contract model	Disadvantages of alliance contract model
• Strong incentives to collaborate between commissioners and providers	• Shared financial and clinical risk, reliant on the performance of other providers
• Limits dominance of a single organisation	• More complex for commissioners to manage
• Strengthens relationship between commissioners and providers	• Requires existing relationships founded on strong trust, which might not be present in all areas
• Retains the active involvement of commissioners	• Possibility of weak leadership and accountability unless appropriate governance arrangements are established

Origin: King's Fund.

Table 1. Advantages and disadvantages of Alliance contract model.

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3. Alliance characteristics

As we said, Alliancing is a method of procuring and managing major capital assets. Under an Alliance contract, a promoter (public or private entity or entities) contractually works collaboratively with private service providers (designers, contractors and suppliers) to deliver the project.

'*Alliance contracting is characterised by a number of key features, which generally require the parties to work together in good faith, act with integrity and make best-for-project decisions. The alliance participants work as an integrated, collaborative team to deal with key project delivery matters'* (Treasury and Finance department, Victoria State) [5].

Under Alliance contracts, all parties assume collectively responsibilities, take collectively ownership of all risks and share any 'gain or pain', although financial exposure lies mostly with the promoter.

Alliancing should be used to deliver large, complex and high-risk projects in which the promoter has skills and expertise to improve the delivery. Mining and oil & gas projects are good examples of this in the private sector [6], such as infrastructures are in the public sector.

Typical projects suitable for Alliances should share most of the following characteristics:

1. The scope is difficult to define upfront or it is expected that changes will occur.
2. The risks cannot be adequately defined or measured before the tender.
3. The cost of transferring project risks to the contractor is too high or nobody would accept it.
4. Very tight timeframes that prevent having enough time to fully identify all risks and/or define better the project scope.
5. Promoter/owner can add value if he is involved in the design/delivery of the project due to his knowledge, skills, experience and/or capacities.

So, before selecting an Alliance, promoters should take into account how the structure of an Alliance contract has different benefits and risks that differ from the associated with more traditional forms of contract.

In addition, Alliance contracts have not been tested so much compared with traditional models, and most of the promoters will lack experience in handling this type of contracts, beginning with the initial phase: The preparation of the contract itself!

This initial phase, together with the limited experiences worldwide with this type of contracts, will demand from the owner an important amount of work.

Also, an Alliance contract is potentially more complex for owners to put together and they would still retain considerable responsibility for co-ordination and act as a 'partner' of the Alliance during the term of the contract.

The four main characteristics of Alliance contracts compared with traditional Engineering, Procurement and Construction contracts (EPC) are:

3.1. One common objective

All members in an Alliance share the same commercial outcomes under one overarching performance framework unlike traditional models, which encourage parties to look after their own interests under their separate respective contracts.

This common goal encourages the parties to act in the best interests for the project as a whole, which should reduce overall costs and project duration, also improving the quality of deliverables.

This does not mean that final investment could be higher than initially expected. But this risk will be managed by the owner earlier and with full knowledge to take the best decision.

To promote teamwork, Alliance contracts include an incentive through a shared reward pain-share and gain-share scheme linked to the Alliance performance.

3.2. One-team mentality

In a contract of this type, success is judged by the performance of the Alliance overall rather than the performance of each single organisations within it. This carries both greater risk and greater reward for owners and providers.

The potential drawback of this is that the success of the project depends on personal commitment and trusting relationships among all parties, something which may be difficult to develop. So, given the mutual dependencies, an Alliance contract might be most suitable where there are ongoing well-established relationships between the owner and the providers.

The Alliance contract will need to define clearly the governance framework through which the money can flow and decisions can be made. This unified agreement under which all parties share the benefits and risks should help to create an integrated structure whereby multiple suppliers and the owner work together in order to deliver the project as a whole.

3.3. Flexibility

Because owner and contractor acts as a team, any information that can cause a change in the delivery is immediately received and analysed by all parties, so they can react and adapt easily the project to the new circumstances. This is critical on large scale, multi-disciplinary projects to solve complex design, construction and environmental issues that may not be evident at the beginning of the project. This is perhaps the key advantage of the Alliance model. With traditional contracts, any changes use to cause a dispute and, very often, a delay.

Also, and even more important, there is a flexible attitude to negotiations, because of the long-term relationship between parties and their common goals, in opposition to the fight to defend each party rights that occur with traditional contracts.

On the other hand, the focus on outcome as opposed to process could create uncertainties in terms of timing and budget. However, a unified cost structure ('open books') as well as enhanced project synchronisation should allow to achieve completion on time and within budget.

3.4. Dispute resolution

In traditional contracts, in case of dispute, it is expected that each party blames the other for any problem that may appear, trying to demonstrate that any failure has been provoked by the other and releasing themselves from any liabilities linked with any problem that may occur.

With both parties acting and working as one team, this attitude disappears because any problem or wrong decision has been taken by the team. Anyway, Alliances include forums for the effective resolution of disagreements amicably and on a cost-effective basis promoting active project management to prevent problems escalating.

At the end, the Alliance steering committee has the final word in case of dispute that usually appears due to uncertainties at the time of the project launch, legal aspects, etc.

4. Alliances practices

To develop an Alliance contract, there are certain activities that should be done by each member of the Alliance (owner and contractors) that could be summarised as follow:

4.1. Owner actions

Owner actions begins before the project is launched, at the time the decision to develop the project is taken.

4.1.1. Decision

Obviously, main and first of the owners action is the decision of using a relationship contract, such as an Alliance, to develop its project. This decision should be based on the reasons previously described.

Considering the complexity of the Alliance model of contracting, they should be used only to deliver large, complex and high-risk projects in which the promoter has skills and expertise that can improve the delivery.

4.1.2. Contract preparation

Regarding contracts, there are a number of possible forms. The best known is the '*National Alliance Contracting Policy and Guidelines for Project Alliance Agreement*' [5] prepared by the Department of Infrastructure and Regional Development of the Australian Government in September 2015.

This template is available for free in the webpage of the Australian government who has developed national guidelines '*for the delivery of infrastructure projects to promote cross-government consistency and the use of best practice approaches'* [5]. These guidelines cover not only Alliance contracting but also traditional contracting and public-private partnerships (PPP).

In the case of the 'National Alliance Contracting Policy and Guidelines', they '*have been developed to promote knowledge, best practice, and give rise to cost savings by creating a consistent national alliance contracting standard, whilst ensuring the existing benefits of alliancing around the nation are maintained'* [5].

These documents include all the resources needed for any owner (public mainly, but can also been easily adapted by private promoters) to develop their own Alliance contract for any kind of infrastructure or even service.

The following documents are available:

- Policy Principles
- Guide to Alliance Contracting
- Guidance Note 1: Language in Alliance Contracting
- Guidance Note 2: Insurance in Alliance Contracting
- Guidance Note 3: Key Risk Areas and Trade Offs
- Guidance Note 4: Reporting VFM Outcomes
- Guidance Note 5: Developing the TOC in Alliance Contracting
- Guidance Note 6: Early Contractor Involvement and Other Methods
- Template 1: Project Alliance Agreement
- Template 2: Alliance Development Agreement
- Template 3: Expression of Interest
- Template 4: Request for Proposal
- Jurisdictional Requirements
- Document Change Protocols
- Appendix A—Developing Governance Plan

As it is stated in the guidance note of the document that Project Alliance Agreement '*has been prepared on the basis that the Project Owner will first enter into an Alliance Development Agreement with one or more Proponents selected under the Request for Proposals for the development of a Project Proposal (which will include the TOC or part of the TOC for the Project). The Alliance Development Agreement will be attached to the Request for Proposals. This Project Alliance Agreement will itself be attached to the Alliance Development Agreement and will form the basis for the development of the final Project Alliance Agreement which will be entered into between the Project Owner and the Proponent whose Project Proposal is accepted under the Alliance Development Agreement'* [5].

http://dx.doi.org/10.5772/intechopen.68228

4.1.3. Pre-qualification of contractors

One of the key factors of success is the selection of bidders. In traditional EPC contracting (or even in other more complex contracting models, such as BOT, BOOT, etc.), this is not so critical because the effort requested to the owner is not so important and the contractors that want to participate in the tender spend most of the resources needed to prepare the tender.

The pre-qualification process begins with the owner announcing their interest in developing a certain project under an Alliance model (**Figure 3**).

All possible interested contractors apply for the project and present their credentials for the job basically, their references, resources and capabilities. Among all, owner selects a shortlist of contractors who are competent and suited for the project. The selection criteria are determined by the owner/promoter but, in some cases, contractors could provide inputs to these required criteria to improve them.

This shortlist is carefully examined by the owner. For example, in 2007, the Water Corporation of Western Australia launched the project for the construction and operation of the desalination plant of Perth. The shortlist included around a dozen of international contractors. All of them were visited and evaluated by the Water Corporation.

In February 2008, two Spanish led consortia, one formed by Técnicas Reunidas S.A & Valoriza Agua, S.L, and the other by Acciona Agua Australia Pty Ltd & United Utilities Australia Pty Ltd were chosen as finalist [7].

Both consortia moved their teams to Australia, where they formed mixed teams with people coming from the Water Corporation and they developed their solutions for half a year. In November 2008, after a careful evaluation of both proposals, winner was announced. They were chosen to develop their solution while the loser consortium was refunded of all cost and expenses incurred during the elaboration of their proposal.

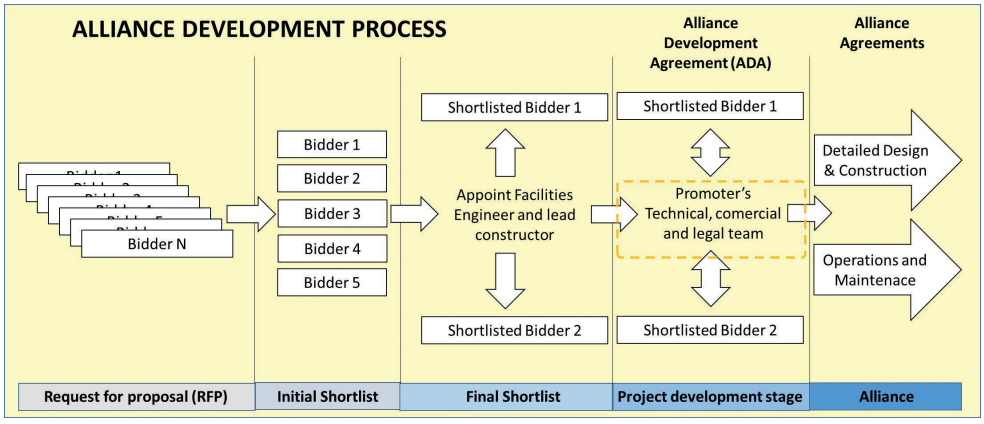

Figure 3. Alliance development process.

This way of working ensures that the selected tenderers (both finalists) commit to dedicating sufficient resources to the tender, because their chances of success are clearly higher than in an open tender with lots of competitors. Further, the evaluation of both proposals by the promoter is done with all available information at his disposal and, even more: best ideas of the loser solution can be incorporated to the chosen project to enrich the final solution.

From a global point of view, this way of working benefits the industry in general because it reduces the costs of preparing/presenting bids. Only the finalists actually spend a significant amount of money and win the contract or are reimbursed.

4.1.4. Right time to tender

Tenderers must have a reasonable amount of time to prepare the tender. The same applies to the owner, who should have enough time to do a professional evaluation process of all characteristics of the project. Time will vary depending on many factors, such as project size, complexity and delivery method.

As we saw in the example of Perth, the full process would take not less than a year since the launching of it to the awarding, divided between: announcement and reception of credentials (2 months); preparation of shortlist (1 month); evaluation of shortlist (1 month); development of the project (+6 months); final evaluation and decision (2 months).

4.1.5. Terms sheet of fundamental issues in the contract

Agreement on the contract terms is one of the more exhausting (and important) activities that are developed in a project. And it is critical for both parties. Even using a standard contract model, such as the one mentioned before, there are a certain number of issues that are fundamental to the establishment of the relationship for each specific project.

In the case of Alliances, where trust and openness is an essential ingredient for the success of the project, the agreement and not the imposition of the terms of the contract is critical, so the contract cannot be documented without contractor input. Contractors should be open and frank in their input to these discussions.

Without intending to be an exhaustive list, here are some of the fundamental elements that must be well defined by the contract:

- Form and scope of contract;
- Owner representative and team members including duties;
- Contractor representative and team members including duties;
- Time aspects, including risks, extensions of time, cost and responsibilities;
- Payment terms, certainty of payment;
- Existing conditions/latent conditions;
- Acceptance/reward/loss;

- Warranties to be provided;
- Guarantees to be provided;
- Risk identification/allocation;
- Securities, retentions and performance requirements;
- Management regimes/forums/reporting requirements/project communication;
- Insurance requirements;
- Change management process;
- Default, suspension, termination;
- Force majeure;
- Dispute resolution procedures;
- Quality requirements;
- Environmental standards.

4.1.6. Risk allocation

It is important to identify in the contract all the risks that are expected to be found in the project and that will require management. After identification, the project team will determine the risk management strategies, including assignment of responsibility and final contingent liability and reward.

4.1.7. Acceptable contract performance rewards

A critical point in any kind of contract is the compensation scheme. In the case of Alliances, where the open books policy entitles the owners to see the benefits of the contractors, this is even more critical.

Both parties, but mainly the owner, should understand and accept that the contractor is entitled to an industry acceptable level of margin (profit plus head office overheads), which could be increased in case of a superior project performance and/or would be decreased or even nullified for an inferior performance.

This generally requires the contractor risking an agreed portion of total margin in exchange for the opportunity to increase the margin for superior project outcome. In any case, due to the risks associated with uncertainties in this kind of contracts, all direct costs incurred by contractors are compensated and only margin could be nullified.

4.1.8. Knowledge protection

After pre-qualification, owners should provide adequate processes to ensure that any tenderer that provides intellectual property or innovation, remains as a 'commercial in confidence' matter

between the specific tenderer and the owner during the tender process and it is protected through confidentiality agreements.

This is a particularly sensible issue during the final phase, when the owners' staff is working with both competitors developing competing solutions.

Once the decision is made and the winner is chosen, the payment of the project produced by the losing team will allow the winning team to use their ideas to improve their project.

4.2. Contractor actions

The contractor's actions change clearly in the Alliance contract compared with traditional contracts, with the main difference being the defence of the global project rather than the interest of their company.

4.2.1. Trust and openness in dealings

As we have just said, the Alliance contract means 'one team for one project'. To be successful, both owners and contractors must be open and confident in their mutual dealings and solve all problems with the 'best for the project' approach.

Among others, this mean that any change in the project that could mean a benefit for the project, even if it does not mean a direct benefit for the contractor, should be shared with the project team for its evaluation. This includes any potential risk.

4.2.2. Appropriate behaviour

Most contractors' and promoters' staff have acquired their professional experience using traditional forms of contract, which means that they have engaged in contracts in which they have played adversarial roles. This behaviour associated with traditional contracting is the opposite to the needed with this new method of project development.

Due to this, behavioural modification is one of the key points to change before starting an Alliance. The staff of both sides, including the staff of the main subcontractors and suppliers, will need to be trained and educated in the particular management and social disciplines required in this type of relationship contracts.

Main point in this education should be to add, among others, the criteria 'best for project' on top of the usual 'bottom line profit at the expense of anything', including other parties' outcome. Other criteria needed both for the owner and for the contractor staff would include relationships, attitude to repeat business, environmental aspects and health and safety performance.

According to the staff working in this kind of projects, this is simpler than could appear at the beginning, because the 'open book' policy that rules this kind of project favours this change of attitude: Because both parties are working together, they can easily detect any mistake or trick tried by the other party.

4.2.3. Right subcontractors and suppliers

The project team, consisting of the owner and contractor's staff, will select subcontractors and suppliers to achieve the best results without compromising safety, quality and environmental impact.

The 'best results' will probably require a greater emphasis on the strategy of buying 'better value' than on the 'lowest price' strategy.

Again, an open books approach (or, at least, behaviour) with the subcontractors and suppliers, respecting their entitlement for a reasonable profit and the implementation of progressive reviews of subcontractors' work rather than historical assessment, enables more cost effective and early rectification of deficient works or underperformance, to the benefit of all parties.

5. Alliances compensation model

One of the particularities of the Alliance model is the compensation scheme.

As stated before, owner and contractor share gains and pains, but with the main financial risk on the side of the owner. In practice, this means that contractor will be reimbursed of all direct project cost incurred during the development of the project, in all phases (engineering, construction, commissioning and operation) plus the project specific overheads.

On top of this, contractors declare a certain corporate overheads and the net margin he wants to obtain with the project. With the open books policy, this is clearly stated and accepted by both parties.

At the end of the project, if the direct cost finally results above the budgeted, the deviation will be shared between owner and contractor according to the specific agreement of the project. In the same way, if the cost results lower than expected, the benefits will be shared.

For example, if we have an Alliance with an agreed budget for direct cost of 90 M€, project specific overheads of 10 M€ and a profit + corporate overheads of 20 M€, and finally the direct costs at the end of the project are only 80 M€, the 10 M€ of savings (gains) will be split between contractor and owner (e.g. 50/50). In this case, contractor will receive 80 M€ + 10 M€ (specific overheads) + 20 M€ (profit + corporate overheads) + 5 M€ (savings) for a total of 115 M€ (21% margin).

On the other hand, if the cost grows to 100 M€, extra cost will also been shared (pains) and the contractor will receive 100 M€ (direct cost) + 10 M€ (specific overheads) + 20 M€ (profit + corporate overheads) + 5 M€ (extra cost) for a total of 125 M€ (12% margin).

In all cases, direct costs and specific overheads are reimbursed, so the worst condition for contractor should be neither profit nor SG & A (**Figure 4**).

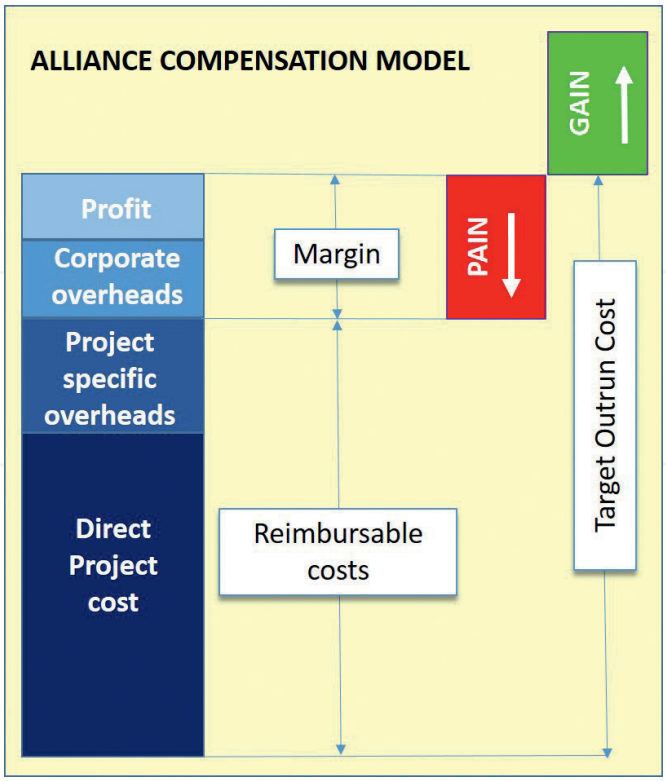

Figure 4. Alliance compensation scheme.

6. Case studies

6.1. Perth desalination plant

In April 2005, Western Australia's Water Corporation chose Degrémont to design, build and operate Perth's first seawater desalination plant using reverse osmosis technology, the largest such plant in the southern hemisphere. Construction commenced in June 2005 after a unique tendering process, which involved a design competition between 2 shortlisted finalists from 11 original submissions [8].

The 143,000 m^3/d plant (**Figure 5**) was built at Kwinana, 25 km south of Perth in Western Australia. The aim was to increase drinking water production capacity for Perth, where conventional freshwater resources are in very short supply.

The facility was designed and built under a joint venture between Degrémont and its Australian civil engineering partner Multiplex Engineering Pty Ltd. It includes seawater intake, pre-treatment structures, reverse osmosis desalination units and pumping and

Figure 5. Perth desalination plant.

remineralisation units. The facility started operating at the beginning of the Australian summer in October 2006, just 18 months after the award.

The success of the project in this short timeframe hinges on effective Alliance between the Water Corporation and Degrémont-Multiplex. The partners are engaged in a trust-based relationship that goes beyond turnkey delivery of the desalination plant: in particular, the Water Corporation has been directly involved in the day-to-day construction of the plant. Then, Degrémont teams will operate the plant during 25 years (**Figure 6**).

The Perth's plant reached 100 GL production threshold, since start of operation in 2008 and achieved 3 certifications:

- ISO 9001 2008 (Quality)
- ISO 14001 2004 (Environment)
- AS/NZS 4801: 2001 (Safety)

6.2. Adelaide water supply and waste water services

In July 2011, South Australia Water commenced an Alliance model for the operations and maintenance of Adelaide's metropolitan water and wastewater systems for, at least, 10 years. The estimated population served is 1,200,000 people [9, 10].

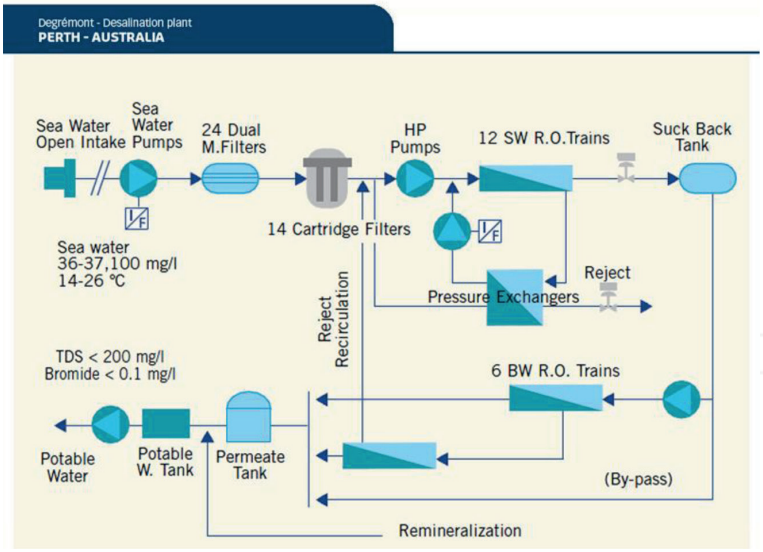

Figure 6. Perth desalination plant. Water treatment line. Origin: SUEZ.

The concept is for the client and its Alliance partners to work collaboratively in a flexible manner, utilising the best skills and resources of each partner, under a shared risk and reward arrangement.

Allwater, a joint venture between SUEZ and Broadspectrum, works in partnership with South Australia Water to define objectives, set targets, established relevant systems and processes to critically deliver improvements to South Australia Water.

The objective is to manage a water network spanning a massive 16,000 km^2, including 6 water treatment plants, 9000 km of water mains, 6 wastewater treatment plants, 7200 km of wastewater mains along with water reuse systems (**Figure 7**).

Highlights in the beginning of the project were:

- Successful transition with no impact on customers despite challenging timeframe and conditions.
- 100% compliance with drinking water, wastewater and recycled water standards.
- Networks: improved efficiency for burst & leak repairs and sewer overflows management.
- Full delivery of the maintenance plans.
- 20 minor capital projects compliant on delivery time, cost and quality.

Key facts in 2015 were:

- $500,000 cost savings on energy

- 93% of capital works delivered on time and on budget
- 5% more energy efficiency at WWTPs1
- >90% overall customer satisfaction with network field crew
- $1.2M fund on Research & Innovation from SUEZ
- 14 Technical Assistance projects

Additionally, Allwater was the first Australian company certified for energy management, achieving ISO 50001 certification for energy management, showcasing the dedication of the teams and the ultimate value of partnerships.

Wastewater treatment plants account for 63% of Allwater's total energy usage. Delivering efficiencies in this area is a key priority. This involves various improvements in aeration control, flow balance between different treatment lines, as well as maximising energy from biogas. Over the past three years, the energy efficiency at the three major wastewater treatment plants has continuously improved by 10–18%.

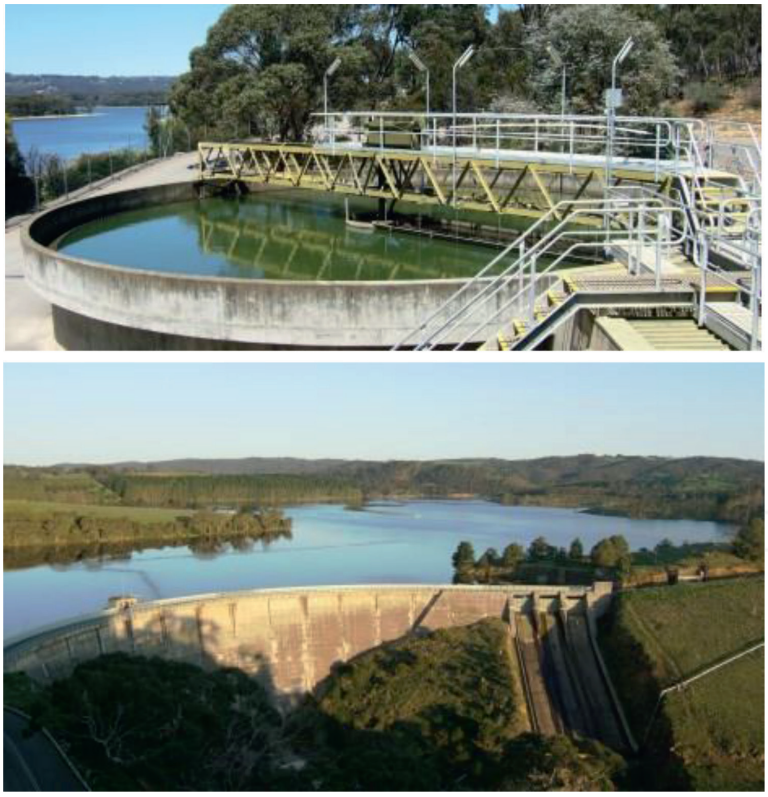

Figure 7. Adelaide water infrastructures.

6.3. Perth water supply and wastewater treatment

The Western Australian Water Corporation selected SUEZ and its partner Transfield Services to operate and maintain the water production and wastewater treatment assets of Perth (**Figure 8**), the fourth largest city in Australia and one of the driest in the world [11].

The contract began on 1 July 2012, and has an initial term of 10 years (with a possible extension of a further 5 years).

Overall, SUEZ and its partners manage and operate 6 groundwater treatment plants, 14 wastewater treatment plants and 2 advanced water recycling plants, as well as 13 dams, 190 boreholes and 520 km trunk mains to deliver reliable services to Perth's 1.9 million residents, through an Integrated Alliance named AROONA.

The AROONA Alliance has a strong focus on driving efficiencies and improving operational performance. It continues to focus on delivering excellent quality and reliable services to the people of Perth, as well as protecting water as a precious resource for Western Australia's future generations.

Highlights at the beginning of the project were:

- $1.4 million of sustainable savings delivered in 2012/2013
- 99.9% compliance with groundwater allocation license (2012/2013)
- 97% compliance with Department of Environment and Conservation (DEC) requirements for wastewater treatment (2012/2013)

Figure 8. AROONA water infrastructures.

- 7% increase in productivity rate
- 100% minor capital works projects delivered on time and on budget

Through the '*Good to Great*' strategy, AROONA continues to present sustainable savings. After 2 years, great results have been achieved across all areas. Significantly, at the end of the 2014/2015, almost 5% of cost savings was obtained. This represents approximately AUD 16 M of cumulative sustainable savings since the commencement of the Alliance.

7. Conclusion

Alliances have showed their success as a good contracting model for managing important investments and services in both public and private sectors.

The experience in Australia and New Zealand, with many European contractors involved, such as SUEZ, Acciona or Técnicas Reunidas, the railways alliances in the United Kingdom and other experiences in northern Europe, demonstrate that this method can be adopted in Europe with little effort [12]. And the same in other areas, such as Latin America or Asia.

In Spain, public concessions for water management share some similarities with alliances (joint venture between administration and private company, long-term focus) and have demonstrated their efficiency in improving water services in cities, such as Barcelona, Granada or Alicante.

Obviously, this requires a shift in the mind of many administrations, used to the traditional methods, and a preliminary work to adapt the legislation and prepare the new tendering documents, even if they could be based on the successful Australians.

But fight against climate change should remove any doubt, because public and private partnership is critical to manage the huge investments needed in this fight.

How complex could be for a city council, who wants to electrify their streets to promote the use of electrical automotives, to prepare a tender that includes all possible aspects of the projects so a contractor can quote a fixed price? What about the evaluations of all possible risks (legal, ownerships, technological, etc.) including problems if they choose the wrong solution? And the time to do it with continues improvements and changes in technology, legislations, etc.?

What about upgrading existing wastewater treatment plants and dumps to transform them into producers of renewable biogas for the municipal buses, taxis, waste collecting trucks, etc.? What are the cost of production and the selling price of the biogas, once fossil fuels are banned? And the technology risk?

In both cases, it is not just to manage the investment; it is also to manage the production and delivery of the electricity or biogas to the users in an efficient way and profitable, not only in terms of economy but also environmental. And to do it with many risk (legal, technological) very difficult to precise now.

The European Union has long been committed to international efforts to tackle climate change, so it should be a matter of time that they promote PPP in their countries to manage those investments. And Alliance would be one of the best ways to do it.

Author details

Fco. Javier Carrillo de Albornoz Portes

Address all correspondence to: fjcarrillo@gmail.com

SUEZ Advanced Solutions Spain, Madrid, Spain

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Chapter 6

Innovative Solutions for Seawater Use in Mining Operations

Edelmira D. Gálvez and Luis A. Cisternas

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68191

Abstract

This chapter reviews the use of seawater in the mining industry in Chile, especially from the perspective of the current situation and the innovative proposals for its sustainable use. This chapter describes the current use of seawater, with and without desalting, in the mining sector in Chile, as well as its future projection. Descriptions are given for the current desalination systems, mining operations currently using seawater and new projects, current water distribution systems, seawater applications in hydrometallurgy and minerals concentration, their environmental impacts, and difficulties in adapting processes in case of use of seawater without desalination. This is complemented by a description of mining in Chile, its importance for Chile and its relationship to the global mining. Finally, problems and opportunities are identified. A second aspect considered in this chapter is the innovative solutions that are being investigated to solve some of the problems indicated above, including integrated seawater distribution systems, seawater biodesalination, partial desalination using carbon dioxide, adaptation of process to the use of seawater without desalination, and uses of discard brines from reverse osmosis plants.

Keywords: mining, desalination, seawater, water distribution networks, Chile

1. Introduction

The major resource of water on the planet is the water in the oceans that represent 97% of available water. The other 3% includes a 2% of available water in ice caps and glaciers and therefore is difficult to use as a water resource. Traditional freshwater resources (groundwater, lakes, wetlands, rivers, among others) represent only 1% of all water on the planet. Overexploitation of these traditional resources in arid and semiarid areas, such as northern Chile, southern Peru, and parts of North and South Africa, Asia, and Australia, has created a

situation of scarcity of the resource that forces them to seek new water sources and improve the efficiency of its use.

Water has become an important research topic since a significant part of the world is not managing to have this resource of adequate quality and because the different sources of water on the planet are affected by human activities. Thus, the publications registered in web of science that include in the title the word "water" have increased from 10,601 to 24,925 from the year 2000 to 2016. As the main source of water is the water in the oceans, research related to seawater has proportionally increased more than the research related to water in the same period. **Figure 1** shows that the publications registered in Web of Science that included in the title the word "seawater" increased from 226 to 753 from 2000 to 2016. **Figure 1** also shows the evolution of publications that include in their title seawater and are related to mining.

The areas in which it is published on seawater have changed in recent years. During the period 1996–2005, the areas with the most publications were chemistry analytical (339), water resources (302), and oceanography (300). On the other hand, during the period 2006–2015, the areas were water resources (731), environmental science (692), and chemical engineering (692). This change reflects a greater interest in seawater as a water resource (see **Figure 2**).

The shortage of fresh water in arid areas is an economic, environmental, and social problem. Specifically, demand for seawater for mining requires energy for desalination and transport from the coast to high-altitude areas. Then, the use of seawater generates energy demand, another scarce resource. This increased consumption of energy can generate more pollution, as is the emission of greenhouse gases. Thus, besides the possible direct environmental effects of using seawater, indirect effects are also generated. Moreover, it is clear that the use of seawater is usually more expensive than other sources. Seawater can be used without desalting, but this requires that the process must be adapted to new conditions. Among these, new conditions are possible interactions of elements dissolved in seawater with minerals, chemicals,

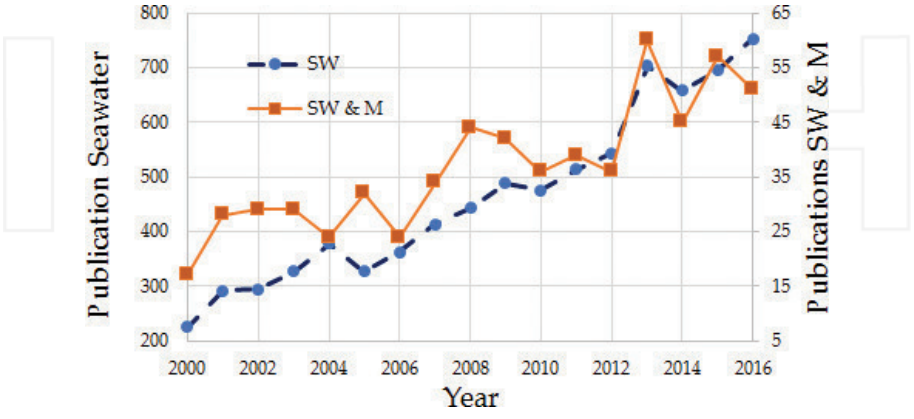

Figure 1. Publications in Web of Science that include in the title seawater (SW) and seawater related to mining (SW & M).

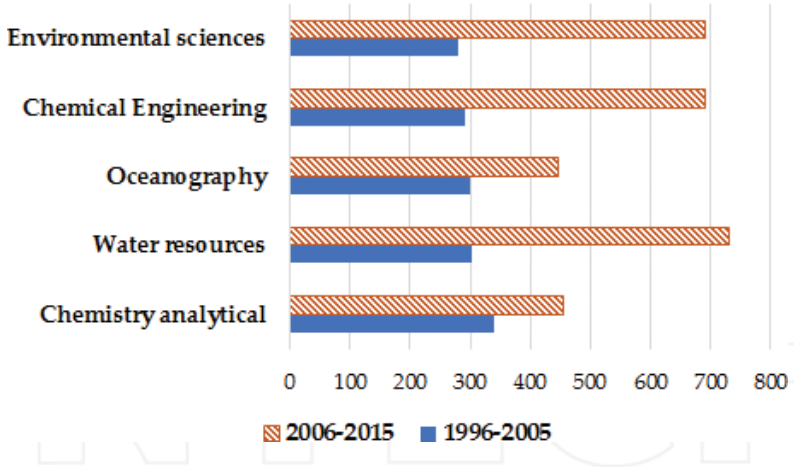

Figure 2. Areas of publications in Web of Science that include in the title seawater.

and materials used in the equipment. Then, new technologies are needed to adapt traditional processes to seawater without desalination.

Chile main economic activity, based on production and income, is mining. The main ore deposits are located in the regions that are part of the Atacama Desert. These regions are rich in copper, gold, molybdenum, silver, iron, nitrate, boron, iodine, lithium, potassium, and other resources. Chile's abundance of mineral resources is remarkable: Its reserves constitute 6.7% of the world's gold, 12.1% of the molybdenum, 13.3% of the silver, 27.7% of the copper, 53% of the rhenium, 57.9% of the lithium carbonate, 60.8% of the iodine, and 100% of the natural nitrates [1]. In addition to its abundant resources, Chile's mining industry is boosted by several other natural, technological, and administrative advantages as such mineral deposits in the vicinity of many seaports, the desert setting surrounding the large deposits facilitates land claiming, exploration, and exploitation, large deposits enable the use of massive and low-cost technologies, among others. However, Chilean mining also faces major challenges, such as the lowering of the grades in its deposits, high energy costs, and scarce-water resources. In 1992, 21% of the world copper production was made from minerals with better grades than Chilean minerals. That percentage has been increasing, and in 2010, 35% of the world production was with better grades than the Chilean ones. It is projected that by 2020 this percentage will be 43% [2]. This means, among other things, that more energy and water resources will be required per ton of copper produced. Chile has one of the highest electricity rates among the mining countries [2], only surpassed by the Congo. Also, and as we will see later, water resources are very scarce, and the use of seawater has a high cost due to the difference in altitude between the coast and the location of mining operations.

Figure 3 shows a scheme of the region of Antofagasta, the main mining region of Chile. After a narrow plain on the coast, the mountain of the coast is situated, where copper mines are found, most of them of medium or small size. These mountains usually have an altitude of about 800 m.a.s.l. Then there is the Atacama Desert where the main mines are nitrates

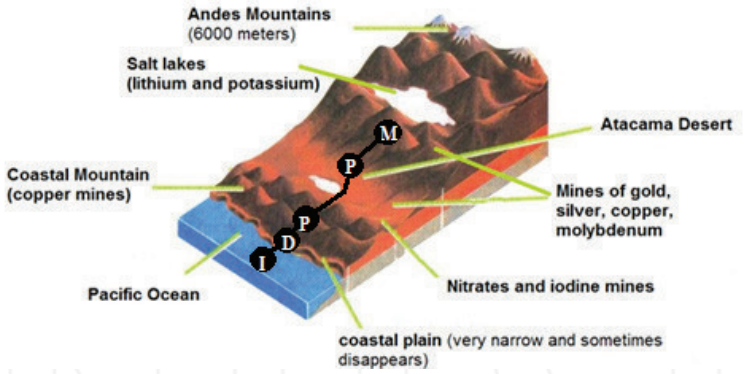

Figure 3. Geographical scheme of the Antofagasta region, mining activities, and seawater catchment system. (I: Intake, D: desalination plant, P: pumping system, M: mine).

and iodine, but where copper and molybdenum mines are also observed. In the Domeyko and Andes mountains are the largest copper mines, along with deposits of gold, silver, and molybdenum. These mountains have altitudes between the 2000 and 6000 m.a.s.l. To supply water from the ocean, it is necessary to have an intake system, seawater pretreatment/desalination, and a pumping system to reach the mining plant located near the mines.

This chapter describes the current use of seawater, with and without desalting, in the mining sector in Chile, as well as its future projection. Section 2 gives a description of the current seawater consumption, the desalination systems, mining operations currently using seawater and new projects, current water distribution systems, seawater applications in hydrometallurgy and minerals concentration, their environmental impacts, difficulties in adapting processes in case of use of seawater without desalination. Section 3 gives innovative solutions for sustainable use of seawater, including integrated seawater distribution systems, seawater biodesalination, partial desalination using carbon dioxide, adaptation of process to the use of seawater without desalination, and uses of discard brines from reverse osmosis plants. Finally, a section of conclusions and comments is included.

2. Current use of seawater in mining

The use of seawater is not new and deposits of copper, zinc, uranium, and iodine have been processed using this water resource without desalination. For example, the El Boleo project processes copper, cobalt, zinc, and manganese minerals (by leaching) in Mexico, and Sierra Gorda SCM processes copper and molybdenum (by flotation) in Chile. Some operations using seawater have closed down, for example, Black Angel (Greenland) floated a lead-zinc ore, and Minera Michilla (Chile) was leaching a sulfurous copper ore. Currently, in Chile, several mining companies use seawater, with and without desalination, let's see the current situation.

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Copper mining, Chile&s main water-consuming in mining, consumes 15.4 m^3/s of fresh water. Of this fresh water, 85% is of continental origin, which includes surface water, groundwater, and water purchased from third parties (see **Figure 4**). The remaining 15% corresponds to seawater, which includes raw seawater and desalinated seawater. This fresh water is used in the mine (0.6 m^3/s), hydrometallurgical processes (2.2 m^3/s), in the concentrator (11.1 m^3/s), smelter and refinery (0.5 m^3/s), and other uses (0.8 m^3/s). The fresh water only corresponds to 28.6% of the water used in the processes because 72.4% (40.4 m^3/s) corresponds to recirculated water. These values were calculated based on information provided by Chilean Copper Commission (COCHILCO) [3] for the use of continental waters and assuming that desalinated seawater is used in the same proportion in the mining areas as continental water and that raw seawater is used 100% in the concentrator.

Not all of the water is recycled because there are losses by evaporation in the leaching process and in the storage ponds, losses in the tailings ponds, filtrations, infiltrations, among others. However, efforts are made to reduce water losses, for example, by covering the ponds

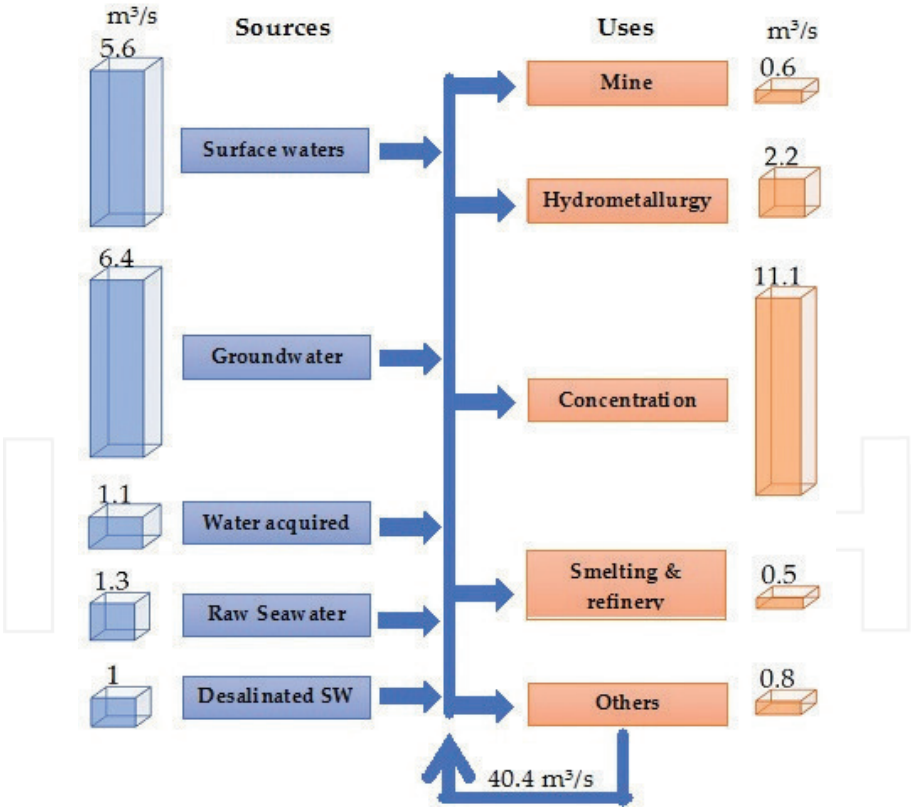

Figure 4. Sources and uses of fresh water in the copper industry in Chile based on COCHILCO studies [3].

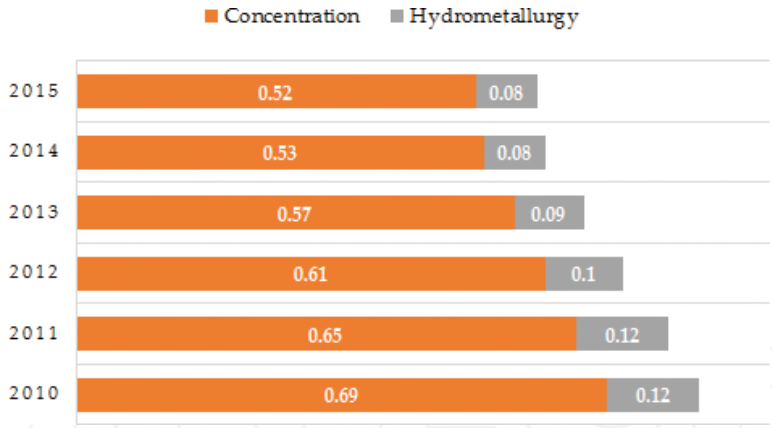

Figure 5. Water consumption in cubic meters per ton of treated ore [3].

and improving the thickening systems. In fact, water consumption per ton of ore has been reduced by 25.9%, from 0.81 m^3/t in 2010 to 0.60 m^3/t in 2015. **Figure 5** shows the consumption of the concentrator and in hydrometallurgy. It can be observed that the consumption of the concentrator plant is 6.5 times the consumption in hydrometallurgy per ton of mineral. Unfortunately, the main mineral of copper and of which there are greater reserves in the world, chalcopyrite, is preferably processed by the concentration of minerals.

