MANAGEMENT OF SEVERE INFLUENCES AFFECTING PRODUCT DEVELOPMENT PROJECTS: UNDERSTANDING THE BEHAVIOUR OF DISRUPTING EVENTS THROUGHT EXISTING CASES

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ABSTRACT

Extensive planning in the development of complex physical products can, in normal circumstances, help product development teams to complete projects efficiently. However, such strict planning can hardly cope with the appearance of severe influences and, usually, a lot of efforts are required in order to make the development proceed again after such a disruption. Since these solutions are usually costly and highly inefficient, it seems imperative to better understand the behaviour of disrupting events and their effect on ongoing development projects, in order to formulate better responses to such occurrences.

Key words: Product development; disruption management; severe influences; secondary data analysis.

INTRODUCTION

Macroeconomic changes, new national and international laws, contractual power of intermediaries in supply chains, relevant market shifts, important changes in the strategic choices of competitors, disruptive technologies, are only some of the potential influences that might affect severely the development of a product development in all its phases.

In some cases, the severity of the consequences of an external influence requires time in order to be assessed and not always the entirety of its mechanisms are clearly understood. Moreover, the complexity of the effects of an influence are sometimes either reduced or empowered by intrinsic characteristics of the product, the team or the company that is developing the product.

Lindemann et al. (2009) provide an example of a severe influence disrupting on innovation processes in the automotive industry. According to Lindemann (Lindemann & alter, 2009) [1] "a multitude of new technical dependencies emerged due to increased integration of mechatronic components in modern automobiles… not only product complexity but also process complexity increased, in part because mechatronics implied an intense division of labour and an increased need for development coordination… the increase of product functionalities resulted in the necessity of an intensified

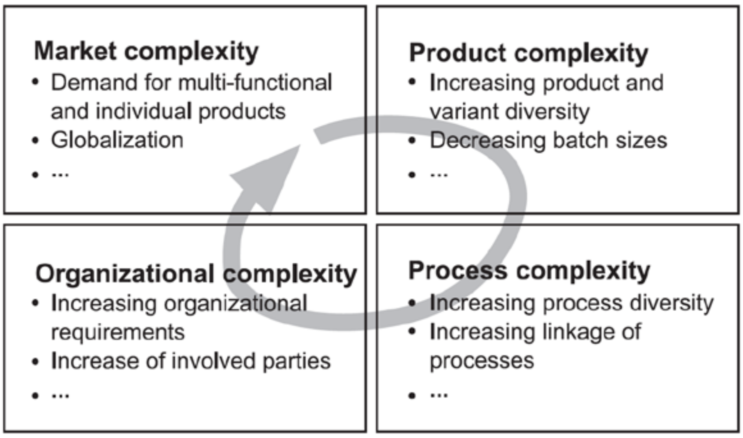

Figure 1: Aspects of complexity in product design

cooperation of both internal and external enterprise departments and suppliers. For this reason, organizational and communication flows also become more complex". It is possible to identify four types of complexity in product development: market, product, process, and organizational complexity (See Figure 1)

Complex technical products and organisations require in fact a lot of efforts in order to change plans. When the development process is ongoing, especially after the planning phase has ended, it might be difficult to change it. For instance, in 1989, Intel had to face serious issues related to one of their products, the X-2 model (Clark, Wheelwright, 2010) [2]. After the entire product was developed and prepared for the production in series, "everything that could possibly go wrong did go wrong": some of the issues that happened were so serious that the product had to be brought back to the design phase in order to adapt it. Under these circumstances, most of the companies that face such events require to spend a lot of resources in order to implement changes in the development plan. The result of such efforts is usually time-consuming, inefficient and costly.

Throughout this research, we decided to focus on cases that meet two conditions: (1) only high-tech complex products or systems and (2) only product development teams that belong to companies with an elaborate organization are considered.

Consequently, this research aims to clarify the following questions:

- RQ 1: How is it possible to define a severe disrupting event in the context of the research?
    - Which classification can clarify the differences among different types of disruptions?
- RQ 2: What are the factors that might cause a disruption in the activities of a product development team after the planning phase has ended?
    - Which factors can be distinguished?
    - How is it possible to identify/classify these factors?
- RQ 3: What are the cause-effect relations among these factors?
    - Which are the relations among the factors?

