ANALYSIS OF THE CONSEQUENCES OF DISRUPTING EVENTS ON ONGOING PRODUCT DEVELOPMENT PROJECTS: THE CASCADING EFFECTS OF SEVERE INFLUENCES

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ABSTRACT

The initial planning of the development of complicated products usually requires time and efforts. However, even the most accurate plans are not able to cope with all the uncertainties that might arise during an ongoing project. If a severe uncertainty affect the development project a critical situation arises and a disruption might happen. The present literature does not offer a comprehensive solution on how to investigate these type of events after they occurred. This contribution presents a model that aims to analyse and better understand disruptions that affect ongoing product development projects.

Keywords: Disruption Analysis, Uncertainty, Organisation of product development, Case study

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Cite this article: Guaragni, F., Ortt, R., Paetzold, K. (2019) 'Analysis of the Consequences of Disrupting Events on Ongoing Product Development Projects: The Cascading Effects of Severe Influences', in *Proceedings of the 22nd International Conference on Engineering Design (ICED19),* Delft, The Netherlands, 5-8 August 2019. DOI:10.1017/dsi.2019.113

1 INTRODUCTION

Progressively more dynamic environments and increasingly complicated organisations increment the need that companies have to plan product development projects more accurately (Gupta and Wilemon, 1990). However, plans cannot be ready for every potential disruption that might happen during the lifetime of the project either because disruptions are unknown or because plans cannot take into account all possible known disruptions. In the latter case, product development project plans would become detailed and precise and thereby lack the flexibility required to deal with disruptions that were not anticipated.

Additionally, in most of the cases, complicated products and sophisticated organisations are not entirely able to substitute plan-oriented approaches with agile practices; agile product development is still susceptible to constraints of physicality (Schmidt *et al*., 2017) and therefore its applicability is usually limited within the type of products and organisations previously mentioned.

However, plan-oriented approaches hardly cope with the effects of important uncertainties; it is not possible to always identify all the influences that are able to undermine development projects and to integrate in a plan all the potential deviations that might occur. In the long term, a company that employs structured plans is bound to face disruptions.

In order to analyse the effects of disruptions, this contribution is focusing on the following research questions:

- How is it possible to define a severe disrupting event that can undermine a development project? Which classification can clarify the differences among different types of disruptions?
- What are the factors that might cause a disruption in the activities of a product development project after the completion of the planning phase? Which factors can be distinguished? How is it possible to identify/classify these factors?
- What are the cause-effect relations among these factors? Which are the relations among the factors?

1.1 Managerial relevance

An organisationally complicated company tends to employ a decent amount of resources in order to prepare or prevent the occurrence or the effects of disruptive events in their projects (Clausen *et al*., 2001). However, the more influences that might happen are important, the higher the costs and the time to solve them might be and, at the same time, many efforts are employed in order to analyse, foresee and avoid such issues. Nonetheless, it is impossible to shield completely organisations and the development projects from the occurrence of disruptions for several reasons. For instance, the barriers against disruptions that the company has put into place can be too weak or present faults themselves, the type of severe influence that occurred might not be included by the present evaluations, or the event affecting the product development project is simply too severe.

1.2 Scientific relevance

"Uncertainties in decision and risk analyses can be divided into two categories: those that stem from variability in known (or observable) populations and, therefore, represent randomness in samples (aleatory uncertainties), and those that come from basic lack of knowledge about fundamental phenomena (epistemic uncertainties also known in the literature as ambiguity)" (Paté-Cornell, 1996). While both of them are potential sources of disruptions, the second one is potentially the most severe one once it affects development projects, since it is a priori more difficult to identify how acute its effects are; moreover, the literature considers more the nature and the effects of the first type of uncertainties rather than the second type. The Literature section of this contribution is going to elaborate more on these concepts.

1.3 Scientific gap

The present literature related to the disruptions that affect ongoing product development is divided in some fields such as product development, project management and, more in general, strategic management. The problem with these literatures is that they either try to analyse the problem with a too narrow scope or try to foresee "a priori" the cause and effect relationships during such events. It seems there is a lack of literature that aims to analyse disruptions with a comprehensive view that

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explores disruptions of ongoing product development projects by exploring the organizational and market environment of such projects (Clausen *et al*., 2001, Eden *et al*., 2000, Guaragni *et al*., 2017).

