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THE INFLUENCE OF COMMON BUSINESS MODELS ON DESIGN PROCESSES LIFE CYCLE AND MAINTENANCE COSTS OF PRODUCTS AND SYSTEMS

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ABSTRACT

The aim of this paper is to make students of engineering aware of the interactions that exist between decisions made during the design phase and their consequence on life cycle and maintenance costs in the context of pre-determined business model. It is well known that the consequence of a technical choice made during the design phase impacts on the product life cycle, in terms of logistics, maintenance and overall costs, and therefore have repercussions on the business model. The former can serve as a handy guide to explain the different development strategies according to the business model requirements. The profitability requires the engineer to identify a balanced product architecture by varying parameters such as component reliability, operational availability, accessibility solutions and maintenance plans. This time-consuming and costly approach cannot be used for all industrial products nevertheless, it is used specifically for technologically complex and long-lasting products such as trains, wind turbines or in manufacturing facilities [3].

Keywords: design process, maintenance cost, reliability, life cycle cost, business models.

INTRODUCTION

This paper highlights the pedagogical approach used to simplify the understanding of complex industrial processes related to company business models. Indeed, the interactions that exist between the design process and the business model that identifies a product can be difficult to consider by the designer. Difficulties are often linked to competitive product and industrial service marketing, anticipation of future technological developments and evolution of consumer behaviour and habits. These are some of the many constraints that can make a product obsolete or incompatible with the common market [1].

The idea is to clarify the different approaches that the designers can undertake in order to consider the business models in which the product will be brought. As an example, depending on whether the product will be sold or rented, the engineering solutions will be affected by this situation. They will have the same availability but will differ inversely in terms of component reliability and life cycle and maintenance costs.

Moreover, if the designers decide to put more emphasis on the reliability of a product at the design stage, the consumer acquisition cost will consequently increase due to the additional verifications, quality control and testing that are required. In addition, the cost related to the availability during operational will also increase as shown in Figure 1. Furthermore, if the designers decide to make a product with the lowest acquisition cost, they will have to choose components of modest reliability without redundancy. Thus, this lack of reliability will be compensated by a sustained availability with consequences on the life cycle and maintenance costs. Indeed, maintenance costs will increase due to multiple interventions and corrective actions which generate a loss during production.

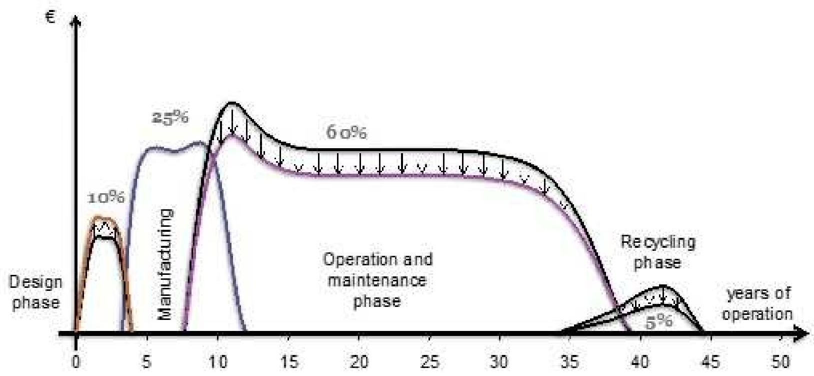

Fig. 1 - Example of train lifecycle cost

In this paper, engineering students will find a global approach which clarifies the different steps of an industrial project considering the business model concept. The objective is to adapt the product to its economic environment while respecting the functions and performance required.

While precautions need to be taken, this approach is expensive and time consuming. It is important to specify that it is only applicable to large multi-technological industrial projects with long life, such as production sites, construction equipment, trains and so on ... Obviously for such products, the reliability of which is a regulatory requirement, such as nuclear, aeronautical and pharmaceutical equipment are not considered by this study.

GLOBAL APPROACH

The overall approach is to consider life-cycle cost into the engineering design phase. The notion of life cycle cost depends on a business model which will enable the product will be profitable for the investors. Often, the relevance of the design is not limited to operational performance but takes into account economic performance. In this case the designers must strike a balance between technology requirements and economic competitiveness.

The trade-off is not easy to find because the behavior of life cycle costs during operation is often disrupted by external factors which are difficult to account for design phase. These external factors may be technical, such as premature wear, or economical, such as the currency instability, or strategical, such as acquisitions and mergers.