In general, it is possible to consider as a disruption every strong influence whose consequences are either to halt the development process or to severely compromise the potential market success of the product before it is even introduced. Concordantly, the first step of this contribution aims to define and classify the different types of disruptions. Secondly, the research continues with the description and classification of the factors involved in the issue at hand. Once the factors are selected and classified, this contribution is proceeding with the analysis of the cause/effect relationships among such factors.

Within the boundaries mentioned earlier, it might be safe to assume that the team in charge of the realization of a complex product, will use a plan oriented process and therefore changing the "product development methodology" might be highly disadvantageous in most of the cases.

It is very unlikely that companies with complex organisations competing in high-tech markets might be able to make their product development teams switch from a plan-oriented approach to a value-oriented one, such as the agile product development. Even with the technologies that nowadays are employed in the development, it is quite hard to think that the agile product development might be applied to the creation of very complex physical products (such as airplanes, cars, etc…): the amount of efforts required to keep the coordination of the people within a huge product development department and with the rest of the company would escalate quickly.

However, it is true that part of a product within very specific boundaries might be created in an agile context; however, this is possible only when specific limits and conditions are created a priori in order to maintain a degree of consistency with the rest of the stakeholders directly involved in the development process. Consequently, it is very likely that the overall project might present a different approach than a plan-oriented one and only specific parts of a product might be developed with a different approach, but only when specific limitations are applied.

Finally, not all organizations and products present the same behaviour and the same context. In the same way, when a similar problem occurs, potential solutions may have to differ fundamentally. In order to fully comprehend the effects of disrupting events on product development processes after the end of the planning phase, it seems wise to select boundaries that isolate both common behaviours and potential short term solutions. This research will consequently focus on complex physical products developed in complex organizations.

The next two sections introduce the theoretical perspective and the methodology used to analyse the different case studies considered in the present research. The analysis proceeds then by describing for each case which factors are involved in the specific disruption and how these factors are linked in terms of cause-and-effect relationships.

THEORETICAL APPROACH

It is possible to find in the literature partial answers to the questions presented earlier; in fact, such literature, on the one hand spans too many fields and, on the other hand, it appears to be non-exhaustive since it lacks a comprehensive view on the topic.

For instance, literature related to risk management and disruption management would only be able to address some of the questions this research is focusing on. Assessing potential threats (Hillson & alter 2004) [3] and the relative impacts and effects is a typical practice of risk assessment; these activities do not aim to understand the behaviour of a threat once it has realized, but aim to clarify which among those potential negative events are most relevant to foresee and overcome.

In the same way, the literature related to the development of products mainly focuses on the issues related to technical aspects of the product. In fact, the field of deviation management mainly aims to understand how it is possible to either bring a project in line with the plan originally or how to adapt an existing project once an unforeseen technical problem appears. While these efforts are indeed relevant, they are not enough to describe the complexity of the effects of a severe disruptive event.

In the field of strategic management there are a couple of notable theories that are relevant for the topic. The Weak Signals theory (Ansoff 1979) [4], for instance, assumes that discontinuities show warning signals prior to a severe event. The aim of this theory is to understand how it is possible to detect such signals and deal with their consequences. However, in some cases such foreseeing is not possible or it is hard to understand the real impact of potential threats.

Coordination theory (Malone, 1980) [5] is a "body of principles about how activities can be coordinated, that is, about how actors can work together harmoniously". Such theory "like other interdisciplinary fields that arise from the recognition of commonalities in problems that have previously been considered separately in different fields." Such an interdisciplinary theory describes the intrinsic need of coordinating activities that organizations have in order to complete complex tasks or objectives. However, on the one hand a product development project that is dealing with the effects of a severe influence, requires additional coordination that normally is not needed; on the other hand, such coordination might not be enough to solve the problem.

Finally, it is possible to find some best practices on how to face severe disruption of ongoing product development processes. These practices tend to solve only one specific aspect of the problem. For instance, the Pulse methodology (Kaya et alter. 2014) [6] aims to improve the coordination of the different stakeholders involved in a development process that has received an important deviation from its initial plan, and it does so through the use of planning boards and frequent meetings. While this best practice absolutely improves the communication and the information when the development team starts to face the effects of a disruption, it is true that it only covers a specific aspect of the problem.