2.1. Consumption of seawater and its projections

Given the depletion of continental water sources, new operations or expansion of new operations in water-scarce areas should use seawater. In fact, the use of surface water decreased from 5.9 to 5.6 m^3/s from 2013 to 2015, while groundwater increased slightly from 6.2 to 6.4 m^3/s. However, the use of seawater in the same period increased from 1.3 to 2.3 m^3/s. **Figure 6** shows the evolution of the consumption of seawater, with or without desalination, from 2010 to 2015 observing a significant and sustained increase. There are currently 10 desalination plants of mining companies that produce between 5 (Minera Pampa Camarones) and 500 L/s (BHP Billiton and Lundin Mining have plants of similar capacity). On the other hand, seven mining operations use raw seawater with capacities of between 5 (Compañia Minera Tocopilla) and 1500 L/s (Antofagasta Minerals). Currently, 15 projects for the installation of new desalination plants are in different stages. Stand out the projects of Coloso BHP Billiton plant (at start-up stage) for 3200 L/s and Radomiro Tomic CODELCO for 1900 L/s, which will significantly increase the use of seawater. Additionally, four projects will use raw seawater with an approximate consumption of 1100 L/s.

Currently, each mining plant establishes its water supply system. This means that there are currently 17 water pumping systems (10 of desalinated seawater and 7 of raw seawater) from the coast to the mountains and that these pumping systems will increase to 36 if each project materializes.

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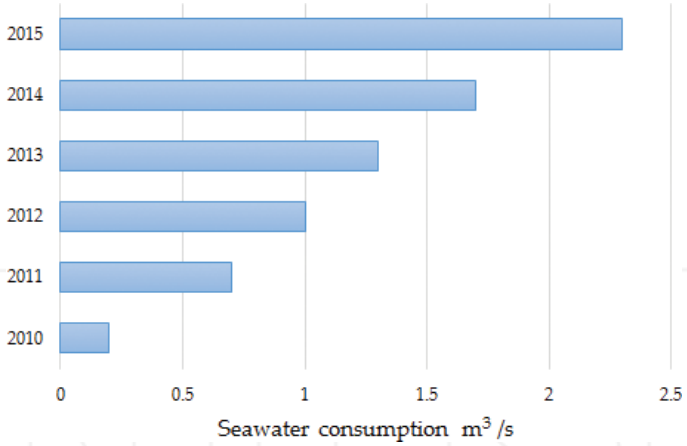

Figure 6. Seawater consumption in mining in Chile [3].

2.2. Reverse osmosis desalination versus raw seawater

The use of raw seawater has advantages and disadvantages. In the treatment of some minerals, its effect is positive favoring the extraction of valuable species, while in other cases, its effect is contrary. This is generated because seawater presents numerous species that interact with the process. As the desalination is not included, there are no high energy costs and their environmental effects are lower. The presence of chloride ions causes corrosion problems in equipment that is in contact with seawater.

The use of desalinated seawater also has advantages and disadvantages. How this water does not contain dissolved species does not observe positive or negative effects in comparison to other process water. Although the process of desalination by reverse osmosis, the technology used in all projects in Chile is the most energy-efficient technology, it requires a high energy consumption. This current energy consumption is not too far from the theoretical minimum energy required for desalination [4]. Electricity generation in northern Chile is based on fossil fuels, which is why desalination generates negative environmental effects. Recently, some solar-based electricity production capacities have been urged, but they are still insufficient. In addition, desalination by reverse osmosis generates a discharge brine, with a salinity of approximately twice the seawater. This discharge brine and the chemicals used in pretreatment and membrane-cleaning can generate negative effects to the environment [4]. Pure desalinated seawater is highly acidic and is thus corrosive, so it has to be posttreated to adjust for pH, hardness, and alkalinity before being piped [5].

It has been demonstrated in practice that both types of water, raw and desalinated seawater, can be applied to mining processes. The decision depends on the characteristics of the ore, the associated costs, and the capabilities or possibilities of adapting the mining operation to the use of raw seawater. **Figure 7** shows that the consumption of both types of waters has been increasing since 2010.

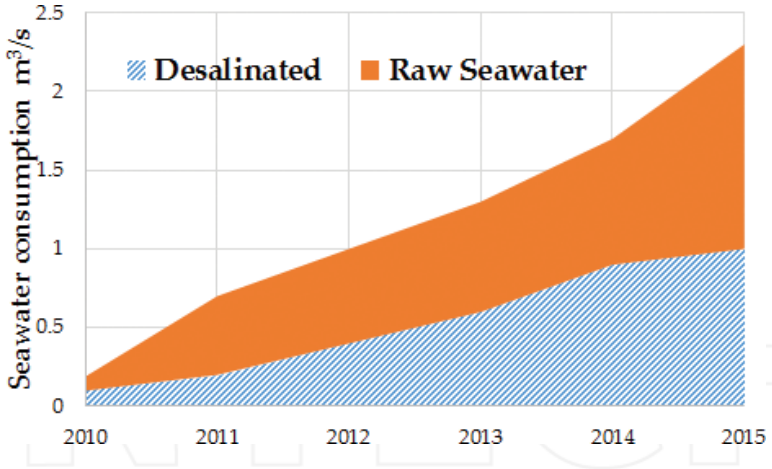

Figure 7. Consumption of raw and desalinated seawater in mining activities in Chile [3].

2.3. Seawater distribution networks

The main mining activities in Chile are located over 1000 m.a.s.l., which creates a great challenge for the industry. **Figure 8** shows the costs of using desalinated water in different countries. It can be observed that the costs of desalination are similar between countries, and this is around 1.5 USD/m^3. However, the operating and capital costs of transporting water in Chile are higher than in other countries. In fact, the costs of transporting can be more than three times the costs of desalination. This is explained by the fact that the altitude of the mining deposits in Chile is higher than in other countries, as shown in **Figure 9**. The operational costs of transportation are mostly the costs of energy consumption associated with water pumping.

As indicated above, currently each mining plant establishes its water supply system. Currently, there are 17 water pumping systems from the coast to the mountains, and these figures can increase over 100% if the new projects materialize. The current strategy is not sustainable in the future, especially for medium and small-scale mining.

2.4. Effect of raw seawater in mining operations

The effects of using raw seawater in mining operations are diverse. Seawater contains dissolved ions that interact with minerals producing positive and negative effects on operations. The major ions dissolved in seawater are sodium and chloride, where the sodium effect is not significant, but the chloride ion helps to improve the leaching of some copper sulfide minerals [6, 7] and helps the stability of the bubbles in the flotation of copper sulfide minerals [8, 9]. Thus, in principle, the chloride and sodium ion may not be withdrawn from seawater. It has been observed that the presence of magnesium and calcium ions produce problems in the molybdenite flotation of copper-molybdenum ores [10]. These problems are due to the precipitation of these ions under the operating conditions of the flotation. Also, it has been observed that by removing or reducing the concentration of magnesium and calcium, the

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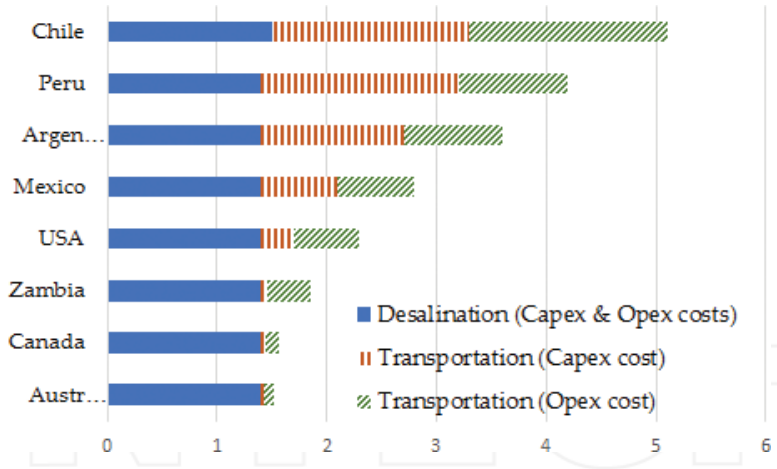

Figure 8. Desalination and transportation costs in USD/m^3 [4].

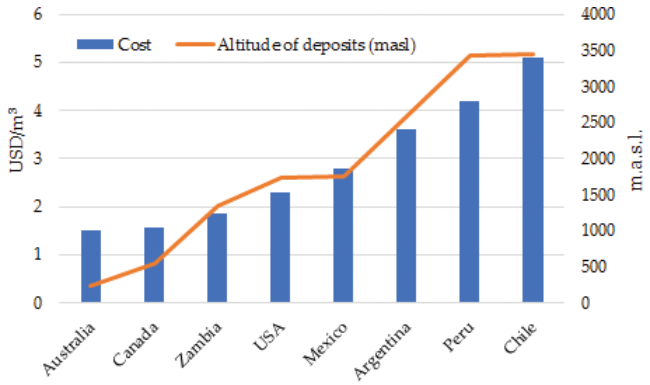

Figure 9. Transportation cost and altitude of mineral deposits [4].

negative effects of seawater in flotation are overcome. In simple terms, it can be said that the partial desalination of the magnesium and calcium ions is enough to use seawater in operations of concentration (flotation) of minerals. It is necessary to remember that the operation that consumes the most water is the concentrator.

Seawater also has gases dissolved by its contact with the atmosphere. The main gases are oxygen, nitrogen, and carbon dioxide, and the latter reacting in aqueous media generating bicarbonate and carbonate ions. The presence of oxygen in all waters produces corrosion, and in the case of seawater, its effect should be lower because the solubility of oxygen decreases as salinity increases. However, the presence of chloride ions generates a more corrosive environment, reason why measures must be adapted to avoid the corrosion of the equipment.

Seawater has also been used in the leaching of caliche minerals [11]. Caliche is a mineral rich in soluble species such as salts of chlorides, nitrates, and sulfates of sodium, magnesium, and potassium, as well as iodine salts. The main products are salts of nitrate and iodine. The use of seawater in the leaching of these minerals does not present great differences compared to non brackish waters because the mineral is rich in salts and the solutions recirculated to the process contain dissolved ions in a much greater concentration than the seawater.

3. Innovative solutions for sustainable use of seawater

This section presents examples of innovative solutions to the problems of the use of seawater in mining processes. These solutions have been developed through the project "Atacama seawater: process integration for water and energy saving." All these research seek to use seawater in a more sustainable way, especially reducing the environmental impact of the use of seawater in mining.

3.1. Integrated seawater distribution networks

As noted above, mining companies have begun to use desalinated seawater as an alternative to supplying part or all of their demands. However, these efforts have been carried out independently, that is, each user or mining company has installed its desalinated water production and distribution system, without considering the possibility of designing an integrated production and distribution system. Currently, the region of Antofagasta has more than 40 mining industries in operation, which are located, regarding distance, from a few kilometers of the coast to about 200 km. However, the most important thing to consider is that these industrial plants can be found between 600 and 4000 m above sea level, due to the complex topographical profiles existing in the region. This location becomes a problem if one considers using desalinated seawater to supply its production systems, significantly increasing the engineering challenges in the design of the water production and distribution system for each mining plant.

Due to the complex topography of the region, the desalinated water supply systems that have been designed and are currently operating have faced several economic, technical, and environmental challenges, such as the high energy requirement of the desalination plant and the water supply system. The desalinated water delivery system consists of a pipeline, a series of reservoirs, pumps, among other hydraulic compounds. The fundamental purpose of the system is to provide a safe supply of freshwater with a certain established quality. The design of the system is basically determined by the distances between the coast and the point of use of the water, the difference in elevation between these same points and the characteristics of the soils where the project will be carried out.

In northern Chile, the capital and operational costs of the desalinated water delivery system are the highest in the entire desalination project. The data provided by Guerra et al. [12] indicate that when mining plants are under 1000 m above sea level, the capital costs of the desalination plant are similar to the capital costs of the desalinated water delivery system.

In contrast, when the mining operation is above 3500 m.a.s.l., the capital costs of the delivery system can be two to five times more than the capital costs of the desalination plant. These costs are increased mainly by the greater number of pumping stations needed to boost the desalinated water to the required point, that is, the costs are a function of the location height of the mining plant. **Table 1** shows the capital and operating costs of six mining projects in northern Chile.

Recently [13, 14], a procedure has been developed to design an integrated desalinated water production and distribution system for the Antofagasta region. The purpose of an integrated water distribution system is to supply different users with different requirements in a more efficient way, both economically and environmentally. This system can be represented by an interconnected network of pipes, pumps, valves, among other hydraulic elements. The procedure developed is based on a mathematical model that represents a set of alternatives, whose solution is obtained looking for the optimal solution from the point of view of cost. This procedure is not described here, but a case study is used to describe the results obtained.

The case study carried out for the Antofagasta region consisted of the integration of six mining sites in the northern region of the Antofagasta region (between latitudes 21° 30'S and 23° 1'S), which were located using geographic information software, Google Earth Pro 7.1 (**Figure 10**). The three indicators shown in **Figure 10** represent the following: the indicator PO represents the reverse osmosis plants, the indicator EB to the pumping stations, and the indicator PM to the mining plants. For each mining plant, different requirements of desalinated water, elevation above sea level and distance from the coast were considered. The desalinated water requirements considered vary between 100 and 400 L/s. The distances of each of these operations toward the coast were defined between 60 and 195 km, while elevations were between 1700 and 3800 m.a.s.l. A maximum of six reverse osmosis plants was considered since the integrated system was born from the integration of six independent systems. Each desalination plant may have sufficient capacity to meet the desalinated water requirements of all the mining plants considered in the study. The drive system consisted of 25 pumping stations. Also, it was considered that the maximum elevation difference to

Capacity RO plant (L/s)	Elevation (m.a.s.l.)	Capital cost (MUS$/year)		Operational cost (MUS$/year)	
		RO plant	Water delivery system	RO plant	Water delivery systems
1000	4150	264.4	428.3	22.4	65
550	4400	190.8	412.4	16.8	47.5
180	830	147.2	328.7	13.2	35.9
700	3650	27.9	29.1	3.24	1.68
500	500	63.4	163.4	11.6	16.9
271	4100	42.8	48.9	6.68	5.16

Table 1. Capital and operational costs of reverse osmosis (RO) desalination projects developed in northern Chile [11].

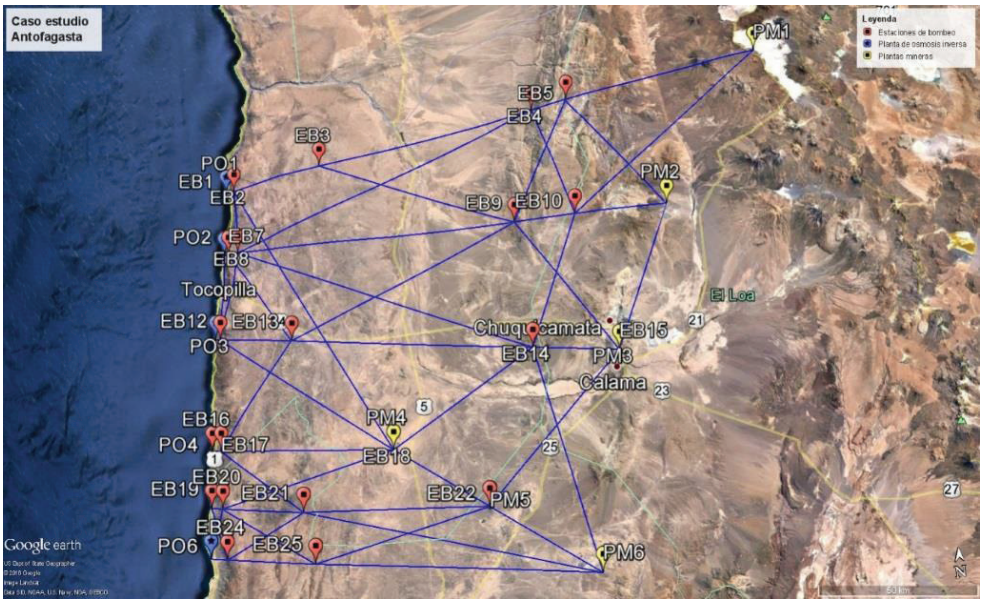

Figure 10. A case study of an integrated desalinated water supply system for six mining plants in the Antofagasta region. PO indicator: reverse osmosis plants; EB indicator: pumping stations; and PM indicator: mining plants [14].

connect two nodes with one pipe was 700 m. Finally, to evaluate the design, five types of pipe diameters were considered that fluctuated between 0.7 and 1.1 m. The investment years considered for the project were 25 years.

The problem was modeled and solved in a commercial optimization software. The results obtained indicated that the optimum model should be constituted by a reverse osmosis plant and seven pumping stations as shown in **Figure 11**.

Alternative 1 represents the current strategy of the mining companies, that is, the use of independent supply systems. Alternative 2 represents the proposed solution. In alternative 1, six reverse osmosis plants must be installed to satisfy the water requirements of each mining plant independently. Alternative 2 indicates the need for only one reverse osmosis plant and fewer pumping stations than alternative 1. Also, the productive capacity of the reverse osmosis plant of alternative 2 is greater than any other reverse osmosis plant considered in alternative 1. On the other hand, the unit cost of production of the reverse osmosis plant is lower due to economies of scale.

The results indicate that the costs of reverse osmosis plants occupy between 29 and 32% of total project costs, pumping stations between 40 and 52%, and pipes between 20 and 27%. The results show that alternative 2 involves a lower cost in the installation of the reverse osmosis plant and pipes. On the other hand, the costs of pumping stations increase slightly relative to alternative 1. In **Figure 11**, alternative 2, it can be seen that the production flow of desalinated water is separated into two streams after supplying the first mining plant. This is

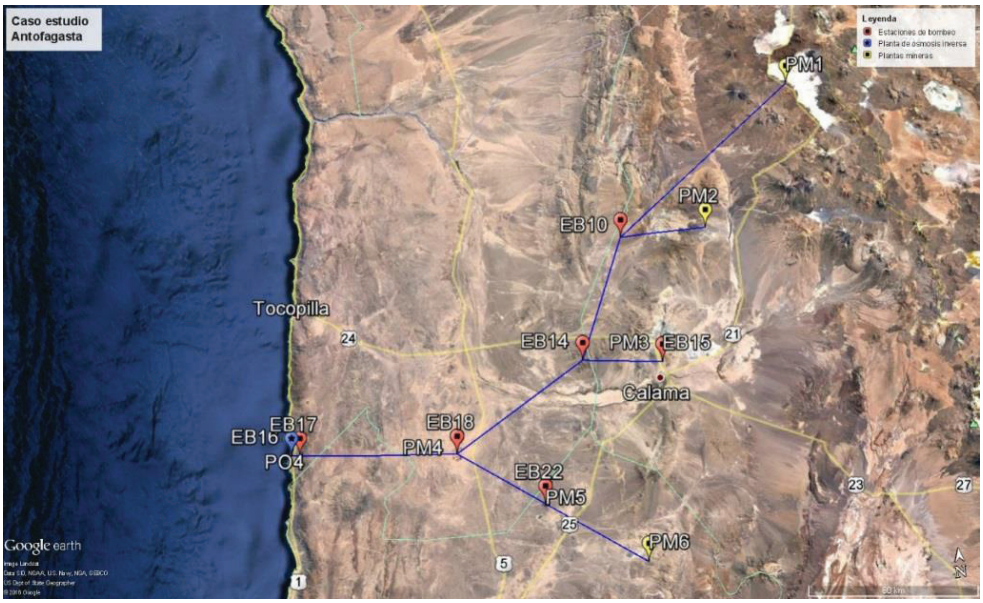

Figure 11. Optimum proposed model of an integrated desalinated water supply system for six mining plants in the Antofagasta region. PO indicator: reverse osmosis plants; EB indicator: pumping stations; and PM indicator: mining plants [14].

mainly because the proposed strategy has a main objective to reduce the costs of the pumping stations, which are directly proportional to the capacity (size) of each station, which is related to the flow driven.

Based on the results obtained, it was observed that there is a relationship between the three considered costs, such as costs of reverse osmosis plants, costs of pumping stations, and pipe costs. These results allow us to propose that an integrated desalinated water distribution system design, which satisfies the requirements of more than one user, is a valid alternative that will also allow decreasing the costs of production of desalinated water to each interested user.

3.2. Biodesalination of seawater

As indicated above, the main problems in using seawater in flotation processes of copper-molybdenum minerals are the presence of magnesium and calcium ions. For that reason, it seems reasonable to look for processes that are capable of eliminating or reducing the concentration of these species selectively. These new processes must be economically and environmentally superior to reverse osmosis plants. The selective removal of these ions, also, allows maintaining the species that are harmless or help to the flotation process as is the case of the sodium and chloride ions, respectively. A biotechnological alternative for the selective removal of these secondary ions from seawater is the application of bacteria that are capable of inducing the formation of insoluble crystals with these ions through a phenomenon known

as biomineralization or microbiological precipitation of carbonates. In this way, the calcium and magnesium ions are removed at a lower cost and in an environmentally friendly way.

The concept of biomineralization or microbiological precipitation of carbonates is defined as the process involving the formation of minerals by living organisms as a result of cellular activity that promotes the physicochemical conditions required for the formation and growth of the biominerals is carried. This process is mainly generated from bacterial activity, which is able to induce the precipitation of minerals by processes classified as biologically controlled mineralization and biologically induced mineralization [15].

In biologically induced mineralization, minerals are precipitated by the interaction between the environment and its chemical changes and the biological activity resulting from bacterial metabolic activity [15, 16]. In this type of biomineralization, the biominerals are secreted due to the metabolism of the microorganisms, and the system has very little control over the deposited minerals. There are a large number of bacteria capable of inducing extracellular precipitation from a wide range of biologically induced minerals, involving the geochemical activity responsible for mineral deposits in terrestrial evolution.

The best-studied mechanism for the precipitation of calcium carbonate is through the ureolytic pathway, in which the bacteria degrade urea by the intracellular enzyme urease, producing HCO_3^- and NH_3. The latter is converted to NH_4^+, alkalinizing the medium, and HCO_3^- is converted to CO_3^{2-} [17]. When the calcium ion is present, and the supersaturation of calcite occurs, the precipitation of calcium carbonate is induced.

Silva-Castro et al. [18] demonstrated the precipitation of calcium carbonate in seawater and brines from desalination plants, using Bacillus and Virgibacillus bacteria isolated from saline environments, confirming that these species can precipitate calcium carbonate when grown in culture media supplemented with organic matter. The precipitation of magnesium from seawater by the use of ureolytic halotolerant bacteria has not been described. However, the precipitation of struvite by chemical crystallization using the NH_4^+/PO_4^{2-} ratios in solution was studied [19], concluding that the use of seawater as a source of Mg for phosphate precipitation is feasible, mainly due to the high concentration of magnesium available (about 1.29 g/kg).

These studies were the basis for studying the feasibility of using ureolytic bacteria and their metabolic products as a possible technology for the removal of Mg and Ca from seawater. Considering the characteristics of the Salar de Atacama (it is the oldest, dry, and hot of the whole planet [20]), bioprospections were realized for the search, isolation, and selection of bacteria with ureolytic activity able to tolerate the salinities present in seawater for the biomineralization of calcium and magnesium. A total of 213 bacteria were isolated from these samples, of which 40 were found to have urease activity and are halotolerant and/or halophilic, capable of growing in seawater [21–23]. The phylogenetic identification of the bacteria with urease activity allowed to determine that they belong to different genera, being the most abundant the bacteria of the genus Bacillus with a representation percentage of 42%. The advantage of using isolated bacteria in the study site means the use of bacteria native to the environment that pose no health risks.

Recent laboratory-scale studies have shown that two of the selected bacteria can remove calcium ions by 100% and magnesium ions present in seawater by 40% in a period of 7 days, inducing the formation of Crystals composed of ~31% monohydrocalcite, ~28% struvite ($MgNH_4PO_4 \cdot 6H_2O$), ~33% halite (NaCl) and ~8% anhydrite ($CaSO_4$) (**Figure 12**). Further studies are underway to establish a process that is capable of partially desalinating seawater.

3.3. Partial desalination using CO_2

A second alternative for the selective removal of Mg and Ca from seawater is precipitation using some alkalinizing agent and carbon dioxide (CO_2 (g)) [25]. This emerging technology could be a potential process to supply the water quality demanded by the process of flotation of Cu and Mo sulfide minerals and at the same time reduce the greenhouse effect generated by the emission of CO_2 (g) and avoid the discharge of brines of reverse osmosis plants to the sea. It is necessary to remember that thermoelectric plants mainly provide the energy used in the north of Chile. They use nonrenewable fossil fuel such as coal. Carbonization has led to an increase in CO_2 (g) emissions into the atmosphere.

When CO_2 (g) is solubilized in seawater, several reactions are generated that eventually generate bicarbonate ion (HCO_3^-) and ion carbonate (CO_3^{2-}). Based on the interactions that occur in the carbonate system and the ions present in seawater, an additional source of CO_2 (g) on seawater promotes a greater formation of CO_3^{2-}, further inducing the precipitation of calcium carbonate ($CaCO_3$), and magnesium carbonate ($MgCO_3$), among other species.

In this work, the removal of calcium and magnesium from seawater of the San Jorge Bay in Antofagasta using NaOH and CO_2 was studied. The experimental tests were performed with NaOH as alkaline reagents (to maintain constant pH) and different doses of CO_2. The tests were carried out at pH 10 and 10.5, with NaOH, without CO_2 and then with injections of 70 and 210 mL of CO_2. The amounts of Ca and Mg, which precipitated under these conditions, were calculated from the difference between the concentrations before and after the addition

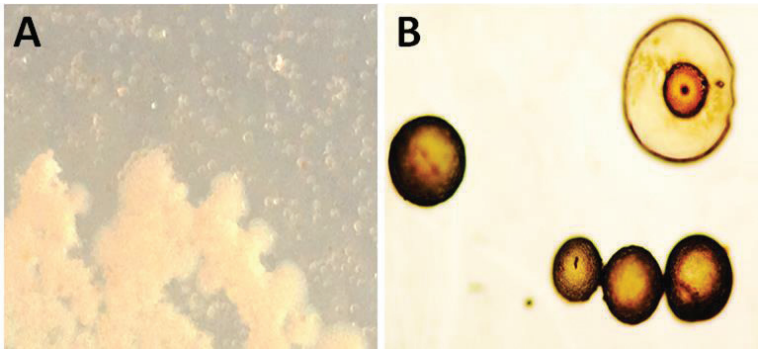

Figure 12. Precipitation of calcium carbonate by strain LN8B. (A) Crystals and colonies in the presence of urea and calcium chloride; (B) microphotography of crystals on day 4 of culture [24].

of NaOH and CO_2. Then, the Ca and Mg concentrations were determined by atomic absorption spectrophotometry.

It was observed that the removal of Ca and Mg increased as CO_2 was added, reaching 31.4 and 70.0%, respectively at pH 10.5 and 210 mL of CO_2. These values are greater than the removal when using only NaOH (without CO_2) corresponding to 11.8 and 13.8% for Ca and Mg, respectively. Subsequent studies using NaOH, Na_2CO_3, and combinations of these alkaline agents and CO_2 injection have shown that this emerging technology has significant economic and environmental advantages compared to the use of reverse osmosis.

3.4. Potential uses for discarding brines from reverse osmosis plants

One way to reduce the environmental impacts of desalination plants by reverse osmosis is to look for uses to the discard brines that they generate. These brines would have a lower cost than seawater since they have already been taken and pretreated. Currently, a very small fraction is used to irrigate roads to reduce dust in mining operations. One possible use is the leaching of caliche minerals.

As indicated above, caliche is a mineral conformation whose composition rich in highly water soluble species makes it a commercially exploitable source of nitrates and iodine. These products have a wide range of applications, such as the use of nitrates for the production of high-performance fertilizers, as well as the use of iodine as an additive in industrial plants and an input in medical products [26]. The processing of caliche for the production of nitrate and iodine salts consists of four fundamental stages: (1) extraction of the mineral, (2) leaching, (3) extraction of iodine, and (4) evaporation and crystallization of the nitrate.

In current reverse osmosis plants, efficiencies of 40–50% are handled, which means that to produce a cubic meter of desalinated water, a similar amount of solution is produced with twice the concentration of salts than the incoming seawater. **Table 2** shows the composition of the seawater and the discard brine of a plant in the north of Chile [27].

Recently, a caliche mineral was leached using seawater (note that seawater is currently used in some plants [26]) and discard brine from a local desalination plant [28]. The leaching was carried out for 22 days in columns of 1.0 m of effective height and 20 cm of internal diameter, and 3 different irrigation rates were used: 4, 6, and 8 L/h/m^2. The liquid samples from the percolates were taken every 12 h for the first 5 days, and after that the sampling was done every 24 h. Samples of caliche and leftover material were also taken. The ions considered throughout this study, both liquids and solids were: nitrate, iodate, chloride, sulfate, perchlorate, boron, sodium, potassium, magnesium, and calcium.

To evaluate the performance of the leaching, the concentration profiles (concentration versus leachate volume) were compared. Some species dissolve rapidly during leaching, such as nitrate, sodium, perchlorate, and iodine, while others do it more slowly such as sulfate, potassium, magnesium, and boron. The differences between the columns watered with seawater and discard brine are small for the first part of the leaching. Afterward, some differences were

Iones	Unidad	Seawater	Discard brine
Chloride	kg/m^3	18.4	36.0
Sodium	kg/m^3	11.1	25.2
Sulfate	kg/m^3	2.8	5.4
Magnesium	kg/m^3	1.4	2.9
Potassium	kg/m^3	0.6	2.5
Calcium	kg/m^3	0.5	0.9
Nitrate	kg/m^3	0.3	0.4
Borate	g/m^3	10	30
Yodate	g/m^3	<10	10
Perchlorate	g/m^3	<10	10
Density	kg/m^3	1020	1040

Table 2. Principal dissolved salts in seawater and reverse osmosis discard brine [27].

observed because once the ore is depleted, the percolates take the initial concentration of the seawater or the discarding brine.

Regarding the extraction profiles, no substantial differences were found in the recoveries between leaching using seawater and desalination plant brine, especially in the species of commercial interest: nitrate and iodine. Their recoveries were similar and reached high values (greater than 97%). These results support the conclusion that it is technically feasible to employ reverse osmosis brines for caliche leaching.

An important point to note is that the use of reverse osmosis brine for caliche leaching does not imply replacing the infrastructure of pipes and other equipment at the mine site, since nitrate operations handle even more concentrated solutions. If the brines are transported instead of seawater from the coast to the mine, a change of piping would not be required either, since the corrosive activity of the brines could be less than that of seawater because the solubility of the oxygen decreases as the salinity increases.

4. Conclusions and comments

The use of seawater in mining generates a series of challenges ranging from the same take of the seawater until its use in the mining plant. Its use must consider economic, environmental, and social aspects. In the Atacama Seawater project, we have taken part of these challenges, some described in this chapter. The search for solutions to these challenges has led us to seek answers that are innovative. Without a doubt, there are still many steps to be taken to materialize these proposals, and therefore further research, developments, and innovations are necessary.

Acknowledgements

The authors thank CONICYT and the Regional Government of Antofagasta for their funding through the PAI program, Project Anillo ACT 1,201.

Author details

Edelmira D. Gálvez[1]* and Luis A. Cisternas[2]*

*Address all correspondence to: egalvez@ucn.cl and Luis.Cisternas@uantof.cl

1 Department of Mines and Metallurgical Engineering, Universidad Católica del Norte, Chile

2 Department of Mineral Process and Chemical Engineering, Universidad de Antofagasta, Chile

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Chapter 7

Microalgae: The Basis of Mankind Sustainability

Francisco Gabriel Acien Fernandez,
Jose Maria Fernandez Sevilla and
Emilio Molina Grima

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/67930

Abstract

Microalgae were the basis of life into the planet, but only recently these microorganisms are exploited at a commercial scale. Thus, the production of pharmaceuticals, cosmetics, feed, and foods from microalgae is today a commercial reality increasing year by year. Additionally, microalgae have been proposed to be used to enhance the sustainability of existing industrial activities, as wastewater treatment and biofuel production. In this way, the utilization of microalgae at a large scale is considered a green revolution in the sustainability of mankind. This chapter is focused on reviewing the real contribution of microalgae to human activities. The last improvements of technologies and its uses, in addition to still existing bottlenecks for the massive exploitation of these microorganisms, are reviewed.

Keywords: microalgae, sustainability, food production, biomass, bioenergy

1. Introduction

Microalgae and cyanobacteria are photosynthetic microorganisms performing oxygenic photosynthesis. There are more than 30,000 species catalogued and classified; however, less than a hundred have been studied, and no more than 20 are actually under commercial exploitation [1]. These microorganisms were responsible for larger transformations into the planet as oxygen production in addition to Fe and S oxidation, which allows the explosion of life into the planet [2]. Moreover, these microorganisms were responsible for CO_2 reduction in past ages transforming it into calcium and diatom rocks, in addition to fossil fuels that we are using now. Today microalgae and cyanobacteria are responsible for most of the solar energy capture and oxygen production into the planet. Thus, these microorganisms are today the

basis of food chain in aquatic systems, thus being a fundamental pillar in the sustainability of the planet. Moreover microalgae and cyanobacteria are majorly responsible for CO_2 transformation to biomass into the planet, thus also contributing to the reduction of the global warming effect [3].

Microalgae are capable of growing in largely different ambients, from warm areas in the tropic and deserts to cold areas in the high mountains and poles. Some of the major advantages of these microorganisms are that they do not require fertile land or usable water and they can grow in contaminated waters [4]. These capabilities allowed humans to use microalgae and cyanobacteria for centuries. Thus, *Spirulina* was harvested by ancient Mexico populations as food especially in the area of Lake Texcoco, a similar scenario taking place in Africa in the areas surrounding Chad Lake, where this fast-growing cyanobacterium grow naturally [5]. Also, different types of cyanobacteria were used, and still they are used today in agriculture to fix atmospheric nitrogen to enhance the production of rice among other crops. The most relevant but usually forgotten contribution of microalgae to mankind is the natural production of feed for aquatic systems used in aquaculture where millions of tons of fish and molluscs are produced on the basis of phytoplankton naturally occurring both in the oceans and lakes [6].

Due to the high capacity to produce biomass and its highly interesting composition, containing proteins rich in essential amino acids, high-value lipids and fatty acids, and valuable carbohydrates, the industrial production of microalgae attracts special attention. The first reports about the production of microalgae were published in 1950 [7] focusing on the utilization of tubular photobioreactors for the production of *Chlorella* in 50 L reactors. Later the production of microalgae in raceway reactors was reported by Oswald mainly for wastewater treatment [8]. These raceway reactors have been applied from the 1970s to produce *Spirulina* at a commercial scale and from the 1980s to also produce *Dunaliella* as a source of β-carotene, these being two nice examples of microalgae-based bioprocesses. Still today these are the strains and photobioreactors largely used worldwide, in addition to *Chlorella*, representing about 20,000 t/year of biomass production. This production capacity is not too much in comparison with other biomasses or crops, but it is increasing more than 10% annually [9]. Thus, in the last 20 years, the number of strains produced at a commercial scale includes *Haematococcus*, *Euglena*, and *Nannochloropsis*, among others, for applications related to feed, foods, cosmetics, and pharmaceuticals.

In this chapter, the major factors influencing the production of microalgae and the technologies used to produce it at a large scale are summarized. Future trends and contributions of microalgae to mankind in the next years will be also discussed to show the relevance of this "green revolution."

2. Major factors in microalgae production

Microalgae are photosynthetic microorganisms equivalent to plants but with some differences: (i) they are micro with size ranging from 2 to 20 μm and usually grow in water bodies; (ii) they grow much faster than higher plants with duplication times lower than 1 day; (iii)

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they do not have roots or large structures, their photosynthetic efficiency being much higher than higher plants; and (iv) they require a supply of large amounts of nutrients, mainly CO_2, N, and P, to maximize their performance. Thus, on the basis of these differences, the microalgae production systems have been developed to satisfy the requirements of microalgae cells to achieve the maximal production capacity at a lower cost.

2.1. Light availability

Light is the main factor in determining the performance of microalgal cells. For the entire solar spectrum, the photosynthetic apparatus only use the light at wavelengths from 400 to 700 nm (photosynthetically active radiation, or PAR), which is being saturated at relatively low irradiances ranging from 100 to 200 $\mu E/m^2 \cdot s$. Because the solar radiation achieves values more than times higher than this saturation value, the photosynthetic apparatus can be oversaturated or photoinhibited at outdoor conditions. To solve this problem and enhance the performance of microalgae cultures, the solar radiation must be "distributed" between the larger number of cells and surface as possible. Thus, different designs of photobioreactors have been proposed. Whatever the photobioreactor design, in microalgae cultures the light impinging into the reactor surface (I_0) is attenuated along the culture as a function of the path length (p), biomass concentration (C_b), and extinction coefficient of the biomass (K_a). This attenuation makes that light gradients exist, the cells being exposed to different light conditions according to the light profile and mixing [10]. Although rigorous calculations about light profile in microalgae cultures have been performed, to approximate the average irradiance at which the cells are exposed to in whatever photobioreactor the equation proposed by Molina is really useful and comfortable (Eq. (1)) [10]. **Figure 1** shows as the higher the biomass concentration the higher are the gradients at which the cells are exposed to inside the cultures, these being higher also the higher the culture depth. Following this argument it would be recommendable to use thin-layer reactors with low biomass concentrations to minimize the light gradients inside the cultures, but in this scenario, the production capacity is largely reduced; then an optimal solution must be found. For this, the optimal design of the reactor maximizing the light on the reactor surface (I_0) while optimizing the culture depth (p) and its adequate operation to maintain the optimal biomass concentration (C_b) is the challenge:

$$I_{av} = \frac{I_0}{(K_a \cdot p \cdot C_b)}\left(1 - \exp\left(-K_a \cdot p \cdot C_b\right)\right) \quad (1)$$

According to the limitations of photosynthetic apparatus, it has been reported that microalgae can achieve a maximal photosynthetic efficiency (PE) of 5% from global radiation. This means that microalgae are able to accumulate up to 5000 GW/ha·year in tropic areas if production systems achieving 5% PE are operated, whereas this value reduces to 400 GW/ha·year when considering 1% PE and temperate locations with low solar radiation availability (**Figure 2A**). Considering the heat value of the microalgae biomass of 20 MJ/kg, this means that the amount of biomass than can be produced per unit area and year is limited by the solar radiation availability at the selected location and the photosynthetic efficiency achieved in the used production system. **Figure 2B** shows that biomass productivity values up to 250 t/ha·year can be obtained in tropic areas if 5% PE is achieved in used systems, whereas this productivity decreases to 20 t/ha·year in temperate areas with low solar radiation if 1% PE is achieved.

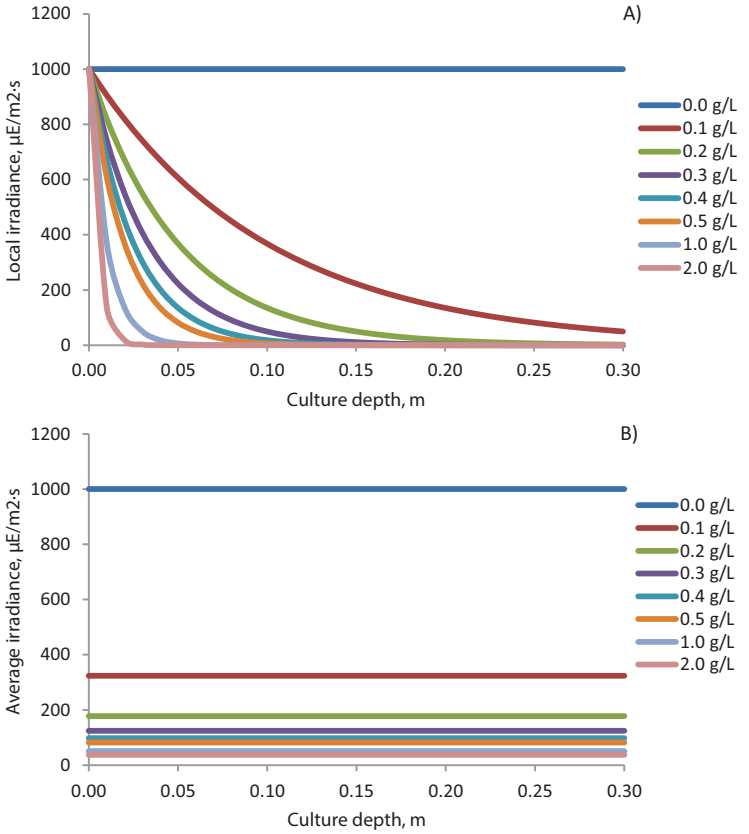

Figure 1. Variation of irradiance as a function of culture depth and biomass concentration in raceway reactors considering a solar irradiance on the reactor surface of 1000 µE/m^2·s and extinction coefficient of the biomass of 0.1 m^2/g. (A) Variation of local irradiance at different culture depths. (B) Average irradiance value estimated for the entire culture.

These values are higher than productivities of corn (12 t/ha), wheat (8 t/ha), or soya (6 t/ha), thus showing that microalgae biomass is a realistic food alternative. Moreover, the large biomass production capacity of microalgae-based processes does that these microorganisms were considered a real alternative to energy crops to produce biofuels [11]. These figures confirm that although solar radiation availability is a major factor in the production of microalgae biomass, the optimization of the used system and at the end the photosynthetic efficiency achieved is also highly relevant in the final biomass production capacity.

2.2. Nutrient supply

Microalgae biomass is mainly composed of carbon (45%), nitrogen (7%), and phosphorus (1%) in addition to oxygen and hydrogen that are directly obtained from the hydrolysis of water. However, the first ones must be supplied, the required amount of these nutrients being directly

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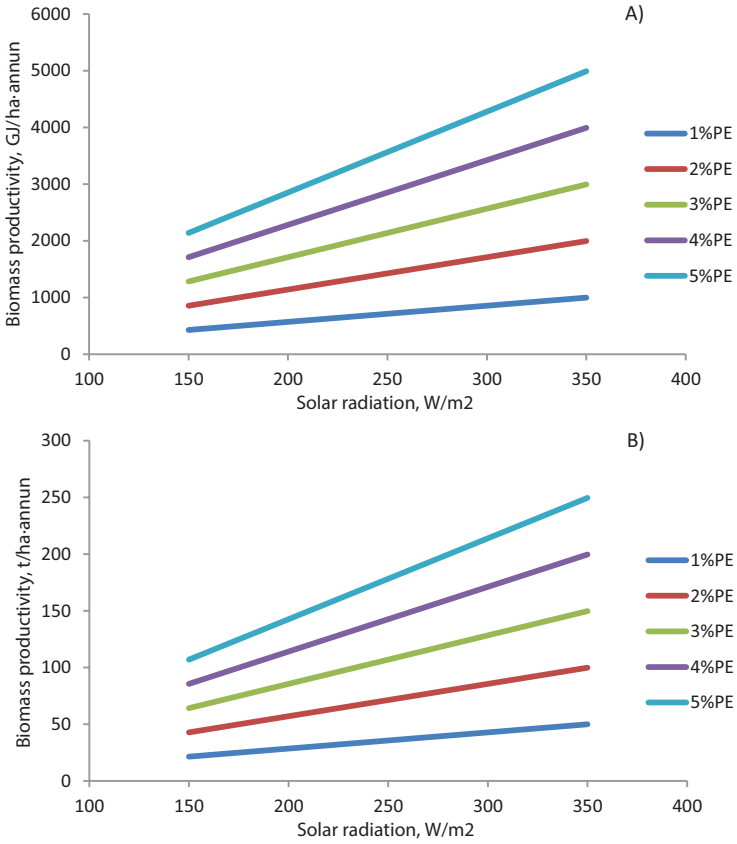

Figure 2. Variation of biomass production as a function of solar radiation availability and photosynthetic efficiency achieved in the production system. (A) Daily biomass productivity per unit surface. (B) Annual biomass productivity per unit surface.

proportional to the microalgae biomass capacity required. Carbon can be supplied as carbonate or bicarbonate, but the utilization of CO_2 is greatly recommended because it allows at the same time to control the pH of the cultures. Stoichiometrically up to 1.8 kg of CO_2 is required to produce 1.0 kg of microalgae biomass, although this value can be modified according to the precise elemental composition of produced biomass. **Figure 3** shows that CO_2 fixation capacity of microalgae cultures is directly a function of solar radiation availability and photosynthetic efficiency achieved in the production system. Values ranging from 190 to 450 tCO_2/ha·year can be fixed in tropic areas at photosynthetic efficiencies ranging from 1 to 5%, whereas in temperate areas with low solar radiation availability, these figures reduce to values ranging from 40 to 90 tCO_2/ha·year at the same photosynthetic efficiencies. Not only pure CO_2 but also whatever gas containing CO_2 can be used to produce microalgae; thus, it is being proposed to use flue gases from power stations, biogas from anaerobic digestion, or fermentation gas from

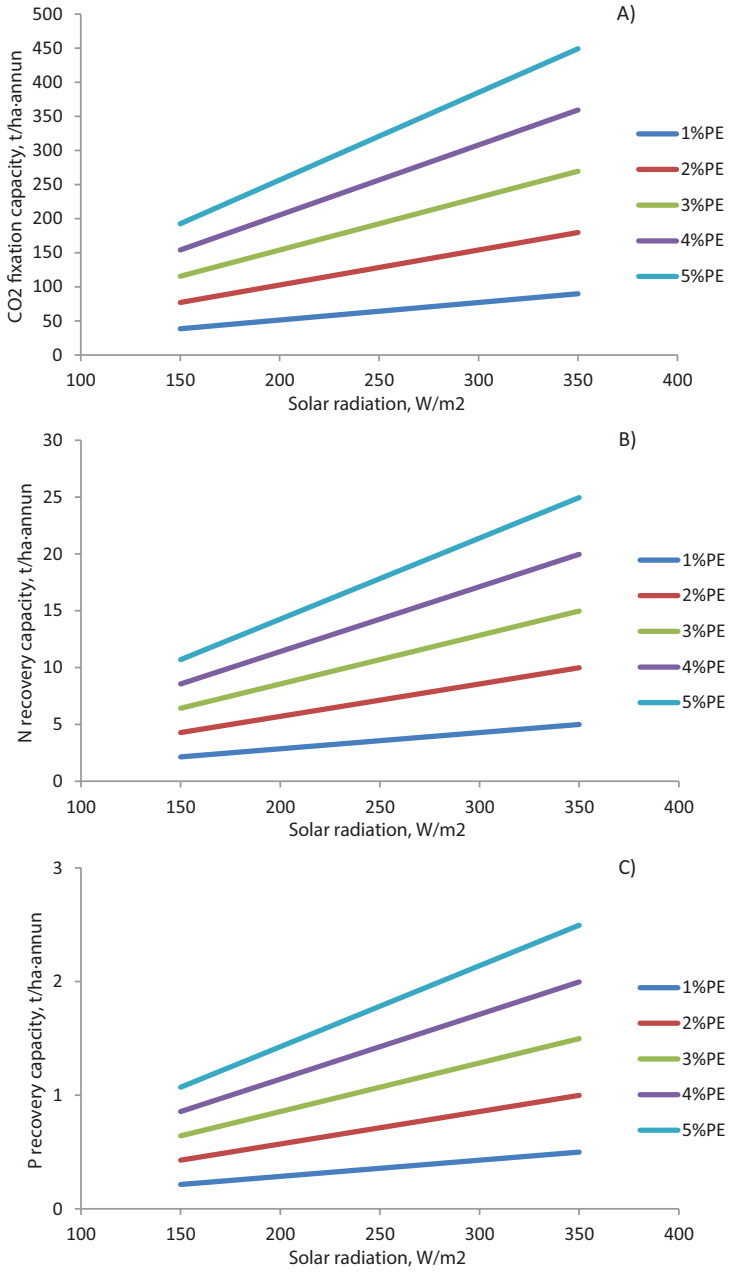

Figure 3. Variation of CO_2, N, and P recovery capacity as a function of solar radiation availability and photosynthetic efficiency achieved in the production system. (A) CO_2 fixation capacity, (B) N recovery capacity, and (C) P recovery capacity.