Before addressing methodological aspects, a brief explanation of business models is presented. Knowledge of the business model in which the product will be exploited is essential to help designers make appropriate technical decisions. The design of a product that is rented is different from the one that is sold. The difference is in the distribution of margin over the product life cycle. In the first case, the company offering the product for rental, can focus its margin during the operation phase while in the second case, the company offering its product for sale can only make margin on design and manufacturing phases. Section "Business models" gives an overview of different best-known models.

The global approach is based on 5 steps. These steps can be performed iteratively. The project manager can vary limited number of parameters to get as close as possible to the objectives sought.

Step 1: identify and characterize the business model in which the industrial product will be exploited and made profitable. The Marketing and Strategy department can play a central role at this stage.

Step 2: develop functional specifications and specify the expected performance, including availability. The value analysis method (VA) is recommended at this stage.

Step 3: propose different design solutions in terms of reliability, product architecture and model the life cycle cost (LCC) of each solution. This is a difficult stage, especially for innovative where feedback is limited or does not exist.

Step 4: set discussion criteria and analyze the advantages and disadvantages of different scenarios using the LCC models developed in step 3. This step involves technical criteria more than anything else; the strategic criteria are addressed in the next step.

Step 5: Add the strategic goals of the company in terms of development or risks and propose a simple or combined solution. At this stage some high level decision-makers of the companies (finance, marketing, strategy, engineers, managers, ...) need to be involved.

On one hand, as noted previously, this approach is based on the value analysis method (VA) which is a group activity that involves brainstorming and the identification of alternative to improve the value of the product, especially for the customer [7]. The formalization of functional specifications and the search for technical solutions to satisfy the functions are part of the value analysis method. This method consists in determining, step by step, the functions, the components and the costs considers the manufacturing and assembly constraints. Section "Value Analysis" provides mode details.

However, the life cycle cost analysis (LCCA) is a decisive step, because according to many reports, up to 80% of a product cost are related to its lifecycle and are locked in at the design development stage [9]. This is understandable because the design cost of any product is directly related to many factors, including tooling, plant and equipment, labor and skills, training, materials, shipping, installation, maintenance, decommissioning and recycling. It can be noted that life cycle cost approach based on maintenance costs is still not a common practice approach. Data from Alstom Transport publicly available shows that 60% of cumulative operating costs of rolling stock are maintenance related. Indeed, some studies confirm that predictive and preventive maintenance are more important than life cycle cost [10]. Section "Life Cycle Cost Analysis" provides more details.

In the following, we present the four best-known business models according to David J. Hoare [6]. The notion of LCC (*Life Cycle Cost Analysis*) used to model the cost distribution during the life cycle phase will then be discussed. This is followed by a brief introduction of the method of value analysis, which provides methodological support to the design. This paper concludes with a discussion and recommendations and help designers to make informed decisions.

BUSINESS MODELS

A business model is simply the overarching plan of a company to generate a profit by selling a service or a product. The business model provides an outline of the company plan to produce a product or service and to market it. This strategy also includes the profile of overall life cycle costs and how the business can maximize profits. There are different business models, each of which may suit different companies and different types of businesses [5]. No single model is the best or the worst; each model works in its respective industry. David J Hoare [6] identified, four distinct business models described below. Nearly all businesses can identify their plan with one or two of the four following models.

The first model is based on a low-volume activity of high-margin. An example of this type of business is a shipyard that is characterized by several years of engineering and material requirements to be built efficiently. Several other examples can be cited, such as aircraft manufacturing (Boeing) or transportation (Alstom Transport). There are certain business attributes that force the industry to exercise this model, especially when a high initial capitalization, highly complex interactions and complex resource management are involved.

The second model is based on a high-volume activity of high margin. This type of model is not as common and often have significant capital barriers to start operations. An example of a large company with a high margin and a high volume is Apple. The I-Phones costs less than $250 to manufacture and get to market. Retail prices run in excess of $500 for the device. Apple sells nearly 100 million units per year. This is a rare business model that has driven the stock price "off the charts". Typically, in these types of business models, the overhead and capitalization costs are higher than other models. This is mostly attributed to the relatively high marketing and advertising budgets spent on these products. Often innovation and development costs easily exceed the difference in low-volume high-margin industries.

The third model is based on a high-volume activity wish low-margin. This type of model is traditionally seen in the retail and other consumer-based product businesses. An interesting business attribute is the low capitalization threshold to enter the market. This model has several attributes, such as low capitalization barriers and low knowledge thresholds. However, the competition is a significant characteristic is such models. The best example for which this model applies is gas stations. In general, most gas retailers have about 18% benefit margin per gallon of gas sold.