It is clear that the contemporary literature solves the problem related to a disruption only partially. This literature is subdivided in different fields of study, each of which deals with specific issues only. However, none of these fields manages to completely cover the problems that are the main focus of this research.

For this reasons, it seems sensible to understand the topic of this research through a secondary data analysis. Selecting and comparing a few case studies present in the literature might help to create a comprehensive view on the problem at hand, while improving the understanding of the behaviour of disruptive events on ongoing product development processes after the planning phase has ended.

METHODOLOGY

The analysis of case studies (Eisenhardt, 1989; Eisenhardt & alter, 2007) [7, 8] seems to be the most sensible choice in order to understand a problem that the literature does not entirely cover, while it is clearly relevant for the industry and it has been described in some occasions.

In particular, it is possible to identify in the literature some cases that describe the unravelling of the effects of disrupting events on product development processes whose planning phase has already ended. For these reasons, it is clear that the best course is to proceed with secondary data analysis of existing relevant cases. However, it is important to define the boundaries of the selection of the case studies and to define precisely which steps are required in order to complete the analysis.

It is possible to elaborate the methodology in four different steps. The research starts with a broad selection of case studies that regard several areas of interest but that must include the description of a product development process disrupted after the initial phase has ended. Such cases must be selected and consequently eligibility criteria have to be created. Since the case studies explored have several differences and only one main feature in common, it seems sensible to proceed with an analysis of the context of the different sources. For this reason, before the analysis of the content of each case, an analysis of the parameters related to the context seems imperative. Once the previous steps are completed the analysis will proceed by building a causal network of the disruptive events present in the case studies.

Eligibility and selection of the Case Studies

The first step of the secondary data analysis is to evaluate the eligibility of the case studies.

The literature presents several case studies regarding issues that happen when a company is developing a new product, but only a limited portion of them is eligible for the purpose of this contribution. The following aspects are at the core of the selection of the case studies:

- The focus of each case study must be on a physical complex product (Murmann and Frenken 2006) [9]; services and non-complex physical goods are excluded from this research.
- The organization of the company must be complex (Gupta and Anish 2009) [10].It is possible to assume under these circumstance that the company must have a plan driven approach to the development of the product and for this reason agile product development cannot be considered a feasible solution to the problem at hand.
- The disruptive event must happen after the planning phase of the product development has ended.

These criteria are of the utmost importance not only because the context of the varies sensibly from one case to another, but also because it is important to focus on those situations where it appears almost impossible to abandon a strong planning orientation. Nonetheless these parameters aim to select a specific set of contexts that can be compared even if the different case studies selected might have significant differences in terms of context.

Context parameters of the analysis

In several secondary case studies, an analysis of the context of the sources can be found (Falkingham & alter, 1998; Dochy & alter, 2003) [11, 12]; in particular, this approach is used when the case studies considered are belonging to different type of fields, journals and perspectives. This procedure is sometimes referred to as context analysis and in other situations as meta-analysis, although the latter usually have a broader meaning. Consequently, the following characteristics are selected for the first part of the analysis:

- Authors;
- Year of publication;
- Year of the study;
- Geographical location;
- Journal / book;
- Perspective / Study domain;
- Product affected by the disruption;
- Company affected by the disruption.

Content parameters of the analysis

The Analysis of the content will focus on which factors that originate or affect the unravelling of the disruption and its consequences. It is possible to find in the literature already some lists of these factors (Gericke & alter, 2007) [13], consequently some factors might be already considered, while others are still not present. Nonetheless, it is important to approach the analysis while distinguishing which factors are internal to the company and which one are external.

However, not all the organizations considered in this secondary data analysis have the same premises and characteristics, consequently it is important to understand and define which aspects of the companies analysed might facilitate the manifestation of a disruption.

Network representation of the content parameters

Several applications of network analysis can be found in the context of product development [14, 15] and business management [16, 17]. For instance, a typical tool for project managers is the Critical Path Analysis; this tool is very important in order to create algorithms whose objective is to schedule project activities in an optimized way. However, in the context of this research, the objective is to build a causal network based on the data elaborated in the case studies.