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ethanol production to produce microalgae biomass at the same time that reducing CO_2 emissions of these industries [12]. When using whatever gas to supply CO_2 to microalgae cultures, two main aspects must be considered: (i) to use efficient systems capable to transfer more than 90% of CO_2 contained into the flue gas to the microalgae culture and (ii) to be sure that the gas does not contain toxics that can damage the growth of microalgae cells (SOx, NOx) [13]. Related to the supply of CO_2 is the removal of oxygen because it is produced at the same rate that CO_2 is consumed, it accumulating into the culture if not removed. Most of microalgae strains are inhibited by oxygen at dissolved oxygen concentration higher than 200%Sat. (c.a. 20 mg/L); thus, adequate oxygen removal systems must be installed and operated to overpass these phenomena [14]. In general, the optimization of mass transfer capacity is a key factor in the performance of whatever microalgae production system [15].

In addition to carbon, nitrogen and phosphorus are the most relevant nutrients required for the production of microalgae. About 0.1 kg of N and 0.01 kg of P are required to produce 1 kg of microalgae biomass. On the basis of biomass production as a function of solar radiation and photosynthetic efficiency, **Figure 3** shows that the N recovery ranges from 2 to 10 tN/ha·year in temperate climates with low solar radiation and from 5 to 25 tN/ha·year in tropic areas, when the photosynthetic efficiency modifies from 1 to 5%. In the same way, the P recovery ranges from 0.2 to 1.1 tP/ha·year in temperate climates with low solar radiation and from 0.5 to 2.5 tP/ha·year in tropic areas, when the photosynthetic efficiency modifies from 1 to 5% (**Figure 3**). Soluble forms of these compounds are produced at a large scale worldwide because they are pillars of the food production by agriculture. Phosphorous reservoirs are limited, and some reports are advertising about the crash of the actual food production system based on phosphorus [16]. To transform P-rich rocks into fertilizers, huge amount of energy is required, whereas nitrogen production systems use atmospheric nitrogen but also are consuming large amounts of energy to transform it into ammonia and nitrate by the Haber process. To avoid these problems, the recovery of nitrogen and phosphorus from wastes and residual streams is mandatory, microalgae being specialists on these processes [17]. Thus, microalgae are capable to completely remove N and P contained in wastewater streams, only using solar energy into the process, at the same time producing valuable biomass. The development of microalgae-based treatment processes is a key issue in this field [18].

2.3. Culture conditions

Microalgae as whatever other microorganisms have optimal conditions that must be known in order to maximize their performance. Optimal salinity, temperature, and pH are strain specific, and the production systems must be adequately designed/operated to maintain it at optimal values. Regarding salinity, although some microalgae can tolerate large variation of salinity, usually freshwater (i.e., *Scenedesmus*, *Chlorella*, *Spirulina*) or seawater (i.e., *Nannochloropsis*, *T-ISO*, *Tetraselmis*) strains are selected according to the salinity of water to be used. Additionally, some hypersaline-tolerant strains can be also produced (i.e., *Dunaliella*), on these conditions the probability of contamination by other strains being reduced. Regarding temperature, most microalgae grow well in the range of 20–30 °C. Over this value, only some extremophile strains show acceptable growth, including some *Scenedesmus* strains and some

cyanobacteria as *Anabaena* [19, 20]. Below the optimal temperature, the growth is reduced, but over the critical one, the culture dies; by this reason to avoid overheating of the cultures is mandatory in whatever microalgae production system. Regarding the pH, it can be controlled by providing acidic solutions to the culture medium, but usually the injection of CO_2 is used to reduce the pH and avoid carbon limitation at the same time. The optimal pH for most of the microalgae strains ranges from 7 to 8, although some cyanobacteria show optimal performance at pH up to 10 [19]. To provide CO_2 for pH control is an engineering problem that must be adequately optimized to minimize the amount of CO_2 consumed while increasing the biomass productivity of the system, always considering the cost of infrastructure and energy consumption involved [13]. To ensure that microalgae cultures are only light limited, the supply of CO_2 is mandatory; this is the reason why most of the production systems worldwide do it.

To provide optimal culture conditions at a laboratory or small scale is quite simple although it is expensive. However, at large-scale and outdoor conditions, to accurately control the culture conditions is simply impossible. As example to control the temperature in large reactors requires large investments and high energy usually it being disregarded, strains to be produced being selected to optimally growth at the ambient temperature prevailing in the selected location. In the case of pH, the injection of pure CO_2 can summarize up to 30% of the overall biomass production cost then the utilization of flue gases or residual streams containing CO_2 being recommendable [21]. Anyway, when considering the control of culture conditions, three time scales must be considered: (i) annual basis that means the mean values of environmental conditions prevailing in the selected location, (ii) daily basis that considers the hour-by-hour variation of environmental conditions due to the variation of solar radiation, and (iii) mixing time that means the time to completely mix the system it influencing the existence of gradients of culture conditions along the reactor. Advanced control methods are being applied now to the industrial production of microalgae to reduce cost and improve the performance of microalgae-based processes [22]. Only an in-depth analysis of main culture conditions and its optimization along the different time scales will allow to maximize the performance of whatever microalgae-based process.

3. Photobioreactors and large-scale facilities

Microalgae production is a process that must be adequately planed and performed. Major steps involved in whatever microalgae production process include (i) preparation of culture medium, (ii) production of biomass into photobioreactors, (iii) harvesting of biomass, (iv) treatment of used water for recirculation or disposal, and (v) stabilization of produced biomass or transformation into end products. The core of the process is the photobioreactor in which the microalgae biomass is produced. Large bibliography is already available about photobioreactor designs and operation, here only a comparison of most used technologies being included [23].

3.1. Open reactors

Open reactors are the most extended for the production of microalgae, more than 90% of microalgae biomass worldwide being produced in these reactors. They are basically large

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water reservoirs with low depth to facilitate the light penetration and increase the biomass productivity. Raceway reactors are the most extended technology but also simple open systems are also used (**Figure 4**). Major advantages of raceway reactors are its low cost, below 10 €/m^2, and easy scale-up, single units up to 5000 m^2 being used at a commercial scale. Another advantage of this technology is its low energy consumption, below 1 W/m^3; thus it is being recommended for low-value applications and the production of biofuels [24]. The major disadvantages of raceway reactors are related to the scarce control of culture conditions and the easy contamination of the cultures. By these reasons they are mainly used to produce strains growing under extreme conditions as high pH (*Spirulina*) or salinity (*Dunaliella*).

Examples of large facilities producing microalgae using raceway reactors are available worldwide. Companies such as Cyanotech (USA; www.cyanotech.com), Earthrise Nutritionals (USA; www.earthrise.com), Parry Nutraceuticals (India; www.murugappa.com), and Myanmar Spirulina Factory (Myanmar) are some of larger producers of *Spirulina* worldwide using raceway reactors in facilities from 10 to 100 ha. These reactors are also used by different companies to produce *Dunaliella* at a large scale such as Nikken Sohonsha Corp. (Japan; www.chlostanin.co.jp), Betatene (Australia; www.betatene.com.au), Nature Beta Technologies (Israel), ABC Biotech Ltd. (India), Tianjin Lantai Biotechnology (China), Western Biotechnology Ltd. (Australia), and Aqua Carotene Ltd. (Australia). The design of raceway reactors is being reviewed in the last years to enhance its performance. Thus, the hydrodynamics, mass transfer, and power consumption are major aspects to be improved [14, 25, 26]. Because these reactors are the most extended worldwide and the technology currently used is performing nicely at a large scale, most of the new microalgae-based processes use this type of photobioreactors. Thus, the development of microalgae-based wastewater treatment or biofuel production processes, and the production of low-cost biomass for biofertilizers and feed, currently uses these reactors [24, 27].

3.2. Closed reactors

Closed reactors are now being used to produce microalgae strains that do not tolerate extreme conditions but contain valuable compounds, thus its price being high. Several designs have

Figure 4. Image of some photobioreactors used for outdoor production of microalgae at a large scale. A raceway reactor of 20 m^3 as an example of open reactor (left side) and ten tubular reactors of 30 m^3 as an example of tubular reactors (right side). All of them installed and operated at Estación Experimental Las Palmerillas (Fundación Cajamar), Almeria, Spain.

been proposed as bubble columns, helical systems, or flat panels, but from all of them, the most extended at a commercial scale are the tubular photobioreactors (**Figure 4**). The basic principle of whatever close reactor is to isolate the culture from the surrounding ambient, thus minimizing contamination problems and avoiding a better control of culture parameters. In the tubular reactors, the culture is continuously recirculated along the solar receiver, which is designed to maximize the interception and utilization of solar radiation. These reactors allow to produce almost whatever strain, including sensible strains such as *Haematococcus* or *Porphyridium*, and to achieve high productivity values, higher than 1 g/L·day, by adequate control of culture parameters. However, they have also disadvantages related to higher cost, higher than 10 €/m^2, and energy consumption, higher than 100 W/m^3, difficulty of scale-up, and reduction of performance by biofouling [23, 28, 29].

Tubular reactors are used mainly to produce high-value biomass for human applications. Thus, companies such as I'age vertd (France; www.agevert.com), SECIL (Portugal), and Roquette Klötze (Germany) produce *Chlorella* for food markets at facilities around 1–2 ha size. Other companies such as Mera Pharmaceuticals (Hawaii, USA) and Algatech Algaltechnologies (Israel; www.algatech.com) are producing *Haematococcus pluvialis* also using tubular photobioreactors. The larger facility based on this technology has been installed in China with up to 20 ha also to produce *H. pluvialis*. Facilities based on tubular photobioreactors are now being installed worldwide, its size and capacity increasing year by year. This is due to the combination of involvement of engineering companies and the requirement of microalgae biomass produced under controlled conditions according to Good Manufacturing Practices (GMP) for human consumption. The utilization of new materials reducing fouling and increasing the stability of the production systems is a major challenge for this technology [30].

4. Microalgae applications

4.1. Microalgae-based market analysis

Microalgae-based products include a large portfolio of applications, some of them only potentially indicated whereas others being realistic at a commercial scale. These applications can be divided in four main groups related to the safety requirements of different markets: (i) production of energy, mainly biofuels; (ii) products for agriculture, such as biostimulants, biopesticides, and bioplastics; (iii) production of feeds for farms and aquaculture; and (iv) products for human consumption, mainly foods and nutraceuticals [31]. When comparing the market size of the different markets, it is observed that biofuels market is requiring enormous productions, higher than 10^7 t/year, that today are far from the actual microalgae biomass production capacity, up to 10^4 t/year (**Figure 5**). The actual production capacity is closely related to human applications, requiring around 10^4 t/year, this being slightly lower than required capacity of agriculture uses, up to 10^5 t/year, and feed applications, of around 10^6 t/year. Regarding market price, the actual microalgae biomass production cost ranges from minimum 5 €/kg in raceway reactors to 12 €/kg in tubular photobioreactors [32]; the market price must be higher than production cost to be economically feasible. Results show as only human

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uses, the production of feed additives and some applications related to agricultural uses, as the production of biostimulants and biopesticides, have market prices higher than the actual production cost (**Figure 5**). From this analysis, it is easily concluded that only these applications are realistic today. Thus, the market value of human-related products exceeds 10^3 M€/year, for agriculture-related products 10^4 M€/year, and for aquaculture-related products up to 10^5 M€/year, demonstrating the relevance of these sectors in the future (**Figure 5**).

To expand the application of microalgae-based processes to other fields, the microalgae biomass production cost must be reduced by one order of magnitude, whereas the production

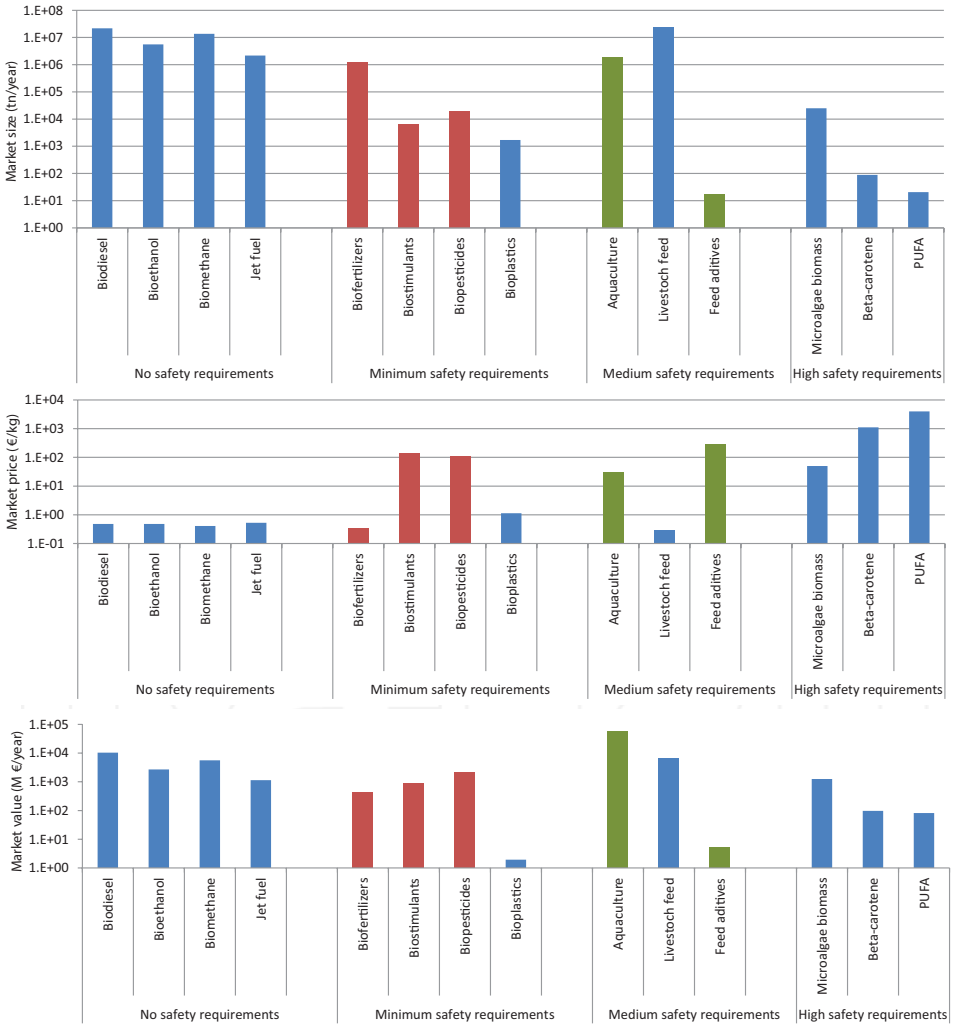

Figure 5. Market analysis of microalgae-based products. Data obtained from Refs. [31, 32, 35].

capacity must be increased by at least three orders of magnitude; that is not an easy challenge. The microalgae biomass production cost can be greatly reduced if the productivity of the actual production systems is enhanced, the facilities are scaled-up, and the coupling with other processes as waste treatment is performed, thus this being the challenge in the future [21, 33]. Regarding the increase of production capacity, only the development of new schemes, using more robust and scalable technologies, in addition to the utilization of more resistant and productive microalgae strains will really allow to significantly increase the production capacity.

4.2. High-value applications of microalgae

High-value applications of microalgae are mainly related to direct human consumption as foods, nutraceuticals, cosmetics, or pharmaceuticals [34]. Microalgae biomass contains proteins, lipids, and carbohydrates, all of them of high quality for human consumption. Thus, microalgae biomass contains large amounts of essential amino acids and polyunsaturated fatty acids, in addition to sterols and carotenoids with antioxidant activity, thus this biomass being considered as a superfood [35]. In this sense, in 2012, the EU adopted a strategy focused to innovate through the impulse of bioeconomy sector, the "Blue bioeconomy" being one of the pillars of this strategy which is being directly related to the production of microalgae as a source of high-value molecules for human uses [36]. Microalgae have been reported to be a "sustainable" source of food and nutraceuticals for human uses, by its higher nutritional and functional properties versus conventional crops as cereals and vegetables and its lower land requirement also reducing the risks related to food insecurity supply in the world [37].

Microalgae biomass can be used as food directly, in different mixtures with other foods, or alternatively by consuming extracts of valuable compounds. Dry biomass of *Chlorella* and *Spirulina* is commercialized as powder or in capsules, also it being incorporated to juices, cakes, pasta, and other foods to enhance the nutritional value or provide healthy properties as antioxidant, among others. Regarding extracts, carotenoids as astaxanthin and β-carotene are extracted from the biomass of *Haematococcus* and *Dunaliella*, generally using supercritical CO_2, and incorporated to suspension as health enhancer. Other compounds as polyunsaturated fatty acids, i.e., eicosapentaenoic cid (EPA), arachidonic acid (AA), and docosahexaenoic acid (DHA), are also extracted mainly from the biomass of marine strains, as *Nannochloropsis* and T-ISO, also mainly using supercritical CO_2, and incorporated to oils and capsules for human consumption. Special mention is the case of the production of docosahexaenoic acid (DHA) from *Schizochytrium* by the company Martek that is incorporated to infant milks in a high-value application.

Major concern about the incorporation of microalgae biomass to foods is related to EU regulation. In spite of largely reported advantages of microalgae biomass for human consumption, only the microalgae now generally recognized as safe (GRAS) can be sold for human consumption. These only include *Chlorella*, *Spirulina*, *Dunaliella*, and *Haematococcus*. Other microalgae must be registered as novel food as recently performed by Fitoplancton Marino regarding *Nannochloropsis*. Anyway, independent of the strain to be produced, the overall production system must be approved for "food industry"; this certification involves the materials, systems, and protocols used during the production process. In this way, the involvement of food companies in the development of microalgae-based processes is mandatory.

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A wide analysis of microalgae-based products for the food and feed sector in Europe has been recently published [32]. According to this review, the global marine biotechnology market in 2011, with microalgae as its main component, was estimated to be €2.4bn, with an expected yearly growth of 10%. Most of this market is related to the health food market as dietary supplements; by these reasons large companies in the food ingredients market as BASF, Unilever, and Dow Chemical are now involved in projects related to microalgae production.

4.3. Low-value applications of microalgae

Low-value applications of microalgae are related to biofuel and biofertilizer production, but all of them are only sustainable if coupling with wastewater treatment [38]. Wastewater treatment is a crucial challenge for the sustainability of human activities. The release of wastewater is continuously increasing by the increase of population and healthy habits. However, wastewater is not always adequately treated; thus, worldwide more people die by diseases related to water contamination that is caused by violence including wars. Moreover, the release of untreated wastewater to environments causes eutrophication problems which are seriously damaging ecosystems. To avoid these problems, the wastewater must be adequately treated to remove pollutants and release water in safe way [39]. Conventional systems based on activated sludge consist of a series of operation units focused on transforming the organic matter into CO_2 that is emitted to the atmosphere, nitrogen and phosphorus being also released to the atmosphere as N_2 or otherwise it being accumulated into the sludge that is finally subject to anaerobic digestion to produce biogas, normally without recovering N or P. Moreover, to perform this process, a large amount of energy is required, up to 0.5 kWh/m^3, the cost of the overall treatment summarizing up to 0.2 €/m^3. The concern about environmental protection is forcing the governments to reduce the limits of N and P content in wastewater for safe release to the environment; then additional treatment processes are necessary, all of them consuming larger amounts of energy and imposing higher costs.

As an example, a company as Aqualia from FCC Group, which is operating more than 250 wastewater treatment plants in Europe, is treating up to 500 Mm^3/year of wastewater. The business related to this activity summarizes more than 100 M€ per year and consumes up to 250 GWh/year, equivalent to the overall electricity consumption of Spain in one day. Moreover, this energy and its CO_2-related emissions are mainly used to dissipate to the environment more than 25,000 tN/year and 5000 tP/year. This large amount of nutrients is sufficient to produce more than 0.5 Mt/year of microalgae biomass, 20 times larger than the actual worldwide microalgae production. The coupling of microalgae production with wastewater treatment allows to reduce the energy and cost of wastewater treatment at the same time that recovers the nutrients contained in wastewater and reduces the production cost of microalgae biomass, to increase the performance of actual technology used being a major challenge in the future [18, 40, 41].

Microalgae can perform the treatment of wastewater in consortia with bacteria. In this technology microalgae perform photosynthesis producing the oxygen required by bacteria to degrade the organic matter to inorganic carbon, nitrogen, and phosphorus that is at the end assimilated by microalgae as valuable biomass [42]. If aeration is not required, the energy cost of wastewater treatment is reduced to half, moreover producing microalgae biomass the net amount of energy

obtained at the end of the process being higher than at the beginning by including solar energy, thus being an "energy positive" process. To couple the production of microalgae with wastewater treatment is not a new idea, and it was proposed by Oswald in the 1960s [8]. However, very few real applications of this technology have been carried out at a commercial scale [43]. There are several reasons for that, but the most relevant is the low efficiency of existing technologies, especially requiring large hydraulic retention times of up to 10 days, thus enormous land requirements being imposed. The improvement of operation conditions and the utilization of new photobioreactor designs as thin-layer cascade have been proposed to improve the performance of microalgae-based systems [44]. Recent advances in the design and operation of raceway reactors, coupled with the reduction of energy consumption and hydraulic retention time required to achieve complete removal of contaminants from wastewater, allow Aqualia to develop the first commercial plant based on microalgae for wastewater treatment with up to 10 ha and be able to treat the wastewater of 80,000 inhabitants in Chiclana (Spain) within the ALLGAS project.

Microalgae can be also used to treat other wastewaters from farms, aquaculture, anaerobic digestion, and industry [42, 45–47]. The development of especially designed microalgae-based processes for these sectors, including urban wastewater, is a challenge that can transform the actual energy/resources consuming conventional treatment processes into energy positive and productive systems in a revolutionary transformation of wastes sector. Moreover, the produced biomass is suitable to be used in the production of biofertilizers and feed for animals, thus largely increasing the sustainability of food production now related to the consumption of large amounts of fertilizers, land, deforestation, and water consumption [48, 49].

5. Conclusions

Although microalgae are known for centuries, only recently they are being studied and produced at a commercial scale. The feasibility of these microorganisms to grow at largely different environmental conditions and its high productivity make it as highly relevant for mankind. The knowledge of the main factors governing the production of microalgae allows developing industrial production processes at a commercial scale. Because still the production capacity is low and the production cost is excessive, the applications of microalgae are mainly related to human consumption. However, the improvement of the actual production systems, and especially the development of new technologies and the "domestication" of highly productive strains, will largely increase the production capacity and the portfolio of microalgae-related applications in the future.

Author details

Francisco Gabriel Acien Fernandez*, Jose Maria Fernandez Sevilla and Emilio Molina Grima

*Address all correspondence to: facien@ual.es

Department of Chemical Engineering, University of Almeria, Spain

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Chapter 8

Innovative Management and Implementation of Applied Research Project "Green Cost-Efficient Package Selection"

Eduard Shevtshenko, Tatjana Karaulova, Meelis Pohlak, Kashif Mahmood, Martin Tamm and Kaupo Leht

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/67541

Abstract

Cost-effectiveness is one of main criterions of innovation. In the current research, the generic mechanisms of university-enterprise collaborative project realization are included, which can be used to introduce the fresh ideas to industry. Such projects are useful for both partners: enterprise and university. Professors receive applied research projects experience and can publish the results of research, the students, involved in the project, can use received knowledge in their master or bachelor theses, and enterprises can employ new and active engineers. The aim of the project was to develop the green cost-efficient package for electronics industry, which should replace the previously used package. The target of this chapter is to bring the project team experience to the broader audience, who can successfully apply it for similar research project management and practical implementation. Today, the companies frequently use expensive package, which exceeds required quality specifications. That means the quality standards used by the company have too high requirements for the product types that package should protect. Purpose of current research project was to reduce the total cost of the packaging process and to select the environmentally friendly materials. Research team has elaborated the methodology for assessment of possible package variants.

Keywords: green package, cost efficiency, sustainability

1. Introduction

1.1. Innovative applied research projects for university-industry partners

The Ministry of Education and Research implements national research policy, organizes the financing and evaluation of the activities of R&D institutions, and coordinates international research cooperation at the national level [1].

The TUT's mission is to create and mediate values that ensure Estonia's development in the globalizing world. Committed to its mission, TUT fosters research, academic, and applied higher education and technical culture and creates synergy between the different sciences to promote societal development. TUT collaborates with research centers and universities from all over the world.

Modern Estonian Knowledge Transfer for You (MEKTORY) was initiated by the Tallinn University of Technology—Innovation and Business Centre and the current partner universities: Tallinn University of Technology, the Estonian Academy of Arts, University of Tartu, Estonian University of Life Sciences, Tallinn University, and Estonian Academy of Music and Theatre [2].

One of the forms of Contracted Research & Development is Mektory projects. Mektory is an interdisciplinary innovation platform—a joint platform between universities and companies, where students supervised by the teaching staff come together to put their knowledge into practice in order to create prototypes and launch start-ups. Mektory is focused mainly on practical science projects. It has the following goals [3]:

- to support the innovation and development of TUT (institutes of higher education) as practically as possible—to get round to prototypes;
- to support the emergence of start-ups;
- to keep talent at university—the students do not go to work but stay to get their academic degrees;
- to create frequent cooperation with international innovation platforms;
- to be an acknowledged R&D partner for enterprises all over the world.

One of the aims of TUT Mektory is to provide services to the companies in three directions:

- design and product development;
- mobile services and media;
- development of business models.

Mektory projects bring together scientists, students, and entrepreneurs to solve practical product development problems and to generate new ideas. The authors have developed the general scheme of applied research project initiation as introduced in **Figure 1**. The tasks to be performed by a company are given in the yellow rectangle; the tasks performed by a university are given in the gray rectangle.

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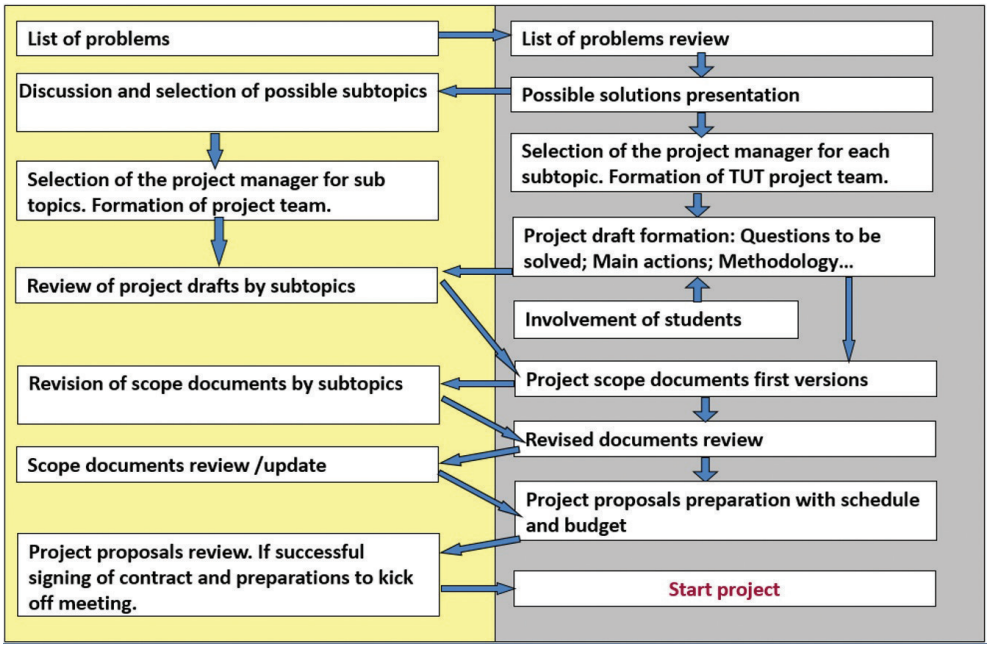

Figure 1. Applied research project initiation.

In order to validate the general scheme, authors have selected the Mektory project "Green-Cost Efficient Package Selection for Electronic Industry" that was targeted to develop the green cost-efficient package in order to replace the currently used package.

1.2. Project "Green Cost-Efficient Package Selection for Electronic Industry" background

Every product must be delivered to customer without defects. The common understanding is that package protects the product inside, but there are actually much more possibilities and opportunities for the companies connected with the package and its design. Each package has four important functions: product identification, product protection, convenience, and product promotion. Package is able to tell to the consumers that your product and brand are different from the same area competitor's one.

Companies have to remember that product's package also has a communication purpose: what your brand stands for and what it means for your customers. It is important to adjust packaging to the product and to consider the necessary protection for material selection. There are a few brands in the world that are different from the others. Apple is a good example. Everybody knows that Apple has a clean, high-quality design of the product and clean and minimalistic design of the package as well, which is well designed and customer friendly. Package can also advertise the company, and it even might have a bigger advertising role than the product itself. Packages are usually covered with the brand logo and other company information. A well-designed package might give the customer a high confidence about the

product and supports positive first impression, which enables to achieve a sustainable relationship with the customers.

Poor packaging has a significant impact on the product quality and company's reputation. It raises the cost of the products due to the defects caused by weak or badly designed package. In addition, poor or nonenvironmentally friendly package can cause the waste of the material, financial resources, and pollute the environment [4]. Packaging may also be harmful to the environment during the whole life cycle. Among the environmental criteria that the manufacturer might consider through life cycle analysis are the following: [5, 6].

- The reduction of packages weight or volume.
- Improvement of energy efficiency in the manufacturing process.
- Optimization of package production process.
- Improvement of product's life cycle.
- Selection of raw materials with a less environmental impact and compatible with recycling processes.

Often companies are using a package solution with too high a cost, and usually, it exceeds the package quality specifications. It means that the companies are using quality standards with too high impact limits for the type of the products that it should protect.

Product package engineering is a science that contains different aspects of the package setup. Product package engineering contains different science topics like material, chemical, and mechanical engineering. When designing a package we need to know what are the loads, in what conditions those packages are stored in, and how the package should protect the product.

The manufacturer should consider multiple aspects during the package design:

- Which material(s) the manufacturer can uses.
- How manufacturer can process them.
- Which company or national standards the manufacturer needs to follow.
- What is the productivity of packaging.
- How many products the manufacturer needs to fit into a single package.

The needs of packaging may be summarized in the following common definitions [7]:

1. Packaging is a coordinated system of preparing goods for transport, distribution, storage, retail sale, and end use.
2. Packaging is a means of achieving safe delivery in sound condition to the final user at a minimum overall cost.
3. Packaging is a technoeconomic function for optimizing the cost of delivering goods while maximizing sales and profits.

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In terms of the different requirements to which packaging are subjected, García-Arca et al. [8] associate packaging with three large functions: marketing, logistics, and environmental. In its marketing function, the package presents customers with information about the product and promotes the product through the use of color and shape. The central purpose of the environmental function is to optimize packaging while minimizing packaging waste wherever appropriate and to reuse or recycle.

The purpose of this research is to reduce the cost of the package materials and to choose environmentally friendly materials. The current research is limited only to the fitments, which have the highest cost in the package set.

The authors have developed and applied the approach on a case study company. This company produces large electronic products, which are transported to different world regions. The selected packaging material should support the use of all means of transportation: train, truck, air, and boat. The limiting dimensions of all these transportation means must be considered during the package design.

The package selected for the case study consists of multiple components (see **Figure 2**), and its primary purpose is to protect the product. Fitments are packaging components, and their purpose is to absorb the impact and vibration loads. Fitments should be able to protect the products against most kinds of damages and electrostatic discharge (ESD) and at the same time suppress the impact. It is possible to produce the fitments from different materials. The commonly used materials are polymeric foams and cellulose-based structures. Protection bag protects the products from moisture and other environmental-caused damages such as mold or rust. Package box is keeping the entire package set together, takes some of the impact loads and pressure of boxes, placed on each other.

The right side of **Figure 2** shows the percentages of the full package set prices for selected products. As can be seen from the pie chart, the largest cost component is fitments with ~60% of total cost, then cardboard with ~20%, and then other smaller components. The fitment solution is the most expensive part of package set, and it has the largest effect on yearly packing cost.

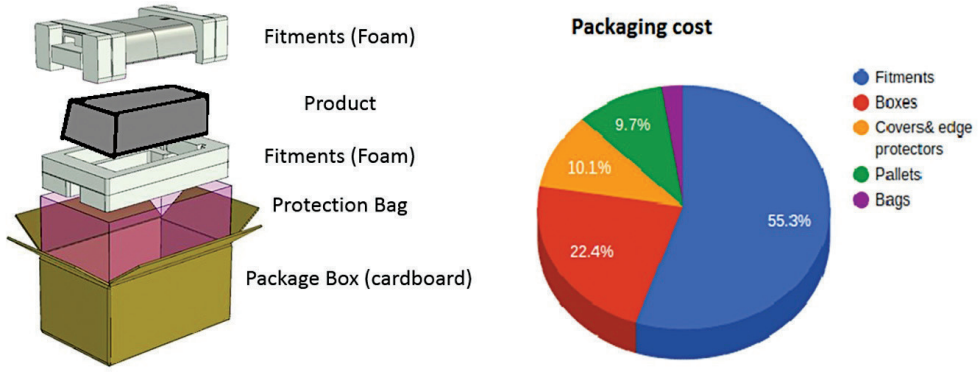

Figure 2. Package set and packaging cost.

The packed equipment must remain protected during a transport period of up to 3 months. The severity of the requirements is in conformity with ETSI EN 300 019-1-2 Class 2.3 "public transportation" [9]. Packed equipment must remain protected during a storage period of up to 12 months. The severity of the requirements are in conformity to ETSI EN 300 019-1-1 Class 1.2 "weather protected, not temperature controlled storage" [10]. When selecting packaging materials and components, tolerance to flora, fauna, chemically active substances, and mechanically active substances must be taken into consideration in accordance with the severities specified in ETSI EN 300 019-1-2 Class 2.3 "public transportation" [9].

2. Packaging alternatives

To design new fitments, a research group has discovered aspects that influence products safety and found the best feasible solutions that fulfill the research objectives (minimum package set price and usage of green materials). In **Figure 3**, the authors introduce the main steps of packaging selection and research methods.

2.1. Evaluation of possible alternatives

In order to develop a new packaged design, research group has generated the list of twenty-two possible new design versions. The sketches of ideas for selected solutions are shown in **Figure 4**. Then added them into evaluation matrix, added suitable materials, evaluated package design

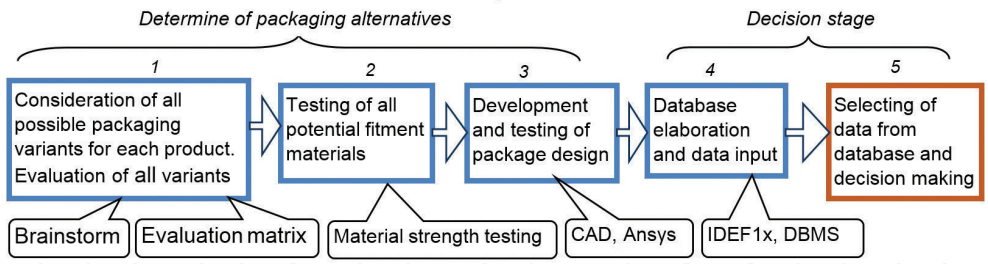

Figure 3. The general scheme of the research.

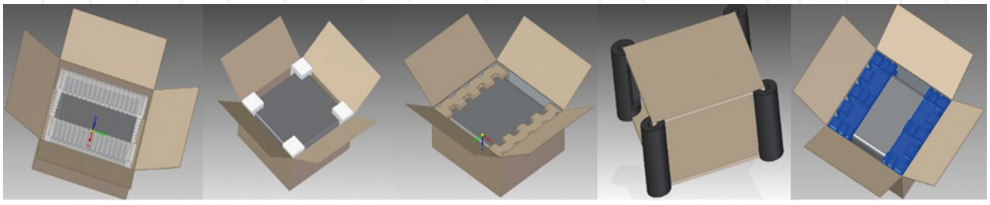

Figure 4. The proposed design versions sketches.

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properties based on green and price categories, calculated the total grade for each alternative solution, and selected possible new design alternatives with highest grades.

In order to compare the different design versions, the researchers assessed the alternative solution in the evaluation matrix by green and price categories (see **Figure 5**). Each category consists of several criteria evaluated on 1–5 scale. The authors have defined each criteria weight in percentage based on enterprise expert's opinions.

The green category consists of following criteria:

- Effectiveness—is the ability of the package to satisfy functional requirements for the particular product. The designer should try to avoid using many different materials.
- Efficiency—is the reasonable usage of materials, energy, and water throughout the package life cycle. The designer should replace heavy materials with lighter ones.
- Recyclable/cyclicality—is the usage of renewable materials, such as wooden particles, paper mold, and bioplastic.
- Safety—for people and the natural environmental, whether it is compostable, biodegradable, etc.

The criteria for the price:

- Additional tools requirement—it is a cost of new complex machines or tools for manufacturing.
- Properties—whether the selected material is suitable for a particular solution, e.g. too rigid materials will not absorb shocks.
- Weight—the ratio of density and material volume; package should use as less a material as possible. For example, overpacking with extra or higher density foams is not required to protect the product from damage.

			GREEN					PRICE					
		Percentage	40%	20%	15%	25%	100%	30%	15%	30%	25%	100%	
Nr	Version	Properties / Material	Effectiveness	Efficiency	Cyclicality	Safety	Common	Additional tools	Weight	Assembling	Properties	Common	Total
1	Soft pillows in corner	Foam, small particles, wooden	3,5	3	3	4	13,5	4	3,5	4	3,5	15	28,5
2	Extruded Clamp	(Bio)plastic, paper board	3	3,5	3	4	13,5	2,5	2,5	3	3	11	24,5
3	Eco pulp	Pulp, recycled paper	3,5	3,5	4,5	4,5	16	4,5	4	4,5	4	17	33
4	Loose foam particles	Foam	2	2,5	3	3,5	11	3,5	3	4	2,5	13	24
5	Bubble film	Biodegradable film	2,5	3,5	3,5	4,5	14	3	3	4,5	2	12,5	26,5
6	Loose thick paper	Paper	2	3,5	3,5	4	13	4	2	4	2,5	12,5	25,5
7	Tension springs	Plastics, rubber	1,5	2,5	2,5	3	9,5	2,5	2,5	3,5	2	10,5	20
8	Fiber mesh	Plastics, natural fiber	3,5	2,5	3	3,5	12,5	3	3,5	3,5	3	13	25,5
9	Inflatable balloons	Rubber, plastic film	3	2	2	2,5	9,5	3,5	3,5	4	3	14	23,5
10	Brush like fibers	Bio plastics	1,5	3	3	3	10,5	3	3	3	2	11	21,5
11	Standard foam plates	Foam	4	3	3,5	3,5	14	3,5	3,5	3,5	3,5	14	28
12	Air tubes	Rubber, plastic film	1,5	2,5	3	3,5	10,5	3	3,5	4	3	13,5	24
13	Small foam laver+imp reaction mat.	Foam capsules	3	2	2	3	10	2,5	2,5	4	4	13	23
14	Thick cardboard honeycomb	Card board	2	3	3,5	4	12,5	4,5	3,5	4	2,5	14,5	27
15	Magnetic leviation	Permanent magnets	2	3,5	3	3	11,5	1,5	2	2,5	3	9	20,5
17	Poroloon, contact	Poroloon	3	3	3	3	12	4	3	4	4	15	27
18	Pressure Balls	Tennis ball, foam ball	2	3,5	3,5	3	12	4	3	4	2,5	13,5	25,5
19	Foam sticks	Foam	2,5	3,5	3,5	3	12,5	4	3	3	2,5	12,5	25
20	4 products packages	Cardboard and foam	3,5	3,5	3	3,5	13,5	3,5	2,5	4	3	13	26,5
21	Minimize the material usage	Foam or other material	4	4	3,5	3,5	15	4	4	4	4,5	16,5	31,5
22	Foam fitments top and bottom	Foam	4,5	4	3,5	3,5	15,5	4,5	5	4,5	4,5	18,5	34

Figure 5. Evaluation matrix.

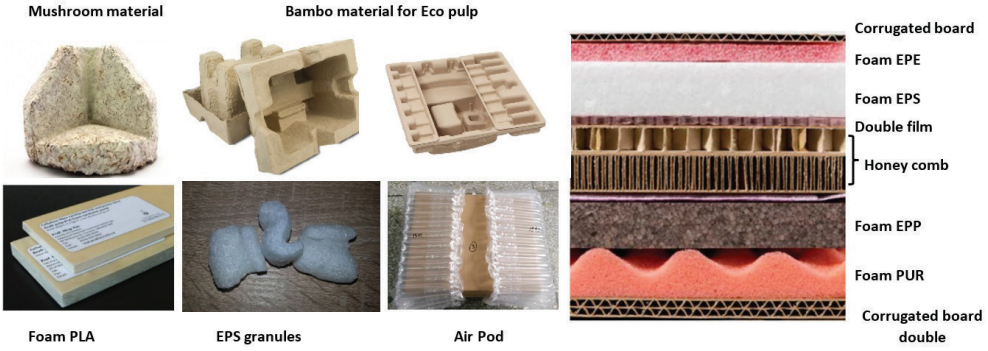
- Assembling—the amount of labor required to pack the product, e.g., too many package pieces used to protect the product.

The results of brainstorming are introduced in evaluation matrix in **Figure 5**.

The evaluation matrix shows that highest ranking have solutions number: 3—eco pulp (pulp recycled paper), 21—minimize the material usage and cover with double film, and 22—foam fitments top and bottom (foam or other material, e.g., mushroom material).

After the authors have selected the best possible design solutions, it is necessary to choose the best possible materials as well (see **Figure 6**). Consideration of the factors in green category is still the same and in price category, authors considered only current market price, the cheaper it is, the better price grade received. There were two materials available in the market that customers can get for less than 1 €/kg, and they got a max price grade 5, others have a higher price and a lower price grade. In the same way, authors have assessed the properties of other materials: effectiveness, efficiency, cyclicality, and safety. Since the company is interested in reducing the cost and making the packaging greener, the price category has a weight 40% and green area in total has the other 60%.