1.4 Focus and approach

The aim of this contribution is to better understand and analyse the effects of the cascading cause-effects relations that happen when a disruption occurs. Analysing these events can help to improve a company's capability to respond or prepare against the consequences of disruptions. Without a proper comprehensive analysis, it would be hard for a company to learn from a previous disruption and therefore only the people that faced such events directly might profit from the experience gained in solving the issues. Moreover, it is not always obvious which influence caused the severe events or it is not possible to recognise all the cause-events without a proper reflection.

Moreover, the lack of specific content related to this topic in the engineering literature led to the conclusion that analysing existing cases was a sensible choice.

Previous research (Guaragni *et al*., 2018, Guaragni *et al*., 2017) proved that by analysing cases in the literature, it is possible to better understand disruptions of ongoing product development projects. For instance, it is possible to classify disruptions not only by its initial causes (or influencing factors), but also by the behaviour of cascading events that occur during a disruption.

However, previous case analyses were limited, since the eligibility parameters where high enough to let most of the existing cases to be analysed. Most of them lack enough data to proceed with a more in-depth analysis.

2 LITERATURE

2.1 Uncertainties, critical situations, disruptions and crisis

2.1.1 The nature and the magnitude of uncertainties

Research by Paté-Cornell (Paté-Cornell, 1996) recognizes that in the development of a product there are two kinds of uncertainties: aleatory (description required between brackets here) and epistemic (basic lack of knowledge about fundamental phenomena). Uncertainties are always source for potential risks, since the lack of information can undermine the robustness of a plan.

Additionally, uncertainty can be related not only to the nature of a potential influence but also to the magnitude of its effects on ongoing product development projects. Consequently, uncertainty does not only lead to risks related to the lack of foresight on a potential event, but also to the lack of capability to recognize the full scope of the consequences; therefore, it might be possible that a product development team might recognize a threat but not the full extent of its effects.

2.1.2 Large organizations and types of uncertainties

A research conducted by O´Connor and Rice (O'Connor and Rice, 2013) clearly state that "uncertainty cannot be ordered or contained, but that it can, in fact, be handled within large established organizations much better than is currently happening. "The same research describes a framework that aims to distinguish which type of uncertainties exists. It identifies "... four categories (market, technical, resource and organizational categories of uncertainty) and three dimensions (uncertainty category, latency and criticality) … they offer scholars a framework within which to further theory development and they offer managers a framework for recognizing the challenges of project management in the RI (radical innovation) context and an approach for preparing project managers appropriately".

Among these dimensions, criticality appear to be the most important selecting factor for the purpose of this research. As previously mentioned, in the field of product development, some events are able to simply interfere with the "Routine" of the ongoing development projects; in these situations, the original plan can absorb an uncertainty with minor changes when it appears.

However, serious problems arise when uncertainties are so relevant that the effects of their occurrence can interrupt the development efforts. When such "Showstoppers" appear, the original plan becomes usually obsolete and the normal development processes is seriously affected. This scenario can be described as a critical situation.

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2.1.3 Critical situations

The concept of critical situation is quite generic and refers to a huge variety of situations that are not to be considered common, which require new relevant choices since the normal organization involved, the normal processes or the standard decisions are either incapable to respond or simply obsolete. However, "…any situation, in which an important decision has to be made, is considered critical. The outcome of this decision can be either positive or negative." (Badke-Schaub and Frankenberger, 2013).

In contrast with the concept of a critical situation, it is possible to consider as common every situation in which it is not possible to recognize important variations from a predetermined plan or already defined organization. While it is not possible to recognize a priori all critical situations, it is true that the more uncertain a specific context is, the more likely it is that a critical situation will appear.

Within the context of this research, the term "critical situation" most of the times has a negative meaning since the consequences of such occurrences in the development of a product usually require an additional expenditure of economic resources (time, costs, etc…) or, in the worst case, it escalates in a scenario where it is not possible to proceed.

Nonetheless, not all these occurrences are the same, in fact a critical situation, for instance, always has the consequence of interrupting a process; without adaptations of the original development plan, it is not possible to proceed with the process and therefore this originates the need for new relevant decisions. Additionally, not all these events have the same severity, since the importance of the consequences of critical events may vary greatly depending on what has occurred; it is possible to distinguish further between "disruption" and "crisis".