The fourth model is based on a low-volume activity with low-margin. Indeed, this model concerns products with high purchase price and subject to a high concurrency. Several examples can be cited such as luxury goods or dealerships. These industries exhibit higher overhead costs and compliance related costs. Since buyers of the product are rare, advertising becomes a significant proportion of overhead costs. The negative attribute of this model is the higher than normal risk associated with acquiring customers. Any reduction in market share can have significant negative impact on the financial profitability of the business.

It is clear that these models influence the design process in the choice of components, their reliability, redundancy and maintenance plan. Designers must take into account the business model in which the product will be used and generate profits. Finally, it should be noted that the analysis of economic models is a prerequisite step for a major design project.

LIFE-CYCLE COST ANALYSIS

Fuller [13] gave a relevant definition close to our work. In fact, he defines life-cycle cost analysis as a method for assessing the total cost of facility ownership. It takes into account all costs of acquiring, owning, and the maintenance of industrial systems. LCC is especially useful when technical alternative solutions that fulfil the same performance requirements but differ with respect to initial costs and operating costs, are compared in order to select the one that maximizes net savings. The results of an LCC analysis can be used to assist management in the decision-making process where there is a choice of options. The main costs can be classified as the ‘capital expenditure’ (CAPEX) incurred when the asset is purchased, and the ‘operating expenditure’ (OPEX) incurred throughout the asset life including maintenance [15]. This approach is particularly pertinent to industrial products or installations whose maintenance costs can exceed 50% of the total cost of ownership.

For example, LCC can be used to determine whether the implementation of a device that facilitates accessibility to critical parts corresponds to the desired business model. Knowing that, making such a decision will increase the initial cost but lead to considerably reduced operating and maintenance costs. Knowledge of the business model in which the product is used and made profitable is a fundamental factor for designers in the choice of components in terms of costs, reliability and availability.

The precision of this LCC model is essential for the decision-making stages. The model should give, for each component chosen, a projection of maintenance costs [4]. However, it is very difficult to predict the behavior of the trends because they are subject to exogenous factors which can invalidate the initial choices. The example of hydrocarbon prices variability or exchange rates variability is often cited.

We have chosen to use the LCC approach which gives an overview of life cycle costs, from design, manufacturing, operation, maintenance to recycling [2]. The confliction between the additional reliability costs during the design phase and their impact on operational maintenance costs is no longer to be proven. Table 1 shows the dependence of the positive or negative evolution of operating / maintenance costs on the additional costs incurred to make the product reliable or not during the design process.

Table 1 - Reliability cost levels

LCC		make the design more reliable	dont make the design more reliable
CAPEX	Design cost	++	--
	Acquisition cost	+	-
OPEX	Maintenance cost	--	++
	Operational cost	-	+

In OPEX, the calculation of life cycle maintenance costs C_{lcm} is divided into three parts. The first part concerns preventive maintenance where the calculation takes into account the costs of systematic interventions C_{sys} and the costs of conditional interventions C_{cdt}. The second part concerns corrective maintenance, where the calculation takes into account the direct costs C_{drt} due to repair work and the indirect costs C_{idrt} due to production losses. If the company has adopted a transition to Industry 4.0, a third part related to predictive maintenance is added [16]. In this case, it is necessary to add data collect costs C_{dt} and costs due to the machine learning use C_{ml}.

The following expression represents the generic analytical form to calculate life cycle maintenance costs ;

$$C_{lcm} = C_{dt} + C_{ml} + C_{sys} + \sum_{n} C_{cdt} + \sum_{m} (C_{drt} + C_{idrt})$$

The remove calculation of systematic preventive costs C_{sys} is based on the maintenance plan which contains the list of all parts to be replaced including their frequency. Generally, component suppliers also provide the associated maintenance plan. The estimated predictive maintenance costs $C_{dt}+C_{ml}$ are based on the costs of using the IIoT (*Industrial Internet Of Things*) system and the use of machine learning time. There are different contract forms to purchase a machine learning time that use sensor collecting data to make smart decisions in real-time.

The estimate of corrective maintenance costs $C_{drt}+C_{idrt}$ is based on the failure rate. m is the number of critical component failures, calculated over a given period. The estimate of the costs of the conditional maintenance C_{cdt} is based on the cost of using monitoring facilities (vibration, acoustic, ...) and the replacement operations (spare parts and labor). MTTR (*Mean Time To Repair*) can be used to estimate the number n of times the monitored component needs to be replaced.

VALUE ANALYSIS (VA)

Functional analysis is a branch of mathematics dealing with spaces of functions and is used in designing industrial products. This begins with defining the needs that the product must meet, then defining the service functions, then the physical definition of the product, and finally estimating the overall costs of each solution.