Corrugated board (single or double) is used for protecting a package. The cardboard box element of product packaging is taking most of the pressure loads. The box must be able to



	GREEN					Price
Percentage	30%	10%	7,5%	12,5%	60%	40%
Properties / Material	Effectiveness	Efficiency	Cyclicality	Safety	Total	Price
Eco pulp, fiber molded pulp	4	3,5	4,5	5	17	5
EPP	4	4	4,5	3,5	16	3
EPE	3	2	4	4	13	4
PUR	1	2	4	4	11	2
Corrugated Card board	1	5	4	5	15	4
Honeycomb	3	4	5	5	17	4
PET	1	1	4	3	9	5
PCL	3	5	4	5	17	1
PLA	4	4	5	5	18	2

Figure 6. Materials considered for packaging.

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protect against pressure and moisture conditions. After the cardboard box has held heavy products during the transportation, it loses its strength and rigidity, and it is not recommended to reuse it again. The recycled cardboard cannot be reused for the next round of dispatch because it is also not as strong as it was before the transportation. Therefore, products inside of recycling boxes are less protected, even if the cardboard has the same thickness and dimensions [11].

Bubble film or EPE (expandable polyethylene) is usually used for low volume products (<10,000 pcs/year). This material does not require many tools, and the required ones are very cheap tools. Those materials are used for inner protection, but they are flexible and deform fast.

Expanded polystyrene (EPS) or expanded polypropylene (EPP) is usually used for high volume products. Their inner protection can be cost-efficient to use; EPS and EPP materials require more complicated and expensive manufacturing tools.

Honeycomb is the lightweight, rugged, and environmentally friendly solution suitable for protective packaging needs. The restriction is that the honeycomb cannot be used as a fitment of the packaging. Honeycombs have high mechanical strength at low densities. Honeycombs have good cushioning properties, but not as good, as do foams. Honeycombs can protect products from shock or vibration damages during transportation, and it is used together with EPE foams due its softness property.

The manufacturer can minimize the environmental impact by using as minimum material as possible either by weight or by volume. Furthermore, it can be achieved by replacing the current heavy materials with lighter ones, by analyzing the changes in transport logistics, product dimensions, product fragility level, and by adapting design quickly to these changes.

2.1.1. Green packaging solutions

The Landaal Packaging System has invented green cell foam. This corrugated-like panel is a sustainable alternative to polyethylene, polystyrene, and polypropylene foams. This foam fully biodegrades in 4 weeks in moist environments and dissolves in water. Foam product has also no-ESD properties, which is perfect for electronic packaging. Green cell foam is also compostable, and it will vanish in every compost facility. After usage, the customers can easily recycle the material together with corrugated or paper materials [12]. Green cell foam easily absorbs the vibration and dropping loads. Accordingly, to the green cell foam official homepage performance, it can even absorb the baseball bat hit [13]. Average person can move the baseball bat up to 80 km/h [14].

Polylactic acid (PLA) is a corn, starch, or sugar-based biopolymer, which is also biodegradable. This very lightweight polymer is used a lot in the food industries. The foams have good properties in heat insulation and impact resistance. PLA foam can be processed with the same tools and same technology as in EPS processing [12]. Since EPSs have a big carbon footprint, then some companies have substituted EPS with PLA materials. PLA unbounded beads can be used also as cavity fillers and also in the toys or in the furniture manufacturing that are using bean fills. PLA can be composted under the industrial composting conditions. PLA foam is

also chemically recyclable to new PLA polymers. The foam density can go between 20 and 100 kg/m^3 using carbon dioxide blowing [15].

Molded pulp is made from natural cellulose fibers and recycled paper. Recycled paper fibers and water will be mixed together as a pulp. Some of the companies add additives or bleaches into the pulp to improve the pulp properties or functions. However, this is not that environmental friendly so that is why most of the manufacturers are not using additives at all or just adding the natural additives (additional fibers). Pulp breaks down comparatively fast in normal landfills and compost piles, and it is fully biodegradable. Materials have been used for decades so molded pulp has a lot of experience and its technology and supply base are very well developed. Molded fibers due to its long-lasting experience base is being quite widely used in consumer packaging applications with really high expectations [16]. One of the main disadvantages of molded pulp is the heavy weight, which raise the emissions during the transportation. It may not be that cost-effective or environmentally friendly if shipping for a long distance.

Bamboo packaging. Sustainably sourced bamboo packaging certified by the Forest Stewardship Council. Benefits: Strong, renewable, promotes healthy soil, local to manufacturing sites, biodegradable, and certified compostable.

Air pod (air bubble) replaces traditional packaging material, such as foam, EPS, cardboard, and bubble wrap, providing customers with a simple and effective solution to protect products from shock and vibration during the transportation process.

Mushrooms (Myco foam 4). Packaging materials are grown from mushrooms. Already used by Dell [17] and HP group. Planning to start using.IKEA group [18], company PUMA [19], and Ford group [18] are also planning to start using it. Transportation cost of materials from USA was higher than the cost of materials. The latest developments are that students of Academy of Arts (Estonia) have studied the material and the test pieces were already grown in EU [20].

2.2. Material testing

The existing package solution was produced from EPP material. The density of the material during testing varied 25–35 kg/m^3. It has Young's modulus 1300 MPa, and Poisson's ratio is 0.001. Material tensile strength can go up to 0.16 MPa depending on the density, which is the same as that of polystyrene. If comparing Young's modulus and tensile strength, the material has the same properties as do silicone and polystyrene, which are also packaging cushioning materials. The material is highly lightweight, has a good structural strength, and is recyclable [21].

2.2.1. Material impact testing

For material impact measurement, authors have used drop hammer test (adjustable heightwise) 23.3 kg, diameter of 20 cm, and surface larger than the test piece (**Figure 7**).

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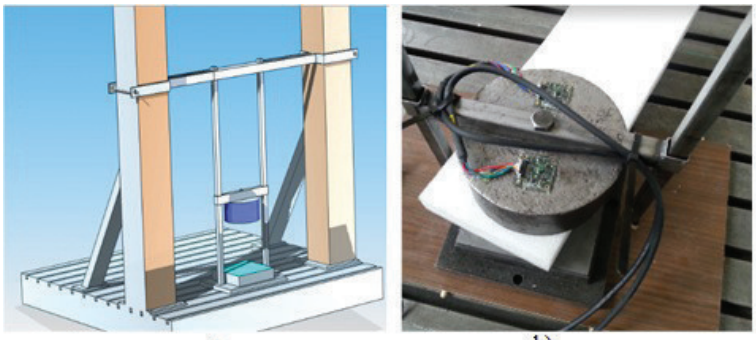

Figure 7. Impact tester (a) and drop hammer with two sensors (b).

Drop height is 250 mm, which corresponds to free fall impact velocity of 2.21 m/s under free fall in vacuum conditions of under standard gravitational acceleration. The equivalent free fall velocity is calculated using the Eq. (1) [22].

$$V = \sqrt{2gn * h} \tag{1}$$

where V is the final free fall velocity in meters per second; g is the standard acceleration of free fall, i.e., 9.80666 m/s^2; h is the measured height, in meters, of the hammer above the test piece. Referred standard is ISO 4651:2000 [23].

Figure 8 shows highest acceleration (g) for different materials.

Material specimen parameters and tests results are introduced in **Table 1**, where one can also see the highest acceleration and deformation. EPE, EPP, and EPS share the similar characteristics of

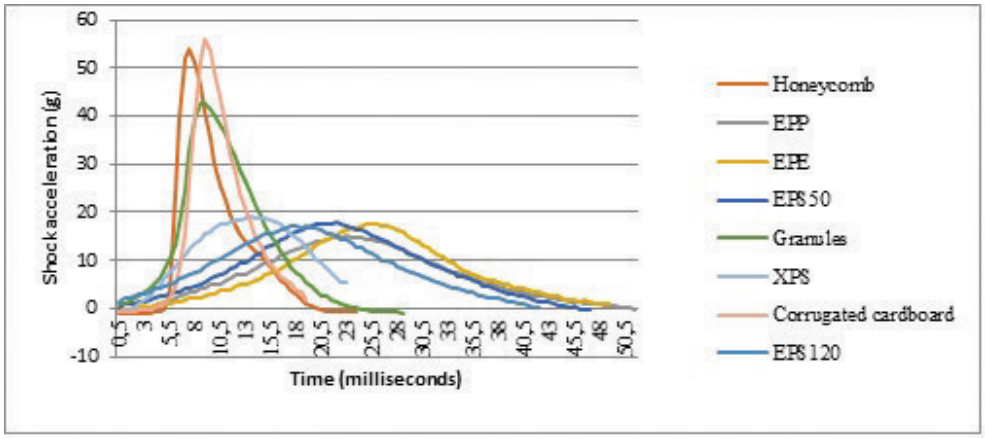

Figure 8. Highest shock for different materials.

Material	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m^3)	Quantity (pc)	Highest acceleration *g*	Deformation (%)
EPE	100	100	45	30	4	18	5
Corrugated cardboard	100	100	45	N/A	4	53	30
EPP	100	100	45	35	5	15	6
XPS (polystyrene)	90	90	50	30	5	18	20
EPS50 (expanded polystyrene)	100	100	45	50	5	18	7
EPS120	90	90	45	120	5	17	12
Honeycomb	100	100	20	N/A	5	55	75
Granules of EPS standard	150	150	110	N/A	3 bags	42	

Table 1. Tested materials description and its properties.

shock absorbing and are the best choice impactwise (drops, sudden collapses against other objects, etc.) to avoid product damage during transportation. Honeycomb is the stiffest and absorbs shock badly 55 g, 75% deformed. Corrugated linear board is the second place accordingly to bad shock behavior, also 53 g but 30% deformation. In addition, EPS granules are in the third place.

2.2.2. Material compression test

For material compression, the Instron 5866 electromechanical testing system was used, which has two flat plates that have larger dimensions than the test pieces (see **Figure 9**). The static load cell 10 kN was used as a precision force transducer (the load cell is shown in **Figure 9a**) [24].

The load and displacement (strain) graphs were recorded for all tests. The test ending parameter compressive load 500 N was applied for EPP, EPE, and bubble film (with both big and small bubbles). The test ending time 3 min was used for honeycomb, and the maximum

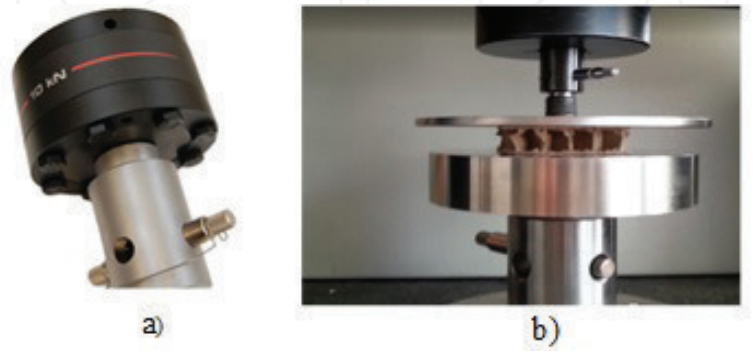

Figure 9. Instron load cell (a) and honeycomb under compression (b).

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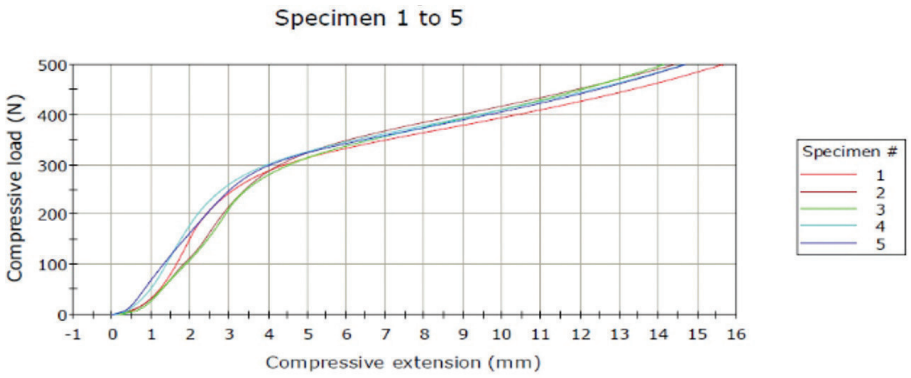
achieved compression load during that time was 10 kN (the loading speed was 1 mm/min). The example of material compressive test results is shown in **Figure 10** for EPP (expandable polypropylene).

As the behavior of both materials is very elastic (EPP and EPE), the compressive strength cannot be seen in terms of where the yield point is (above which plastic deformation starts), then we can only compare the extension interval and see from the vertical axis, the corresponding force. The deformation of EPE is 5 mm, and the force is 50 N; whereas for EPP, the force corresponds to ca. 350 N and one more, e.g., from 10 mm, for EPE, the force resulting is as 100 N compared with 400 N for EPP. Meaning the EPP needs more force to deflect to the same level as EPE, meaning the latter is a softer material. Also when doing this testing, the material needs to be even on size as any residue over the edge that touches the platens, although lightly may alter the result.

From the all studied materials the best material would be one with the smallest deformation of EPE by having the biggest elastic modulus 0.77 on an average. On comparison of EPE and EPP with honeycomb at the same load of 500 N, they had only deformed ca. 2 mm, whereas the EPP and EPE had already 15 and 20 mm, respectively, so at least in static stacking, the honeycomb has an advantage.

Material recycling coefficients *embodied carbon* (*EC*) and *embodied energy* (*EE*) are taken from inventory of carbon & energy (ICE) standards [25]. Comparison with existing package (based on current standard) is given in **Table 2**.



	Maximum Compressive load (N)	Compressive extension at Maximum Compressive load (mm)	Compressive stress at Maximum Compressive load (MPa)	Maximum Compressive strain (mm/mm)
1	499.63	15.63	0.20	0.52
2	499.24	14.38	0.20	0.48
3	499.49	14.11	0.20	0.47
4	499.29	14.62	0.20	0.49
5	499.50	14.66	0.20	0.49

Figure 10. EPP compressive test results.

Material type	Density (kg/m^3)	Best impact performance (acceleration *g*)	Worst impact performance (acceleration *g*)	Deformation (%)	Elastic modulus	Embodied energy EE = MJ/kg	Embodied carbon EC = kgCO_2/kg
EPP	25	12	15	6	0.158	93.1	1.32
EPS50	50		18	7		88.6	2.04
EPS120	120		17	12		88.6	4.896
XPS	25		18	20		88.6	1.02
EPE	60	15	18	5	0.13	80	1.02
Eco pulp	325					25	1.74
Myco foam 4		35	50	47		25	0.26
Air bags (PE)	18	25	34			77.2	1.69

Table 2. Testing results.

2.3. Fitment design

The manufacturer can perform the testing of packaging also virtually. One possibility is to do a virtualized testing in a simulation software. It enables the users to predict the product performance in case of impact, vibration, etc. Simulation software can create complete virtualized impacts or other scenarios considering mechanical or other perspectives [26].

To design a new cheaper and greener fitment, we need to define the current package solution's pros and cons, and to do that, it is important to see how fitment reacts when it could get accidentally dropped. The manufacturer can minimize the environmental impact by using a lesser and lighter material either by weight or by volume respectively. Furthermore, it can be done by replacing the current heavy materials with lighter ones, by analyzing the changes in transport logistics, product dimensions, product fragility level, and by adapting designs quickly to those changes.

2.3.1. Current package testing

When packages are transported or handled from one location to another, a lot can happen. People and machine can make mistakes, and therefore, some mechanical or manual handling can make a lot of damage to the product. Products may fall down from the pallets, from the machines, or from the warehouse shelf. That is why a lot of package design solution companies are doing the drop test. This is the main indicator to say that package can protect the product.

Dropping type of events can happen usually during mechanical or manual handling of the product. Product falling can happen also during vehicle cornering or braking, automated warehousing or forklift wrong package placement. Drop test (free fall test) is usually performed according to ASTM 5276 standards. Where all the tested products will be dropped down from the same height, but in three different angles—in the corner, on the edge, and the flat side [27].

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Compression can cause problems for the products in the packages during pallet stacking in warehouse or during long transportation. Compression tests are performed according to ASTM D4169 and ASTM D4577 standards where packages will get preloads, and those loads will be increased up to maximum 20%. Compression test can be done empty or with the full packages.

In **Figure 11**, we can see that packaging fitments are designed according to the need of protecting the product in different directions. Each of the bulges has important tasks. In **Figure 11(a)**, we can see when the product falls down onto the edge, then the main impact loads will go to the pads where the falling is directed—in this case, the direction is on edge. Also, we can see that when the product is falling to the edge, the bending will happen and fitment is going to break if the product mass will be higher. Also, we can see that in edge angle, the products have the highest values of Von-Mises stress, and this level of stress remains in the same value for some time. This means that the fitment is bending and suppressing the loads.

In **Figure 11(b)**, we can see the stresses in the flat falling situation, where the impact occurs directly on the whole product's lower case. For this, the situation designers have added falling protection pads. Those pads will protect the product and cushion the falling better than without the pads. Without pads, the shock will affect whole product inside and may break the assembled product, and also it has less weight than the whole fitment bottom covered with thickness of the pads. In the original products, fitments are covered with the cardboard package so that the cover will also take some of the loads and cushion the landing. Since the loads are scattered into a huge area, then stress value is low, even in the highest peak (**Figure 12**).

2.3.2. Alternative solution for modeling and simulation

In the current paper, we could not show all results of tested designs with various materials. Tests and simulation calculations will be done for molded pulp material according [28].

Material properties will be set according to the Hunan University of Technology scientific research whose experiments were done with the molded pulp packaging, and it was supported by Huilin Packing [29, 30, 31].

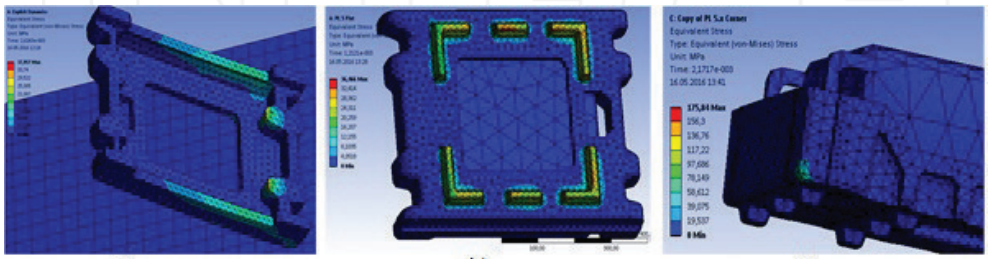

Figure 11. Fitment (a) edge drop, (b) flat drop, (c) corner drop.

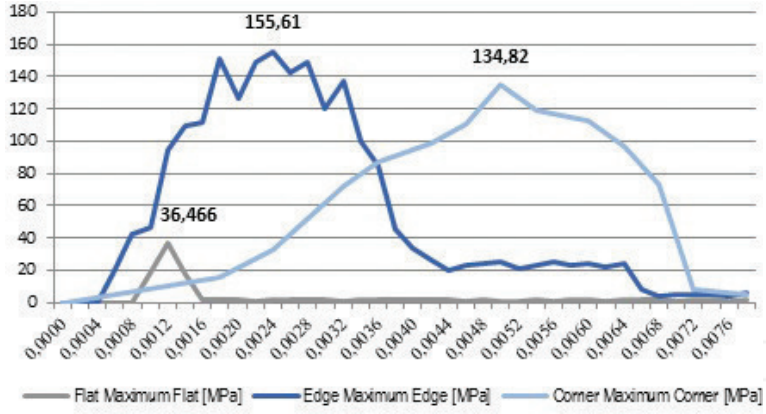

Figure 12. Equivalent stress results.

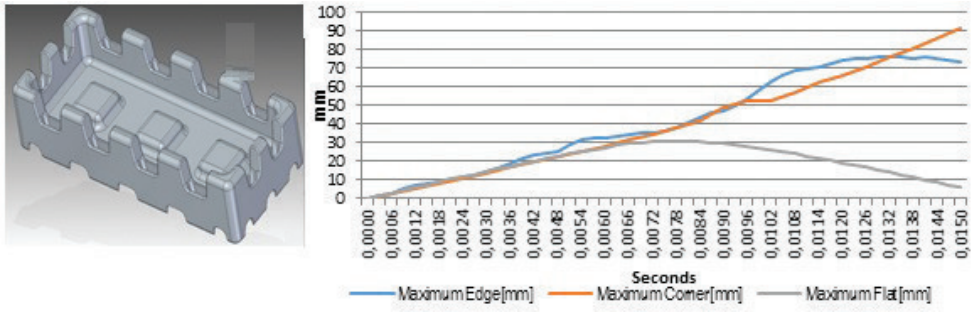

Figure 13. Molded pulp design and its total deformation.

According to the simulation, which can be seen in **Figure 13**, the total deformation is affecting the bulges that are red in the picture. That area will get the maximum level of the deformation in flat angle drop test. So we can say that this area is well designed and covers all of the cushioning needs for the product. Also, flat angle deformation is only 6.22 mm in that area. In edge and corner angles, the deformation will last longer and might break the product protection, if the loads will go higher. In corner dropping, the product cushioning material will have total deformation more than 90 mm that means that in this angle-molded pulp design needs more angled edges and some additional bulges.

In **Figure 14**, we can see that the product will need some additional shape optimization and rounding in the CAD (Computer Aided Design) modeling because the sharp edges are getting more loads, and these are not scattered around to the larger areas. So this means that product might break and then the fitments cannot be reused again and needs to be recycled again. More yellow and red colors are marked as stress areas, areas where fitment design needs more attention or different solution. We could expect that edge and corner Von-mises (see **Figure 15**)

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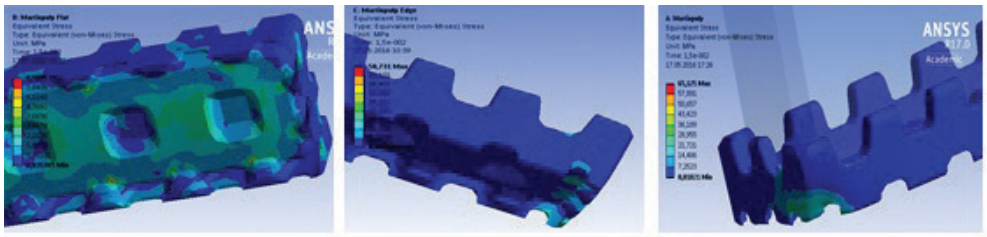

Figure 14. Molded pulp design (flat, edge, and corner).

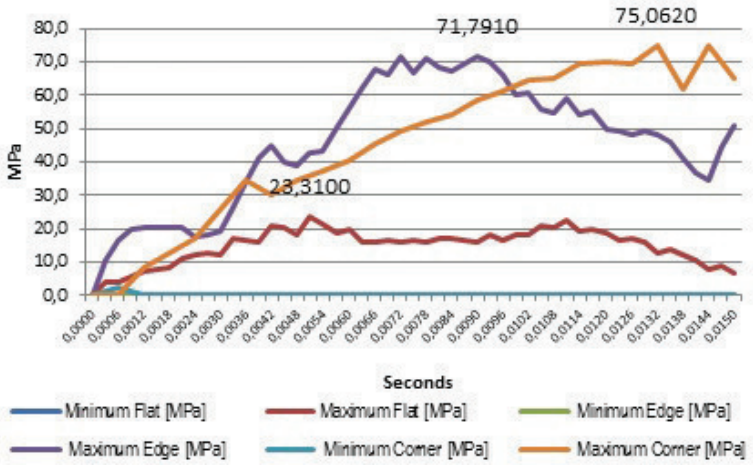

Figure 15. Molded pulp Von-Mises stress during test simulation.

stress is higher than flat dropping, but the difference is really big. It means that a little more inclination will lower the edge and the corner stress level and higher a little bit flat stress and that will dispel the risk of breaking the product on those angles.

Figure 16 shows the molded pulp acceleration behavior in the given conditions. In this graph, we can see that flat and edge angled product works quite the same—acceleration will go up in the middle of the measurement time and then the accelerations will slow down and then bump a little in the end. But for the corner, we can see that acceleration will go up slowly until the measurement time is ending. According to the acceleration probe, we can see that the acceleration will not go over 1600 m/s^2, and this is more than two times lower than the current solution. So this kind of solution will have a really great potential to substitute the current solution. Biggest minus for this solution will be that if the product will be fall down, then the fitment is broken, and this cannot be used again, and it will not suppress the loads after that. This fitment needs to be recycled again to be able to be used again.

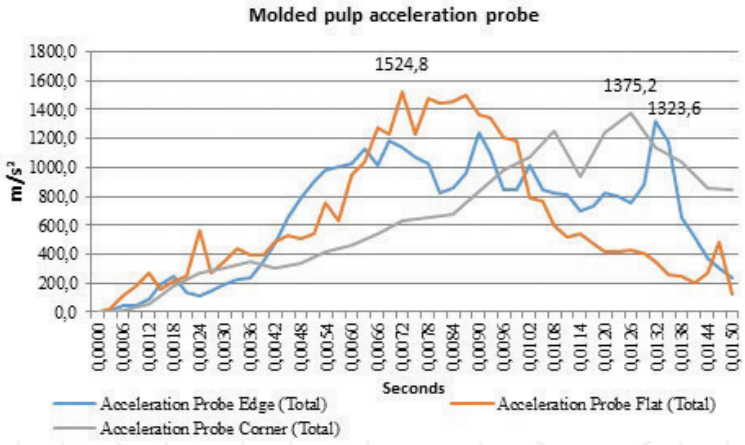

Figure 16. Molded pulp acceleration during test simulation.

Acceleration probe	Edge (m/s^2)	Corner (m/s^2)	Flat (m/s^2)
Current product	3845.1	2272.7	22206.0
Molded pulp	1323.6	1375.2	1524.8

Table 3. Acceleration probe maximum value.

The most important characteristic of the cushioning solution is to reduce the peak of the acceleration for the protected product. Therefore, acceleration probe was selected onto the product that was inside of the cushioning material. Compared with the current solution's acceleration to new solutions (see **Table 3**), we can see that the acceleration is really low for molded pulp fitment, which means that this type of fitment can absorb well the impact loads and protect the product. We can say that in this kind of solution, product is protected.

2.4. Database for packaging data

Authors have elaborated the database structure for data collection by using Computer-Aided Software Engineering (CASE) methods IDEF1X (Integration DEFinition for information modeling) and *ERwin Data Modeler (all fusion*) software. All objects (tables) are connected by the key attributes. This structure may be used directly by several database management systems (DBMS) for data collection, analyzing, and selection.

All objects (tables) are connected by using key attributes: primary keys are shown in the top part of every object and can be moved to other objects as a foreign key (FK) (see **Figure 17**).

Structure consists of the next main parts:

Packaging structure data that consist of the description of fitments (*fitment drawing number*, *type*, *weight*, *size*, and *cost*), boxes (*drawing number*, *type*, *weight*, *size*, and *cost*), and secondary boxes (*SecBoxType*, *weight*, *sizes*, *cost*, and *number of included boxes*).

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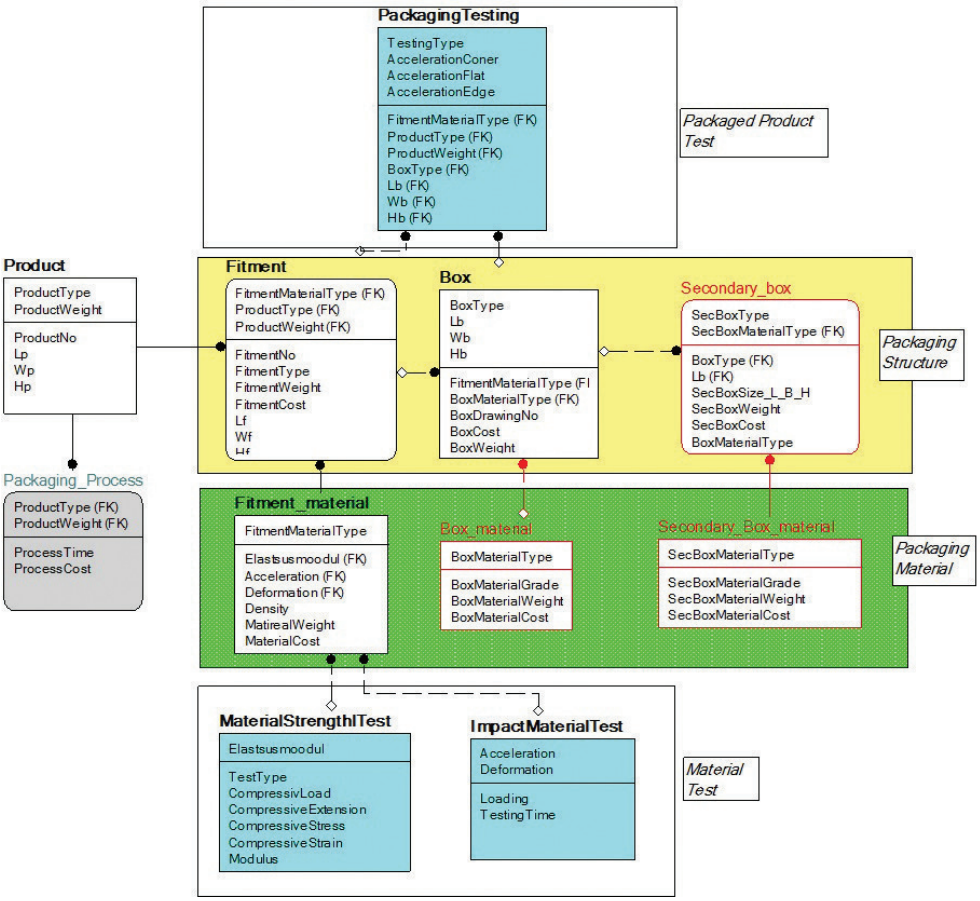

Figure 17. Database structure for packaging.

Packaging process data consist of process *time* and *cost*.

Material tests data by test parameters.

Packaged product test data consist *of testing type*, *acceleration probe by corner*, *edge*, and *flat*.

Packaging data must be included according to the DB structure for several types of products. Theoretically, new fitment with decreased volume can be made from different materials, and it gives an overview of the possible solutions in the tables they are marked as "Theoretical." Furthermore, a few new package solutions were tested using alternative material including ecomolded pulp, Myco foam 4, and air bubble bags. **Table 4** is presented in several fitments data for two product types.

Selection algorithm for fitment design and material selection for decision-making is introduced in **Figure 18**.

Product					Fitment					Material									Price
Product type	Lp (mm)	Wp (mm)	Hp (mm)	Weight (kg)	Fitment no.	Weight (g)	Lf (mm)	Wf (mm)	Hf (mm)	Material type	Density (kg/m^3)	Acceleration (g)	Deformation (%)	Elast modulus	Embodied energy EE = MJ/kg	Energy (MJ)	Embodied carbon EC = kgCO_2/kg	CO_2 (kg/per fitment)	Price (€/ kg)	Fitment mat cost (€)
Product A	705	310	180	22.2	RLX12345	489	777	376	270	EPP	25	15	6	0.158	93.1	46	2.7	1.32	12	5.87
Product A	705	310	180	22.2	EPF.04.00	400	2 × 180	2 × 395	2 × 260	EPP	25	15	6	0.158	93.1	37	2.7	1.08	12	4.80
Product A	705	310	180	22.2		800	2 × 180	2 × 395	2 × 260	EPS50	50	18	7		88.6	71	2.55	2.04	0.87	0.70
Product A	705	310	180	22.2		1.920	2 × 180	2 × 395	2 × 260	EPS120	120	17	12		88.6	170	2.55	4.90	0.61	1.17
Product A	705	310	180	22.2		400	2 × 180	2 × 395	2 × 260	XPS	25	18	20		88.6	35	2.55	1.02	3.8	1.52
Product A	705	310	180	22.2		600	2 × 180	2 × 395	2 × 260	EPE	60	18	5	0.13	80	48	1.7	1.02	5.4	3.24
Product A	705	310	180	22.2	ECO.04.00	1350	2 × 160	2 × 360	2 × 220	Pulp	325				25	34	1.29	1.74	2.74	0.58
Product A	705	310	180	22.2	MUS.04.00	200	765	370	240	Myco foam 4		50	47		25	5	1.29	0.26		5.50
Product A	705	310	180	22.2	BUB.04.00	205	2 × 200	2 × 365	2 × 260	Air bags	18	34			77.2	16	1.69	0.35	0.7	2.00
Product B	518	470	186	26.3	RLX67890	580	690	535	286	EPS	35		6		88.6	51	2.55	1.48	1	0.29
Product B	518	470	186	26.3	EPF.04.00	580	2 × 160	2 × 570	2 × 260	EPS	35	15		0.158	88.6	51	2.55	1.48	1	0.58
Product B	518	470	186	26.3		800	2 × 160	2 × 570	2 × 260	EPS50	50	18	7		88.6	71	2.55	2.04	0.87	0.70
Product B	518	470	186	26.3		1 920	2 × 160	2 × 570	2 × 260	EPS120	120	17	12		88.6	170	2.55	4.90	0.61	1.17
Product B	518	470	186	26.3		400	2 × 160	2 × 570	2 × 260	XPS	25	18	20		88.6	35	2.55	1.02	3.8	1.52
Product B	518	470	186	26.3		600	2 × 160	2 × 570	2 × 260	EPE	60	18	5	0.13	80	48	1.7	1.02	5.4	3.24
Product B	518	470	186	26.3	ECO.04.00	1450	2 × 110	2 × 526	2 × 220	Pulp	325				25	36	1.29	1.87	2.74	3.98
Product B	518	470	186	26.3	MUS.04.00	200	578	530	246	Myco foam 4					25	5	1.29	0.26		5.50
Product B	518	470	186	26.3	BUB.04.00	200	2 × 160	2 × 530	2 × 260	Air bags	18				77.2	15	1.69	0.34	0.7	1.80

Table 4. Product/fitment data for 2 products.

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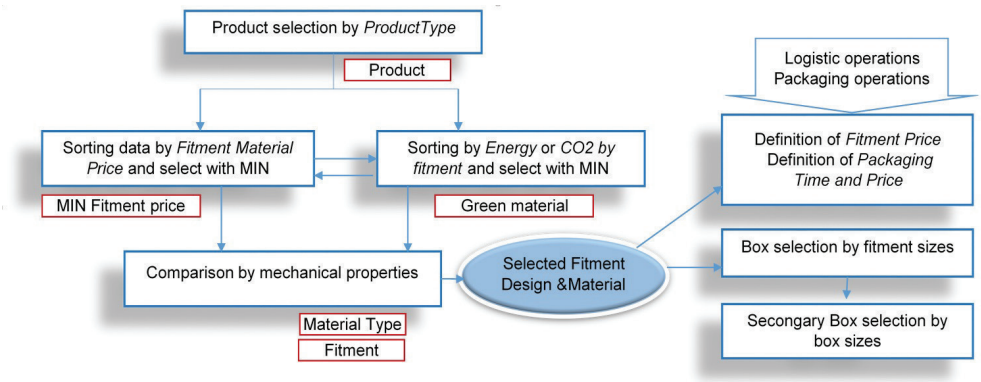

Figure 18. The algorithm for green and cheap packaging selection.

2.5. Suggested alternative solutions

The following alternative solutions are based on the current data, and the comparison is based on the current fitments of expanded polypropylene (EPP) material:

A green solution of mushroom fitments is made from Myco foam material: This packaging solution can be used for all the products. It has lower emissions, but the cost of material is comparable with current EPP fitment (material cost reduction 5%). The outbound logistics costs are the same because it is possible to fit approximately the same amount of boxes to the pallet.

Green and eco pulp are made from bamboo and bagasse blend: The bamboo-based material enables to apply the packaging solution for all products. Compared to the current solution, the inbound logistics costs are smaller because more units can be stacked into a container, and it has lower emissions. Moreover, the cost of material is (20–35%) less when compared with current fitment, the outbound logistics costs are minimized by 25%, since it is possible to fit more boxes on the pallet.

Bubble solution (or air Pod): Inbound logistics costs are very cheap, which depend on the product. It has lower emissions due to 2% of film and 98% of air, and the cost of material is much lower (65%) when compared with the current fitment. The outbound logistics costs are lower because it is possible to fit more boxes on the pallet (up to 25–30%), but it is more risky in a way that extra protection corners should be added to secure the product from damage.

Hence, the eco pulp fitment solution is the suitable feasible packaging solution as compared to current using packaging material.

2.6. Outbound logistics volume comparison

With the new developed packaging solutions, we also made the calculations of how they impact the outbound logistics and whether the new solutions contribute to cost reduction. During the analysis, we used the standard 40-foot container and EUR-pallet, trying to fit the maximum amount of products onto the pallet and then the pallets into the container in double-stacks. The summary table fragment of the calculation is shown in **Table 5**.

Version	Product	BOX size			Per pallet			Total	Total products per container	Change (%)
	Product type	Lb (mm)	Wb (mm)	Hb (mm)	L prod	W prod	H prod			
Current	Product A	787	385	278	1	3	3	9	378	0
New decreased	Product A	775	400	260	1	3	3	9	378	0
Molded pulp	Product A	750	370	220	1	3	4	12	504	25
Muco foam4	Product A	775	380	250	1	3	3	9	378	0
Air bags	Product A	270	550	380	3	2	2	12	516	27
	Product A	380	550	270	2	2	3	12	504	25

Table 5. Logistic volume comparison.

2.7. Package financial forecast comparison

Package price will depend on the package material and the material processing. Material price for ARPRO EPP (expandable polypropylene for automotive dunnage, the reusable shipping containers) is approximately 5 €/kg [32]. This price takes into account raw material price, and as we know that processing EPP is very hard and it takes money and time to produce, it means that processing cost can be double amount of the raw material price so altogether this will be 15 €/kg, and if we also consider that one product uses 0.4 kg of EPP material, which is almost same weight as current material's lighter version (25 kg/m^3). Then this means that from the economical perspective, this solution will need more development and shape optimization to lower the material usage. Material weight should be maximum 0.35 kg and processing should be easier or almost at the same level as current solution. So then the initial goal will be successful.

Pulp raw material and processing proportion are divided into 23 and 77%. Molded pulp raw material is 0.35 €/kg and adding 1.15 € for processing cost, then all together it is 1.5 €/kg. Since the fitment design for upper and lower part will be same, the processing cost for package set will be lower when compared with the EPP design.

When adding this calculation to the manufacturing forecast for the coming year for seven several types of products, then we will get the picture as shown in **Figure 19**.

In **Figure 19**, we can see that monthly average product groups package cost is close to 6% and end of this figure, we can see that monthly cost is close to 4%. This is compared with the initial fitment solution's yearly cost for package sets. Old fitment line shows that on an average, the new solution will reduce the packaging cost by 2% per month. This means that by the end of the forecast, the company will have reduced 24% of the fitment cost. According to this information, the initial goal has been reached and project is successful.

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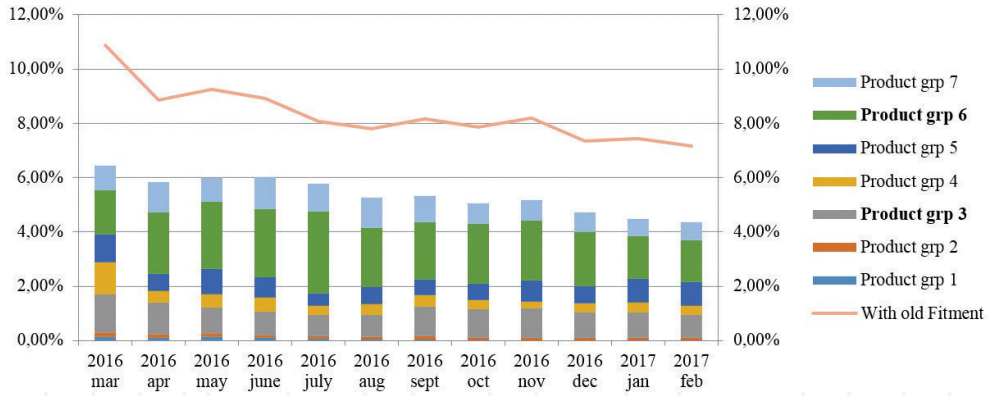

Figure 19. Monthly forecast with new materials.

3. Conclusion

The goal of current innovative research project was to reduce the package cost and choose an environmentally friendly material that is easy to process. Material and design selection were done using several methodology steps, which were shown in the general scheme of this research. All of the results were applied to the most expensive product groups. Current material values were compared with the new material values, and the final selection was done based on those values. This research study is giving an idea about packaging design and corresponding aspects needed to be taken into account in material strength testing, line capability wise, and packaging cost. Proposed framework enables decreasing the inbound logistics costs and leads to more fitments that can be loaded on to one pallet. It has lower emissions and material costs. The outbound logistics costs decreased only based on fitment material weight.

Such applied research projects are useful for both the enterprise and the university. The professors get applied research projects experience and publish the results of the research, and the students involved in the project can use received knowledge in their master or bachelor theses, and enterprises can employ new and active engineers.

Acknowledgements

This research was supported by Estonian Ministry of Education and Research for targeted financing scheme B41, F15027 and by the Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, Grant 2014-2020.4.01.15-0016 funded by the European Regional Development Fund.

Author details

Eduard Shevtshenko, Tatjana Karaulova*, Meelis Pohlak, Kashif Mahmood, Martin Tamm and Kaupo Leht

*Address all correspondence to: tatjana.karaulova@ttu.ee

Tallinn University of Technology, Estonia

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Chapter 9

Innovation in Limited Markets: Managing PCP Projects in the UK Defence Industry

Shaun Gee, Miles W. Weaver and Grant MacKerron

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/67543

Abstract

This chapter will outline guidelines developed to both support and enhance innovation within the context of procuring complex performance (PCP) contracts. Such contracts are currently being employed across a range of sectors where limited market conditions exist. Such contracts and market conditions are set to remain the dominant form of defence procurement strategy for the foreseeable future. The case of the Typhoon combat aircraft programme is presented as an example of a typical, large-scale, complex procurement programme for the defence industry. The MoD and the UK defence industry have developed new, contractual models for procuring complex equipment, such as aircraft and naval ships. These models involve the contracting for complex performance, which has changed the paradigm in the relationship between the customer(s) (MoD, UK Armed Forces) and the supplier (UK Defence Industry). Outcome-based contracts for procuring complex performance (PCP) have been employed widely by the defence industry and other sectors in limited or oligopolistic markets. Ten theoretical propositions are presented in this chapter, to help us discuss PCP contracts. The literature review will include servitisation, complex performance models and discuss innovation strategies in the context of limited markets. Lessons learnt from the case, and guidelines for enhancing innovation are presented.

Keywords: innovation, projects, procuring, performance, UK defence industry

1. Introduction

With the national defence budgets reducing over time as a result of environmental changes and continued economic uncertainty [1], the MOD and the UK defence industry have developed new, contractual models for procuring complex, technology-driven equipment, such as aircraft and ships. These models involve contracting for complex performance, which has changed the paradigm in the relationship between the customer(s) (MOD, UK Armed Forces) and the supplier (UK defence industry).

In procuring complex performance (PCP) contracts, a close, long-term relationship is developed that requires all those involved in the value-chain, including the customer and the extensive supply network, to co-operate in an enterprise approach to deliver competitive advantage with no single actor having the internal capability to achieve the totality of the requirement. Incentivising the supplier is key to delivering innovation, both radical and incremental, which requires suitable mechanisms built into the contractual and organisational construct. However, it is suggested that innovation within the defence industry may now be inhibited by the way that these new business and operating models have been implemented [2]. Innovation is a widely explored subject but, currently, no guidelines exist for supporting innovation in PCP contracts for organisations engaged in this type of procurement activity. Therefore, this chapter seeks to identify from the literature a set of *trends, success factors and barriers to support and enhance innovation within the context of a PCP contract.* Each of these will be reviewed in the context of the UK Typhoon combat aircraft programme, a major project in the UK Defence industry in order to move towards a set of guidelines that may be of interest to a practicing manager who has responsibility for managing a PCP project. This topic is relevant and of significance as PCP contracts are being employed across a range of sectors where limited market conditions exist and are set to remain the dominant form of defence procurement strategy for the foreseeable future.

Innovation is a feature of all successful enterprises and essential to provide future growth while remaining competitive and adaptable in a dynamic world [3] but setting the right conditions for enabling innovation within companies and organisations is not simple. A taut definition is provided by Tidd and Bessant [4] is '*the successful exploitation of new ideas*' (p. 19) inferring that innovation is a process whereby new ideas are converted into value either monetary or otherwise. Innovation involves integrating technological, market and organisational change. Being innovative is vital to the UK defence industry to ensure that it can meet the MOD's, and, ultimately, the Nation's requirements for continual adaptation of capabilities to meet the challenges of the future which was reinforced by the Secretary of State for Defence [5] in the 2015 UK Strategic Defence and Security Review (SDSR):

> *'Given those challenges, my third and final point is that being efficient would not be enough. We also need to innovate. We are determined to take the opportunity offered by the SDSR to build a culture more ready to take risks and more open to change. We want to do everything we can to augment our force structure, speed up the integration of new technologies, adopt new operating concepts and incentivise modern working practices'.*

The trend towards 'performance-based contracting', such as 'power-by-the-hour' in aviation, 'contracting for availability' (CFA) in defence for air, land and maritime forces and performance-based

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contracts in public-private healthcare is reshaping service support networks in many capital-intensive industries and is part of the wider movement towards integrated 'servitisation' models [6]. Performance-based contracting is designed to replace the traditionally employed fixed-price and cost-plus contracts to improve product availability and reduce the cost of ownership by directly linking a supplier's compensation to the output value of the product generated by the customer. Key features of PCP contracts are the shift in emphasis from output to outcome and the transfer of risk from the customer to the supplier for additional revenue [7, 8]. PCP contracts are an example of servitisation as an innovation strategy.