The aim is to enrich the understanding of the cause-effect relations among the factors involved in disruptive events happening after the planning phase of product development projects has completed.

ANALYSIS

Table 1 presents the case studies eligible and the relative context information.

Table 1: Context Parameters of the cases studied

Source Title	Authors	Year of publication	Year of the study	Location	Journal / Book	Perspective / Study domain	Product	Company
Managing new product development and supply chain risks: The Boeing 787 case	C. S. Tang, J. D. Zimmerman, and J. I. Nelson	2009	2003	United States of America	Supply Chain Forum: An International Journal	Supply Chain Management, Risk Management	Airplane	Boeing
Disruptive technology: How Kodak missed the digital photography revolution	H. C. Lucas, J. M. Goh	2009	1990 - 2000	United States of America	The Journal of Strategic Information Systems	Information System Management	Digital Photography	Kodak
The origins of the turbojet revolution	E. I. Constant II	1980	1921	United Kingdom	(Book)	Historical Study	Airplane	British Aircraft Corporation
Of bicycles, bakelites, and bulbs	W. E. Bijker, W. B. Carlson, T. Pinch.	1995	1939	United States of America	(Book)	Social Construction of Technologies	Luminous Lamp	General Electric
Subsequent Niche Strategies for High-tech Products during Market Formation	R. J. Ortt, L. Kamp, V. Bruinsma, S. Vintila	2015	1988	Germany	Proceedings of ISPIM 2015	Market Formation for radical new products	Car	Porsche

All the selected case studies fulfil the requirements to make the studies eligible for our research. The cases are different and hence heterogeneous but they also share some aspects. For instance, more recent studies belong to journals, whereas older ones have a more extensive documentation and have been extensively described in books. It is possible to notice that most of the cases are geographically located in the United States of America. Finally, it is possible to recognize strong differences among most of the cases, both in the perspectives and the products that are the focus of the case studies.

Boeing 787 Dreamliner

The Boeing 787 Dreamliner (Tang & alter, 2009) [18] case is interesting because the company decided to implement both a new supply chain system and important technological innovations at the same time.

The case presents two different levels of disruptions: the original product design features and the supply chain operations. Moreover, the authors assume that the latter issues are the main ones and for this reason avoid to talk in depth about technical disruptions, and instead focuses on the difficulties resulting from a new supply chain network.

From a technological point of view, the most important improvement of the product compared to its predecessors was the introduction of a new alloy as main material for the airplane; such material would have presented several improvements: faster cruising speeds, cost savings, increased comfort and finally fewer delays due to mechanical problems. However, when the development team moved from the planning phase to the realization of a complete product, the application of the alloy turned out to be unfeasible in large parts of the product.

Additionally, the supply chain network was strongly centralized and all the different suppliers communicated directly with the company; while not being the most efficient choice, it is true that all the suppliers were directly in contact with the company and they could be directly selected and coordinated.

The new supply chain organizational structure required for the production of the new line was more complex compared with the previous centralized structure. While being more efficient in normal scenarios, this change would bring a higher degree of complexity in case of disruptions.

This supply chain required three different tiers of suppliers in order to gather components and partially assemble them before reaching the Boeing assembly line. The company had to face several risks. For instance, the material used for the new product had not been tested on the scale of the airplane which lead to the partial redesign of the product itself. However, both the time to understand the problem and the redesign required extensive efforts both in term of resources employed and coordination activities with the different actors involved.

After extensive efforts and delays, the company managed to deliver a product that was, however, less ambitious than the one originally planned due to the complexities in the design presented earlier.

In order to mitigate the negative effects of these additional time and resources, customers had to be extensively informed of the problem at hand in order to make them better understand the situation.

Internal Factors:

- Technology, infeasibility of the material in flight tests
- Modularity, increased modularity and number of externalized parts
- Supply chain, decentralization and partial outsourcing
- Supply chain, Tier-2 suppliers might lack know-how
- Process, lack of coordination between Boeing employees and suppliers down the line
- Management, management inexperience
- Risk of delays in the delivery of the product

External Factors:

- Employees strikes due to dissatisfaction mainly caused by augmented outsourcing
- Customers, concerned and unsatisfied due to potential delays in delivery of the product or cancellation of orders.