2.1.4 Disruptions and crises

The literature tends to describe these two phenomena in a similar way and sometimes it appears that their meaning is completely overlapping. Even though it is difficult to distinguish the terms, it is possible to define at least a couple of aspects that might be able to support the distinction. For instance, the main difference between these two occurrences is the severity of the consequences of these events. In particular, when referring to a product, it is possible to "… consider as a disruption every influencing factor that might strongly interfere with the development of the products or severely compromise their success on the market" (Guaragni *et al*., 2017).

However, when such influence is so severe that the premises of the development itself are compromised and the scale of the critical situation might reduce the priority of resuming the development process too much, then the situation escalates into a crisis, since the situation might have become so complex that the priority of the company could be survival itself. For instance, many natural catastrophes create such severe consequences that not only the development of the product but the entire company might cease to exist.

2.2 Product development

In the product development field, most models and the related literature focus on analysing and solving technical issues regarding the product or its development process. The Failure Mode and Effects Analysis (FMEA) (Stamatis, 2003) and the Fault-Tree Analysis (FTA) (Lee *et al*., 1985) are important examples of these efforts. The FMEA is a bottom-up model that examines the failure modes of the components within a system and seeks the potential consequences of each component failure mode on the performance of the larger system.

On the other hand, the FTA is a top-down approach that focuses on the identification and analysis of conditions that lead to the occurrence of a particular effect. The field of deviation management mainly aims to understand how it is possible to either bring a project in line with the original plan or how to adapt an existing project once an unforeseen technical problem appears. While these efforts are indeed relevant, they do not fully describe the complexity of the effects of a disruption.

2.3 Project management and risk management

Assessing potential threats and the relative impacts on projects 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 (Hillson and Hulett, 2004). The typical matrix employed with this orientation is the risk matrix, which has two axes: probability and impact. A few models are employed in project management. One of

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them is the Ishikawa model (usually referred to Fishbone too, due to its typical shape). “Its purpose is to organize and display the interrelationships of various theories of root cause of a problem” (Juran and Godfrey, 1999). This qualitative type of network is frequently used when it is important to understand how several different roots unravel intro a single problem. This type of network hardly copes with the degree of complexity that usually is typical of disruptions: there might be more than one problem and therefore analysing only one “root” would be very limited.

2.4 Strategic management

In the field of strategic management, the Weak Signals theory (Ansoff, 1980) states that discontinuities show warning signals prior to a disruptive event and consequently this theory focuses on the detection of such signals before their disrupting consequences become manifest. Foreseeing important issues is certainly an efficient way to avoid disruptions. However, recognising disruption before they escalate is not always possible since it is hard to completely understand the real impact of potential threats. Moreover, in some cases, even when it is possible to foresee an important critical situation, it is not possible to completely avoid or mitigate its effects. Coordination theory (Malone, 1990) is a “body of principles about how activities can be coordinated, that is, about how actors can work together harmoniously”. Such a theory “like other interdisciplinary fields that arise from the recognition of commonalities in problems that have previously been considered separately in different fields” describes the intrinsic need of coordinating organizations' activities in order to complete complex tasks.

2.5 Psychology

As mentioned in the introduction, the disciplines described so far lack a comprehensive understanding of disruptions that affects ongoing product development projects. Most disciplines focus on specific aspects of the disruption or try to foresee its occurrence. On one hand, the scope of disruptions tends to affect many parts of the company and consequently disruptions usually escalate outside the boundaries of a specific project; on the other hand, it is impossible to foresee the occurrence of all of them.

In the field of psychology, the Swiss Cheese Model and the Tripod Theory of Accident Causation recognise that disruptions often originate from an interaction between outside events and internal company characteristics.

The Swiss Cheese Model (Reason, 1990, Reason *et al*., 2006, Reason, 2016) describes that organisations normally have to face the effects of influences that threaten their ongoing activities and that they consequently prepare “layers of defence” in order to avoid or mitigate the negative effects of such influences.

However, organisational structures and their defences are not perfect and consequently they still allow the occurrence of accidents. In particular, this model recognises two main type of failures: latent failures (such as organisational weaknesses) and active failures (such as errors or violations).

This model has been concretized in the Tripod Beta (Doran and Van Der Graaf, 1996), an incident and accident analysis methodology that supports the investigation of the consequences of negative events that affect an organisation despite its barriers; this methodology is divided into three sections that answer related questions: What happened? How did it happen? Why it happened?

These contributions and the literature of the previous sections provide the foundation for developing our own model in the next sections.