Drucker [9] suggests that innovation is the *'discipline of the entrepreneur'* and the systematic search for *'windows of opportunity'*, which suggests that innovation is a process that can be learned, managed and influenced and reinforces, Myers and Marquis's [10] conceptualisation of innovation as a non-linear, integrative process. The major choices a company make to influence performance through innovation are defined as innovation strategy [11]. Examining and critically comparing the innovation strategies of the defence companies and agencies involved in the Typhoon combat aircraft programme, which has been procured using the PCP model, will enable an analysis of the challenges of innovation in limited markets and an opportunity to explore how innovation can be enhanced to deliver more value within the context of PCP contracts in the future. The intention is to build on current theory to understand the level of influence that contracting for complex performance has had on the innovation strategies of UK defence companies. These are categorised into *trends*, *success factors* and *barriers to innovation* that influence innovation in complex performance contracts.

To highlight these issues in practice, the case of the *Typhoon Combat Aircraft* is presented that is representative of a typical, large-scale, complex procurement programme for the defence industry. This programme is international, multi-mission, combat aircraft designed and manufactured by companies from four European nations. In this case, we shall draw on fourteen interviews with personnel from three UK defence companies at different levels (e.g. strategic, operational and commercial) and the MoD involved in contracting for complex performance. A number of lessons learnt are drawn on from considering each of the *trends*, *success factors* and *barriers to innovation* in the single case. It is intended that this moves us towards a set of guidelines that will be of interest for private firms and public agencies to enhance innovation capability within the context of programmes that have been procured using the contracting for complex performance model. Further work is suggested to provide a multi-case analysis to enable a critical comparison of the approaches taken and are representative of the agencies that undertake this type of activity.

2. Research issues in contracting for complex performance

The literature review is bounded within the areas of innovation strategy and management within the context of contracting for complex performance in limited markets. First, innovation strategies within limited markets are discussed (Section 2.1), followed by introducing the strategy of servitisation (Section 2.2), concepts and principles in contracting for complex performance (Section 2.3), knowledge management and incentivisation in PCP contracts (Section 2.4) and reviewing timeframe, managing risk and the design of PCP contracts (Section 2.5).

2.1. Innovation strategy within limited markets

Innovation has many facets, but Tidd and Bessant's [4] definition: 'the successful exploitation of new ideas' provides a holistic interpretation and introduces the concept of innovation as a process. The process view of innovation is widely supported [10–13] with process complexity increasing as concepts have developed from relatively simple, linear process models to the integrative and networked fifth generation models of innovation suggested by Rothwell [14]. The concept of open innovation introduced by Chesbrough [15] suggests that innovation activity and knowledge accumulation can take place beyond the boundaries of the firm. To be successful at innovating, firms or organisations should develop routines, which encourage knowledge sharing and absorptive capacity together with a culture that supports innovation and a climate that encourages creativity [16, 17].

Knowledge creation is an essential part of successful innovation practice, which involves creating and sharing knowledge throughout the organisation which can then be embodied in new technology or products [18]. Smith and Reinertsen [19] build on this idea, identifying that resources and organisational capabilities are the ingredients of successful innovation with repeatable, codified innovation routines being the fundamental building blocks of an innovative company. Building capabilities can be achieved through organisational learning by various methods including working closely with customers and suppliers, joint ventures and alliances. Pursuing incremental innovation is a strategy for many firms but Strecker [11] asserts that focusing purely on incremental innovation can harm firm performance in the long-term and does not prepare a firm for discontinuous or radical innovation where the 'rules of the game' may change. Radical innovation can lead to a greater return on investment as well as superior competitive advantage [20]; however, radical innovation is inherently risky and does not always lead to success for pioneers of new products [4, 21]. Henderson and Clark [22] suggest that firms, which have an incremental or radical orientation, will require quite different organisational capabilities. Therefore, a tension exists in configuring for incremental or radical innovation. Many firms or organisations would still potentially seek to achieve both attributes.

In limited markets, like the defence or the rail industry, this tension will be particularly acute due to the characteristics of specialised markets with limited buyers and sellers. Limited or restricted market structures dominated by a few sellers are defined as an oligopoly. The theory of an open market structure suggests where competition between sellers is not restricted, this should generate low prices and high productivity whereas oligopolistic power can lead to imperfect outcomes and behaviours which can generate high prices and low productivity [2, 23, 24]. Imperfect markets are a challenge; further to this governments have pursued greater efficiency and effectiveness demanding greater innovation from industry, this has, in part, initiated adoption of strategies like 'servitisation' and the shift to new operating models, like PCP contracts. In the context of a PCP contract within a limited market structure, Caldwell and Howard (2014) indicate that firms will particularly struggle to configure to address the challenges of continual incremental innovation whilst also seeking to provide a radical innovation capability.

The extension of new concepts, like servitisation, through various sectors is indicative of more open forms of innovation. With the spread of technologies and methodologies across sectors

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due to the effects of globalisation, particularly the rapid development of information technologies, the influence of technology on the changes to institutions and vice versa is clear. Spin-offs or concepts of 'dual use' across sectors of technology and methodologies are commonplace [25]. It can be argued that national, sectoral and technological innovation systems play a part in driving change. National innovation systems are assessed as the totality of institutions and practices that interact to produce and diffuse new technology whereas sectoral and technological innovation systems are concerned with adoption of certain technologies in or across sectoral boundaries [26]. It is suggested that it is the co-evolution of national, sectoral and technological systems that has shaped specialised industries, like defence, and that innovation is driven or stifled by the interactions, inter-linking processes and changes in technology and institutions [27–29].

2.2. Servitisation strategies in the context of defence projects

As industries evolve, new strategies like servitisation are developed. Baines et al., [30] define the concept of 'servitisation' as the innovation of an organisation's capabilities and processes to shift from selling products to selling integrated products and services that deliver value-in-use with manufacturers becoming 'service-manufacturers'. Servitisation has become a key source of growth for many industries, including defence, with integrated solutions being developed, which generate greater customer value. Long-term relationships are emphasised with a shift towards organisational innovations, such as PCP contracts, to create new opportunities and gain a competitive advantage. In the context of servitisation, Gallego et al., [31] suggest that innovation needs to be progressively understood as an open and interactive process, which requires efforts, capabilities, and competences from various sources. This fits with Chesbrough's [15] concept of open innovation where incoming information and knowledge from outside the firm's boundaries is useful to the innovation processes.

New models of operation, such as servitisation, have challenged the traditional hierarchical architecture among the state, firms as systems integrators and subcontractors within the industry and the management of complex programmes. With knowledge and capabilities becoming more widely distributed, the design and development of complex programmes require new interactions between the public and private sector, which implies new knowledge combinations and capabilities between these parties. To integrate and manage the system effectively will require architectural knowledge as well as technological and organisational competence [29, 32, 33]. To be effective systems, integrators will require that current processes and functions are re-evaluated to develop new forms of exchange between the customer's, the firm's and, most likely, the array of sub-contractors' processes, behaviours and systems. Success in this area requires a true understanding of the meaning of value as it can be argued that a constant focus on 'value-for-money' by the state could undermine UK industrial capabilities. Many authors such as James [27] have argued that the creation of value should be a co-creation activity. The instigation of organisational routines and processes that support learning will enable designers, integrators and suppliers of complex product systems to build capabilities based on previous activity which, in turn, may develop 'repeatable solutions' or enhanced solutions based on experience [2].

In limited markets, like the defence industry, a close relationship between customers and suppliers is inevitable. As there are clear dependencies then a relationship between the organisations built on trust, vision, effective communication, collaboration and teamwork is an enabler for success [34–37]. To provide effective support and enable joint innovation, the firm requires intimate knowledge of the customer's operations. However, close co-operation between suppliers also requires appropriate protection of intellectual property (IP) to encourage and sustain innovation [38, 39].

By developing customised solutions for the customer alongside the physical product, the firm can reduce the overall costs associated with owning and using the product [40]. With a service-based approach, a firm can improve its capability to deliver higher value which has been regarded as a strategy of innovation for firms to remain commercially competitive [41, 42]. Focusing on benefits and value in totality by not separating products from service, firms will be able to innovate for better outcomes in product design or enable better human processes. Vargo and Lusch [43] propose service as 'the application of specialised competences (knowledge and skills) through deeds, processes, and performances for the benefit of another entity or the entity itself' (p. 2). Success in the development of services will be largely determined by the innovation culture, which should encourage and support openness, creativity and going outside of the norm [44].

Transforming a firm towards being service-orientated from a production-orientated entity requires an innovative, integrative approach, which combines traditionally separate aspects of a firm. Areas such as manufacturing, engineering, operations, marketing, business management, strategy and HR will have to work in an integrated fashion to co-create value with the customer to deliver an effective and efficient service [45]. Service development process, organisation and culture are all elements of a new service-orientated structure combined with measurement and rewards, suggested by Neu and Brown [46] as the five factors that enable successful service development. A service-based structure would have a customer-orientated, value-in-use based approach focused on outcomes provided by products or actions [47].

2.3. Contracting for complex performance

PCP contracts are a manifestation of the servitisation approach, which emphasise performance outcomes rather than how the outcome is to be achieved. Contracting for complex performance requires the service performance to be defined and linked to payment with an implicit transfer of risk to the supplier. Service performance is tied to financial penalties for poor performance and incentives for exceeding performance or innovating. PCP contracts are designed to be 'through-life' solutions to complex projects providing sustainable support, maintenance and upgrade over extended periods, often decades.

PCP contracting is 'outcome' focused. Customers only pay when outcomes have been delivered rather than for completed activities and tasks. This holds implications to the established architecture of 'production' and 'manufacturing' driving firms to be more innovative in the co-creation of service value, such as reducing costs, implementing new customer-focused processes and re-engineering of business processes [48]. A focus on customer outcomes means that PCP contracts encourage collaboration and co-ordination along the supply chain through

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the alignment of incentives [39, 49, 50]. In turn, it is suggested that this combination supports innovation in the long term as suppliers may have an interest to invest in designing more reliable products, with more efficient repair and logistics capabilities to increase profitability [51]. Through an examination of organisational control in terms of agency theory and socialisation models, Johnson and Medcof [52] demonstrated that PCP contracts support long-term, proactive innovation. PCP contracts, vis-à-vis behaviour-based contracts, engender self-initiated agent innovation as outcomes are specified but not the means to achieve the objectives of the contract leaving space for innovation. The incentives for achieving the outcome with fewer resources are increased profits through the reward scheme built into the contract. It is argued that the literature currently underplays the challenges associated with supplier-led innovation in product, process and working methods and that the empirical evidence is limited [53, 54, 79]. However, there is a generally accepted view that PCP [54] contracts do engender incremental innovation by the supplier [2, 8].

2.4. Knowledge management and incentivation in PCP contracts

Innovation, to a large extent, derives from the knowledge exchange between organisations [56, 57]. In terms of seeking to set the right conditions for innovation, Avadikyan and Cohendet [58] state that the central and challenging issue faced by the buyer is effective governance mechanisms which can deal with the trade-off between short-term efficiency and the long-term, relational aspect of knowledge economics. Furthermore, strategic knowledge management is a fundamental element of innovation processes with inter-organisational arrangements such as networks, long-term partnerships, communities and knowledge platforms recognised as important features. Long-term, partnered PCP contracts in the defence industry are an example of evolving knowledge management networks with management practices aimed at collective learning and co-construction of competencies between the public and private sector. Swart and Harvey [59] build on this idea suggesting that the key knowledge within projects exists across the boundaries between organisations, such as the customer-supplier boundary, and that this area is one of the most fertile regions for innovation. Utilising a knowledge-based view provides a mechanism for knowledge creation and structuring organisations or processes. Routines which encourage knowledge sharing and absorptive capacity are important to organisations that wish to be successful at innovating [16]. Ng and Nudurupati [47] suggest that, in the PCP context, sharing knowledge reduces uncertainty and unpredictability which would support innovation.

Incentives are a critical factor in supporting mechanisms for innovation in any context [60]. There is plenty of historical evidence of investigating methods to enhance innovation within defence contracts with Sumner [61] examining incentive mechanisms *'apart from profits to induce innovation'* looking at ways of jointly engaging parties in government contracts. Link [62] suggests that public/private activity is part of the national innovation system as efficiencies from R&D can be leveraged. Thereby, PCP contracts can be a mechanism for supporting innovation where new technology is being developed for reliability improvement or capability upgrades.

Agency theory views 'contracts' as instruments for aligning incentives and sharing risks especially in the context of environmental uncertainty and lack of information [63, 64]. For

example, long-term contracting within the defence sector has many uncertainty issues. On the supply side, there is technology obsolescence and on the demand side, variation in the employment of defence forces [65]. Selviaridis and Wynstra [54] conceptualised performance-based contracts along three key dimensions, as shown in **Figure 1**. Within a PCP contract, incentives are a fundamental aspect and the structure of financial and non-financial incentives will, therefore, have a major impact on supplier behaviour. The package of financial rewards or penalties within the contract can encourage suppliers to innovate or create negative consequences, such as opportunism [66, 67]. Rather than traditional fixed-cost or cost-plus, PCP contracts utilise target cost, incentive fee contracts which provide a mechanism to share profits between the customer and the suppliers [8]. However, Behn and Kant [68] highlight that experimentation, innovation and continuous improvement will be inhibited if exceeding higher performance targets is not appropriately rewarded.

As manufacturing firms move to a servitisation approach, delivering value takes a different form with many of the activities performed by customers through the lifecycle of the product [40]. The supply chain relationships are 'bi-directional' where customers also act as suppliers [69, 70]. Within the PCP context, this bi-directionality of supply chains is emphasised with the customer having clear roles in achieving desired performance or co-production of outcomes. Although this complicates service supply chain innovation, it also offers plenty of opportunity for innovation in design, or where capabilities should be placed or how value is delivered [35, 71]. It is particularly important that PCP contracts align the goals of the customer and the supplier through behavioural incentives. For instance, Ng et al., [45] and Caldwell and Howard [2] emphasise how the customer utilises the equipment over the life of the product and its impact on the way the supplier delivers the service.

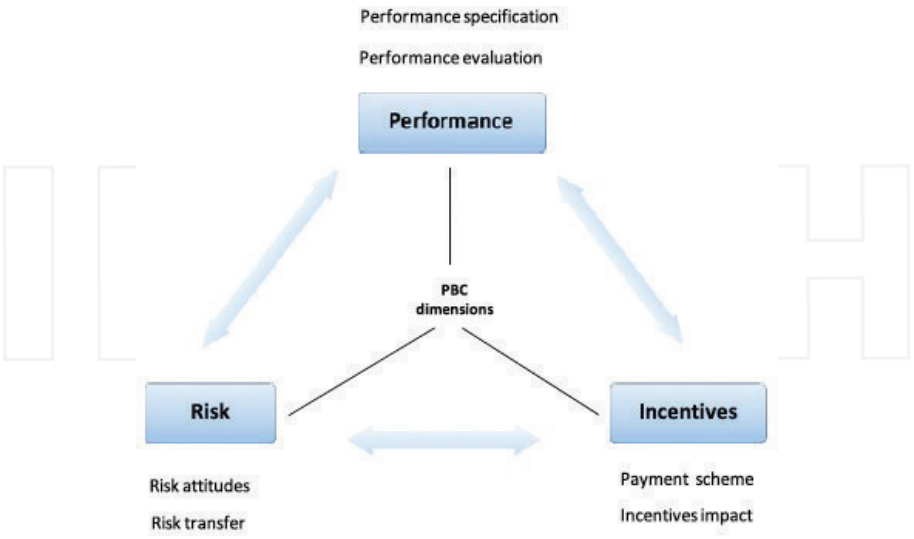

Figure 1. Stylised model of PCP contracts (as presented in Selviaridis and Wynstra [54]).

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Kostas and Andreas [72] indicate that PCP studies stress that incentive systems should reflect a good balance of risks and rewards for customers and suppliers. As well as the alignment of goals with the customer, the prime contractor must also focus on the relationship with the extensive network of sub-contractors. Opportunity for innovation exists within this network but as Spring and Araujo [73] indicate, sub-contractors are not compliant bundles of supplementary resources, they are *'innovating, multi-product, 'flesh-and-blood' organisations*' (p. 154), in their own right. Sharing the cost of uncertainty, but also the rewards for innovation with sub-suppliers, will potentially enable a prime contractor to achieve sustainable success on PCP contracts.

2.5. Timeframe, managing risk and the design of PCP contracts

The financial drivers for firms to move to service strategies are higher profit margins and stability of income [38, 40]. With the lifecycle of complex equipment, like fighter aircraft often being decades, the costs of support are approximately seven times the manufacturing costs [74, 77]. Regular income from PCP contracts is attractive to firms as it balances unfavourable economic cycles and the effects of mature markets [30, 75, 76]. For the customer, PCP contracts can elicit desired behaviours arising from the incentives within the contract, thus reducing the cost of contract and the more expensive through-life costs of the equipment over the longer term. Over time, by understanding the use and outcomes required by the customer from complex equipment, firms are able to change business models shifting customer interaction from purely transactional (i.e. selling products) to a relationship basis [77].

Hooper [78] suggests that to make performance improvement focused investments, suppliers require incentives, which are often long-term agreements which enable amortisation of the investment and profit for the firm [79], whereas Eldridge and Palmer [80] propose that short-term contracts do little to promote investment in innovation. As performance incentives need to be sustainable through-life, Lane [81] also indicates that PCP contracts are not appropriate for a short timeframe. However, an optimum period exists for the length of the PCP contract or contract review. This is because it is difficult to judge, over time, how sustainable performance-based incentives in long-term contractual relationships are as supplier learning occurs and service improvements become marginal [54].

A key element of a PCP contract is the transfer of risk to the supplier as benefits are now tied to the achievement of performance outcomes [82]. Therefore, risk appetite and the process for managing risks through the contract are fundamental issues in contract design and management. The level of risk that a supplier will accept will be contingent on how comfortable the supplier feels and risk appetite may be low where the supplier perceives a lack of control or limited ability to manage the risk [47, 53]. Where customers are risk averse and are willing to transfer financial and operational risk to suppliers, then PCP contracts provide a suitable vehicle. Even with significant risk transfer in regulated sectors like defence, the buyer is still accountable for service failure [83]. The supplier's risk appetite can be a key limiter to successful PCP contracts and innovation within this context with some of the literature contending that a reticence from the supplier to accept risks related to service failures due to untested technologies or failed experimentation with working methodologies will inhibit innovation [53, 54, 78]. Therefore, risk management is key to successful innovation within a PCP contract.

Theoretical propositions identified in the literature review			Key contributions
Trends	*TP.1:* In a limited market, PCP contracting may inhibit radical innovation capability.	Incremental innovation is a strategy for many firms but focusing purely on incremental innovation can harm firm performance in the long-term. Firms which have an incremental or radical orientation will require quite different organisational capabilities which will be an issue for firms in limited markets involved in PCP contracts.	[2, 11, 19, 22]
	TP.2: Innovation is driven by a co-evolution of the technologies and the institutions.	Industry dynamics are driven by the interactions between technology and institutions, and their interlocking elements and processes are a potential source of inertia or transformative pressure. Clear connections exist between innovation systems and the rest of the economy.	[25, 28, 29]
	TP.3: Managing complex programmes in the servitisation context requires new capabilities and knowledge combinations.	Servitisation has become a key source of growth for many industries. Longer-term relationships are emphasised with a shift towards organisational innovations, such as PCP contracts. Complex programmes require new interactions between the public and private sector which implies new knowledge combinations and capabilities between these parties. Organisational routines and process that support learning enable designers, integrators and suppliers of complex product systems to build capabilities based on previous activity.	[2, 29, 30–33]
Success factors	*TP.4:* A shared, strategic vision between customers and suppliers combined with a service-based approach integrated across the whole enterprise supports innovation in PCP contracts.	In limited markets, close integration between customers and suppliers is inevitable. Innovation is supported by a shared strategic vision together with effective communication, collaboration and intimate knowledge of the customer's operations. A service-based approach focused on outcomes provided by products and actions can be a strategy for innovation.	[35–38, 41, 42, 44, 46, 47]
	TP.5: PCP contracting can engender long term, proactive agent incremental innovation.	PCP contracting being outcome focussed with the customer only paying for delivered outcomes rather than activities and tasks implies changes to the established architecture of 'production' and 'manufacturing' driving firms to be more innovative in the co-creation of service value. PCP contracting supports innovation in the long-term as suppliers may have an interest to invest in designing more reliable products or improved processes.	[37, 39, 48–52]
	TP.6: Systems for knowledge sharing should be built into the enterprise.	Innovation, to a large extent, derives from the knowledge exchange between organisations. Key knowledge within projects exists across the boundaries between organisations, such as the customer-supplier boundary, and this area is one of the most fertile regions for innovation.	[16, 47, 56–59]
	TP.7: Appropriate incentive structures are key to promoting innovation in PCP contracts.	Incentives are a critical factor in supporting mechanisms for innovation. The package of financial rewards or penalties within a PCP contract can encourage suppliers to innovate or create negative consequences. PCP studies stress that incentive systems should reflect a good balance of risks and rewards for customers and all suppliers.	[8, 35, 40, 45, 60, 62, 66, 67, 71]

Theoretical propositions identified in the literature review			Key contributions
Barriers	*TP.8:* Short-term contracts do not support innovation within the PCP context.	To deliver complex equipment programmes where through life-costs are high, regular income for firms and cost reduction for the customer supports the PCP approach. Long-term contracts provide a key incentive to promote innovation.	[30, 38, 40, 47, 54, 79–81]
	TP.9: Inappropriate risk management will inhibit innovation.	A key element of a PCP contract is the transfer of risk to the supplier with the process for managing risks being a fundamental issue in contract design and management. The supplier's risk appetite can be a key limiter to successful PCP contracts and innovation within this context.	[47, 54, 78, 82]
	TP.10: Service-design boundaries can inhibit innovation.	Success within PCP contracts begins with the design of the contract including definable, measurable outcomes, appropriate incentive structures and the right governance. Barriers to innovation could come from restricting the supplier's freedom to service design and a rigid specification may inhibit a supplier's willingness to bear risk and be innovative.	[8, 54, 84, 85, 87–90, 99]

Table 1. Theoretical propositions grouped into trends, success factors and barriers to innovation within PCP contracts.

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In pursuing success within PCP contracts, the design of the contract provides the fundamental building blocks, which are clearly definable, measurable outcomes, appropriate incentive structures as well as the right mix of contractual and relational governance mechanisms [54, 83, 85]. This idea is supported by Olsen et al., [86] who concluded that trust, authority and appropriate incentives are key factors, in governance of complex outsourcing contracts. Moreover, the contract must also be flexible as a rigid specification may inhibit a supplier's willingness to bear risk and be innovative [8, 87]. Contract design sets the conditions for innovation over the life of the contract and the types of governance mechanism will play a key part in enhancing or restricting success [88–90]. Barriers to innovation could come from restricting the supplier's freedom to service design. This is highlighted by Axelsson and Wynstra [91] who indicate that there is a link between contract specification methods and the design of incentives for supplier-led innovation [54].

2.6. Summary of theoretical propositions for innovation within PCP contracts

The preceding literature review provided the foundations to arrive at a set of theoretical propositions, summarised in **Table 1**. These theoretical propositions are suggested in terms of *trends*, *success factors* and *barriers* to be used to analyse innovation within the context of PCP contracts in a limited, specialised markets. The following section will explore each of these propositions in the context of the case of the Typhoon project in Section 3.

3. The case of the defence industry and the Typhoon project

In this section, the UK defence industry and the Typhoon project are presented drawing on fourteen interviews with key personnel in three UK defence companies and the MoD. These individuals are involved in contracting for complex performance at the strategic, operational and commercial levels. Each of the theoretical propositions presented in **Table 1**, is reviewed in the context of the Typhoon project to offer some lessons learnt in the context of the case, before moving towards some guidelines that may be applicable to other practicing managers in this area.

3.1. UK defence industry

The defence industry is a specialised market with some unique characteristics that influence the business strategies adopted. Blom et al., [92] provide a number of factors, which explain the idiosyncrasies of the market: firm heterogeneity, stable structure, high innovativeness, high export propensity and active public involvement. Defence firms are highly heterogeneous with a varied array of technical competencies and product portfolios operating in a stable oligopolistic market structure that has a low exit and entry rate. High innovativeness is a feature of most defence firms with respect to technological innovation with collaboration between private and public organisations being commonplace. Additionally, defence is a monolithic customer which will buy major equipment, like fighter aircraft, in batches or tranches from a single manufacturer under a prime contract that it will likely keep for up to

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30 years or more [93]. The industry has a high export propensity with a large proportion of firms, which sell products; is of strategic importance from a military and national security perspective; it is heavily regulated and there is extensive, active public involvement with the public sector providing a key, stable source of income.

Maintaining defence capabilities is expensive with the UK committing £46Bn in 2016 which is 2% of GDP as required by NATO [94]. Governments have realised that it is unaffordable to have national capabilities in every area; therefore, governments have addressed the issue by reducing the costs of maintaining a domestic industry through privatisation, engaging in the export market which reduces unit cost through scale, and engaging collaboratively with other nations [92]. In turn, this explains why defence trade is a facet of national security strategy as it enables a balancing between spending and security. **Figure 2** shows how the network functions.

Changes in the approach to procurement from the MOD, which began to apply a more commercial mind-set as a result of the Levene reforms in the 1980s and, more recently, the Grey review [96], introduced competitive tendering processes as well as more stringent contracts which transferred risks for development, production and support of equipment from the MOD to industry. These reforms had a fundamental impact on the strategies for defence companies as traditional cost-plus contracts were replaced by target-cost, incentivised contracts together with a partnered approach to procurement.

3.2. The Typhoon programme

The Eurofighter Typhoon programme was established in the 1980s to design, develop, and support a new European fighter aircraft. Britain, Germany, Italy and Spain formally agreed to start development of the aircraft in 1988 under a complex, collaborative arrangement designed to share the huge costs of the programme with the UK eventually purchasing over 100+ aircraft in a number of staged buys or tranches. The European dimension created a significant

Figure 2. The defence industry and national security network (reproduced from PWC [95]).

complexity within the organisation and design in addition to the complex nature of the technology being developed and supported. Each partner nation was awarded a work share under the principle of *juste retour*[1] with the aim of the programme to share work, technologies and develop national capabilities. Programme management is led by an agency, which represents the four countries, and the Eurofighter consortia provides the industrial construct representing the prime contractors involved in the programme. A schematic of the programme management is provided at **Figure 3**:

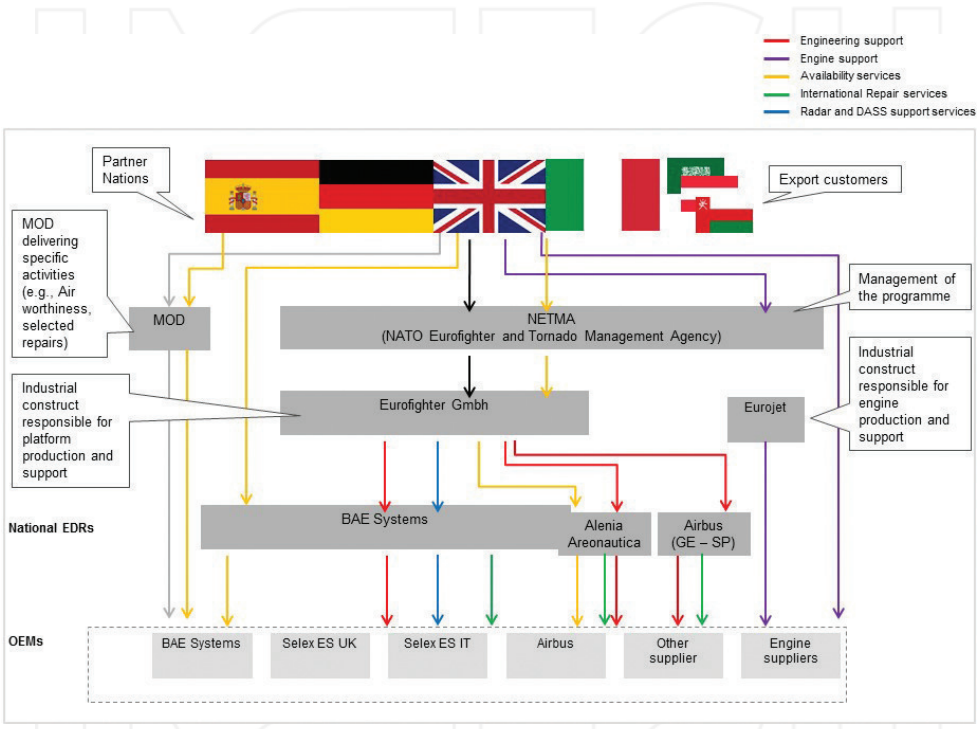

Figure 3. Typhoon programme management construct (reproduced from MOD [97]).

The differing requirements, influences, and aims of all the agencies all contribute to creating significant issues in managing the programme or striving to create an environment for innovation. In the case of Typhoon programme the decision-making cycle is measured in years of the programme, neither weeks nor months. This creates issues in getting everyone harmonised around a particular course of action, particularly as many agencies are involved, in four partner nations and companies and two management agencies. Within the supply chain, there a host of other agenda's—physical, economic and industrial.

[1]Principle that the funding granted to project participants from a given country/region under a joint call is in proportion to the budget contributed to the joint call by that country/region.

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3.3. The UK support construct

The programme is designed to maintain alignment across all of the partner nations but permissions are built into the construct to enable individual nations to develop the capability of their aircraft using different approaches especially in the support construct with an expectation of potential convergence and reintegration at a later date. Over the last 10 years, this has enabled the UK to develop a service-based, availability solution for the Typhoon aircraft support which will become truly outcome-based with the latest iteration of the contract, the future state operating model (FSOM), worth £2.1Bn over 10 years, although the engine remains a separate availability contract.

An outcome-based solution enables the MOD to address the key issue of affordability, reduce complexity and transfer risk to the provider [8]. Prior to availability contracting, Royal Air Force (RAF) personnel carried out maintenance and upgrade of aircraft in-house with spares, equipment and technical support purchased from a range of contractors on a piecemeal basis by MOD staff; this model became unaffordable and did not exploit the capabilities of industry. Aligned with the governmental drive for more outsourcing under the MOD's SMART procurement initiatives [89, 96], moving to a service-based, PCP contract enables a prime contractor to take on the responsibility for a defined output, such as available flying hours, in exchange for a fee [45]. Adopting this strategy provided industry the opportunity to reap the benefits of servitisation, such as higher profit margins, stability of income and protection from economic cycles [38, 40] at a period when the outlook for the number of large-scale production programmes has reduced. The risks and rewards are co-shared appropriately through the creation of painshare and gainshare mechanisms within the contract, which are common on one-off, complicated programmes [8] with long-term partnering relationships being emphasised between the MOD and industry.

For military aircraft, there is a requirement to constantly upgrade as new technology becomes available to defeat potential threats and contracting for availability (CFA), which first appeared in the mid-90s, enables upgrades to be achieved at the point of routine servicing which keeps costs down and availability up. CFA is a form of PCP contract where equipment, such as aircraft, are made available for tasks normally measured in flying hours. There have been various CFA for combat aircraft including Tornado, Harrier and Typhoon. In addition to the UK, armed forces from across the globe are moving to this form of delivering defence capabilities [98].

Due to the political, organisational and technical complexities involved with the Typhoon programme, the steps towards an outcome-based contract have been evolutionary. The first Typhoon availability service contract signed in 2009 was in reality four outputs: aircraft, spares, technical information and training rather than a single outcome: flying hours. Because the construct did not focus solely on the real value to the customer, which was flying hours, there were significant issues with the initial contract with apparently little co-creation of service value [48] or collaboration and co-ordination along the supply chain due to misalignment of incentives [36, 39, 49]. The issues are exemplified by a number of respondents:

> *'That's what the output was, you then had the frontline squadrons integrating it and turning it into flying hours and we spent our lives fighting over moderation of why our aircraft were delivered late'.*

> *'…because it was a claims culture, we had a room of people to work out where we were failing in our commitments so they could put a claim in. We had a room of people claiming against [Contractor X] lack of output performance and it was a battle…it definitely did not stimulate innovation. It might have stimulated innovation within our own organisations to win those battles but it did not actually stimulate innovation across the organisational boundaries'.*

Over the last few years, the programme has been in the midst of re-negotiation of a new contract, which is reaching culmination. The FSOM contract is structured so that the supplier effectively only gets paid for the number of hours flown by the customer. The catalyst for the new contract was a review which demonstrated that the funds to support the platform could potentially run out before the end of the programme. Neither the MOD nor industry could countenance the aircraft not being in service as the Typhoon provides a key defence capability which could not be replicated and being without UK Typhoons would seriously inhibit the potential for future export sales of the platform. The difficult question for the MOD is how to incentivise the suppliers, who are still heavily orientated towards a manufacturing/production culture, in the conditions that prevail within the oligopolistic market structure of the defence industry [92, 93] to enter into a more challenging contract that potentially reduces further the revenues from support? A key element of the solution was the principle of 'recycling' savings from support into funding equipment capability (i.e. product) development programmes which would benefit industry by guaranteeing opportunity for revenue and providing work for engineers and benefit the customer by reducing support costs while generating more defence capability. By introducing the recycling principle, there is a better alignment of the goals of all parties within the enterprise, which has the potential to stimulate further innovation beyond what has already been baked into the contract [2, 45].

3.4. Review of key propositions in the case of the Typhoon programme

The theoretical propositions' combining *trends* (discussed in Section 3.4.1), *success factors* (discussed in Section 3.4.2) and *barriers* (discussed in section 3.4.3) to innovation within PCP contracts are discussed in relation to the Typhoon programme in this section. Lessons learnt are offered for the Typhoon programme that have implications for a set of guidelines that will be useful to the practising manager involved in PCP in the future, either as buyers or suppliers.

3.4.1. Innovation trends

3.4.1.1. Radical innovation capability (TP.1)

Innovation is about managing the process of turning uncertainty into knowledge. Incremental innovation, although not risk-free, is a strategy focused on developing improvements from a position of some certainty whereas radical innovation involves starting at the limits of knowledge [4, 22]. In a limited market such as the defence industry, political constraints and government regulation, both nationally and internationally, and a lack of investment inhibit manufacturers going it alone on large-scale or high-risk programmes which reduces the propensity for radical innovation. The ability to link advanced technologies to market opportunities is a crucial aspect of radical innovation. When markets do not yet exist, it is difficult to persevere when there are organisational pressures for immediate profit [20]. A respondent

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commented that *'regulation is great … as it provides government security but does limit the ability of anyone to invest in [the defence industry]'* and that the majority of the risk is jointly managed with the customer (The MoD). The respondent suggested that this hinders the *'ability to generate dislocative technologies'* that provide options to both the customer and business as such innovation is often determined by political will to support and sponsor. Safety assurance, governance and the size of market creates difficulties for innovation in this context which is risk averse compared to less constrained, consumer-led markets, such as telecommunications or information technology markets. Moreover, the time to market performance for technology or process development may be too great to match customer need. One of the respondents discussed how contracts can drive the type of innovation and can lock down the opportunity for radical innovation as PCP contracts tend to be structured around removing cost through incremental innovation or optimisation. This suggests a need for a strategic focus by governments and firms on this issue, if the industry is to retain a radical innovation capability.

3.4.1.2. Co-evolution of the technologies and the institutions (TP.2)

Governmental commitment to outsourcing on large programmes has driven innovation in the support market and the development of PCP contracts. As the support market is taking a more dominant or equal position, this is reshaping the strategies of firms. Additionally, the unique nature of the market and the linkages with national security strategies [92] drives the relationship between the organisations, public and private, within the industry. As the industry has tended towards a transnational growth strategy, the dynamics of the relationships are continually evolving with different models of support and more organisations influencing the environment [25]. This view was supported by respondent from a supplier who highlighted the change in nature of their business from *'leading developing in Europe, to one that was a follower in the US'* noting that in 2007 they were 70% dependent on the 'domestic customer' and by 2017, 70% dependent on the export market. The challenges faced by the industry may require taking greater risk to match perceived market needs, such as investment decisions may need to be earlier in the technology readiness cycle. Aligned with the findings of Lazaric et al., [29], exploitation and development of dual-use technology, ranging from drones to data analysis, between the defence and the commercial markets remains important with commercial technology now tending to lead defence technology development (e.g. data analysis and forecasting capability in financial technology industries that can be used to improve spares forecasts).

3.4.1.3. New capabilities and knowledge combinations for managing complex programmes in the servitisation context (TP.3)

Avoiding bespoke solutions where possible, spreading learning back and forth across sectoral boundaries and leveraging the extensive technology base that already exists within defence companies as well as outwith potentially provides a fertile landscape for innovation. However, flexible contracts will be required to enable technology insertion and exploitation. The industry consolidated considerably following the end of the Cold War in the 1980s and

further market-led consolidation is suggested in the future [99]. With high entry barriers and limited competition, the market could evolve through the consolidation of the UK support structure. Potentially, in a limited market, collaboration between some of the lead players could lead to better innovation by focusing on the value chain of the capabilities that each of the firms has to offer. Centres of excellence for particular equipment or technology-types could lead to better solutions. Although this was not a common innovation strategy across the firms researched, some of the new relationships developed between firms for the FSOM contract are indicative of this approach. In this regard, a level of integration should not entirely shut down the competitive landscape to prevent SMEs or new entrants from entering the market in future. Further research could be focussed on the threats and opportunities from further consolidation of the sector.

To better manage complex, product-service programmes within a limited market requires different capabilities [2, 96, 100], such as the ability to analyse enabling processes and lead change. Sophisticated, strategic, enterprise-wide modelling tools and learning processes should be built into contracts to enable value to be co-created between the parties [27, 29]. However, boundaries, regulatory, commercial or otherwise, across the organisation can create significant blockers. To enable models to be developed requires clean data which can be shared which was a challenge for the Typhoon programme and, although full enterprise-wide modelling tools do not yet exist, models and frameworks have been developed which have supported the new contract development. To be truly focused on value generation, innovation needs to be encouraged from across the enterprise from other non-traditional areas, such as commercial and finance not just R&D, engineering or production and in all phases of the lifecycle, as detailed by a number of respondents.

Routines and processes developed across the organisation that support learning enable designers, integrators and suppliers of complex product systems to build capabilities. For example, adjacent industries, such as space or rail for the aerospace industry, can also act as a source of innovation, providing routes to new ideas or markets. Measuring innovation is difficult and can be stifling but benchmarks, internal or external, can provide a useful gauge of innovation to guard against being too self-referenced. Dobni [101] suggests setting up innovation benchmarking within lifecycle management and design review as a method of developing capability. Project learning enables repeatable solutions [2] to be developed which can be used by a range of different customers or markets.

3.4.2. Success factors for innovation

3.4.2.1. Shared strategic vision (TP.4)

A fully, service-orientated organisation with an integrated approach supports innovation, but it is not easy to create this type of organisation for companies originating from a manufacturing or production background which is demonstrated in the case. Abandoning product-centric for customer-centric structures can meet resistance for fear of changes to the structure, missing performance targets and lack of understanding of a service strategy. The transition to services does not necessarily ensure the expected high returns which has been referred to

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as the 'service paradox in manufacturing companies' without overcoming organisational and cultural hurdles [30, 38]. A respondent representing a Senior Director of a supplier pointed out *'Where I believe we have to be is a much more service orientated organisation, where I believe we are DNA-locked into is a much more product orientated organisation'*. Evidence from the case underpins the theory that integrating traditionally separate areas together with leadership to develop a service innovation culture and environment supports the business transformation [46]. It was also recommended by two respondents that creating a separate arm of a business can be an effective strategy.

Leadership is required to inculcate the service ethos across all areas of the business from the composition of the board to the servicing bays focused on co-creating value with the customer to deliver an effective and efficient service [45]. Appointing an innovation or service support director together with investment in a distinct business unit identity are all visible statements of intent which can support the cultural change required. Other examples highlighted included not being afraid of failure or experimentation, creating the right environment, use of social media and writing innovation into job descriptions. However, cultural change takes time, as the behaviours are at both the conscious and unconscious level, and all of the organisations were still learning and adapting to the service culture. For effective innovation in a partnered, PCP context, the service-based approach and culture will extend across the customer-supplier boundary with an enterprise approach which should be underpinned by a shared, strategic vision. Setting a transparent, strategic vision between the customer and supplier is always going to be challenging as it involves attempting to align national security goals with the goals of private companies but is key for partnered innovation over the decade-long horizon of PCP contracts to provide reference points. Co-locating those who are designing, delivering or managing the service also positively develops the right culture; the integration between the customer and supplier organisations has already been extensive. Some firms have established service delivery centres on RAF sites and others have formed joint teams separate from firm HQs.

Another key consideration in joint, collaborative working is appropriate protection of intellectual property (IP) [39] and the current MOD rules for IP applied in the PCP context could be stifling innovation. This was exemplified by a Commercial Director from one of the suppliers who indicated *' … the way the contract is set up means that we would have to share all of our background intellectual property with all of those companies for the RAF to benefit'*. Even though many of the boundaries have been eclipsed with the advent of PCP contracts in defence, a fully integrated, enterprise approach does not exist as yet with many silos either across the internal boundaries of firms, such as between production and support, or at the external boundaries of the partnered organisation, such as maintenance on the flying squadrons who deliver the output. In a complex organisational mix like the Typhoon programme, there are various cultures including the military culture of the RAF, the MOD procurement agency and the business units of the private companies. Strong cultures can be a positive, but can also inhibit innovation by potentially being blinkered to different delivery models for the same effect. A value-based, service-orientated approach taken across the enterprise could allow more innovation and create a more cost-efficient or effective solution. The PCP contracts for export customers have different boundaries for similar outcomes and provide a contrasting view to current UK support models.

3.4.2.2. Long term, proactive agent incremental innovation (TP.5)

PCP contracts support the development of innovative ways to reduce cost or improve delivery led by the agent. Directly linking payment to outcomes which provide value to the customer, like delivery of flying hours for the Typhoon, creates collaboration along the supply chain through incentive alignment [50]. The conditions for innovation in the long-term are created as suppliers have an interest to be more efficient in service delivery and make products more reliable to increase profitability [51]. By moving away from traditional cost-plus and fixed cost commercial models to a target cost, incentive-fee (TCIF) model is innovative and provides a framework for further innovation (**Figure 4**) but, unlike traditional models, TCIF requires active management from organisations with the right capabilities.

Building in a continuous improvement approach through the development of the service culture can enable innovation within a contract. As suggested in the literature, the challenges of obtaining supplier-led innovation are evident [53, 54, 78] but the PCP framework can set the conditions. On the Typhoon programme, significant costs have been removed over the life of the current contract and there are many examples of continuous improvement including developing a lean learning academy to improve maintenance efficiency, improving structural health monitoring data to improve engine life, and reducing the repair-loop times in the UK or Europe. However, the learning has taken place iteratively over successive generations of contracts with the next contract planned to drive out almost 40% of the cost.

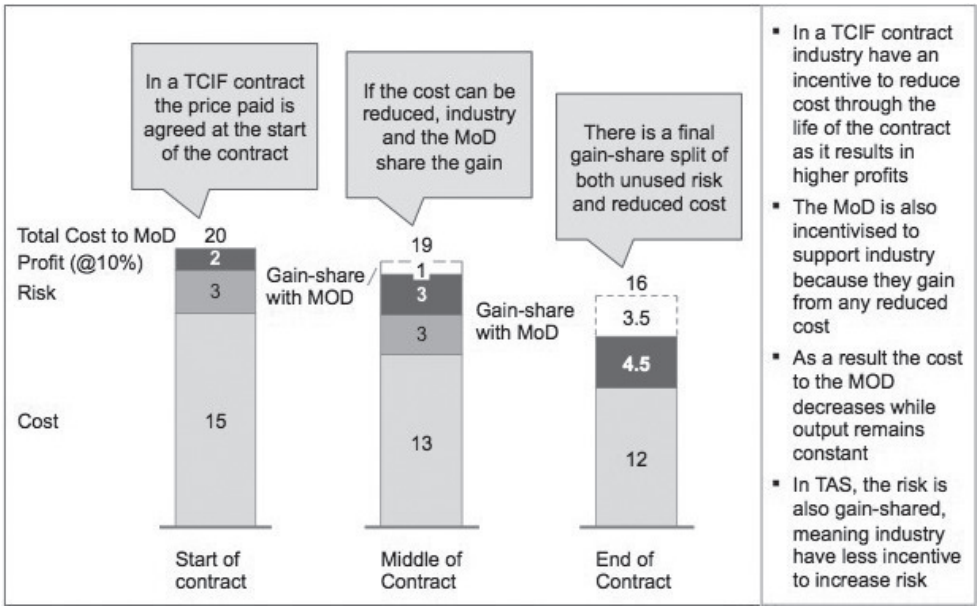

Figure 4. TCIF contract illustration (reproduced from MOD [97]).