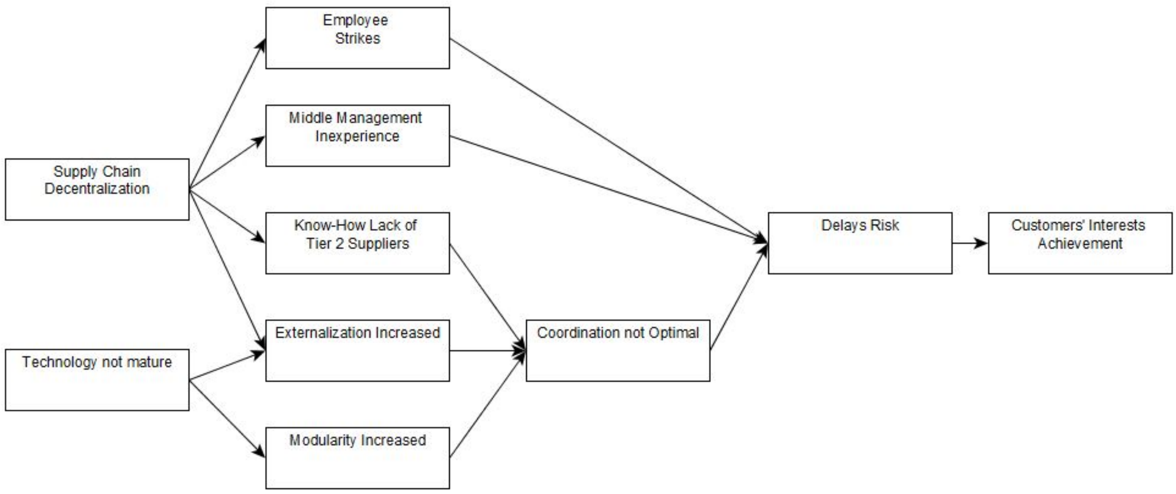

Figure 2: Boeing 787 Dreamliner network

Kodak and the digital photography

This case (Lucas & alter, 2009) [19] describes how the major company in the world in the market of photography had to face a new technology that disrupted its market. The focus of the document is on the incapability of the company to quickly and effectively respond to a new technology and consequently to adapt the company to make it in line with the changing market environment. Kodak did misunderstand the relevance of digital photography although it had itself, decades ago, originated the development of digital photography.

Managers at all levels in Kodak consistently underestimated the growth of the market for digital cameras. In fact, they were convinced that the professional photographers would be the first adopters and that amateurs would move more slowly.

After the initial blindness of the high level management to the relevance of this technology, Kodak needed several efforts in order to compensate the time lost: not only the culture of the company was resisting the new technology, but also the product development team lacked the skills necessary to develop products whose quality could match the ones already on the market. We conclude that rigidity of the organization was present at all levels. The resistance of the middle management against digital photography and their limited knowledge of that technology were only some of the challenges the company had to face.

Finally, the company managed to overcome most of the issues that limited its capability to develop a successful product; Kodak decided to create a separate unit, mostly independent from the rest of the company, a new manager was selected to lead the development efforts and new technical skills were acquired by employing new professionals.

Internal Factors

- Lack of technical skills in digital photography
- Company Culture, resistance towards the new technology
- Middle Management, lack of competences on digital photography
- High Level Management, initial denial of the successfulness of the new technology
- Organization, late creation of a separate unit
- Risk of ulterior delays

External Factors

- Competitors, actors in the market were already more mature
- Customers, adopted the new technology faster than expected