The functional analysis step is an important phase in any product design process. It leads to the definition of all the service functions, including the interaction functions and the adaptation functions. These functions are prioritized and characterized in a specific table. This phase is also called external functional analysis. The second phase is to find technical solutions in terms of components and design architecture. There are different ways to associate technical solutions with service functions. The FAST (*Function Analysis System Technique*) diagram is a popular graphical method. The last phase is to estimate the total costs of ownership for each of the proposed solutions. Several approaches can be used, including analogous estimating, parametric cost estimating and engineering build-up cost estimating also called “grassroots”.

As shown in Figure 2, designers can identify several technical solutions for the same functions. In simple terms, the difference between the proposed solutions lies in the choice of components in terms of acquisition cost, reliability and maintainability cost. It can easily be shown that the component reliability is inversely proportional to the maintenance cost.

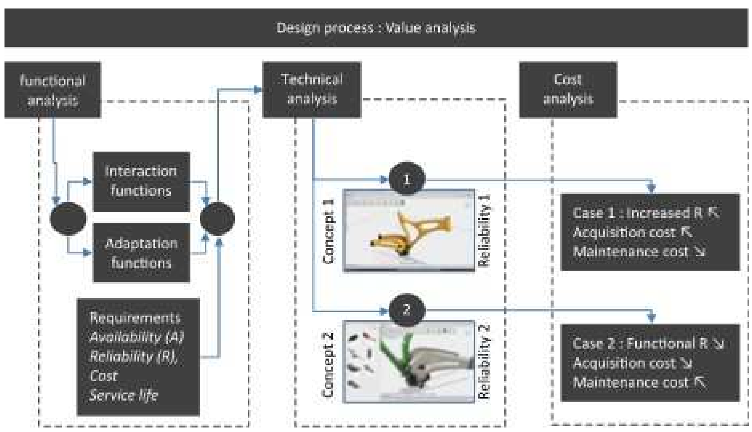

Fig. 2 - Value analysis process

With regards to acquisition cost, the reliable components are more expensive to acquire but generate lower maintenance costs. on the other hand, the less reliable components are less expensive to acquire but generate higher maintenance costs. This difference must not affect the product quality, qualified here by the availability, which must be the same whatever the components reliability. This poses the question, which solution should the designer focus on?

There is no direct answer to this question; this is why the proposed approach allows young designers and students of engineering to evaluate the overall costs of different technical solutions in order to carry out an objective analysis [17]. In reality this preliminary work is designed to make a final decision, but to clarify the advantages and disadvantages of each solution in order to facilitate the decision-making. This is what will be developed in the last section.

RESULTS AND CONCLUSIONS

As stated previously, the final business decisions are made after discussions between the different leaders of the company namely marketing, finance, human resources and development. These discussions can be organized around several objective criteria. The amount of initial investment, strategic orientation, overall costs, different risks, obsolescence, technology and skills are to name a few. The methodology proposed in the paper is considered as a decision-making tool.

In order to illustrate the proposed approach, three cases are treated and compared. In the approach, some hypotheses are first introduced. These are an operating life of more than 20 years, technological complexity and significant maintenance costs. Assuming that in case 1 an industrial equipment is to be designed and sold without a maintenance program; the client is supposed to take care of maintenance himself. In case 2 the designed equipment is to be sold with a potential maintenance program because the client is not equipped to carry out maintenance themselves. In case 3 the designed equipment is to be rented, and the client pays only for the time of use but the rent includes the maintenance operations. Figure 3 illustrates this example.