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3.4.2.3. Systems for knowledge sharing (TP.6)

Knowledge exchange between organisations is a key factor in innovation [56, 57]. Within partnered programmes, shared data of the right quality is a key enabler to driving innovation. To understand how cost could be removed from PCP contracts required visibility across the partnered community of cost drivers which 'open-book' accounting has gone some way to facilitating. However, in maintenance support contracts, much of the uncertainty comes from how equipment is being used, so getting usage data would provide focus to drive cost reduction or other operational benefits (e.g. sharing data in real time would provide operational benefits over the long term). Setting up appropriate mechanisms for cross-fertilisation of ideas across organisational boundaries can also stimulate innovation. With the development of the partnered approach, knowledge management networks have been set-up, designed around collective learning and co-construction of competencies between the public and private sector [58] which are evident in the Typhoon programme. Involving partners in early stages of product development lifecycle enables potential improvements in design from a supportability or operational perspective but this may involve overcoming difficulties, such as security or competitive rivalry. Due to a silo approach and cultural issues, the MOD has struggled with cross-functional learning across domains and platforms with successful ideas from air not necessarily being transposed to the land or maritime domains or between the various air platform contracts. As Van Baalen et al., [102] suggest that frameworks and tools, such as innovation portals, are proven mechanisms for promoting innovation, providing novel methods for interaction, unblocking innovation ideas and unlocking latent talent within the organisation. Investing in an enterprise-wide toolset could enhance innovation across the partnered community. For instance, the Innovation Manager at a supplier indicated that over 60% of the winning ideas come from an area outside of where the challenge originated.

3.4.2.4. Incentive structures to promote innovation (TP.7)

Incentivisation is vital to promote innovation, with alignment of goals of the parties involved being a key aspect [55]. In availability contracting, the servicing of equipment and spares is secondary to the provision of the main outcome, which is flying hours for future state operating model (FSOM). Previously, the incentives were wholly misaligned as contractors got paid to repair parts and equipment which had broken so more work meant greater revenues for the suppliers. Under the new model, industry is incentivised to provide reliable and capable equipment, reduce maintenance downtime, improve logistics support as well as provide available aircraft. With the latest contract, the link between outcome, flying hours, and the contract is absolute which truly aligns the goals of the user, the RAF, with the procurement agency, the DE&S, and the industry partners which should drive the behaviours necessary to co-create value. Gainshare arrangements under the TCIF model enable both parties to reduce cost and mitigate risk-providing industry appropriate profit margins which should not limit innovation. Moreover, in the latest contract the MOD has added further incentive by committing to recycling costs saved in support into capability upgrades for the Typhoon aircraft which drives the right behaviours, delivers more defence capability as well as maintains the defence industrial base for potential exports. As one respondent noted FSOM is a model that

drives the right behaviours and highlighted that there is a perceived reward for innovation. This has implications for efficiency as well as better technology that satisfy customer needs. Driving sub-contractor innovation in the supply chain is challenging for the prime contractors as volume remains a key driver lower down the chain and many suppliers are dependent on production rather than support. Less money but greater margins is an obvious incentive but different partnering arrangements or alignment between the various suppliers of the industrial base can provide new dimensions which has occurred within areas of the new contract.

3.4.3. Barriers to innovation

3.4.3.1. Short-term contracts (P8)

Long-term contracts support innovation by promoting investment, and enhancing partnered relationships in the development and support of large, complex programmes like Typhoon which have a lifecycle of up to 30 years. The steady, predictable revenue for industry from PCP contracts is attractive to firms as it balances unfavourable economic cycles and the effects of a mature market [30], enabling an adequate return on investment compared to potentially more lucrative returns elsewhere. Over the lifecycle of the programme, the customer will be able to significantly reduce support costs. Longer contracts create the conditions for industry and the joint enterprise to invest in strategic capabilities. Additionally, in complex programmes, many of the opportunities for innovation, such as equipment reliability modifications, require time to mature. An alternate view could be competition but in the context of PCP, competition may not drive innovation in the long term and could be an expensive method with more risk than the collaborative-partnering model as the national scale of the market is probably insufficient. The Strategic Director of a supplier had indicated that competition can drive short-term benefit but may not be a sustainable position for delivering the capability in the long-term.

An appropriately balanced approach to the overall length and the review points of PCP contracts is suggested as the best approach to support innovation enabling iterative learning through the life cycle of the programme. A long-term approach is required to support investment and develop learning but sustaining incentives for innovation over time becomes difficult as improvements become marginal [54]. An empirical review of various PCP contracts to determine optimum length and review cycle to support innovation could be an avenue of further study. The transfer of risk to the supplier is a key feature of PCP contracts [82] but risk needs to be managed in the right place to enable innovation. Some firms are well placed to manage the level of risk required for the innovation expected of the supply chain by the customer in the new contract, with the right capabilities in place and a good understanding of what is required to deliver the right level of performance. Others do not have the same risk appetite either because the capabilities are not in place or the level of incentives that flow through the contract are perceived to be insufficient as indicated by a number of respondents.

3.4.3.2. Risk management (TP.9)

The corporate processes in place within both the customer and supplier regimes restrict nuanced risk management which inhibits innovation. A highly regulated environment, strict

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approval systems, high-levels of scrutiny rather than autonomy make for risk averse organisational structure which stifles innovation. Some of the processes appear to be still focused on a production mentality rather than the agility required for innovation in support services. The result is an erosion of risk transfer as the contract is developed which will potentially mean less innovation over the lifecycle. Risk management can be improved through better data from greater modelling capabilities, and by having people who have developed the confidence to manage risks through experience in the PCP context which suggests retention of capability, learning and employment across similar projects.

3.4.3.3. Service-design boundaries (TP.10)

Governance mechanisms will play a key part in enhancing or restricting success in innovation for PCP contracts [90]. Bureaucracy during contract development and the service design phase introduces time or inertia implying a tension between an appropriate balance of assurance versus the freedom to innovate. Contract design sets the conditions for innovation over the lifecycle and barriers to innovation could come from restricting the supplier's freedom to service design [91]. The scope of the contract is potentially the limiting factor with clear silos in design remaining. These potentially prevent the enterprise-wide, value driven approach and the current boundaries could be tested for opportunities, including further internationalisation, such as placing repairs in non-traditional locations outside of Europe or the US. However, organisational appetite may be limited by various factors ranging from revenue generation to IP issues so the incentives would have to match. The design start point will also impact the outcome and a 'bottom-up' approach to contract design focused on removing cost from the current state may be a constraint rather than starting with top-level principles which could broaden thinking and approach (i.e. outcomes focused on a shared vision with a understanding of marketing constraints and operating capabilities).

4. Conclusion: towards some guidelines for enhancing innovation in limited markets

This chapter has presented a literature review to identify a set of ten theoretical propositions that have been categorised into *trends*, *success factors* and *barriers* to innovation within PCP contracts. Further to this, each of the propositions have been reviewed in the context of the *MoD Typhoon Programme* in order to arrive at a set of lessons that can be learnt for managing a PCP project in the UK Defence Industry. These lessons learnt are shown in **Table 2** below, it is intended that these lessons learnt will be useful to the practising manager managing PCP projects and that further work is necessary to arrive at a set of guidelines for enhancing innovation in limited markets.

The chapter is limited in terms of generalisability by offering a single case and focusing within the Defence Industry. However, it is argued that the Typhoon Programme is representative of a typical and complex case that will be of interest and relevance to the practising manager. This work is grounded in a strong conceptual base but further empirical work is required to

	Lessons learnt from the Typhoon case	Supporting theoretical proposition
1	For effective innovation in a partnered context, the service-based approach and culture should extend across the whole enterprise underpinned by a shared, strategic vision.	4
2	Building a continuous improvement approach linked to a service culture enables innovation within a contract and over successive generations of contracts through iterative learning.	10
3	Frameworks and tools for promoting innovation (e.g. such as an innovation portal) should be considered to encourage enterprise-wide innovation.	1, 2, 7
4	Partnering arrangements within the supply chain should be examined to exploit different potentially innovative arrangements beyond traditional constructs.	4, 7, 8, 9, 10
5	A balanced approach should be applied to the length and review period of PCP contracts to support innovation through the lifecycle of the programme.	5, 8,
6	Investment is made in modelling capabilities and human capability should be retained within organisations so that learning can be exploited across similar projects.	6
7	The boundaries and scope of a PCP contract should be carefully considered within the service-design phase and at contract review points to ensure that future opportunities for innovation can be exploited.	10

Table 2. Lessons learnt from reviewing the theoretical propositions in the context of the UK MoD Typhoon Programme.

further refine, develop and validate a set of guidelines in different sectors to improve the generalisability of the findings. It is intended that a set of guidelines can be incorporated into a process framework to guide a Capitalise Project Management (PCP) project manager through a large-scale and inherently complex procurement programme. This chapter has also illustrated the challenges of innovation within the PCP context which set to remain the dominant form of defence procurement strategy for the foreseeable future.

Author details

Shaun Gee[1], Miles W. Weaver[2]* and Grant MacKerron[2]

*Address all correspondence to: m.weaver@napier.ac.uk

1 Royal Air Force (RAF), British Armed Forces, United Kingdom

2 Edinburgh Napier University Business School, Edinburgh, Scotland

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INTECH

Chapter 10

An Education Towards the Future

Luis Rey

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68320

'(…) we will have computerised devices the size of blood cells and in the 2030s they will go non-invasively into our brains and basically put our neocortex on the cloud'

Ray Kurzweil [1]

Abstract

By the 2030s, we will have computerised devices the size of blood cells that will put our neocortex on the cloud. Current 3-year-olds will graduate in 2031. Borders are progressively irrelevant and a global approach is essential. Teachers must prepare their students for a global society of permanent access to varied information and resources: from AI-assisted processing to actions carried out by robots and autonomous vehicles. Four main conditions seem essential: Permanent *updating*: Standards and practices must be constantly revised, exactly like software is and for the same reasons. Collaboration: A multi-faceted approach indispensable to develop high-quality education through combined efforts. Autonomy: Educators see their mission hindered by one reform after another. Governments must allocate the appropriate resources and let professionals do their job. Individualisation: There are endless variations of human brain and capacities. We must serve all that diversity: it is a duty towards each individual and a benefit to humanity. The chapter will illustrate four eras of knowledge through human history. It will analyse the contributions of the International Baccalaureate. And it will outline the approach at San Francisco de Paula, Sevilla International College, inspired by the International Baccalaureate (IB) and Singularity University.

Keywords: educational innovation, entrepreneurship, international education, technology, learning, knowledge

1. Introduction

The statement above may sound shocking; still, it acquires even more relevance if we consider that current 3-year-old students will graduate in 2031 and today's pregnant women will see their children enter university in 2035 or 2036 (what university may have become by then is a part of the conundrum, too).

Teachers today face the challenge of preparing their students for a world that will bear little similarity with anything we have known so far. A society of global, permanent, instant access to the widest variety of information, and resources—from complex AI-assisted, 'mental' processing to physical actions carried out by robots and autonomous vehicles. Sharpening flint arrow-heads when planning to get a steak for lunch is as relevant to us today as many of the current school activities will be to the students in their near future. It is not only to *future* students but also to *our* youngest students, already in our classrooms; those who will have a full-brain-capacity computer before they start their secondary education, given the pace of technological evolution. The world is accelerating at an increasing rate, as Singularity University (SU) shows [2].

The question, then, relies on defining what should be taught, with specific reference to the role of technology. In order to do so it is important to note first that the changing relevance of knowledge has been accompanied by a transformation of the nature and purpose of knowledge itself.

A parallel, related trend is the progressive irrelevance of borders. Humans travel more often, faster and farther, or, instead, they adopt an even more evolved version of travelling, getting in touch with others through a variety of real-time, long-distance communication means. Growing interconnectedness has an impact on traditional power structures, including nation-states. A global approach is increasingly essential in order to facilitate fruitful co-operation. In this respect the International Baccalaureate (IB) [3] makes a unique contribution. Since its role as educational provider is widely renowned, we will limit ourselves to briefly describing how it operates in order to achieve that universality.

Not just *what* to teach but *how* to do it is also relevant. Pedagogy has traditionally been considered an art. Nowadays we are learning more and more about how the brain works. Many of the best practices that educators have employed through ages are being explained by discoveries in neuroscience, thus confirming their intuition. We can no longer plan our activity without taking into consideration what works and what does not in relation to the brain; some examples will be given below.

A final aspect we will ponder combines *who* and *when* about education. For a long time now it has been established that teachers are no longer the central figure in learning. The student's role has arisen and the individual has acquired ownership (and accountability) of their achievements. But it is not just that, as we will see, the IB has included that what happens *outside the classroom* as one of the *essential elements* of learning [4]. This has enormously interesting implications that we will analyse in a specific section.

That central role of the student has obvious similarities with a ubiquitously praised character, the entrepreneur. In every country the need is felt to have a sufficient number of individuals who combine the creativity, the stamina and the skills needed to give birth to innovative companies and generate wealth. Here again SU provides valuable inspiration. We will describe specific actions that schools can take to stimulate entrepreneurship.

Our last sections will deal with two additional requirements for schools to thrive: continuous professional development and autonomy.

General principles lay foundations, and the devil lies in the detail. We will draw some practical examples from a specific school, San Francisco de Paula-Sevilla International College (SFP-SIC, onwards) [5]. Its involvement with the IB and SU has fostered educational evolution along the lines of a global approach and technology-based innovation.

2. Knowledge as a need: the fourth educational paradigm in history

The human brain has changed little in the last myriad years. Human society, on the contrary, has evolved dramatically, and even more so have human tools. Arguably, this overall process has been enabled by an exponential growth of information and knowledge. Data are information; knowledge is the conscious use of organised information, the result of applying intelligence in order to process of all those data.

According to the accessibility and the amount of knowledge, human history can be divided in four eras—the fourth one having just started.

Knowledge as a privilege: In pre- and ancient history only kings and lords had access to knowledge, whether they were of a secular or a religious nature. We will not take into consideration for this purpose the practical skills that progressively enabled cattle breeding and agriculture, as well as primitive housing or handicrafts. That development was open and widespread; so much more so if compared with worldly administration and the mysteries of health and sickness, leading to the myths about death and an afterlife. The apparatus served the mighty, who received data and controlled knowledge. Accounting records on clay tablets in Mesopotamia appear alongside the Egyptian hieroglyphs of pharaohs and dignitaries on their journey to the underworld.

In the Western world, the Greeks and the Romans created more complex societies. Their systems concerning governance and law enabled an ever increasing participation for citizens, a concept that included just a fraction of humans. In Eastern Asia, China and its examinations for civil service is another example of how knowledge and privileges were two sides of the same coin. From the eighth century onwards, the Arabs promoted learning at the largest scale so far; it was still restricted to the mighty and wealthy, but this latter aspect could be seen as a transition to the following phase. The 400,000 volumes of the Caliphs' library in Muslim Córdoba [6] deeply contrast with the Christian world: the Papal library at the time in Avigon (the sole to own over 2000 volumes) [7], or 300 volumes of two of the greatest Christian booklovers: the Spanish Cardinal Gil de Albornoz (1304–1367) and the French Jean, Duke of Berry (1340–1416).

Knowledge as a luxury: Gutenberg's invention[1] of the printing press with moveable type pieces created a completely new scenario. The Limbourg brothers took 2 years to produce the Very Rich Hours for Jean de Berry; the first printed books, the incunabula, were instead issued by the hundreds; with over 30,000 editions in the second half of the fifteenth century, it can be estimated that 20 million books were published in that period alone [8]. Books became increasingly relevant in commerce. Knowledge became an element of trade for businessmen and entrepreneurs [9]. Erasmus (1466–1536) was in fact the first author ever to live off his books.

Still, the average literacy in Europe was below 10%, with Italy peaking at 15%. In other parts of the world that number would be close to 0%, including Sweden [10]. This means that 90% of the European population had no access to other than practical knowledge. Actually, Michael Faraday (1791–1867) one of the greatest scientists of the nineteenth century, had no formal instruction, and started his adulthood as a book binder; his life would probably have been very different without a very special present he received: a ticket for Davy's lectures at the Royal Institution, the turning point in his career [11].

Education was accessible only to the wealthiest families, who could employ private tutors or send their children to one of the very few schools at the time. Personalised learning was combined with travels that expanded views and experiences, like the Grand Tour that British nobility used to enjoy. Research in the different domains was developed largely by those who could afford employing their time and resources in activities other than earning their living.

It is worth noting that current trends in education underline again these very aspects, which had already been identified by the earliest theorists of pedagogy, very particularly, Johann Heinrich Pestalozzi (1746–1827). In a way we are moving back to the mode of learning that upper classes developed when they did it as a passion.

Knowledge as a right: During the nineteenth century, a joint consequence of the industrial and social revolutions was the progressive development of education. Under the principles of uniformity and universality, educational systems grew; by the late 1880s, a French Minister of Education boasted that he could say what every child was doing in any school, at any moment.

This process went ahead in the twentieth century, resulting in a general rise in literacy levels around the world as well as an increase in university graduates. A professional title, and especially a degree, was a way to improve socioeconomic status and it normally secured a job for life. It could hence be seen as an investment, which is arguably, at least in part, behind the fees increase, especially in the United States: for example, the University of Pennsylvania has almost doubled their fees each decade for the past half century [12].

In spite of that, national educational systems have had two major downsides.

On the one hand, they have been utilised as a means to fulfil political agendas or even to impose a given view of society. At a national scale this has frequently led to political controversies: parties have changed laws and regulations when they have reached power. From a

[1]Or more precisely re-invention, since it had existed in the Eastern world for half a millennium.

global perspective, national (or even regional) approaches are found to favour biased feelings, thus hindering intercultural understanding and co-operation.

On the other hand, every right comes with a duty, and many children have struggled to comply with those uniform regulations established for their achievements. With some well-known exceptions, national systems do not have mechanisms in place to ensure an appropriate degree of individualisation, a research-based practice nor (as we will further elaborate below), a general policy of professional development for educators and school administrators. There ensues a high rate of dropout, particularly among adolescents: the consequence is an unbearable cost in the form of frustration among students, teachers and families and the huge loss of human capital.

Knowledge as a need: In his classical paper, Maslow classified human needs into a hierarchy of five categories: physiological, safety, love, esteem and self-actualisation [13]. He specifically set aside the cognitive needs (pp. 384–385).

More than 70 years have elapsed since Maslow's paper was published. This period has witnessed an unprecedented growth of information and processing capacity. In the mid-sixties, Gordon E. Moore predicted the exponential evolution of microprocessors in price performance, which has been called Moore's Law [14]. Later, in his book *The Singularity is Near*, Ray Kurzweil showed Moore's Law to cover just one phase of an ever-growing calculation power [15].

What Kurzweil calls Law of Accelerating Returns [16] has tremendous implications for human society and thence in the education world. This effect is multiplied by a general increase in life expectancy, which has more than doubled in the period 1913–2015 [17]. Individuals are bound to experience an ever accelerating world and they will need to adapt to it: they will have to learn how to live in a different environment, doing new things which will imply more complex processes. Knowledge, therefore, becomes a basic resource. It is no longer Maslow's cognitive need arisen out of curiosity, but something rather related to safety, if not a truly physiological need, once human beings are augmented through technology.

As already mentioned, these facts have to be taken into account when planning day-to-day teaching activities. And it is a requirement that derives from the main objective of education, i.e. the students; but teachers themselves have the same need. They can now, less than ever, rely on the knowledge they acquired in undergraduate school; they have to adapt and evolve their teaching practice in order to apply new knowledge and cater for their current students' new needs.

3. Education and technology: keys to navigate uncertainty

It is often said that we teachers are very reluctant to change our professional practices. The discussion whether that statement is more or less accurate, or at which extent it might be true or false, goes beyond the scope of this article. We will nonetheless expose some of the reasons that could lead to such a situation, particularly when dealing with technology. An average teacher is

- a single digital immigrant faced by 10–30 digital natives;
- one individual who feels the need to prevent misuse of devices by the rest;
- an adult concerned about students' learning, progress and success in life;
- a university graduate with much experience on methods that have worked well for them, so far;
- a decades-long professional without specific legal requirements to update or get professional development;
- someone who must comply with national regulations on curriculum content.

Of all those factors, the external requirements account for much of the barriers to educational change. They include legal regulations, general examinations and especially their consequences on university admissions. Thence the concern for students' success pointed out above.

And yet, traditional curriculum programmes and pathways continue to lose touch and relevance. Over 10 years ago, the late founder of Apple, Steve Jobs, spoke about that in his world-famous speech at Stanford [18]. More recently, the founder of LinkedIn, Allen Blue, stated that head-hunters do not rely 'so much on degrees but on skills and professional achievements. If they believe that the candidate is prepared enough, it does not matter the degree they show on their profile'; and he adds 'Things have changed, individuals do not need to finish their degrees or get a specific diploma, they may just prove what they can do'. [19]. The 'Big Four' consulting companies (E&Y, PwC, Deloitte and KPMG) agree along the same lines, according to news published some time ago [20]. Of course corporations have a degree of agility and freedom light-years away from the educational world.

That said, we teachers have the responsibility of preparing our students for *their* own future lives. We need to behave like explorers of those new worlds our youth will inhabit, to anticipate their needs and to set the requirements they will have to meet in order to succeed as adults. Doing that means coping with a certain amount of risk. Whether we like it or not, we have to face the challenge of innovating, changing, trying and making mistakes. And we had better learn to enjoy it, as Chesterton said about English weather, 'So we may be perpetually reminded of the indefinite hope that is in doubt itself' [21].

As stated, technology is one of the (exponentially) changing aspects of life. Many professional fields have already been transformed by digitalisation, from flight control to manufacturing. Education has not yet, in spite of the numerous ongoing initiatives; but current students will soon be adults. Isidore of Sevilla was declared patron of the Internet; Heraclitus of Ephesus should have been appointed patron of the new digital world, where you can truly never 'bathe twice in the same river'. We teachers have an unavoidable obligation to get our pupils accustomed to using ever evolving technologies. Technological evolution itself must be factored in. In order to do so we must learn to navigate uncertainty, since only thus will we live up to the expectations placed upon us.

That attitude is much more necessary since we can hardly imagine today how education will be when cognitive augmentation becomes mainstream. When writing these lines augmented

http://dx.doi.org/10.5772/intechopen.68320

reality is embryonic, we are slowly starting to have connected wearables; we only have some elementary measurements of body parameters including brain waves. We need to experiment in order to peep into the unknown. Students are not just understanding, but involved, when they see their teachers strive in order to provide them with better, newer, brighter learning opportunities.

Of course we cannot ignore everything we were teaching. History provides us with wonderful examples of human behaviour, languages enable communications and thinking, whilst philosophy empowers it, music and art foster creativity and enjoyment, maths and science explain how the world works and give us the foundations for further progress. We must choose the relevant examples, make them meaningful, work on them in order to reach true understanding and draw conclusions which can then be extrapolated. We must also decide what we have to discard, like flint arrow-heads lost importance at a given point. Employing the state-of-the-art technologies makes sense only if they enable new approaches and benefits for the students.

In this respect we may be reassured about one point: given the pace of change, the mistakes we will undoubtedly make will be soon overcome by the next step, provided the overall direction is right. In order to guarantee that correctness we must go back to basics such as honesty, commitment, alertness. Honesty to recognise one's own strengths and shortcomings and others' pre-eminence, when due; commitment to one's very best rejecting underperformance of any kind, since early childhood, for them to grow in accountability and self-demand; alertness to detect both errors and unexpected opportunities.

These three fundamental requirements have a corollary. More important than any syllabus or method is the set of values that we model and transmit. In this era of uncertainty the ultimate demand we will have on any individual will be an acceptable way of behaving towards neighbours and nature. Only this will ensure a fruitful collaboration in building a better, fairer society. And this is something a school needs to reflect upon, publicly declare and conform to. In that respect, the International Baccalaureate (see below) can be considered one of the best available options.

4. Some examples of technology applied to classroom activities

Twenty years ago, a group of teenagers produced the first example worldwide of virtual reconstruction of an entire roman city: Italica, 7 km north from Sevilla, the native land of emperors Trajan and Adrian [22]. It started as a Comenius co-operation project. It ended up being presented as a public exhibition at the National Archaeology Museum in Madrid (April through June, 2003) [23].

That was the first large-scale tech project developed at SFP-SIC. It took 6 years, considerable funding and an exceptional degree of flexibility in the circumstances of the leading teacher. Students drew the entire topography of the site and cartography of the building using an early version of AutoCAD®; they also produced realistic renders for the surfaces. Such a project

requires someone with very special characteristics, brilliant in their specific achievements but capable of causing a considerable amount of discomfort within an organisation. This has to be taken into account when choosing to embark on this kind of endeavour, alongside the aforementioned willingness to navigate uncertainty.

Some degree of certainty, however, is needed when managing a school. A strategic plan for technological infrastructure is essential in order to lay the foundations and enable further deployment. Consultation with experts was the choice we made in Sevilla a few years (and a couple of triennial plans) ago. Objectives and their requisites are hence defined and taken into account when budgeting upcoming years.

It is also important having someone who oversees development. Teachers are too busy planning their lessons, assessing students, individualising activities and striving to meet parents' requests more often than not showing a personal involvement that goes far beyond mere professional duties. An overall view and clear directions need to be taken care of. In our case, following SU's inspiration, we appointed Mr Mark Polko as an advisor for Exponential Technologies in Education. In collaboration with our advisor for educational innovation, Ms Pauline Bullen, they have summarised a few examples of the last steps made at our school

- *STEaM lab*: a physical laboratory space we have created in school where over the weekend teams of youngster tackle a real life business challenge, e.g. design furniture for the classroom of the future. Prior learning and knowledge gathering from STEaM domains come together in search of a creative solution. The real life relevance is enhanced when learners meet and share thinking with business professionals working in local community.
- *Sensor technology*: forms an essential part of the science curriculum, whether this be to measure muscle strength to several decimal points of precision or to measure the amount of oxygen produced by plants in parts per million, familiarity with technology as a tool in scientific research is simulating in the classroom, laboratory practice professionally.
- *3D printing*: hands on learning with 3D printing allows learning in science to take place in far greater depth: e.g. an anatomical study of the heart might now include an initial laboratory dissection then move to 3D scanning so that the dissected heart can be labelled in the round using 3D software, copied to a digital portfolio providing the option of creating a physical model.
- In the nursery school children as young as 3 or 4 years of age are helped to grasp complex ideas around emotions with the aid of holograms projected by the teacher using a tablet software.

Early findings have shown us that a willingness to experiment with even the most up to date technologies, some still in stages of early adoption and development, has led to greater engagement with the learning process and especially with complex conceptual thinking. We have seen evidence of increasing autonomy in decision making and a freer reign for creative imagination. Trial and error and persistence become an integral part of the learning process.

In this respect technology is enabling a promising process: the generalisation of that personalised learning that used to be available just to the wealthiest (see section 'education as a luxury').

This is a part of the 6D transformation. Peter Diamandis [24] mentions: digitisation, deception, disruption, dematerialisation, demonetisation and democratisation. Adding a powerful AI-assisted system and the dream of really individualised education will be a fact. Imagine the connected brain and then simply stop dreaming: that will change the rules so dramatically that we cannot extrapolate our current concepts and experiences. That is Kurzweil's *Singularity*.

There is still some way to go, of course. In the nearest future, next steps in this evolution at our school will be: (a) definition of a digital curriculum for students and teachers; (b) redesign of learning spaces; (c) increase of interdisciplinary activities based on problem solving; (d) game and app-design, 3D-printing and coding to become mainstream, integrated into subject curricula.

5. Neuroscience in the classroom

Howard Gardner has mentioned in public [25] his original surprise about the success of his seminal book on multiple intelligences [26]: it was acclaimed mainly by educators, not by psychologists. In retrospect it is not that strange; we try to get the best possible results from our students. That means adjusting our practice to the way the brain works. Thence the growing popularity of neuroscience among teachers, in spite of what the business world calls the entry barrier; brain research generally takes place far from schools and we need specific introductions to its findings.

The following examples of neuroscientific practices applied to the classroom have been provided by Ms María del Carmen del Castillo, a graduate in medicine who teaches at SFP-SIC[2]. It is worth noting that her approaches gained her the top appraisal among the student body in her very first year as a teacher, which is a most unusual achievement.

- To explain how the brain works: The brain has developed strategies to ensure survival, its main function, among them, is reward-seeking. Underline some crucial aspects (breakfast, physical exercise, sleep, self-control, and mood). Induce reflection and building of the self through weekly analysis of a given aspect in their lives (being often late, getting bored, having heartbeat when nervous or in love, feeling tone-deaf).
- To combine curiosity and play through competition for fun [27]: Challenging peer presentations with humour causes positive emotional states (unlike stressful situations). Adrenaline and dopamine foster thirst for learning. Happiness improves insight, interconnection of ideas and more creative responses. [28]. There ensues the need to careful monitoring of the students' emotional state.
- To build a theme upon questions posed by students: After a 30-min introduction, they have to upload questions on a shared document, and they cannot repeat them, so the complexity increases. They find the answers co-operatively.

[2]Ms Castillo teaches a course on Applied Anatomy; she is also Advisor for Wellbeing and Customer Relations in the School

- 'The odd question': The brain generates dopamine (thus guaranteeing learning) in front of the unexpected [29]. Examples such as 'Why is it successful, from an evolutionary perspective, privileging a single organ, thus preventing life in case of damage?' 'Can we consciously control our heart as we would any other muscle?'
- Stimulation of creativity: Creativity is increased by training. The effect is greater in the average individual rather than the highly skilled one, and in adolescents rather than adults [30]. Creative questions followed by scientific explanations foster learning. Examples such as 'How could we relate going shopping and applied anatomy?', 'Art and anatomy', 'Beyond dreams', 'Love, a chemical experience in our brain'.
- Training for an exam: Learning how to relax in order to control anxiety: music, some movement, a moment of relaxation, plus a biscuit after 30 min. Contrary to the usual experience when passing a test, fear is avoided and the exam reinforces learning.
- Doing exercise in every lesson: Physical exercise stimulates the hippocampus, key in explicit memory and learning [31]. It improves brain plasticity and strengthens neuronal connections to favour learning [32]. Blood circulation is increased, augmenting the amount of nutrients that reach neurons; neurogenesis is also fostered [33].
- Transdisciplinary topics: Collaboration between subjects of very different nature, like applied anatomy with mathematics or literature. Example: 'rhetorical devices and anatomy'.
- Artistic activities: Music, drama, handicrafts, humour, creativity, involve different brain regions. Example: dramatising the functions of the nervous system when studying the nervous impulse.

As a final remark in this section, it is worth noting that these techniques support the aforementioned requirements of honesty, commitment and alertness in a very explicit way. Honesty is ensured through enhanced co-operation, friendly challenge in public, a sense of community; commitment is increased thanks to enjoyment and purpose; alertness is fostered by the need to make creative contributions to the group.

6. Education for a better world: the International Baccalaureate

It is unlikely that the founders of the IB could imagine the impact they would have half a century later. To begin with, and as its name was meant to indicate, it dealt with the *baccalaureate*, 2 years previous to entering university; furthermore, it was destined to a handful of highly mobile students attending a few international schools around the world. Today the IB offers four programmes, covering the 3–18-year range. They are followed by over a million students, in close to 5000 schools (mainly state schools) established in more than 150 countries.

The uniqueness of the IB arises from three main characteristics

Values: Its holistic approach is intrinsically driven by a deep humanistic approach. This sense of purpose is reflected in the learner profile [34]

- Inquirers
- Knowledgeable

- Thinkers
- Communicators
- Principled
- Open-minded
- Caring
- Risk-takers
- Balanced
- Reflective

Beyond beliefs and personal opinions, which are fully respected by the IB philosophy, there is a genuine emphasis on mutual understanding and peaceful co-operation, as well as on a mindful relationship to the environment. The sentence that 'others, with their differences, can also be right' encompasses much of the IB philosophy and is an urgent need in today's world of fundamentalism, fear and anger. The fact of being a foundation, and hence acting on a non-for-profit basis, allows it to devote all its resources as best serves its aims.

Independence: The IB has no particular link to any organisation, belief or government. Hence it develops its programmes attending only to best practices and research-based advancements.

Co-operative evolution: Through a careful planning, programmes are designed, students are assessed and practices are revised. Educators from all over the world contribute to the best of their knowledge to progress for all.

The IB learner profile is more than an extremely powerful tool to guide any educational review and improvement. It keeps the focus on the main attributes that a well-rounded person needs to develop. A community of such citizens is bound to flourish no matter how much society evolves or technology advances, they will always make the most of what is available.

The global perspective that the IB adopts makes special sense in an interconnected world. Arguably, the most important challenges that society faces today (whether hunger or terrorism) come from a lack of principles and care for the other. The belief that others are wrong whilst we are right paves the way to confrontation and war. Highlighting differences instead of commonalities is a very traditional means of protectionism which is one step away from plain rejection. History is full of examples and the list continues unfortunately to grow.

7. The IB primary years programme (PYP): holistic education 24/7

We have so far dealt with what happens in the classroom. We educators hope that all those things we do will end up having consequences on the world we inhabit, furthermore, *positive* consequences; we hope that students will behave according to those principles and practices we have talked so much about.

Yes, hope we do.

And…?

And little more, actually. We teach our subjects, we test the students on them; unless there is deeper and/or further connection, many schools have almost no clue whether they succeeded beyond the exam. It is often impossible for teachers to know what the student does outside the school, apart from daily homework. (Thank goodness, many would say!)

What students do outside the classroom might seem irrelevant in terms of subject content, only 'might', and not even that as we will see. But it is definitely relevant with regards to values, behaviours and application to real life of what might otherwise be to them nothing but bookish dead content.

As a matter of fact, what a student does at home, on the street and elsewhere *is* learning. Children, adolescents and adults learn through their entire lives admittedly, with varying intensity. A given experience, a single conversation outside formal school setting can be a deterrent or a life-changing stimulus for a student. We just have greater difficulty to measure it. Or rather we had; things have changed now thanks to the Primary Years Programme (PYP) [35].

The PYP has brought many felicities to the educational field. We will mention two which are particularly relevant in the context of this book

Learning is organised in 'Units of inquiry': Students are not *taught* a prescribed curriculum, but fostered in their collaborative research around the broad transdisciplinary theme of study. They have to find and verify sources of information, compare contrasting opinions, defend their own, make choices and come up with a product. They are, in fact, entrepreneurs of their own learning.

The programme is structured around five 'essential elements', only one of which (knowledge) is mainly what we used to call 'content'. Another of those elements is 'action', which stands out as the most innovative part and onto which we would like to focus our attention.

'Action' is the *subsequent* result of the educational process. It is what the student actually *does* because of the insight they have gained through the acquired learnings. There ensues that action has to be assessed through evidence, i.e. the child has to be seen or heard doing something that proves their learning. Seen or heard by whom? The answer is obvious: mainly by their parents (or close adults).

Involving parents in assessment implies, on the one hand, a few challenges. One needs to ensure that they understand what is required; also, busy parents are not always inclined to participation; a mechanism has to be created to facilitate gathering contributions; and they have to be objective, so that children do not get the message that 'making up' reality is acceptable.

But, on the other hand, it has enormous benefits. It makes parents aware of what their child will do at school in the following weeks; it catalyses conversations about it at home and outdoors, enhancing learning; it helps the students create links between what happens in the classroom and the outside world; it makes students realise that what they do and say outside the school has an educational value and it makes families proud that their children are learning 'so much' in line with expectations.

Here are some literal translations of evidences given by parents in Sevilla

- (He) identifies his entire body, right and left. He knows that boys have penis and girls have vulva. He can say what each part of his body is for. He identifies the different members in a family and he recognises that each person has their own family. He is aware of having a roundish face (after the song). He is happy to bear a resemblance to his father. And he knows that eating a lot of lettuce will grow him big as his cousin (X) [3-year-old].
- We have observed how he is aware of what he is learning, once outside the classroom, and he can see it and apply it on a daily basis. When we are all together, he names each member of the family and he knows who constitute it. What his role is, how to contribute and that he can help. Trees that he sees every day and he asks whether they are perennial or deciduous. Rain, how and rubbish, why it is generated and how we dispose of it (4-year-old).
- (He) has gone over responsibility and change, the key concepts of this unit of enquiry, outside the school. He recycles properly all the objects he uses, he is aware that plants need water and how sustainable farming works. He has improved considerably, having become more tolerant in his interactions with his younger brother. He is very much striving to overcome his frustration when he doesn't manage to communicate successfully (5-year-old).
- We have noticed the varied vocabulary he has acquired on a diversity of topics: weather, clothing, seasons, landscapes, geography. His comments on climate have been especially striking, he seems to be the weatherman. And he loves talking about clouds and the colours in the morning sky, the weather in other parts of the world, how people are likely to dress and how animals live in heat and cold. He also loves nature books (6-year-old).
- (He) has started to show interest about TV news during these weeks. He has always enjoyed nature documentaries but now he seems to wonder about other topics. He has astonished us with some very infrequent questions, like who was the narrator of the plot in a novel about which we were talking to him. He has enjoyed doing some school activities, like finding out the biography of the inventor of TV. He felt very motivated to do it well (9-year-old).

All these quotations are taken from individual students assessment reports. It is easy to imagine the tremendous stimulus they are to the students. Not just they have the proof that their learning means something to their parents, but they see that what they do outside the classroom is collected alongside the results they obtain at school. Furthermore, they can find the coherence between those apparently independent worlds.

If we want students to be really engaged, we need to make them value what they learn and do: nothing better than a shared, connected and co-ordinated partnership between parents and teachers. We are all educators, and there is no non-educating time. The sooner we become aware of it, the better: better for our youth, and also for ourselves, since they will be the doctors who cure us, the engineers who design our services and the lawyers who defend us once we retire.

8. Technology-enabled: IB middle years programme on-screen assessment

The Middle Years Programme (MYP) is designed for students in the range 11–16 years old. As it is the case with the PYP, it does not prescribe a syllabus. It is instead defined in terms of skills and competencies that the students have to develop.

In 2015, the IB launched its pilot for an on-screen (not online) assessment. It went mainstream in 2016. This is the first time ever that an on-screen examination has been offered worldwide.

There are a few reasons why this is a high-interest initiative

- The test is specifically designed to assess competencies. The absence of a written curriculum makes it especially versatile and appropriate to serve today's changing needs.
- A global benchmark. Schools carefully analyse the detailed reports provided by the IB on the results. These data include comparisons with the predicted grades and the world averages. They become tools for improvement.
- The MYP is being seen with increasing interest as a means to meet the objectives set by most international measurements, like PISA. A recent study conducted in Spain by an educational research team [36] showed its superiority to the national regulation [37]. Actually, the City Council in Sevilla has unanimously agreed to implement the MYP in five state schools, including some in deprived areas. The venture will start in 2017, being the first of its kind in Europe.
- Students are increasingly accustomed to working on computers. A pen-and-paper exam is becoming alien to them. Also, applying their learning to an unknown situation is at the same time a challenge and a stimulus.

The IB is aware that not everyone yet has broadband connection to the Internet. That is the reason for the exam not being online. It poses some extra organisational requirements, in terms of staff and time to upload the tests.

The main achievement, though, is having designed a cutting-edge assessment, independent from the specific syllabus and hence applicable all over the world. It is a significant step towards an individualised and simultaneously comparable society.

9. The exponential entrepreneurship programme

Among the variety of courses and events that SU organises, the nine-week Global Solutions Programme (GSP) stands out as one of the most unique and sought after professional (and personal) development offers in the world [38]. Around one out of 100 applicants are accepted at the NASA-based campus to work in ideas related to 12 global grand challenges [39]. In words of co-founder Peter Diamandis, ‘the world's biggest problems are also the biggest business opportunities’.

The GSP at SU is focused on promoting entrepreneurship applying digital (exponential) technologies. The challenging goal they present to participants is ‘how will you improve the lives

of a billion people in 10 years'. A few dozen innovative companies have been created out of GSP team projects.

Creativity, as stated above, can be developed. Entrepreneurship is creativity applied to business. And the entire world needs individuals who create wealth and employment whilst making the future look brighter, happier, healthier, in every domain.

Why should we then wait until university in order to foster and grow this thinking mode? An adaptation to teenagers can be done, as shown by the Exponential Entrepreneurship Programme®. This is an initiative of Fundación Goñi y Rey [40] and SFP-SIC in collaboration with the SingularityU Sevilla chapter [41]. The programme had its first edition in the academic year 2015–2016.

In a way, it is a natural extension of the MYP personal project [42]. Students gather in teams, to choose a real-life problem or opportunity related to one of the global grand challenges. They generate a business idea, work up a development plan and outline its potential for investment and incorporation as a company.

There are some lessons learned from that pilot, which have been taken into account when planning the second edition

- Although many students find it challenging at start, most (if not all) become really engaged and come up with interesting ideas which they shape as an entrepreneurship project.
- At the end of the year they feel confident enough about their progress to do public presentations of their prospect businesses in front of potential investors and answer questions [43].
- Alongside the refining of their ideas, an individual insight process takes place whereby team members define their roles. They find which aspect of the business world appeals the most to each one and they start to think seriously about their future.
- Last, but not least, this kind of course is better coached by individuals with previous experience in the innovation and business world. The present case has had the invaluable co-operation of Mr Jaime Aranda and Ms Teresa Suárez, the extremely active founders of a business and innovation association called SevillaUp [44].

In conclusion, we can state without doubt that pre-university students do have the willingness and the capacity to get involved in the business generation process. Success stories (or *Unicorns*, as investors call them) are always difficult to find. But, as Picasso put it, 'may inspiration find you at work'.

10. Teachers and school leaders as lifelong learners

We cannot stress it enough; continuous professional development is as essential as careful planning when aiming to provide quality education which in turn is inseparable from *updated* education. Also, on the one hand, it is a way to model the attitudes we demand from students; on the other hand, it prevents burning out through providing newer and different challenges.

The right mind-set needs to be infused in the organisation. Time has to be devoted. Budget must be allocated. Involvement and lead from senior and middle managers are essential.

Best-practice sharing, lesson observation, collaborative planning are extremely powerful tools. It is well known that one can find deeper differences within a given school than between two different ones. Appropriate, constructive feedback should be combined with improvement objectives.

At SFP-SIC we have designed a complex system of performance-related pay, with clear and objective indicators. We use it as a way to define the important extra aspects to develop, once full compliance with the high-standards requirements has been met. They include research and co-operation projects, external results (when applicable), parents' and students' surveys, line-manager appraisal. For middle managers, indicators are their team's satisfaction results, overall students' performance, homogeneity of group results throughout the department or section, among others. In no case we use indicators that can be altered by the individual who is being assessed, an obvious example would be the marks given to one's own students. Depending on the year it has even reached a 15% supplement to a given teacher's annual salary.

In addition to the in-house courses, a few stand out as really interesting

- The IB offers a high number of workshops, seminars and conferences. Some are specifically directed to teaching the IB programmes (categories 1 and 2). Others, instead, focus on specialised aspects of general good teaching and learning practice (category 3). A yearly calendar is published on the IB website. They are open to general public registration. Online courses are also available [45].
- Especially relevant to the purpose of this chapter is the Future of Learning Institute organised by the Harvard Graduate School of Education [46]. It starts in late July every year.
- SU has 5-day executive programmes [47] that provide a sufficiently deep insight on technological evolution, as well as a unique experience at their NASA-based headquarters in Silicon Valley. An easier alternative, also mind-blowing though shallower, are their Summits, held in different parts of the world. The Singularity University Summit Spain 2015, [48] that SFP-SIC co-organised, was attended by our entire teaching body as well as over 100 students. The voice was spread and other summits around the world have also received teenager participants.
- Learning and the brain is a series of events privately organised in the US [49]. Many of the leading neuroscientists present in each edition, with an approach that is often specifically directed to educators.
- Finally, the Educational Collaborative for International Schools (ECIS) also offers a number of conferences [50]. The annual executive conference is a benchmark for school leaders and administrators, positions that do not always receive the attention and training needed for an entire school to operate successfully.

When planning professional development, very specific attention needs to be paid to school managers. In most cases middle and senior leaders were trained as teachers: they are often

recruited among the most brilliant ones. But leading adults is a totally different job. Other skills are needed and a completely new set of responsibilities must be faced. An extensive training programme has to be designed and offered to facilitate successful and efficient management.

One cannot overstate the importance of middle managers in a school. Senior leaders may come up with the best ideas: they will fail pitifully if they lack the appropriate collaborators to implement them. Hence, one of the main tasks of a head is to ensure the effective promotion and development of staff.

All this applies to entire countries or regions. A new educational law is meaningless if it is not supported by an intensive training programme. No one would be crazy enough to change the flight-control system without having controllers duly trained: but it is everyday practice dictating a law and waiting for it to have some kind of miraculous effect on its own. Policy makers think they can change classroom practice this way. They cannot. Even more, they *should not*. Education must evolve on a *continuous cycle of reflection and improvement* and not just when a given minister believes it to be appropriate. There, again, the IB is exemplary.