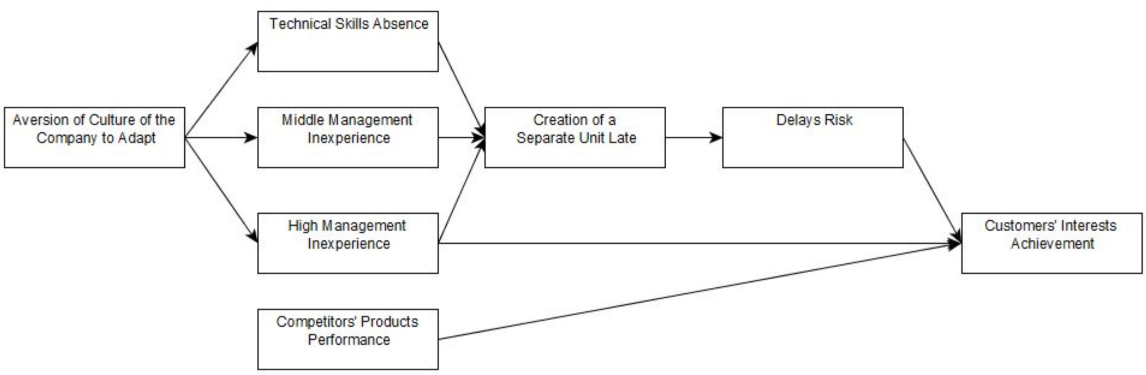

Figure 3: Kodak network

The Turbojet revolution

The turbojet (Constant, 1980) [20] can easily be recognized as a radical innovation not only because of the impact it had on the aviation market, but also because of the complexity of the knowledge needed to master the technology. Such knowledge had to be derived from several fields which at the beginning were considered not even coherent. For this reason, it is possible to state that the technology at the core of this case is founded on almost two centuries of studies.

Once completed, the technology at the core of the turbojet airplanes radically distinguished itself from the previous employed knowledge, not only in its technical aspects but also in its performance. However, the developed technology needed time in order to be consolidated and at the same time the present knowledge related to the rest of the airplanes was inadequate to support a turbojet engine.

Consequently, other technical problems where encountered once the technology reached a quite mature level. In particular, the aircrafts that employed this technology needed to have on one hand particularly aerodynamic shapes in order to sustain the power of the engines and, on the other hand, the turbojet engine required a fuel able to provide enormous amounts of energy.

Finally, important external influences affected the development and later the sustainability of the product. Even if the new technology was able to reduce drastically the time of long distance travels, it still had a very high cost and consequently a very high price for the customers. In addition, external social stakeholders were concerned with the product and in particular with its reliability.

Most of the problems related to the technical aspects were in general solved. A lot of efforts were employed throughout the entire life of the technology in order to mitigate the other issues mentioned earlier; however, such problems had never been solved completely.

Internal Factors

- Aggregation of complex knowledge coming from several fields of study
- Technology still not mature
- Definition of the complex dominant design
- Several patents needed to defend the technology
- Need for highly aerodynamic shapes of the airplanes
- Need for a new type of fuel for the engines
- High costs of the airplanes

External Factors

- Customers unsatisfied
- Social stakeholders’ concerns about the reliability of the product

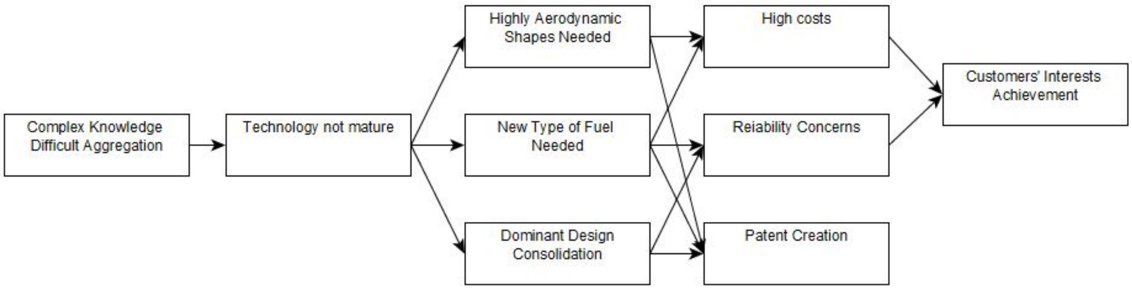

Figure 4: The Turbojet network

The Luminous Lamp

The fourth case study (Bijker & alter, 1995) [21] of this analysis is the one related to the development and commercialization of the electrical Luminous Lamp almost a century ago. The complexity of the product development is mainly related to the novelty of the technology that is at the base of the product. The first issue that the companies had to face was the initial difficulty in defending the product with strong patents and consequently to maintain a relevant position in the market. Once General Electric managed to acquire a dominant position, it had to face issues in the improvement of the product but also to defend it against external stakeholders. The entire American population was considered as potential customers, but most of the people still had to adapt to electrical products. In fact, even the acceptance of the new technology was not easy to handle.