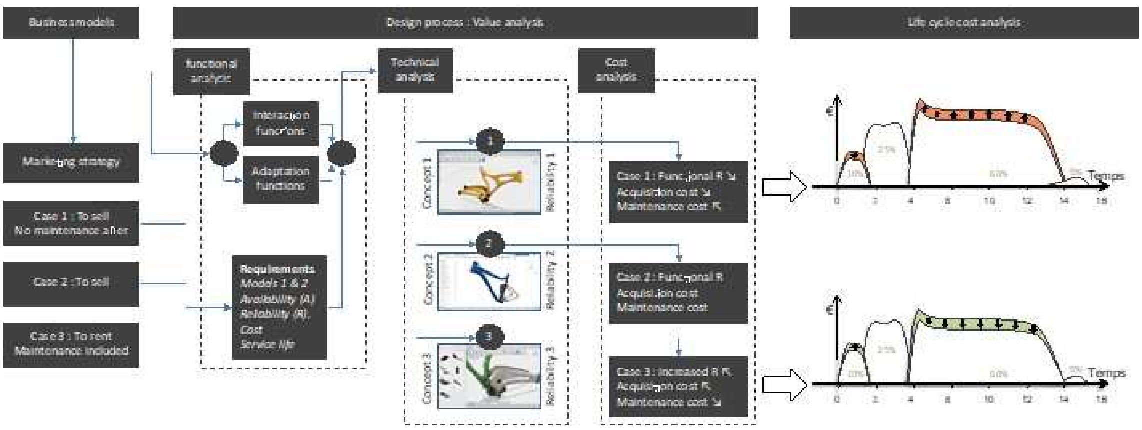

Fig. 3 - Global approach

As with any business, it is the pursuit of profits that guides most decisions. Thus, for case 1, it is to be noted that the company can only generate profits for the design and manufacturing step. This information prompts designers to reduce design and manufacturing costs to maximize the profit margin. The direct consequences are that less attention in given made to improve reliability, a choice of the cheapest components, less quality control in manufacturing and a choice of lower quality materials. The indirect consequences are high maintenance costs to maintain the required availability in addition, to the production losses caused by breakdowns or downtime for maintenance.

Comparatively, this case generates a higher life cycle cost than cases 2 and 3. Nevertheless it is interesting for companies that have modest capital investment, because the acquisition cost of this industrial equipment is attractive. In addition, case 1 is generally suitable for companies that use similar equipment and are able to conduct efficient maintenance themselves.

Before considering case 2, let's focus on case 3 first. It would then be easier to consider case 2. Case 3 considers the company that designs and manufactures the product remains the owner of the equipment and maintains it. According to the rental contract, the customer pays monthly fees or user fees or a combination of these two possibilities. This model implies that the equipment is very reliable in order to generate least breakdowns during the operating phase and limit maintenance interventions to maximize the operating margin. In addition, a reliable and well-maintained product retains a residual value which is part of the overall profitability model of the life cycle of the equipment.

In terms of design engineering, the designers need to optimize maintenance during the design phase in order to reduce operational maintenance costs and maximize the margin during the operating phase. This approach generates additional design costs due to increased reliability and the cost of acquiring high performance components, which practically reduces the design and manufacturing margin. Ultimately, this strategic choice leads to a lower lifecycle cost than the other cases, but it mobilizes significant capital investment at the start of the project.

In case 2, the company that designs, manufactures and sell the industrial equipment wishes to sell a maintenance program to get additional payments. It is understood that maintenance operations generate more profits than design and manufacturing activities and therefore targets client that cannot maintain equipment. Thus, the company can decide to take the risk of transferring part of its benefit margin over to the operating phase and in particular during the maintenance activities, and therefore caution should made in the selection of the proper design solution and the choice of components. There is a risk is that the client will want to negotiate the best maintenance prices during contract renewal or opt for other new technologies. Therefore, there might be a risk for the client to go through calls for tenders because the equipment supplier company may disqualify.

In this situation, designers practice optimizing maintenance at the lowest cost in order to limit risks. This approach should not generate significant additional design costs, it is essentially based on solutions using components of modest reliability. The idea is to allow for an additional small margin of the cost in the design and manufacturing phase in the event that the company does not obtain the maintenance contract. This strategy includes life cycle costs in the overall cost between case 1 and case 2. There are also other cases not presented here, in particular hybrid solutions.

In conclusion, it can be said that this article is intended primarily to be educational. It attempts to explain how business models influence design process and life cycle and maintenance costs. As described, business decisions are often motivated by the search for maximum profits and preferably for short periods. For this they adopt different marketing strategies based on various economic models which may vary from one product to another. As an example, it can be noted that in recent years the emergence of car acquisition offers via long-term rental with limited mileage, forcing literally clients to accept new offers and therefore keep them in cycle of new car acquisition. For car manufacturers, this business model is more profitable in short term than the direct acquisition model. In addition, it allows a regular return of money, which gives more visibility to manufacturers and therefore reassures shareholders.

In this context, designers have to take business models into account in components choice, product architecture and manufacturing process so that the product remains compatible with the marketing strategy and the profitability model. However, to have a powerful tool that estimates life cycle costs as accurately as possible, it is necessary to introduce influencing factors such as discount rate, inflation rate, exchange rate, learning curve and technological readiness level [14].

This paper presents a structured approach which gives students of engineering a global vision of the links that exist between the industrial processes and the strategic requirements of the company while respecting the functionalities, the quality requirements, the regulatory requirements and expected performance. These represent many constraints that makes it difficult to achieve the objectives. Therefore, the success of a business model lies in the application a rigorous decision-making approach which limits the risks of arriving at a product with limited commercial interest.

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