11. Independence, funding: independent funding

All the examples and initiatives above arise, at the very beginning, from the capacity to make the most appropriate choices for the school, which means first and foremost, what suits the students best. Curriculum design, school ethos, human resources policy, organisation and priorities are crucial variables that require deep reflection and careful management.

The degree of independence varies from one system to another and, within a given one, according to the funding entity. The larger the freedom, the deeper the educational accountability and the higher the chances of developing an interesting project, provided, of course, that honesty, commitment and alertness pervade the school operation.

Being a vocational educator implies devoting one's time, energy and imagination to help the world improve. It is a very long-term process, given the turnover rate: a generation takes 20–30 years to blossom—up to 15 of which are often spent at pre-university school. Therefore, one needs to plan things far in advance, as said at the beginning. In trying to do so, one finds nothing more harmful than the short-time reasons behind many of the political moves. Thence the importance of school independence from the political and governmental debates.

There also ensues the need to invest. The process of nurturing the human brain, the most complex structure in known universe, requires resources. It brings far higher benefits to humanity than bombing people, though at longer terms. When considering who wants bombs being dropped the clear answer is: certainly, not those being hit. We need to improve education in order to make a more peaceful world and not just mathematics and language, but ethics and related values.

Again, schools must be able to operate towards those goals. Citizens will eventually manage to free education from short-sighted political-party policies, at least we hope so. In the meanwhile

educators' professional audacity and parents' financial sacrifice will be the only way to guarantee that students receive the stimuli they need for their future to be brighter.

12. Conclusion

Throughout this chapter we have tried to outline the main features that education today needs to have in order to prepare students for the future. We have illustrated them with a few examples, but much more can be done.

At end of the day, in the time when knowledge was a luxury, education involved a preceptor—a full-time, adapted, private teacher, personal trainer. A relatively similar situation might end up being available to all when AI becomes mainstream.

To summarise, four main requirements seem essential to enable a way forward:

- Permanent *updating*: Standards and practices must be constantly revised, exactly like software is and for the exact same reasons. Professional development on neuroscientific progress, technology, management, social change, associated risks. All those aspects are crucial to make educational approach to evolve as society needs. Teaching is an enormously absorbing task. Myriad aspects require one's attention, from the individual student's well-being to planning class activities. Educational administrators need to manage time and resources in order to support agile response to changing times. In a world of lifelong learning those who prepare learners must be the first to stay at the cutting edge.
- Collaboration: All human progress has taken place through further contributions to a shared body of knowledge. The role of each individual is crucial, but since the Greeks we are also aware of the importance of discussion and co-operative advancement. Science showed long ago the power of multi-disciplinary teams. On the one hand, globalisation makes a multi-faceted approach indispensable for individuals to learn about sensitivities and diversity. On the other hand, a high-quality education has increasing complexity and variety: it can only be developed with the combined efforts of educators around the world. Pedagogy is a science, with all the attributes that science has.
- Autonomy: There would be a civil revolt if a government were to dictate the medical treatment of a disease based on their political beliefs; the same if one-fifth of those sent to a hospital died systematically. Nevertheless, educators around the world see their mission hindered by one reform after another, according to the creeds of the party in power; and in some regions an appalling proportion of students drop out of education. Education is to society what medicine is to the individual. A wrong treatment may kill the individual. Poor education may kill the future of an entire society. In so far as it happens long term, it is more difficult to detect; often those who caused it are no longer in power when the irreparable effects become obvious. As representatives of their people, governments do have the right and the obligation to set the minimum requirements for the progress of society which has little to do with the results of a given test; they must allocate the appropriate resources which citizens contribute through taxation; and they must allow professionals the autonomy to do their job.

- Individualisation: Philip of Macedonia made his way into history for having secured the best available education for his child. He called Aristotle and the investment definitely paid off, according to the standards of the time: Alexander 'the Great', the most widely acclaimed emperor ever. Noblemen used to follow his example and enrolled the best preceptors for their offspring. Industrialisation introduced standardised tests, focused on the easiest items to measure. Current knowledge has uncovered the endless variations of human brain and capacities. Each one's contributions are unique, like one's needs. We must strive in order to serve all that diversity: it is a duty towards each individual; it is in benefit of the entire humanity.

Definitely, exciting times to be in education!

Author details

Luis Rey[1,2,3]

Address all correspondence to: director@sfpaula.com

1 Sevilla International College, San Francisco de Paula, Sevilla, Spain

2 International Baccalaureate Organisation, Switzerland

3 SingularityU Sevilla, Sevilla, Spain

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INTECH

Chapter 11

Management of Entrepreneurship Projects from Project-Based Learning: Coworking StartUPS Project at Universidad Politécnica Salesiana (Salesian Polytechnic University), Ecuador

Juan Pablo Salgado Guerrero,
Ignacio de los Ríos Carmenado and
Miriam López González

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68492

Abstract

In the engineering education field, there is an identified need of innovative learning and teaching methods to improve students' entrepreneurship competencies in order to make connections between engineering and real society. This chapter addresses a management strategy for entrepreneurship projects in the university framework. It is the result of a cooperative experience from the Research Groups of Salesian Polytechnic University (UPS), the Technical University of Madrid (UPM), and the collaboration of other external entities. The management strategy is applied to undergraduate and postgraduate programs at UPS and has been called Coworking StartUPS Project. The research method is made up of different teaching methodologies—project-based learning, coworking, case studies—and different activities in and out of the university. The data were collected from students who were enrolled in the Coworking StartUPS Project, along with students and researchers from the three University Branch Campuses in the cities of Cuenca, Quito, and Guayaquil. The Coworking StartUPS Project links teaching & research activities with entrepreneurship are founded in cooperation and interaction, offering multiple possibilities for entrepreneurial skills development in the international context. This preprofessional experience promotes students to integrate the knowledge they have learnt and apply the new knowledge in an entrepreneurship project.

Keywords: entrepreneurship, innovation, project management, competency-based approach

1. Introduction

Entrepreneurship is an old but continually emerging field that attracts the attention of academics, policy makers, and practitioners in various fields of economics, finance, management, and sociology [1]. In recent decades, it has been studied as a catalyst for development and a key factor for achieving economic growth, job creation, and increased productivity [2, 3]. Nowadays, the theory of entrepreneurship has expanded to new concepts where entrepreneurship is not only considered for its concerns for business success and benefits but also for subjective welfare and noneconomic well-being [4] which people can achieve through their capabilities [5]. Policy makers seek to promote entrepreneurship at a macrolevel through education on the basis that greater understanding is likely to create more adept entrepreneurs [6]. In this sense, there is an ongoing debate, related to academia, about whether we can actually teach students to be entrepreneurs [7]. The great increase in the number of entrepreneurship education programs in universities suggests that the general consensus is that entrepreneurship can be taught [8] Higher education institutions (HEIs) are expected to play a key role in promoting entrepreneurship, and entrepreneurship-training programs are spreading rapidly in universities and colleges throughout the world [9–11]. Although much has been written about this topic, universities around the world are still searching for new methods and practical tools, in a way that emphasizes "learning by doing," which should accelerate student mastery [12]. Furthermore, as societies become more entrepreneurial, work is becoming more modularized and structured in project work. In other words, work will depend largely on shorter term engagements and will be specific to a particular project that connects the supply and demand of labor, showing that our societies are becoming more entrepreneurial [13, 14]. In addition, current and rapid changes in society require new methods to develop a wide range of skills or competencies. Related to engineers, it should be a skill set outside of their traditional domain to address the needs of modern organizations. Our societies require more entrepreneurial professional engineers with good teamwork, communication, project management, and financial skills, along with proficiency in their core engineering skills [15]. Abiding by this objective, entrepreneurship project management is one of the topics which is taught in several disciplines. Thus, teaching and learning was identified as a major theme in the international debate on rethinking project management [16, 17]. Understanding the student experience will enable institutions of learning to address pedagogic and education factors within project management to be more effective in the future [18].

In this context, this chapter presents an entire entrepreneurship-training strategy, using a competency-based approach from project-based learning (PBL). The entrepreneurship-training strategy, called *Coworking StartUPS Project*, is the result of cooperation between Salesian Polytechnic University (UPS), a private University in Ecuador, through the Educational Innovation Group, GIE-Project, and Technical University of Madrid (UPM), Spain, through the Gesplan research group. The methodology is based in the Working with People (WWP) model [19–21] and integrates the competencies of project management, according to the International Project Management Association (IPMA) [22, 23], and the scientific foundations of project-based learning (PBL) [24, 25]. The data were collected from 827 students who were enrolled in the Coworking StartUPS Project and 79 teachers and researchers who were involved, all belonging to the 3 UPS University Branch Campuses: Cuenca, Quito, and Guayaquil. This management strategy covers two different aspects: first, "young entrepreneurs" and second,

http://dx.doi.org/10.5772/intechopen.68492

the integration of technical, behavioral and contextual project management competencies in UPS students in real situations of innovative and entrepreneurship projects. The success of this approach is the belief that students are not passive recipients of knowledge, but should become engaged in an experience (entrepreneurship project management) with real content. As a result of the entrepreneurship strategy, 103 ideas were identified, of which 48 are currently ongoing projects so far.

2. Experience of educational innovation in UPM: "project-based learning"

The creation of the European Higher Education Area (EHEA) has offered European universities the opportunity to improve and restructure strategic lines of education. In the context of Technical University of Madrid (UPM), this has resulted in a strategy to foster relations between research and educational activities through its Institutional Quality Program, approved in May 2005 by the Government Council of UPM. Within this program, a General Teaching Quality Plan —with the educational innovation or Educational Innovation Group (EIG)-Project experience as a central strategic element—is developed. This experience is carried out through the creation of Educational Innovation Groups [26] and the launching of a call of Educational Innovation Projects. Several Educational Innovation Groups have been approved and consolidated since then. The members of these groups present background, experience, training, and a project for the future of sufficient consistency in topics related to educational innovation, such as engineering and project management.

Thus, the EIG-Project starts at UPM with the main objective of conceiving a new dimension based on projects adapted to generate the development of competencies and early professional experiences. Project-based learning (PBL) [24, 25, 27] is used by the EIG-Project as the most powerful method to obtain effective competency-based teaching [28–30]. According to trends in psychology of knowledge, PBL is based on the thought that humans create new knowledge on the basis of what we know [31] and we have experienced previously, what is achieved through interaction and active participation with others.

3. "Coworking StartUPS Project" as a part of UPS's strategy

The entrepreneurship strategy presented in this chapter is part of UPS's strategy, which is oriented toward the need of becoming an innovative and research university. As expressed in the document "*Cuaderno de reflexión universitaria 14 Hacia una comunidad académica que investigación*"[32], as a part of the teaching component, innovation, and entrepreneurship are considered as "levers of change" with the strategy and potential to guide new institutional policies, and whose progressive implementation will allow an effective transformation of UPS in the short and medium term.

In 2015, a series of agreements to integrate the culture of "project work" were adopted in order to develop measures to promote innovation in UPS. This process of change has been accompanied by training for UPS agents (teachers and students) to develop a culture of

entrepreneurship and their project management competencies. The idea of fostering entrepreneurship from project management competencies was aimed at creating an Innovation and Entrepreneurship Ecosystem (Coworking StartUPS Project). This strategy is part of the implementation processes of Research Groups and Educational Innovation Groups (EIG) at UPS, jointly promoting Research and Educational Innovation, based on the participation of students and teachers who are competent for Project Management.

4. Coworking project methodology

The methodology used in this experience is based on the Working with People (WWP) model. This model aims to build up innovation and learning dynamics based on projects by connecting expert and experienced knowledge. At the same time, values are being incorporated to the people who are involved in this process and participate and develop with the entrepreneurship projects [19–21]. This WWP process has been applied in numerous innovation projects by working with university agents (students and teachers) and society involved in the design and implementation of projects [33–35]. This methodological framework integrates project-based learning (PBL) processes for the building of entrepreneurship initiatives considering three dimensions of competencies: social-ethical, technical-entrepreneurial, and political-contextual, based on the standards of the International Project Management Association [22, 23] and ISO 21500 [36].

From the socio-ethical component, the personal competencies (behaviors, attitudes, and values) of students and teachers that interact along the innovation processes necessary for the entrepreneurship initiatives are considered. In this sense, Coworking StartUPS Project actions developed competencies in relation to creativity, leadership, teamwork, communication, and negotiation among others.

The technical-entrepreneurial component integrates the competencies for the formulation and evaluation of entrepreneurship projects, such as technical and business instruments that allow the generation of goods and services for society. From this component, technical and entrepreneurial competencies and tools are provided in order to support entrepreneurs in the process of defining their projects, products, or services, identifying their clients and their business model.

The political-contextual component allows entrepreneurship projects to adapt to the needs of society in the contexts in which they work, in this case to achieve university-society relations. Thus, the contextual competencies necessary for the management of the projects, the knowledge of the organizations, and the implementation of projects are developed.

Finally, an integrating component is social learning, oriented to developing a network of entrepreneurship among the university's entrepreneurs, through spaces of learning, discussion, and reflection generated in different areas of the university with the participation of faculties and courses. This component is mainly undertaken by the Entrepreneurship Centers, or Coworking spaces, which serve as support to the entrepreneur and allow their interaction. This way they find the physical space of work and the necessary advice so that their ideas and learning are connected with the national and international markets. This connects the UPS entrepreneurship ecosystem with the local, national, and international level.

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5. Coworking project implementation: findings and results

The Coworking StartUPS Project was introduced in 2015 in a UPS Educational Innovation strategy as a reference point of a new perspective for developing entrepreneurship competencies, according to IPMA [22, 23], for project management teaching in engineering higher education [37] and links Teaching & Research.

The implementation model of the strategy and the relationships that are established from the contextual point of view is summarized in **Figure 1**. Within this implementation model, the creation of coworking spaces has resulted in a series of facilities and spaces that can be used in this and future initiatives promoted by the university.

The implementation of the phases carried out and the results are shown in the next section.

5.1. Phase I: Community Creation and competencies development for entrepreneurship project management: PBL process

Mission, vision, and values of UPS guide the Governance Strategy and the management system. People start projects without looking at a map first and without the competence to design, manage, and evaluate a project. As a result, they waste time and money, experience frustration, disappoint clients, and lose businesses.

Therefore, to foster the entrepreneurial culture and ensure the success of projects, in this first phase, the governance strategy integrates actions for the Community Creation and a teaching process for the development of project management competencies. This process is based

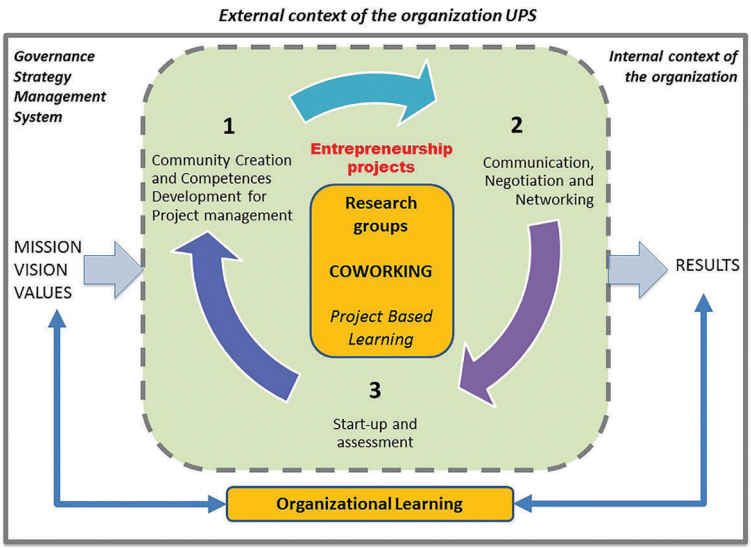

Figure 1. Outline of "Coworking StartUPS Project" strategy at UPS. *Source*: Gesplan Research Group and UPS.

in the PBL method, it consists of students in small groups who plan, design, and evaluate an entrepreneurship project that meets real needs for a real client—private or public—coordinated by professors who teach project management Competencies (**Figure 2a**, **b**). In this process of approximation to reality, group activities and interactive workshops are carried out in class for the course of project management using active methods [38] to get the direct involvement of students, similar to a real entrepreneurship project.

In these sessions, the teacher acts as a mentor for the tasks performed by the students and as a learning incentive for active absorption of knowledge. The active method of learning by doing [38–40] is presented in the area of project management and entrepreneurship with special relevance, great potential for originality, and development of creativity that can be fully assembled with scientific and technical knowledge. At the end of this training period, different groups of students (also with professors of research groups) must present and defend their feasibility study (Business project) of entrepreneurship projects with teachers and managers involved.

The knowledge of 46 competence elements necessary for entrepreneurship project management is integrated in this PBL process. Although there is more relevance for technical competence essential for project management, some contextual and behavioral competence elements are also considered. In PBL, which has been defined as "early professional experience" [24], which is part of the idea of "learning by doing," learning from reality. Participation in entrepreneurship projects with real content, which respond to real needs, give students the opportunity to leave the classroom, come into contact with external agents to solve real problems, and seize business opportunities [24]. This characteristic is a dynamic element for the educational process where students learn to see themselves as entrepreneurs, working cooperatively with research groups.

PBL consists of a small team (students and professors from research groups) working on an entrepreneurship project. According to IPMA, teamwork is a group of individuals who cooperate and interact among them in a coordinated manner, being responsible for the development of a project or activity achieving the expected outcomes [22, 23]. Coworking is teamwork

Figure 2. (a) and (b) Project management course: competencies development.

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learning processes that respond to a logical structure. According to methodological phases for formulation process, the following stages could be considered for entrepreneurship projects: initiation, planning, execution, monitoring control, and closure. Each stage contributes to the overall success of the project with the same importance. Within each stage, there is a distinct set of activities that lead the process from the first idea to its conclusion. The development of the project course is basically a learning process designed to teach methodologies, which have an organic process where phases and concepts are linked to each other. This logical process follows the subsequent phases [41] (**Figure 3**).

Within the preparation for the project formulation phase (1), three sections can be distinguished: (i) establishment of the project team and the necessary resources (administrative, logistics, and financial), (ii) terms of reference, and (iii) activities implementation plan according to schedule at this stage. This phase could be the most important in the sense that it establishes the conditions or terms of reference in which the project will be carried out. Therefore, it is necessary to carry it out successfully since, otherwise, the project could have a high probability of failure. At this stage, the scope of the project is decided, the business plan is defined and the stakeholder's expectations are established, so the time spent on each of these steps will help increase the probability of success.

Subsequently, in the analysis and diagnosis phase (2), students roleplay different aspects of the specific situation of the project team. During this phase, students are trained in research techniques and analysis for the collection and examination of data (analysis) and qualitative and quantitative techniques in order to identify the main causes of the situation (diagnosis). At the end of

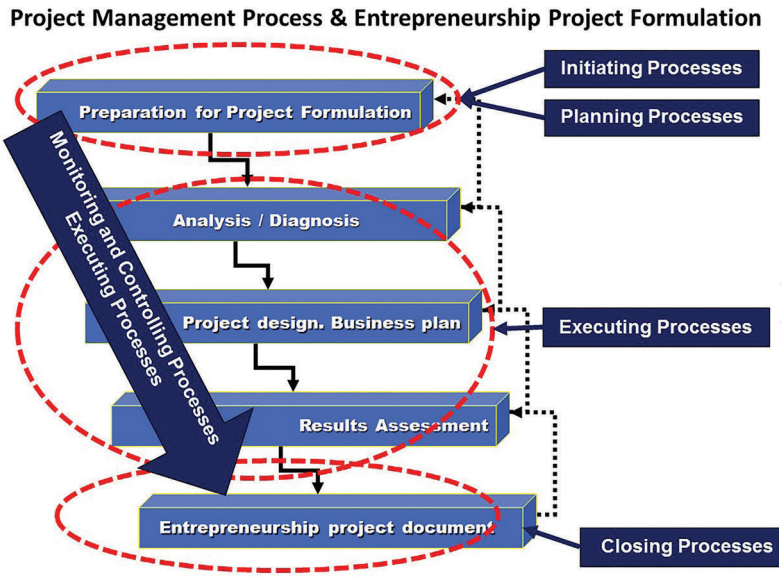

Figure 3. Project phases course with the PBL approach and project management process.

this phase, all teams must identify possible proposals to improve the current situation and solve uncertainties, as well as have understood what needs to be done in the entrepreneurship project.

Once the teams have collected the conclusions obtained in the analysis and diagnosis phases, the project design phase (3) is proceeded in order to develop, in a more precise and detailed way, the investment proposal integrated in the Business Plan. Throughout this phase, students are provided with training in design and planning tools to deal with technical specifications of the project components. The nature of the project will determine the specific level of detail, however, all teams must verify the feasibility of products, systems, and technologies, as well as defining the timetable, estimating costs and benefits, project organization, and resource management.

Once the project design phase is documented and completed, the multi-criteria assessment phase (4) is conducted to examine the effects and impacts of future project implementation. These results will provide a reference to guide the economic, social, technological, and environmental viability of the project. The elements of competence that are specifically addressed in this phase are costs and finances, business, resources, ethics and security, and environment.

The final phase—project documentation (5)—includes results and final reports made by students. At this stage, it is important to adequately communicate the relevant information to teachers and other external agents, so the ability to synthesize is essential. In this phase, external professional-tutors of UPM evaluate and issue opinions based on the entrepreneurship project documents and students' competencies.

Entrepreneurship projects are chosen due to the existence of business opportunities, society needs, and situations that need to be improved, as well as from the competence elements from the three business project dimensions (technical, contextual, and behavioral).

The main results of this phase were the participation of 827 students and 79 teachers who were informed about the project and the identification of 103 projects with 32 teachers who were involved. Many of these projects' scope changes, some disappear, and others are combined. The projects that were launched are based on a wide range of topics, including the development of industrial prototypes, computer applications, educational gadgets, etc. They all have innovation in common in order to add value to the entrepreneurship projects.

Subsequent to the official launch of the project, in the first month, there were visits to different classrooms, and university studies were also conducted. The visits involved a creativity workshop and the invitation to be part of the ecosystem.

There were workshops with teachers and meetings with different groups of the university such as the Entrepreneurs Club, the Robotics Club, Research groups, the Students federation, and others.

All the activities carried out during this phase were essential for creating a community. The main objectives of the community are to create a link between students and teachers, motivate them to be part of this ecosystem of innovation through a personal explanation of the project; share tools of accelerated entrepreneurship; identify projects that are already undertaking at the prototype level; and initiate the generation of networks with entrepreneurs at UPS.

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5.2. Phase II: building up of coworking spaces

This phase consists of the creation of Entrepreneurship Centers or coworking spaces that support entrepreneurs and allow their interaction, here they find the physical space and the advice needed so that their ideas are connected with the national and international markets.

There are four coworking spaces on a national level (**Figure 4**): Cuenca, Guayaquil, Quito "Girón" campus and Quito "Sur" campus, managed by the Head of research. These spaces can be used by current or former UPS students, with no age limit, who are committed to learning, sharing, and undertaking innovation projects. In the case of people from other institutions, they must take part in an entrepreneurial project from this institution. In these spaces, there are activities such as workshops, mentoring, training, business development, recreation activities, fairs, networking integration, brainstorming, research, innovation, and activities that add value to the ecosystem and the student.

Currently, there are *48 projects* that are being worked on constantly, 62 intermittently. There is an average of 80 people per month, who visit the different spaces on a national level to learn what it is and how they can become a part of it.

The creation of coworking spaces, as part of the strategy, has allowed the creation of permanent facilities that may continue to be used by students and researchers of the University.

5.3. Phase III: communication, negotiation, and networking

In a third phase of the Coworking StartUPS Project, within the same PBL approach, as part of specialized workshops (Bootcamp and Campus Party), students complete a new cooperative learning process aimed to deepen the enterprise culture and complexity of business management. For these coworking activities, students use their own projects, previously discussed

Figure 4. Coworking spaces: (a) Cuenca, (b) Guayaquil, (c) Quito-Girón.

and designed by their own teams. These new analyses are done in work teams with cooperative learning. With the results, each team prepares a report that is communicated orally and is the basis for the discussion of learning, joint discussions, and exchanges. The participation of new stakeholders (entrepreneurs and research groups) in these workshops increases innovation and learning, establishing interdependencies and links between teaching & research activities with entrepreneurship and professional background, offering multiple possibilities for entrepreneur skills development in the international context.

In this third phase, the PBL methodology evolved through collaboration agreements between UPS and public and private stakeholders for the implementation of entrepreneurship projects. These new cooperation agreements have been the basis for consolidating an approach to PBL that has been developed to adapt the methodological issues in teaching real problems. The success of this approach is the belief that students are not passive recipients of knowledge, but should become engaged in an experience (entrepreneur project management) with real content.

5.3.1. Campus Party

About 60 students from the Salesian Polytechnic University's branch campuses in Cuenca, Quito and Guayaquil attended the Campus Party of the "*Mitad del Mundo CEMEXPO*" Convention Center for 4 days (**Figure 5**). The students had the opportunity to enrich themselves with content suitable for the development of their entrepreneurship projects through 260 hours of content, 12 hours of master content, 30 of workshops, and 18 of participatory forums. In addition to attending the conferences, students presented their projects to visitors, students from other universities, journalists, headhunters, authorities, ministers, councilors, and the vice president of the Republic of Ecuador. Furthermore, it generated a community between students and teachers, who shared activities and dynamics that allowed them to integrate.

Figure 5. Campus Party of the Mitad del Mundo CEMEXPO.

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The objectives of this activity are to exploit creativity focused on production, technology, human talent, futuristic vision, and student entrepreneurship; provide students with an opportunity to present their projects; create links between students from different universities and create an interdisciplinary community.

The main results of the Campus Party are students presented their projects to visitors with different profiles (**Figure 6**); it was possible to integrate students from all three Campuses; links were generated between authorities, professors, and students; and students acquired knowledge during the forums and talks.

5.3.2. Bootcamps: accelerated entrepreneurship camp

A Bootcamp or accelerated entrepreneurship camp is defined as a program that seeks to transfer tools to innovate and develop entrepreneurial skills. A group of entrepreneurs, who meet for a few days, present an idea that will later be a prototype. This should be tested through the use of several empirical tools. Finally, a business model will be tested that allows that prototype to reach a market in a sustainable way.

That is the idea of Bootcamp, a concept that in the world of entrepreneurs makes sense and allows people who are in a clarifying phase to have concrete projects, quickly take them to practice acquiring knowledge through intense experience. In addition, participants have the opportunity to analyze their own profile of entrepreneur and to generate alliances with other entrepreneurs during the Bootcamp. Challenges are developed and alliances are generated with other entrepreneurs.

To sum up, they are spaces for accelerated learning. Connecting with others allows you to develop creative ideas for solving problems. The figure of the mentor emerges in this model as an individual who connects with the entrepreneurs and accompanies them on their path, not responding to their concerns but helping them to respond to themselves.

Figure 6. Project-idea presentation.

5.3.3. "Science, Technology, and Culture" Bootcamp

In April 2016, the "Science, Technology and Culture" Bootcamp' took place in the presence of 24 national and international mentors, plus 100 entrepreneurs from Cuenca, Quito, and Guayaquil, as well as authorities and a logistics team.

The main objective of the event was to consolidate the UPS-innovation Ecosystem, as well as to identify the progress of the projects that are part of this ecosystem. Additionally, it was sought to identify entrepreneurial tools and connect them with experts in different areas.

5.3.4. "From teacher to mentor" Bootcamp

This event was held in August 2016. Several activities were developed to train teacher-mentors to become involved and support the Ecosystem of Innovation and Entrepreneurship of UPS. The objectives of this activity were the "From teacher to mentor" *Bootcamp* sought to develop the basic skills that a teacher must possess to be a mentor (**Figure 7a**, **b**). Furthermore, this *Bootcamp* sought to generate a community for mentors to support the StartUPS Projects.

Sixty teachers from UPS's three branches participated in this *Bootcamp*. Several activities were held with teachers on the following topics: redesign the experience of giving a gift through the design thinking methodology; the UPS mentor (characteristics and scope of the proposal); the experience of designing a mentor; learning the ontological dimensions (body, emotion, and language); knowing types of mentoring and their designs; and designing mentoring sessions in UPS.

5.4. Phase IV: startup and assessment

5.4.1. Competence and learning assessment process

The Coworking StartUPS Project's learning activities begin with a competency self-assessment by students, using the same questionnaire requested in the IPMA certification process. This informative activity is a key element to guide the development of learning activities. In this

Figure 7. (a) and (b) "From teacher to mentor" Bootcamp.

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self-assessment process, perhaps the main problem detected has been the difficulty of students to reflect on their own experience and knowledge. On the other hand, a gradual effort has been required to sensitize teachers on the need to change the system and approach of student assessment—by assessing competencies more than knowledge—as a result of adaptation to the new requirements of higher education and also of the current professional world. In general terms, it can be said that there are still some difficulties in incorporating the competencies assessment system into training programs.

The self-assessment activity is repeated at the end of the Coworking StartUPS Project to evaluate the progress in the competence learning process based on the National Competence Baseline (NCB) competencies by comparing the results. This process is structured around two axes: a process of continuous evaluation of students' individual character and a participatory group assessment to contrast and discuss individual assessments collectively. The activity is part of the quality assurance system, using learning evaluation processes of the participants in the Coworking StartUPS Project. It consists of two sessions: first with Coworking students and then with the StartUPS management team. Analysis and reflection of the proposals and conclusions of this process can draw a series of "lessons learned" to keep improving the integration of entrepreneurship skills in future editions and for the design of new activities in the Coworking StartUPS Project.

Table 1 summarizes the results of knowledge and experience in each group of competencies acquired by students after learning through the "Coworking StartUPS project."

Analysis and reflection of the proposals and conclusions of this process can draw a series of "lessons learned" to keep improving the integration of competencies in future editions.

Moreover, through entrepreneurship projects, students examine the interactions of a large number of the NCB competence elements [22, 23]. So far the experience tested with entrepreneurship projects, following the PBL approach, is ideally suited for students to link the technical and contextual elements to the entrepreneurship context, with the needs of the productive sector and real social problems. From this formative point of view, personal competencies such as teamwork, communication, leadership, commitment and motivation, self-control, self-confidence, openness, creativity, results orientation, efficiency, consultation, assessment values, adaptability, and innovation in problem solving are also developed.

	Average knowledge improvement (%)	**Average experience improvement (%)**	**Average knowledge + experience (%)**
Technical competencies	24.42	22.81	47.24
Behavioral competencies	13.48	15.81	29.29
Contextual competencies	27.19	27.68	54.87

Source: Compiled by authors.

Table 1. Development of competencies.

Figures 8–10 show the comparison of different results obtained from the initial participation to the end of the project management course.

5.4.2. StartUPS project evaluation

Although the launched projects are in different stages of implementation, in fact, some of them in the early stages, UPS has plans to establish a continuous assessment system with the ultimate goal of supporting the establishment and success of all these projects.

Figure 8. Technical competencies comparison.

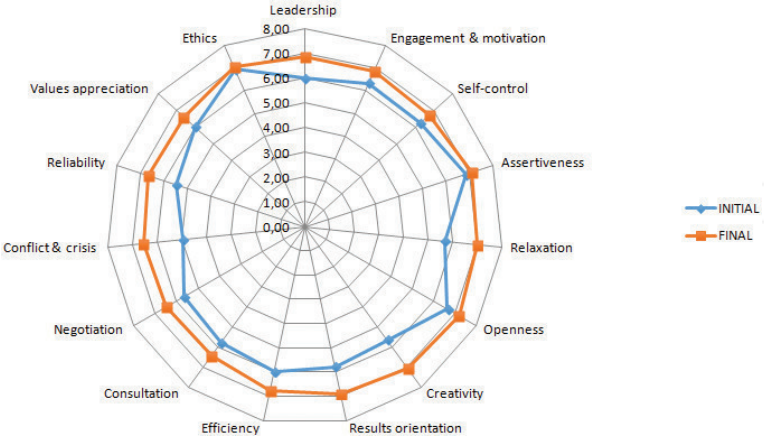

Figure 9. Behavioral competencies comparison.

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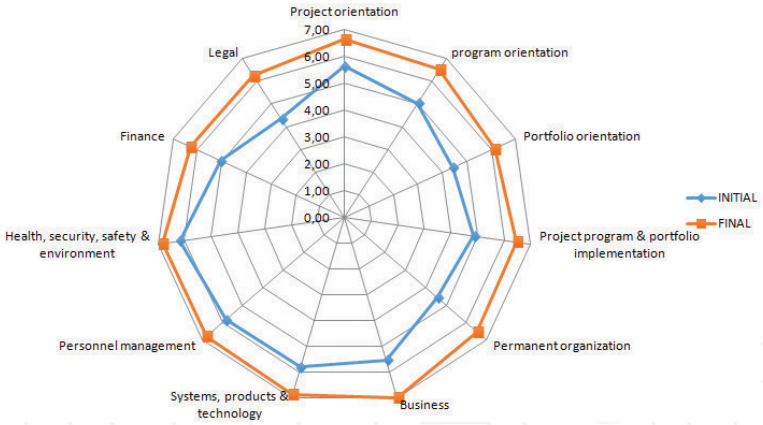

Figure 10. Contextual competencies comparison.

6. Conclusions

The methodology described above, with a competence-based approach, is the result of an experience of project-based learning that has been validated and specifically suited for the development of technical, contextual, and behavioral competencies. The learning methodology links teaching with the students' professional background, and is founded in cooperation, active participation, and interaction, offering multiple possibilities for competence development in the global and international context. The success of this approach is the belief that students are not passive recipients of knowledge, but should become engaged in an experience with real content. This preprofessional experience promotes students to integrate the knowledge they have learnt and apply the new knowledge in new ventures.

Students themselves have stated an improvement in their technical skills (with an improvement of 47%), behavioral skills (an improvement of 29%), and particularly in contextual skills (with an improvement of 55%).

The development of personal competencies, through the organization in working groups, and the challenge of facing complex real situations are part of the processes and activities integrated in the methodology and needed to encourage entrepreneurship in the university environment. Through these processes, creative ability and innovative research are fostered, generating new knowledge, as well as increasing students' enthusiasm and motivation to solve problems. Both, the strategy developed and its instruments—community building, PBL, agreements with institutions, interaction with external agents—offer new opportunities for educational innovation and the development of competencies.

The Coworking StartUPS Project has shown to be an opportunity for educational innovation, establishing new connections among the university (through Research Groups) and the

professional world (through the implementation of entrepreneurial projects), having international standards recognized in the field of project management as a benchmark. The fundamentals of IPMA are inserted into the higher education strategy to facilitate this international framework of competence-based training. This integration also links research projects and professional certification systems offering greater employability for future graduates and more efficiency of research groups from the culture of project management. Using this model, Salesian Polytechnic University has confirmed a clear position for incorporating entrepreneurship development project management skills, and concrete objectives that lead the way toward the University's strategy, the quality of education and the links to self-employment from business projects.

Moreover, some general conclusions from a series of "lessons learnt" have been drawn through the assessment process, which will serve to refine and improve the strategy in the future. On the other hand, a series of factors in the evaluation process of competencies that make evaluation more difficult, such as the different conceptions of each teacher, the greater burden of work required by ongoing evaluation, and the students' lack of familiarity with this kind of evaluation system, are identified. The development of behavioral competence with cooperative learning activities is especially valued and considered necessary to successfully address the complexity of the entrepreneurial projects. Finally, the creation of the community is the essential part of the Entrepreneurship Ecosystem and it is inevitable that it will become a process of consolidation.

Author details

Juan Pablo Salgado Guerrero[1], Ignacio de los Ríos Carmenado[2]* and Miriam López González[2]

*Address all correspondence to: ignacio.delosrios@upm.es

1 Universidad Politécnica Salesiana (UPS), Salesian Polytechnic University, Ecuador

2 Universidad Politécnica de Madrid (UPM), Technical University of Madrid, Spain

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INTECH

Chapter 12

Novel Health Mobile Technology as an Emerging Strategy in Diabetes Management

Satish Kumar David and Mohamed Rafiullah

Additional information is available at the end of the chapter

http://dx.doi.org/Chapter DOI: 10.5772/67508

Abstract

Advances in mobile phone technology and its applications coupled with equally robust growth of telecommunication technology can serve to give patients a better access to the healthcare. More and more healthcare providers and patients started using these applications. Mobile applications are useful in handling various aspects of healthcare namely, health promotion and disease prevention, diagnosis, treatment, monitoring and supporting health services. Clinical studies evaluating mobile applications often come up with mixed results. In this chapter, application of mobile health technology or mHealth in diabetes management is presented as a case study. We have reviewed 25 articles from pubmed database that fulfilled our selection criteria which included original clinical studies that evaluated mobile health technology in the management of diabetes mellitus. Most studies (88%) reported positive outcomes after use of the mobile health applications in various aspects of diabetes treatment such as disease management, behavioural monitoring and patient education. Educational SMS were effective but inferior to Smartphone Apps or teleconsultations. User-friendliness of the systems influenced patient compliance and outcomes. Smartphone/web applications offer significant benefits for patient care, education and behavioural modifications. As providing continuous patient support would require adequate infrastructure and personnel, cost effectiveness of such interventions need to be studied.

Keywords: smartphone apps, mHealth, health informatics, diabetes management, mobile health

1. Introduction

The huge developments and advances in mobile phone technology and its applications coupled with equally robust growth of telecommunication technology can serve to give patients a better access to health care information, which can make their life easier and enable efficient self-care. Electronic health services or eHealth is the use of information and communication technologies for health which continues to grow rapidly worldwide. It can also make the web-based health services easier, quicker, accurate, and cost effective. Chronic diseases need to be addressed in every possible way to contain their growth through awareness, education, and implements that enable self-management of the disease by patients. In this aspect, IT technologies together with mobile handsets can play a pivotal role in facilitating the dissemination of information and hence help better management of the disease. The rate by which mobile technology grows is something that cannot be overlooked; for example, a recent study has shown that there will be 11.5 billion connected mobile devices on use worldwide, and the global mobile data traffic will increase 10 times by the year 2019 [1]. Thus, the health care delivery can ride on this growth to reach the patients with innovative health care solutions.

The ever-expanding computing ability of smartphones together with the increasing footprint of the communication network, and the ever pervasive IT can be exploited to bring health care services to the patient's doorstep. Mobile technology can be used by both the health care service providers and the patients equally [2]. For example, doctors are adopting smartphone apps to seek clinical knowledge and case studies while patients are utilizing the same to have access to health information that will improve their understanding and management of their diseases [3, 4].

2. mHealth

Mobile health (mHealth) is a part of the broader field of eHealth that employs mobile phones as the base of health care–related solutions. mHealth services can also make the health services easier, quicker, accurate, and cost effective. WHO defines mHealth as "mobile health (mHealth) is an area of electronic health (eHealth), and it is the provision of health services and information via mobile technologies such as mobile phones and personal digital assistants (PDAs)" [5]. mHealth intends to enable the patient to self-care and helps the health care professionals to remotely follow-up their patients. For supporting the self-care, it would require the device to collect the data and provide advice automatically using embedded software that analyzes the data. On the other hand, remote care would require in addition to data collection, data transmission also. The device will collect the data and transmit it to a portal which the health care professional can access. Any decisions or advices from the health care professional after reviewing the patient data can be automatically communicated to the patient device using the same gateway. While the data can be entered manually by the patients using an appropriate interface, there are already devices available that can communicate the data wirelessly to the mobile phones. However, integrating various biosensors into mobile phones has not been widely followed yet. This may be possibly because of perceived prolonged regulatory approval process, which may be longer than the shelf life of many mobile phone models themselves.

http://dx.doi.org/Chapter DOI: 10.5772/67508

3. mHealth in health care

With the emergence of electronic health records (EHRs), digital health services started increasing rapidly. EHRs are the database of patient health information stored in digital form that can be retrieved anytime using a secure access. mHealth systems which are part of digital health can be effectively integrated into hospital-based EHR systems with controlled access given to both patients as well as health care providers. With advances in mobile phone technologies, the functionalities of mobiles phones have increased tremendously. The new generation mobile phones also known as smartphones have several features such as voice calls, video calls, SMS, apps, and web access. These functionalities can be utilized to provide the access to mHealth. Smartphones also can be connected to certain medical devices. The mHealth applications used commonly in disease management programs are smartphone apps. Other features of smartphones can also be utilized for improving the health care. Voice calls, SMS, web/e-mail access through smartphone browser, and third party applications such as WhatsApp are other functionalities that have been explored to mHealth.

Smartphone application, popularly known as app, is a dedicated application developed using the mobile operating software. It provides the user with all the options that are usually available in a desktop computer when accessing a website. Apps use the Internet connection to access database, hospital information system, or even a web portal. Patients enter their daily activities as input data, which will be saved in the phone memory or in a web database. The database may be in the cloud or in the hospital itself depending on the service provider. Apps may provide the automated feedback based on the patient data. There are some apps which provide access to health care worker to review the patient entered data and provide feedback.

The availability of mHealth apps has been increasing rapidly. Presently about 165,000 mHealth apps are available [6]. Various dedicated mHealth applications have been developed for the chronic diseases management recently. Several health care organizations started already using these applications to improve patient awareness. Simplest use of such mHealth application is the follow-up of clinic visits of patients. Patient-centered applications are designed to be used by patients to enhance the patient awareness about their condition, track their health parameters, and help self-management. These apps utilize the GPS tracking, accelerometer, and connectivity features available in most of the smartphones to provide specific functionalities. Common examples of patient-centric applications are diet apps, physical activity monitoring apps, behavior modification apps, and smoking cessation apps.

Clinical decision support systems are apps that are exclusively meant for health care providers. These apps provide access to patient history, current data, and clinical decision support. Clinical decision support systems assist the health care workers in interpreting patient reports and prescribe medications. This will greatly enhance remote treatment and monitoring of patients and will help to decrease the frequency of hospital visits. They also have alerts, reminders, and customized data entry forms for documenting patients' health information. mHealth applications aim to realize an improved health care system by targeting various aspects of medical care such as health promotion and disease prevention, diagnosis, treatment, and monitoring and supporting health services [7]. **Figure 1** illustrates the simplest possible framework of implementation of a mHealth setup in a hospital.

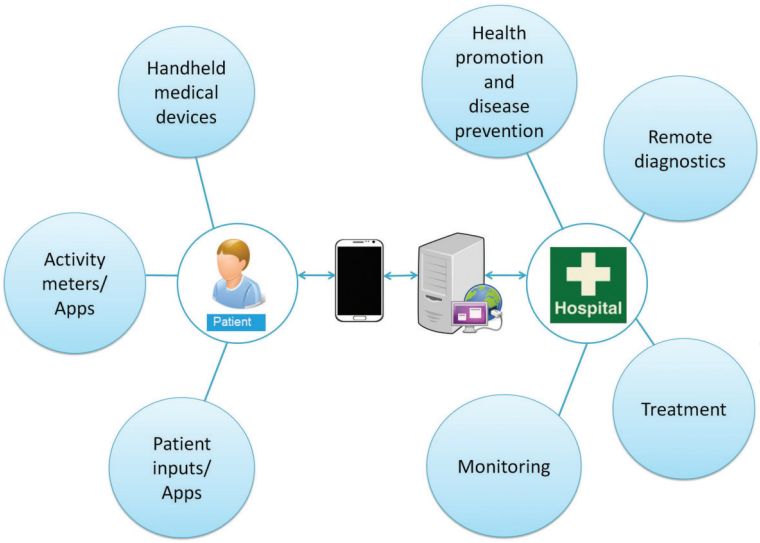

Figure 1. Schematic diagram of implementation of mHealth in a hospital setup.

3.1. Health promotion and disease prevention

Health promotion and disease prevention target the modifiable risk factors that contribute to the development and worsening of chronic diseases. These are mostly behavior modification strategies intending to change the poor eating habits, tobacco usage, and lack of physical activity. Behavior modification has been the key target of health promotion and disease prevention strategies. These interventions are meant to promote healthy behavior among patients. With the ability to reach individuals en masse, mHealth apps can address the communities with health promotion and disease prevention strategies and provide strong thrust in initiating healthy behavior. With wireless self-tracking sensors and activity monitors, behavior of the patients can be monitored. This will help in inducing the behavioral change among patients. In addition to the behavior monitoring, patients can be provided with personalized feedbacks that can influence the effect of healthy behavior.

In a meta-analysis, to examine the efficacy of mobile devices to influence the physical activity, it was concluded that mobile technology is an effective platform for influencing the physical activity [8]. The studies included SMS, mobile software, and personal digital assistants (PDAs) as means of intervention. The effect was larger for pedometer step counts. Mobile phone intervention yielded a significant effect while with the PDA, the effect was not significant.