Other important social stakeholders that the companies had to deal with, were the companies that managed the electrical utilities: when more efficient products were created, these companies showed their concern about a potential drop in the electricity consumption. This required extensive communication and negotiation in order to avoid such resistances against the innovative product. The case study describes the evolution of the product from its first design to the consolidation of a dominant design, even if it mainly focuses both on the social effects that such radical innovation brings and on the complexities of relating to a set of stakeholders that are unfamiliar with the new product. Peculiar in this case is that the company does not begin a learning process as a consequence of the difficulties presented. However, it is interesting to note what influences intertwined and how they originate from several actors both internal and external to the company.

Internal Factors

- High novelty of the technology
- Need for several strong patents
- Definition of the dominant design

External Factors

- Acceptance of the new technology by the customers
- Defence of the product against competitors
- Difficulty in maintaining a relevant market position

- Resistances of the companies producing electricity to efficient products

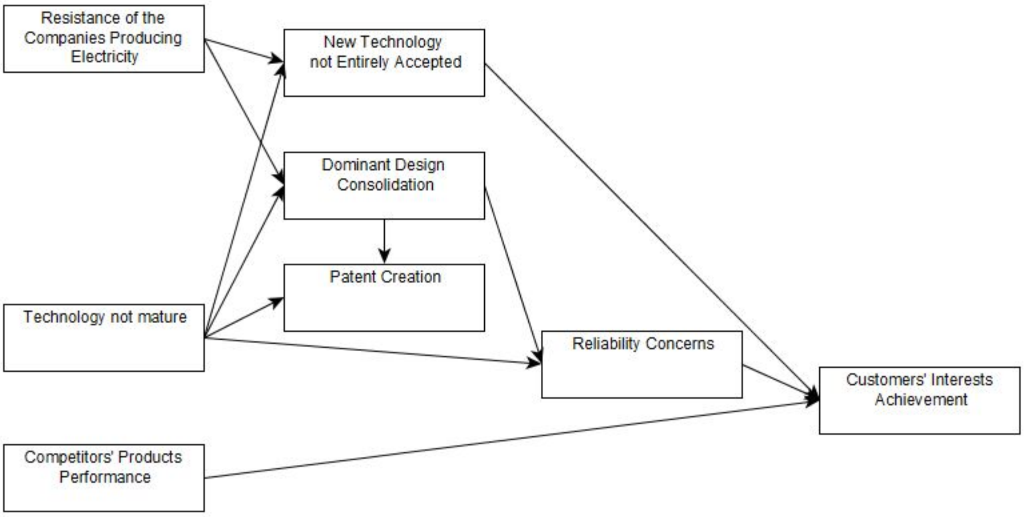

Figure 5: The Luminous Lamp network

Dual Clutch Transmission at Porsche

The final case (Ortt & alter, 2015) [22] considers a part of the development of the Dual Clutch Transmission (DCT) at Porsche. The DCT technology and the 969 Porsche car model are the focus of the last case considered in this research. While the DCT technology was initially developed in 1935 by a former Citroen engineer, it took several years for the technology to consolidate and to overcome several barriers that were limiting its application. In 1988 Porsche decided to apply DCT technology to its 969 car model. Many efforts were employed in order to develop the product, however after two years the prototype was cancelled.

"Firstly, the main potential market, the US, was suffering from an economic recession. So, the economic situation as an influencing factor created a barrier among potential customers. Secondly, the system was considered not reliable enough by the engineers. So, the knowledge of technology (influencing factor) was still insufficient to create a reliable product…". In fact, due to the lack of reliability of technology, the FIA as an institution banned the use of DCT in racing competitions. Additionally, it is important to underline that there were better technological alternatives at the time Porsche tried to implement the DCT technology in the 969 model; in fact, "the advanced automatic transmission systems with torque control were still outperforming DCT". All these reasons brought the company to disregard the still immature technology and consequently to interrupt its development.

Internal Factors

- DCT technology still not consolidated
- Reliability of the DCT technology
- Performance of alternative technologies

External Factors

- FIA ban of the DCT technology
- Economic Recession
- Customers potentially not able to sustain the price of the product.