When the effect of mobile apps to promote weight loss and increase physical activity was evaluated in a systematic review, it was found that use of mobile phone apps resulted in a significant weight loss when compared with control group. However, the physical activity did not differ significantly between the groups [9]. A report from Sax Institute, Australia, analyzed seven systematic reviews on physical activity and/or weight loss outcomes and concluded with mixed results [10]. Despite the improvements in healthy behavior after using

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mHealth, sustaining the changes were often faced with difficulty. Patients tended to drop-off once the intervention was removed. Long-term interventions are limited by the cost of such implementations. Patient behavior monitoring systems should be integrated with the disease management systems to lessen the cost of such interventions. However, patients and care providers may find it too much for every day routine as these systems might require too many data entries and feedbacks. Automated systems can be used to tackle this burden but at the cost of a higher budget.

3.2. mHealth in diagnosis

With the increased use of handheld point of care diagnostic devices, it has become possible to decentralize the diagnostic procedures. Many of these devices are user friendly and can be operated by patients at their home. There are web-connected devices which can capture the patient health data and communicate to the designated portal. If these devices can be integrated with smartphones, it can used to analyze, interpret, and also communicate the data. This will help the patients to carry out the self-diagnosis but still under the monitoring of a health care worker even without having to visit the health care facility.

These connected devices can also be used in primary health centers of remote locations in developing countries where the reach of expert medical care is not easy. The data can be communicated in real-time to receive an expert opinion. This will also help the care providers with more time to review the data and make informed decisions. With the rapid increase in the screen resolution of mobile devices, using mobile screens for viewing diagnostic images has also been explored. Owing to their handy and connectable nature, these devices will be very valuable in remote diagnosis. Kumar et al. [11] used an iPhone-based specific image archiving and forwarding program (i2i telesolutions) to view and report the diagnosis on diabetic retinopathy fundus images in the mobile phones. It was found that the diagnosis using mobile phones matched with that of computer-based technique, and the quality of images on the iPhones was reported high by the ophthalmologists. In a review on smartphones, tablets, and mobile applications for radiology, 11 applications were identified as diagnostic reading applications [12]. It was concluded that the use of smartphone or tablet screens resulted in comparable outcome to the respective gold standards. It may be noted that the mHealth applications that are intended for diagnostic purposes are considered as medical devices by the USFDA and therefore will require prior approval for the clinical use [13]. This could be the reason behind the lower utilization of mHealth for diagnostic purposes when compared to the other forms of mHealth usage. Even some mHealth apps carry the label “not for diagnostic use” to avoid the tougher regulatory journey.

3.3. mHealth for treatment of chronic diseases

Treatment of chronic diseases requires continuous follow-up and monitoring of the progress. By implementing mHealth, patients can be kept in the loop for appointment reminders, medication reminders, or any other important alerts. Apart from these general service, patient-specific treatment follow-up can be done using specific applications. Patients will report the health information to a designated portal using the point care of care devices connected to web directly or through a smartphone. The health care team will review the

patient data and make the necessary changes in the treatment with or without the help of clinical decision support systems. This will greatly help in reducing routine and emergency hospital visits. Dose adjustment of medications while initiating new treatments will require frequent visits to hospital or even frequent phone calls. If web-connected devices are used in such situations, checking the patient health status and adjustment of treatment can be carried out remotely.

Several attempts have been made to study the impact of mHealth technologies in the management of chronic diseases. Diabetes, cardiovascular diseases, chronic lung diseases, osteoarthritis, and mental health are the commonly studied chronic conditions where the mHealth intervention was found to be useful. De Jongh et al. assessed the effects of mobile phone messaging applications designed to facilitate self-management of long-term illnesses, in terms of impact on health outcomes and patients' capacity to self-manage their condition in a systematic review [14]. The phone messaging interventions provided benefit in supporting the self-management of long-term illnesses. They concluded that the long-term effects, acceptability, costs, and risks of such interventions needed further investigation. mHealth tools facilitated adherence to chronic disease management, but the evidence supporting its current effectiveness was found to be mixed in another systematic review [15]. A review by Sax Institute found that meta analyses and systemic reviews conducted to study the effect of mHealth interventions on cardiovascular disease, chronic lung disease, and mental health produced mixed outcomes [10]. Interestingly, majority of the studies that evaluated the mHealth interventions in chronic diseases included diabetes. Therefore, we decided to focus on effect of mHealth interventions on the various aspects of managing diabetes mellitus.

4. mHealth in diabetes

Diabetes mellitus has been the most common chronic disease affecting human beings as reported by the International Diabetes Federation with more than 366 million people currently affected and is expected to reach 552 million by the year 2030.The high mortality and morbidity as a result of chronic complications which make diabetes the leading cause of blindness, renal failure, ischemic heart disease, and limb amputation [16]. Diabetes mellitus is considered to be costly disease in terms of economic burden since the health care expenditure for diabetes in United States during 2011 was 7.7 billion US dollars with direct costs of 3.4 billion US dollars and indirect costs of 4.3 billion US dollars [17].

Treatment of diabetes needs self-management by patients to achieve stable control of the disease. Diabetes management is often cumbersome and demanding as it requires the patients to do regular home-based glucose monitoring and apply continuous lifestyle modifications. Typical diabetes management plans always include diabetes education and regular follow up of patients in order to achieve the treatment goals. Evolvement of smartphones and their wide reach has paved way for development of various mobile health applications. This has attracted a lot of attention from diabetes health care researchers as it aptly suits for implementing various aspects of diabetes management plans such as patient remote monitoring, data collection, patient education, and medical intervention.

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5. Case study

The case study was intended to review the effectiveness of mobile health applications in management of diabetes mellitus using original articles that were published in ISI indexed journals from PubMed database. About 209 scientific articles were captured from the PubMed database starting by the year 2007 till 2014. The search key phrases were "clinical study on use of mobile phones for diabetes," "clinical study on use of smart phones for diabetes," "clinical study on use of cell phones for diabetes," and "clinical study on use of mobile applications for diabetes." The search resulted in 66, 64, 62, and 17 articles, respectively. From these 209 articles, 131 were found to be duplicate. Of the remaining 78 articles, 25 fulfilled our selection criteria which included original clinical studies evaluating mobile health technology in diabetes mellitus management. These articles were grouped under three categories such as applications used for diabetes treatment, applications used for modifying patient behavior, and applications used for patient education.

5.1. Mobile applications for diabetes management

5.1.1. Mobile-based diary applications

A paper-based diary is provided to the patients by diabetes clinics to ensure patients record their blood glucose readings and hypoglycemia events. This is done in conjunction with regular phone calls by the clinical team to support the self-management of patients. Advances in mHealth comes in handy to help the patients to record their data and communicate it to the health care team. A mobile phone–based diabetes digital diary that can be accessed by the health care team via web is a reality now. However, use of such mobile phone–based diabetes diaries resulted in mixed outcomes in clinical studies. When a mobile diary app was used in type 2 diabetes patients for self-titration of insulin dose, there was a significant decrease of Hemoglobin A1c (HbA1c) [18]. However, there was no significant reduction in HbA1c and other glycemic parameters such as Fasting blood glucose (FBG) and Postprandial glucose (PPG) in type 1 diabetes [19].

5.1.2. Web-based diary applications

Smartphone apps can be used to collect the data and upload it to a web-based server. This will make it simpler to integrate the mHealth applications with the web-based health information systems already available in the health care organizations. Effect of web-based patient monitoring and intervention in diabetes management was explored in different studies. Even though the web-based diary intervention improved the patient self-care, many patients expressed frustration over using the app multiple times every day [20].

When patients were given access to online web diary and received optimal recommendations through e-mail or mobile phone after uploading their daily blood glucose readings, there was a significant improvement of HbA1c and postprandial glucose levels after 12 weeks [21], 6 months [22], and 1 year [23]. Hee-Sung [24] evaluated a web-based patient monitoring and nurse's education through SMS in type 2 diabetic patients. HbA1c levels were found to be

significantly decreased. It should be noted that despite having improvements in glycemia after using these mHealth interventions, patients reported frustration with the intervention. Hence, necessity of frequent use of smartphone and websites may lead to a decreased compliance among patients in long term.

5.1.3. Other applications

A smartphone app (Diabeo) for insulin dose adjustment improved the HbA1c among the patients who used that app along with teleconsultation [25]. When a telehealth system with real-time graphical feedback and remote nurse monitoring through mobile phones was implemented for the dose adjustment of oral hypoglycemic agents in type 2 diabetic patients, it lead to a decrease in the HbA1c levels [26]. The telemonitoring of patients with mobile phones provides a closer and real-time support to the patients. It seems that access to the health care team and timely feedback facilitated the treatment optimization and increased patient compliance.

5.2. Mobile applications for patient behavior modification

Treatment of diabetes includes lifelong lifestyle modifications. To successfully implement the lifestyle modifications, continuous patient monitoring strategies are required. However, these strategies often fail to bring the desired lifestyle changes due to the lack of efficient patient monitoring systems. Wide availability of smartphones has brought the patient remote monitoring possible. Patient behavior modification includes monitoring the patient behavior, adherence, and self-care.

5.2.1. Patient behavior monitoring

Patient behavior monitoring will help the care providers to plan the effective intervention strategy for individual patients. A cellphone-connected glucometer along with telephone and SMS communication was used to monitor the behavioral pattern of adolescent type 1 diabetic patients, resulted in a significant improvement in the self-management profile and a reduction in HbA1c [27]. A telehealthcare program was used to monitor self-management behavior in adult type 2 diabetic patients [28]. They used an online diabetes self-management system with teleconsultant service, in addition to a cell phone–connected glucometer. This improved healthy behaviors, increased glucose monitoring, and a significant reduction in HbA1c. Behavioral monitoring of the patients with the cell phone–based applications was beneficial in inducing lifestyle modifications that lead to a better glycemic control.

5.2.2. Patient adherence monitoring

Diabetes treatment requires multiple medications and lifestyle changes. This is a huge challenge for both patients and care providers in terms of patient adherence. Diabetic clinics closely follow the patients to make sure that they adhere to the instructions. mHealth technology can be applied effectively for such patient follow-up programs. It is very interesting to note that despite the conventional telephone-based patient follow-up and the SMS communication resulted in similar adherence, the SMS-based follow-up was more effective in

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decreasing the HbA1c [29]. Mobile phone–based ecological momentary assessment tool to measure the patient adherence behavior [30] was comparable to the traditional self-reported data. This supports the use of mHealth interventions for improving patient behavior and adherence.

5.2.3. Applications supporting patient self-care

Self-care and self-efficacy are the two important patient behaviors that have a direct influence in the diabetes treatment. mHealth applications can be utilized to develop patient support systems to promote self-care and self-efficacy behaviors in patients. When an interactive cell phone technology in which patients would receive recommendation messages after uploading their data were used, the self-care and the self-efficacy scores were significantly improved. However, there was only a negligible decrease in HbA1c levels. This was attributed to the low patient adherence arising out of the lack of user-friendly system [31]. Most of the patients reported positive lifestyle changes when they were asked to record their daily self-care activities in a web-based diary using their mobile phones and received feedback messages [32]. Remote monitoring of the patient activities with care provider feedback is supportive in improving patient self-care.

5.3. mHealth in patient education

As patients with diabetes are required to take multiple medications, check their blood glucose levels, and implement lifestyle modifications, awareness about their disease and understanding of the care providers instructions are very important. Lack of awareness about the disease will impact the diabetes treatment by affecting the self-care activity. This is often the reason for treatment failures in many cases. Clinical guidelines on diabetes management include patient education. Patient education using the mHealth technology can prove to be highly useful as the patient can carry the mobile handsets and apply the informational tips whenever needed.

5.3.1. SMS-based patient education

With the availability of audiovisual communications, mHealth technology offers better ways to deliver the patient education effectively. SMS is the simplest form of communication that mHealth technology can utilize for patient education. When unidirectional educational text messages were sent to patients using a specific messaging program (TExT-MED), it increased medication adherence, quality of life, and decreased emergency visits [33]. But there was no improvement in glycemic control. Lack of patient interaction in the unidirectional messaging might have been the reason behind the ineffective glycemic control. However, sending educational SMS according to the patient preference increased the adherence and improved the HbA1c and lipid profiles [34].

5.3.2. Smartphone apps for patient education

Smartphone applications can be a valuable tool in the patient education programs as it can engage the patients more effectively than the unilateral SMSs. Patient specific data are collected through the app, and the educational content is tailored to suit the patient requirement.

"Glucose Buddy," a freely available iPhone diabetes management application, was used in type 1 diabetic patients. It collected patient information and send educational SMSs based on the patient data. Despite a significant improvement in HbA1c, the quality of life and self-care activities were not improved [35]. However, it may be noted that the self-care activities and quality of life do not always correlate with HbA1c in type 1 diabetic patients [36].

A smartphone-based diabetes diary "Diab-Memory" was used to collect and transmit patient data to a remote monitoring center in patients with type 1 diabetes. The app sent reminder messages to patients with analyzed data output and statistical trends. It was well accepted by the patients, and the glycemia improved significantly. 'Ubiquitous Chronic Disease Care' (UCDC) system for a Smartphone app for diabetes care was investigated in type 2 diabetic patients [37]. Patients received alarms to remind about daily self-care activities. They also received educational messages after sending their data. This intervention improved the clinical parameters such as HbA1c, Blood Pressure (BP), and lipid profile. The educational messages and reminders supported the patient self-care, whereas the use of smartphone app engaged the patients and helped increasing the patient adherence.

A patient coaching system using mobile diabetes management software was evaluated in diabetes patients. The system sent automated, real-time, educational, behavioral, and motivational messages to patients. The messages were tailored to suit the patients by reviewing the patient entered self-care data. Care providers were either given access to only patient data or patient data along with decision support. Patients showed greater improvement in HbA1c when the care providers with given access to decision support [38]. This study has showed the decision support system when integrated with mHealth can enhance the clinical outcomes in chronic diseases.

6. Limitations

Care should be exercised while interpreting the results of these clinical studies, as many of them reported that the patient entered data without any validation. Age could be a significant factor which can influence the effect of mHealth interventions especially in chronic diseases. Educational level and the experience of using smartphones among patients are other important factors that can affect outcome of the implementation of mHealth. These factors also should be taken into account before interpreting the results of studies that evaluated the mHealth-based interventions.

7. Conclusion

Results of many systematic reviews and meta-analyses indicate that intervention of mHealth applications for most of the chronic diseases resulted in mixed outcomes. However, in our case study, to review the use of mHealth for diabetes has shown positive outcomes from most of the studies (88%) after use of the mobile health applications in various aspects of diabetes treatment such as disease management, behavioral monitoring, and patient education. Even many of the studies have shown that the simple text messages are very effective in improving the clinical and behavioral outcomes. The reason may be that the text messages are easier to

http://dx.doi.org/Chapter DOI: 10.5772/67508

handle and can be read by the user whenever they have convenient time. Even though the text message–based interventions were found to be effective in improving clinical outcomes, they were inferior to the relatively complicated smartphone apps. Sending such unidirectional messages by the health care organization may not be able engage the patients effectively as there is no active interaction between the patients and care providers. To overcome this, several smartphone apps with integrated messaging system have been developed. Patients enter their data using the app which then goes to a dedicated repository which the care provider has been given secured access. After reviewing the patient data, the care provider can send instructional or recommendational messages to patient's mobile using the same app. Some apps even automate this feedback messages; in such cases, the software will analyze the patient data and provide automated feedback.

Patient compliance will be an important factor in long-term mHealth interventions. Many patients may not be comfortable with being monitored remotely. Hence, patient privacy–related issues can be another hurdle in the way of mHealth. However, the biggest challenge is in providing continuous patient support with this technology. This would require adequate infrastructure and trained personnel in place. Cost of such interventions needed to studied with respect to the available options. Cost benefit and cost-effectiveness analysis studies with mHealth technologies are therefore necessary before implementing these systems on large scale.

Acknowledgements

The authors would like to thank Strategic Center for Diabetes Research, College of Medicine, King Saud University, Riyadh for facilitating the conduction of this work.

Author details

Satish Kumar David[1]* and Mohamed Rafiullah[2]

*Address all correspondence to: skumar@ksu.edu.sa

1 Department of Information Technology, Strategic Center for Diabetes Research, King Saud University, Riyadh, Kingdom of Saudi Arabia

2 Department of Pharmacology, Strategic Center for Diabetes Research, King Saud University, Riyadh, Kingdom of Saudi Arabia

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INTECH

Chapter 13

The Arts in Clinical Health Programs for the Recovery of Diseases and to Improve Quality of Life

Amador Cernuda Lago

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.69344

Abstract

The Psicoballet is a tool, which combines science and art. This method uses art and its different expressions (dance, ballet, theater, and pantomime) to improve the quality of life of people with disabilities and psychiatric problems and, in some cases, to rehabilitate these patients and help them become incorporated into society. In 1984, after analyzing over 25,000 cases successfully treated using this method, the recognition was granted by the UNESCO with the establishment of this organization as the UNESCO Psicoballet Company of Cuba and appointed Georgina Fariñas as its director. Since 1989, in the University King Juan Carlos, we are adapting and validating the Methodology of the Psicoballet to our culture, with clinical applications and social intervention in different contexts: (1) the intervention with victims of gender-based violence, terrorism, violation, sexual exploitation, all of them with optimal results. (2) Neurodegenerative disorders (Parkinson and Alzheimer). The works of investigation of some doctoral thesis directed by the author and realized in collaboration with the IMSERSO. (3) We have verified its efficiency in the problems of corporal image and eating disorders, chronic diseases (acquired immunodeficiency syndrome (AIDS) and breast cancer), and people with disability.

Keywords: Psicoballet, gender-based violence, quality of life, mental illness, anxiety

1. Introduction

The pioneer works in this line of intervention and investigation arose in Cuba, in the decade of 1970. The late Dr. Eduardo B. Ordaz, the former director of the Havana Psychiatric Hospital, the mythical Prima Ballerina Assoluta Ms. Alicia Alonso, director of the Cuban Company "The National Ballet of Cuba" and the prestigious Cuban Psychologist, Dra. Georgina Fariñas, all together created Cuban psychotherapeutic method known as "Psicoballet" [1].

The Psicoballet is a tool, which combines science and art. This method uses art and its different expressions (dance, ballet, theater, and pantomime) to improve the quality of life of people with disabilities and psychiatric problems and, in some cases, to rehabilitate these patients and help them become incorporated into society. In 1984, after analyzing over 25,000 cases successfully treated using this method, the recognition was granted by the UNESCO with the establishment of this organization as the UNESCO Psicoballet Company of Cuba and appointed Georgina Fariñas as its director [2].

The Psicoballet arises as method of infantile psychotherapy to treat children with disorders of conduct that they were not evolving with play therapy and occupational activities. As method psychotherapeutic and psycho-corrective, the Psicoballet was applied to pre-school and school that were presenting disorders of conduct, as anxiety, hyperactivity, aggressiveness, isolation, and so on. In addition, the parents of these children received education in the school for parents.

From the year 1977, the Department of Public Health does a review of the method of the Psicoballet and verifies its therapeutic character; for what in the same year named officially and assigned to the Psychiatric Hospital of the Havana, already as department. Once the method was made official, they realized its normalization and introduced a code of practice for what, having perfected the methodology, its use is extending and in the treatment are included children and teenagers with mental delays, blind and visual problems, deaf weak and deaf/hard of hearing; adult and the elderly with moderate, severely, and deeply mental problems [3].

In February 1984, the National Commission of Cuba of the UNESCO constituted the group UNESCO of Psicoballet, due to the scientific welfare contribution and the achievements obtained in the treatment of the children, teenager, and adults with psychic, mental, motor, and sensory neuropathies. Today, its efficiency has led it to apply to a wide group of mental and neurotic severe patients and old people.

In 1989, in the Foundation Dance "Alicia Alonso,"—it was located in the Complutense University, where we started as pioneer studies of dance with the guide and support of his Magnificent Rector Mr. Gustavo Villapalos—we started the first investigations to adapt and to validate the Psicoballet's Methodology to our culture with clinical applications and social intervention in different contexts. With the direct advice of Alicia Alonso, in the practical part of the procedure, and Alberto García, who guided us in the forms of theoretical work of the model as the first Cuban expert, we were mounting the Chair Alicia Alonso in the Complutense University. Simultaneously, we began the studies with a Magister based on the program of the existing studies on Cuba and, later, developing the Master with an experimental program, as we were confirming the discipline with the legal agreements of the Council of Education and the Department of Education.

In addition, a network of national institutions participating in the project was established with University of Alcalá of Henares in Madrid and with University of Castellón and Alicante. Also with the Valencian Generality that, in that time, was when the University of Valencia which had awarded a Honoris Causa Doctorate to Alicia Alonso, May 6, 1998. In this year, the University of Valencia only awarded two doctorates Honoris, the other one went to the

historical maker of the Spanish transition to the democracy Mr. Adolfo Suárez Gonzalez. It was there, in the preparatory ones of her appointment like Doctorate Honoris where, in very emotive conversations, we took the initiative to start working toward a legal validation of the Psicoballet's Cuban Methodology in Europe, but that process is not yet complete.

From these dates, different historical dancers of the National Ballet of Cuba, who have been exercising the teaching in our Institution and who have been occupying prominent positions in the international world of art, showed us procedures experienced for them in the National Ballet of Cuba. Not only they were showing to the world the ballet company, the most virtuous and universal global acclaimed, they also realized social and clinical labor in the shape of cultural enrichment and social positive action to raise the quality of life of the Cuban population with special needs.

Other companies have followed this example. At present, the English National Ballet, directed by the brilliant and prestigious ballerina, Dra. Tamara Rojo—"Prince of Asturias Prize" and the maximum distinction of the British Government, that realized her studies in our Institution and she took doctor degree [4] under the direction of the author of this chapter—is realizing meetings held in her headquarters in London of support to needy groups.

At that time of development of Psicoballet's processes in Spain, we have been fortunate to have been supported by Loipa Araujo, Aurora Bosch, Marta Bosch, Mirta Pla, Lienz Chang, and Adolfo Roval; they were indispensable until we are in direct relation with Georgina Fariñas and her historical equipment who supervises, advises, and supports all our projects.

2. Eating disorders and mental illness

The first work and subject matter that we develop arose being the author the person in charge of the psychological direction of the Olympian Equipment of Gymnastics. One matter called us the attention, the dancers of the National Ballet of Cuba, neither had problems of corporal image nor the consequences derived from eating disorders. For this, we began an agreement of cooperation with the Royal Spanish Federation of Gymnastics that they adopted, to complete their trainings, the methodology of the Cuban School, which supposed a radical change that benefited to both institutions and that led to win a Golden Medal of the Spanish Equipment of Rhythmic in the 1996 Atlanta Olympics. Later, it applied to other disciplines obtaining also historical achievements as the First Medal of Gold of World Champion of Artistic Feminine Gymnastics and the First Olympian Medal of Artistic Feminine Gymnastics [5–7].

We realized the first intervention with 28 teenagers with problems of eating disorders that managed to overcome their problems of corporal image with the Psicoballet and with it to improve and to overcome finally their eating disorders [8–12].

These positives changes encourage us to develop later works with serious mental illness, realizing in 1989 the first process. The study was performed at the Psychiatric Hospital of the Havana, with a small group of 17 psychiatric patients where they obtained an enormous improvement of their quality of life and of a good number of symptoms.

In 1990, we began the first interventions of support to groups of elder people generating a system of intervention in psycho-geriatrics, a process that has taken us to the current pioneering experiences in neurodegenerative diseases, as the investigations in process that we are realizing in "CREA" in Salamanca, center of reference of the IMSERSO over Alzheimer. They show the beneficial usefulness of the dance in the processes of support to the cognitive recovery, advances already gathered in different presentations in international congresses of maximum level, and in a doctoral thesis that the author has directed [13].

The intervention with victims of violence of gender, terrorism, violation, sexual exploitation, and so on had obtained ideal results. In neurodegenerative disorders (Parkinson and Alzheimer) this method has proved to be an effective instrument to reduce the speed of the degeneracy and helps to recover cognitive plots –it has been mentioned in the works of investigation of some doctoral theses directed by the author and realized in collaboration with the IMSERSO.

We have verified its efficiency in the problems of corporal image and eating disorders, chronic diseases (human immunodeficiency virus (HIV)/acquired immunodeficiency syndrome (AIDS), and breast cancer), and disabled persons. We have realized several interventions with patients with these illnesses [14–16].

A new intervention was made with patients diagnosed of fibromyalgia [17]. We are facing here a disease that does not find an organic test to explain an intense and diffuse pain, together with a great quantity of symptoms such as sleep problems, fatigue, depressive symptoms and anxiety, morning stiffness, and irritable bowel syndrome. From the Psicoballet, the person works with the body, with the movement, and with the expression. The objective psychotherapy is through the art as, developed and practiced with patients, that the changes in the movement will produce changes on the psychic level and emotional level. They pay attention to the pain and try to make the person explore through the body and the movement and in a secure space and with other people in the same situation, which will make all communications very easy.

This study was performed with a group of 27 women diagnosed of fibromyalgia and pharmacological therapy, of a middle age of 41 years. Before beginning the process and on having finished it, several clinical interviews were conducted on them and different tests of psychological evaluation were applied: Spielberger's STAI and Rosenberg's Self-Esteem Scale and POMS. They received 20 sessions of 90 min (60-min session of Psicoballet and 30-min session of cognitive technologies). A session lasted a week for 5 months.

The activity physics-artistic that the Psicoballet contributes improves the quality of life of this type of patients, strengthening their capacity of communication, improving the self-esteem and the vigor, and reducing the fatigue and the perception of the pain. The arts are a tool validated of great usefulness in therapeutic and social interventions: improve the quality of life, the self-esteem, and the self-confidence level, and reduce the anxiety.

Starting on our valuation of the usefulness of the ballet as therapeutic instrument, we want to mention by exposing the illustrious intellectual Cuban Alejo Carpentier in his closing speech to the IV Festival IV of Ballet of the Havana (December 9, 1976). The speech described an experience personal that Georgina Fariñas has told us often and that exemplifies the value of

the Ballet as channel of communication extra-verbal naturally. Carpentier narrated us that his friend, an anthropologist, transferred two aborigines from Amazonian jungle to Caracas. He wanted to obtain some type of communication with the aborigines. He took them to several places, as way of stimulation, but the aborigines were not interested for anything in the new civilization. Carpentier and his friend, without many hopes already to achieve the wished communication, took these men to a ballet representation, but the aborigines had the same attitude during the presentation. Already frustrated in their attempts, they left the men in the room at the hotel that they were occupying and they withdrew theirs. In the middle of the night, Carpentier and his friend listened to a few strange noises in the room of the aborigines. They observed, with great surprise, as these men, smiling, with grotesque movements, were repeating the delicate variations of the ballet that they had observed in the theater. Carpentier concludes that from this moment, the aborigines showed them receptive and then it turned out to be very easy to establish relation with these men, seemingly apathetic and insensitive. For the observed, Carpentier assures that "About our culture, established on the word, we do not think that, in certain circumstances, it turns out to be difficult and in occasions impossibly to communicate across it."

We think that this is the case of the majority of the mental patients, in occasions, so severely upset that they can have lost the whole contact with the world that surrounds them and, without having to come to extreme cases, we know that this case is also of anyone who suffers an emotional severe alteration. Anyone who is in deep condition of worry, melancholy or depression, finds it difficult to support a conversation beyond a few minutes, but the artistic forms, with intention of communication, have a great importance for these patients immersed in intense problems.

In the interventions that we have realized with chronic diseases, the works realized with AIDS patients stand out. The process of the disease of the AIDS is complex and very little understood for the population in general. It has different phases in which they have different emotional conditions that can be attenuated by physical and artistic activity, as we have seen in the Cuban experience of using the technologies of the Psicoballet for the treatment of different ailments.

3. The sexual infantile violence

Another area that we have investigated and adapted the experiences of the Psicoballet is the intervention with children and teenagers who have been victims of sexual abuse [18]. In this experience of adjustment of the methods of Cuba to our culture, 19 children and 13 teenagers took part, where a battery of tests were applied (Self-esteem of Rosemberg, Spielberger's STAIC/STAI, CDS depression) before the meetings to begin Psicoballet. Two meetings took place for 6 months every week, and on having finished, 81% of the participants were showing low self-esteem to the pretreatment. To the posttreatment, this number descends to 53%. The level of anxiety in the pretreatment was 77% and to the posttreatment it descended to 41.3%; the depressive symptoms that before initiating the treatment had an incident of 83% descended to 51.03%. In the controls after 6 months of finishing the process, 47.6% not only improved in these variables but also recovered from the point of view clinic.

The sexual infantile violence has consequences in their victims. The whole series of repercussions and adverse psychological sequela, emotional and social, puts in commitment the integral development of the person and determines a series of neurological pathologies. A meta-analysis with articles of 22 countries showed that 7.9% of men and 19.7% of women have suffered some form of sexual abuse before 18 years [19].

The sequels of a sexual abuse committed in the infancy or adolescents studied by several authors are fear, nightmares, disorder of posttraumatic stress, depression, social withdrawal, neurosis, regressive conduct, somatic disorders, inappropriate conduct sexual, regressive social behaviors, delinquency, problems of learning and hyperactivity, disruptive conduct, or direct affectation in the development psychosocial. All this can affect in the future conduct of the person with an increase in the delinquency and the sexual problems during the adulthood.

The Psicoballet occupies a modality inside the Therapies Artistic Creative or inside of the Body-oriented therapies and psychotherapies (BOT/BOP) [20]. It defined the use of psychotherapeutic movement inside a process that chases the psychophysical (body-mind) of the individual. It is characterized by the use that it does of the way and artistic process (in this case, the dance and the movement) to help settle the emotional or psychological conflicts. Part of the basic premise that any corporal movement can take in turn to change in the psyche promotes the health and the personal growth: The body, its movement, its language, and its forms of expression. The Psicoballet promotes and provides a soft way to repair the damages caused by the sexual abuse, in this case, occurred in the infancy. It offers a way of approaching the memories and painful recollections with dynamics and body techniques that are less challenging for the patient, promoting a therapeutic work embodied, focused on the emotional objection through the corporality that could offer well-being in the current and future life of the patient. The Psicoballet introduces the use psychotherapeutic of the movement and the dance as a creative form of the emotional, cognitive, and social integration, using the body and its own corporal language. In addition to suffering significant physical, psychological and emotional consequences, these victims are often limited in their ability to work and to interact day in and day out.

The Psicoballet is a very useful tool to work with these problems because facilitates the access to the body to psychiatrists and psychologists, breaking the cuirasses that block the body with the movement and the communication [21].

4. The Psicoballet's methodology

The Psicoballet can be defined as a therapeutic method that integrates science and art, specifically the Psychology and the Ballet of harmonic and balanced form. From these two previous systems, the Psychology and the Ballet, the Psicoballet conforms as a new dynamic integral system in which diverse elements or subsystems are interrelated: technologies and psychological methods, which use it as base, dance, music, pantomime, dramatization, physical culture, movement, and games.

http://dx.doi.org/10.5772/intechopen.69344

Psicoballet's method takes elements of the educational methods as the learning that is achieved in elementary technologies of ballet and dance; it is in addition a therapy of movement, where we use the action, the movement systematized inside the ballet technology, which is the instrument to realize the therapy. This forms part of the group of artistic therapies, specifically dancing, which is of great usefulness as a method psycho-corrective, given to the rectification of the structure of the personality and of the mechanisms psycho-corrective.

This method chases as aim the psychic and social adequacy of the patient across the correction and compensation of his disability, achieving independence, self-confidence, self-assessment, self-esteem, improvement in their communication, and familiar and social interrelationship, with the results of the Psicoballet as therapy of movement.

The systematizing of the steps helps in the development of the muscular coordination, the control of movements, the sense of the space, and the rhythm. The use of the dance in the meetings of Psicoballet helps in the royal enjoyment of the activity, which is very important for a therapy; by this way, an easy and agreeable communication establishes extra-verbal that it is not required, it does not attack, and it provides happiness and possibilities of creation.

The general aim of this work is the rehabilitation, fitting out, or reeducation of these people in search of a feeling of self-realization, as human beings are more part of their community and of their family of society. The preventive aspect develops in addition, with the aim to anticipate possible emotional disorders. The correct position is about obtaining a correct aesthetics of the body and a socially suitable behavior. In consequence of their diseases, these patients are inclined to choose a shod position that makes them look like guilty; it is important to work on the position, a matter that the ballet technologies facilitate. This constant growth, that is required in any class of ballet, help them to get a correct placement of the body.

The process of the education is a joint activity between teacher and student who possesses a double aspect: the instruction and the education. The method and technology for the therapeutic treatment of the Psicoballet possesses a methodological program, where the elementary level of the Cuban School of Ballet is selected. This program develops in five levels. In addition, the program possesses an offer of exercises as guide for the teacher and therapist to achieve that the mental is to the physical united.

The session of Psicoballet divides in three parts:

Motivation in bar is the moment where the therapeutic exchange begins to achieve the best correction of the steps with the fastened patients of the ballet bar. Here, it is where the steps are taught for the first time and a better balance is achieved for his future development; this is where the motivation of the therapy begins for the continuity of other meetings.

The fitting out in the center is already in the center of the lounge, where the steps that have been studied in the bar by a major balance are executed. These steps have the purpose of enabling the patient to move to this new form, with the rigor and pertinent adjustments.

The creative liberation is the moment of inter-relationship, maximum communication, of discovery, and where the equipment can analyze to the patient in certain secret messages that

they find hard to transmit verbally and to use the movement to express his personality. This is where the aim of the class is valued and where they look for the acceptance and not the conformity.

Taking advantage of this benefit that the ballet brings to us is the use of it as therapy to improve, in this case, the life of the persons with HIV/AIDS improving his quality of life, raising their conditions, finding the reasons of stress, the self-confidence, in routes to optimize, and to balance the system of defense.

A very narrow relation exists between the emotional disorders and the lack of harmony of the movements. This lack of harmony appears across a sign of discomfort because any disorder concerns equally the body and the mind, the psychological problem reflects in physical problems and vice versa [22].

An abundant number of experimental studies show that the establishment of a program of exercise consistent and prolonged in the time has the effect of increasing the self-esteem and of reducing the anxiety. The accomplishment of exercise can eliminate the anxiety and the tension. It is verified that the program of exercises of moderate intensity has a beneficial effect on the immune system. Specifically, we found that the exercise of moderate intensity was reducing the number of days of disease. The improvement of the immune function can derive from the reduction in the stress and from the benefits of the exercise as for the reduction of the concentrations of the hormones related to the stress as the cortisol [23].

The effects of the movement imply from the decrease of the immunosuppressant up to the increase of the self-esteem. The increase of the self-esteem transformed into an improvement in the quality of life. As for the physical qualities, an increase is registered in the perception of the force, the resistance, the flexibility and the balance as well as also in the physical appearance and in the physical skill. All the dimensions of the physical auto-concept are transformed into strength and flexibility.

5. The victims of gender-based violence

From the numerous established educational programs, it is necessary to distinguish the line of applications of the dance in situations of posttraumatic stress that we initiate immediately after the tragic events of the terrorist attack on Madrid in March 2004. The attempts of March 11, 2004, were a series of terrorist assaults in four trains of the network of Surroundings of Madrid carried out by the jihadist terrorists. It is a question of the second major attempt committed in Europe up to the date, with 10 almost simultaneous explosions in four trains to the rush hour of the morning (between 07:36 and 07:40). Later, after an attempt of deactivation, the police would detonate, of controlled form, two appliances that had not exploded, and deactivate a third party that would allow, thanks to their contents, to initiate the first inquiries that they would lead to the identification of the authors. A total of 191 people died and other 1858 were hurt. On December 17, 2004, Gregorio Peces Barba was high Commissioned for the Support to the Victims of the terrorism for the Cabinet.

The own Gregorio Peces Barba, connoisseur of the Cuban experience, put in touch with our Institution to suggest us the creation of a program of attention to the victims of the attempt. We created a system of intervention combining the artistic therapeutic activities of the dance. We used and verified Cuban experience of treatment with the Psicoballet with cognitive technologies of treatment of the posttraumatic stress, incorporating new technologies in that moment in our country as the EDMR, desensitization, and prosecution for ocular movements, a psychological therapeutic technology used to desensitize and to re-process psychological traumas in a natural and rapid way.

We initiate the contacts with victims of the attempt and their treatments, but the political questions ended up by bringing over to the victims of gender violence. We have realized seven programs with this group and have attended more than 700 victims of this type of violence, with very beneficial results of the decrease of anxiety and depression and elevation of self-esteem [24, 25]. To the beginning of the last course, they requested a similar intervention with victims of sexual violence; the dance is a great auxiliary tool of support to an experience who realized Psicoballet by 21 women of an average age of 32 years who had suffered violation and had symptoms of posttraumatic stress [26–32].

On having finished the procedure, the participants showed positive changes to psychological and corporal level; 37% diminished his levels of anxiety in 45% as average and those of depression and their self-esteem increased significantly, 42%, which allows us to affirm that the dance therapy is useful to treat this type of patients.

It is slightly functional to treat patients who present experiences from sexual abuse without a specific attention of the body, question that the Psicoballet allows and that canalizes and amplifies any therapeutic process. The utilization of the art-therapy technologies under a cognitive behavioral model of intervention is very advisable for a problematics as the treated one. The use of an instrument to mobilize the body as the dance amplifies the effect of the psychological conventional treatments, and it allows overcoming the corporal inflexibilities that this type of disorders generates in their victims. On having unified the mental work with technologies of movement that allow to liberate tensions and be aware of the corporal condition, joining this fact the positive effect of being employed at a group of persons with same and delicate problematic opens channels of communication.

The tango is a dance characterized by passionate and marked movements; generally, it is associated with the Argentine and Uruguayan culture. Though it needs concentration and agility at the same time, a study realized in Washington verified that the dance turns out to be an excellent physical therapy for the patients with Parkinson's disease. Besides favoring physically the persons with Parkinson, the tango might be a great source of social integration that, at the same time, would improve the self-esteem of the patients and with this one, their emotional health.

The movement alterations seen in Parkinson's disease are one of the most important symptoms and are the more concerning the quality of life. The dance-like artistic and therapeutic practice can help in the rehabilitation of alterations neuromuscular and motor skill. We realize an exhaustive evaluation of studies that were investigated which brings over if the dance favors the rehabilitation of the patients with Parkinson.

Styles different from dance showed favorable results in parameters such as physical function, balance, walk, risk of fall, and quality of life. In spite of few clinical tests, the analysis of the results will arise that the dance can improve the rehabilitation of motor skill alterations; it appreciates a diminution of risk of fall on having improved the balance and the walk. All this would carry a better quality of life.

The Parkinson is one of the neurodegenerative diseases more prevalent in the population of advanced age and one of the principal reasons of falls. Difficulty with walking and the balance are common between the individuals with Parkinson, contributing to a major incident of falls. In these patients, the alterations of the movement are characterized by slowness and the accomplishment of short steps dragging them for the soil with a flexed position. Haste and/or freezing of their movement can be included. They are in the habit of presenting difficulties of balance on having realized drafts and having walked backward. The works of investigation that have studied alternatives of movement across the dance in patients of Parkinson have demonstrated benefits in the neurological condition and the initiation of the movement. The Argentine tango has arisen recently as a promising approach to lessen the problems of balance and walk. It is a combination of the following steps: they imply the beginning and frequent cessation of the movement, spontaneous way changes, rhythmic variation, alternative change of center of mass of a leg to other one, and a wide range of speeds.

These characteristics can direct for him specifically the alterations motorboats associated with Parkinson's disease, as the difficulties with the beginning of the movement, the deficiency of the length of the stride, the freezing of the walk, and the drafts and the bradykinesia that these patients suffer. The Argentine tango is a form of expression artistic and full of meaning. The music of tango believes an environment of contemplation, desire, and intellectual stimulation. Provided the attention of a dancer must be divided between the navigation and the balance, the tango helps to develop cognitive skills, as the double task. On having used the Psicoballet with a group of patients of Parkinson, we could state benefits in the quality of life and improvements in their processes of walk and major safety and self-esteem.

To psychiatric level and of severe mental illness, we have realized several interventions; some of them in process form a part of doctoral theses in process of ending, besides the pioneering investigation mentioned with schizophrenics, and recently we finish a process with bipolar patients. The bipolar disorder, considered a mental serious disorder, named traditionally as maniacal-depressive disease, is characterized by a changeable state of mind that fluctuates between two opposite ends: the obsession, or phase of exaltation, euphoria and grandeur, and the depression, or phase in which they predominate over the sadness, the inhibition, and the ideas of death. A chronic disease limits the functionality of the patient, needs a mixed pharmacological boarding and psychosocial. In the cases badly diagnosed and with bad orientation of treatment, the effect in the disease is devastating and implies important economic loads and socio-sanitary.

Often, the results for the patients with bipolar disorder where they are treated with medicament therapy only are suboptimal. The evidences suggest that the exercise is an adjuvant treatment psychosocial for the treatment of these patients. The exercise increases the aptitude to adapt to stressful environmental and it might reduce scoreboards of allostatic load reducing the activity

of the axis hypothalamic-pituitary-adrenal (HPA), the sympathetic nervous system, and the corticosteroids. The experiences of the Havana's Psychiatric Hospital with the introduction of the Psicoballet in these problematic complement the effects of the physical exercise on having included, plus the own exercise, adjuvant therapy of communication, accomplishment, and an increase of the self-esteem.

An experience was realized with a group of 21 adults of bipolar disorder applying Psicoballet's Cuban Methodology—the same way as carried out at the Havana's Psychiatric Hospital—to study the effects with patients, of our culture, to whom a follow-up was realized with clinical interviews [33].

The dance as physical exercise has the advantage of that the effort can graduate and adapt to the needs of every participant, without demanding a physical effort that fatigues and demotivates the people. The dance increases the communication and turns into a motive of expansion into the day that helps to the treatment.

This original therapeutic production, which had his historical origin in Cuba and which has spread over numerous countries of America, Europe, and Asia, was recognized by the UNESCO. We have studied and adapted, in our University in Madrid, Spain, the original Cuban methods to our culture and have studied their effects in different groups of disease and contexts, finding an undoubted usefulness of support for the clinical evolution of some disorders and in the evolution of the quality of life of the patients who suffer these problematics [34–37].

Psychology and Psychiatry have forgotten the body. The psychologists and the psychiatrists work on mind, thoughts, emotions and behaviors but they do not observe body, nor intervene on it, but art therapy is a way to get back to the body.

The patients work with the body and with the movement in company of other persons who have the same problems, traumas, and emotions with similar blockades. They enter a spontaneous communication of their problems that favor the work in groups, and moving and using the body as part of the therapeutic process, they liberate the blockades and inflexibilities shooting the efficiency of the psychological treatment.

The great contribution of this group of artists and clinical Cuban is an important advance to raise the quality of life of the patients for the effects that the art has in the brain: the music, the dance, the dramatization, and the singing [38].

Clinical meetings with psychologists, psychiatrists, doctors and professional artists to plan and to supervise the processes of treatment take place at all time.

6. Conclusions

We can conclude that the number of clinical tests with a suitable randomization and methodologically rigorous is not numerous in the international bibliography, being necessary to increase the investigation in this matter in order to obtain clear conclusions.

Nevertheless, several studies coincide in indicating the efficiency of the art therapy in the reduction of the negative symptomatology in mental illnesses as the schizophrenia. In this respect, there are promising results referred to the dance therapy and to the corporal psychotherapy, being, of between all the modalities, the most robust evidence for the music therapy. With regard to other variables, the superiority of the art therapy could not have demonstrated opposite to standards care, and though the music therapy has presented positive effects on the mental general condition or the social functioning, these are not considered in all the studies.

In September, 2008, the National Institute for Clinical Excellence National (NICE) published a document "Draft Full Guideline for Consultation" that dedicates a few pages to the expressive therapies and to the scientific evidence that has been demonstrated in the last studies of investigation. This study concludes that the principal benefit of the application of artistic therapies is the improvement in the negative symptomatology of people with psychosis. In the same document, details that the person who guides or executes the abovementioned practices must possess a specific formation in the matter.

In 2009, this Institute included a paragraph which mentioned the Artistic Therapies including them inside the "Psychosocial Interventions." NICE recommends prescribing artistic therapies such as art therapy, dance movement therapy, corporal therapy, drama therapy, and music therapy as complement to the psychotherapy and to the pharmacotherapy.

The Cochrane Library has published different studies which have an effect on exhaustive review of articles that evaluate the art therapy as adjuvant treatment for the mental illnesses in comparison with the standard treatment and other psychosocial treatments. In its introduction quote "The British Association of Art Therapists (BAAT) [39] defines Art Therapy as: Art Therapy is the use of art materials for self-expression and reflection in the presence of a trained art therapist. Clients who are referred to an art therapist need not have previous experience or skill in art, the art therapist is not primarily concerned with making an aesthetic or diagnostic assessment of the client's image. The overall aim of its practitioners is to enable a client to effect change and growth on a personal level through the use of art materials in a safe and facilitating environment."

The arts have a clear future in the clinical, social, and educational applications, and their utilization, consolidated in some pioneering countries in the matter as Australia, Cuba, Canada, The United States of America, the United Kingdom, and Israel, is universalizing according to evidence confirmed of their utilization and attested by a certificate by transnational organizations as the UNESCO.

Author details

Amador Cernuda Lago

Address all correspondence to: amador.cernuda@gmail.com

King Juan Carlos University, Madrid, Spain

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