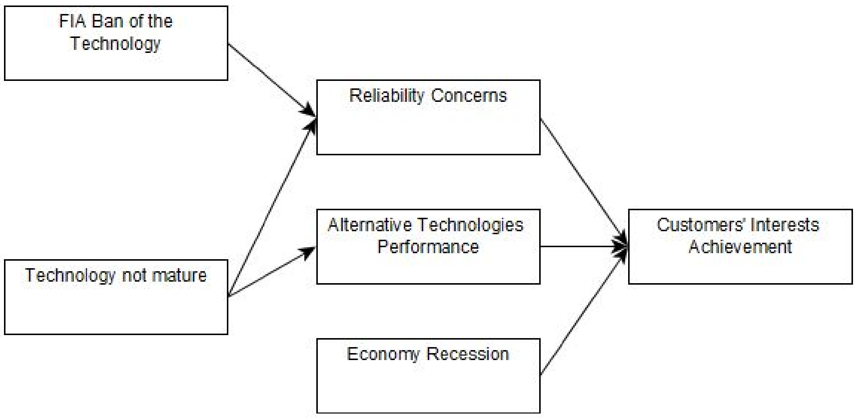

Figure 6: 969 Porsche model network

CONCLUSION

The secondary data analysis provides some interesting insights even if the case studies considered were not created for the specific purpose of this research. They enrich our understanding about how the effects of disrupting events have an effect on the product development processes in a company after the planning phase has ended. The literature does not clearly define the concept of disruption that is at the core of this research and, in some cases, it is applied to different field of studies (ex: disruptive technologies, Christensen). Additionally, the list of factors that have already been defined are bound to be incomplete since the list of potential causes that might lead to a disruption are both bound to the specific characteristics of a company and at the same time they might be unforeseeable. However, it is possible to refer to some recurring factors that are related to similar issues, while others seldom appear. Consequently, it appears to be more relevant to develop models that are adapted to the context of the case, each time a new set of factors is about to disrupt an ongoing product development process.

By considering the causal networks of the cases described in this research, it is possible to identify some recurrent patterns. It appears that there are three parameters that grant a first classification of the behaviour of the disrupting events: number of starting factors (single, multiple), number of ending factors (single, multiple), and number of intermediate nodes in the network (representing the complexity of the network). While the first two parameters describe the nature of a disruption, the third one identifies the complexity of the network; it is then possible to define a network as "standard" when it has a low number of intermediate nodes and as "complex" when the number of nodes rises. By combining the first two parameters, it is possible to envision four different scenarios (Table 2).

In a “Linear” scenario the disruption has a singular starting point and a final ending point. In this case it is possible to assume that the disruption is more easy to understand and that the difficulties related to it are highly relevant, even if the event was hardly foreseeable. In this context, the difficulty to recognize the cause – effect relations should be easier than the other cases, while the factors involved have intense consequences.

In an “Avalanche” pattern the causal network presents a starting point where a single problem unfolds into several different consequences that can potentially branch out even more, while in the “Condensed” pattern, several causes lead to a specific consequence. On the one side it is possible to recognize a starting node that emanates several edges (high outdegree), while on the other one we have an ending point where several nodes focus in a specific node (high indegree).

When it is not possible to recognize these standard patterns, the “Extended” scenario appears; the Boeing Dreamliner case, for instance, shows a more elaborated yet understandable pattern since there are two main starting points, compared to an “Avalanche” scenario that only shows a single cause. In fact, the additional complexity of this case is mainly related to the fact that there are two starting issues, one technical and one organizational; such consequences not only create a set of severe consequences, but also some of them interact.

There are several ways to classify a disruption (origin, conclusion, behavior, etc..). However, the matrix is able to enrich the definition and the classification of a disruption by describing and combining the main aspects that compose it. Additionally, such a model tentatively tries to enrich the starting definition of disruption, by envisioning sub-categories that fall under the main definition, but at the same time describe an additional degree of specification.

Table 2: Behaviour matrix of the disruptions

Number of Starting Factors	**Multiple**	“Condensed” Kodak Luminous Lamp	“Extended” Boeing 787 Dreamliner Porsche
	Single	“Linear”	“Avalanche” Turbojet
		Single	Multiple
		Number of Ending Factors	

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