3 MODEL

A previous secondary data analysis (Guaragni *et al*., 2018) showed which information is required in order to create a model that is able to describe the unravelling of the events related to a disruption affecting an ongoing product development project.

Moreover, for the purpose of this research, it was considered adequate to use network theory in order to describe and analyse such events. Network Theory has the advantage of representing systems of any size and complexity in a relatively simplified way.

Moreover, it is possible to compare different cases from the same company or different companies with the proper premises and limitations. Finally, some types of networks are specifically designed to represent complicated cause-effects relations.

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As mentioned before, it is possible to find in the literature applications of network analysis in the context of product development (Latour, 1996, Latour, 2005). These applications are in general quite limited and do not cope with the issue that is at the core of this research.

The research conducted so far and the literature hint us that there are some minimum requirements that are needed in order to complete an “a posteriori” analysis of a disruption affecting an ongoing development project; therefore, it is possible to identify which characteristics and pieces of information are relevant in order to build the model.

On one hand, among the characteristics that are relevant, the model should aim to describe both the detailed flow of the events that cause the disruption of the project while describing the complicated relations among the issues that occurred; compared to a generic accident, a disruption is more complicated and the issues that affect the development project might be many and quite intertwined one another. Moreover, the model should not only trace these cause and effect relationships forward, but also retrace the cause-effect relations backward; the purpose of this characteristic is that the model must describe the sequence of the cascading events while being able to uncover latent issues that might weaken the robustness of the organisation.

On the other hand, the model requires at least the following pieces of information: the project plan, a quite detailed organisation chart and the network of the issues related to the disruption of the ongoing development. One of the premises of the research is that a project plan is formed prior to the development project. We explore the situation that a severe influence affects a previous development plan. This plan may usually present different degrees of detail from case to case, but at least it should be possible to describe the flow of the main development stages like in a GANTT chart, for instance. Secondly, it is important to recognise the organisation chart of the company that is at the centre of each case with particular attention to the sections that are affected by the disruption itself. Finally, the network of the issues describe which events contributed to the occurrence of the disruptions and how one is related to another. In an optimal state, it should even be possible to quantify the relevancy of the issues and the importance of the relations that they have among themselves. The combination of these three major pieces of information should lead to a detailed description of where the plan is affected, which issue is influencing directly or indirectly the project and who in the organisation is affected.

4 METHODOLOGY

For the purpose of this contribution, it seemed sensible to analyse an existing case in order to consider how the model described in the previous paragraph has to be applied.

On one hand, it is prudent to proceed with a case already existing in the literature before proceeding with a direct empirical gathering of data, since it is important to verify and, if needed, improve the robustness of the model.

On the other hand, it is quite difficult to find existing cases that fit adequately the purpose of this research, therefore there are few examples that can be used and most of the time the information they contain is lacking for the purpose of this research. The Boeing 787 Dreamliner case has the advantage of describing a highly complicated situation in detail while keeping a good amount of knowledge regarding the overall disruption that occurred during the development process.

5 RESULTS

The Boeing 787 Dreamliner case (Tang *et al*., 2009) is very interesting for the purpose of this contribution for two main reasons. In fact, the company decided to implement a new supply chain system and to apply to its product important technological innovations regarding composite materials in airplanes.

Moreover, the complexity of the disruption that occurred was fuelled both by several direct issues and by latent weaknesses that were different in nature, origin and severity. The authors of the case describe the events quite in detail and, for this reason, it is possible to recognise the high-level GANTT chart of the project (see Figure 1).

Figure 1. Project GANTT – Boeing 787 "Dreamliner"

It is clear that the partial decentralization of the supply chain led to an "externalization" of part of the project. As mentioned, this decision reduced the strain on the company in terms of efforts to manage all the suppliers, but at the same time lowered the capability to coordinate directly the suppliers and leaving this responsibility mainly to the Tier 1 suppliers. On the other hand, the case does not describe in depth the organisational structure of the company at the time of the disruption and the related information is therefore limited. However, there is an in depth description of the change in the structure of the supply chain: the company moved from a very centralized structure to a decentralized one with Tier 2 and Tier 3 suppliers. This change was pursued for three main objectives: Tier 1 suppliers had the duty to deliver entire parts of the final product (not just single components), the internal organisation of the Boeing company had to manage and coordinate a reduced amount of suppliers, assembling the final product was planned to require only three days (with the previous supply chain structure, this process lasted 30 days). After the recognition of the organisational structure and of the planned steps of the projects, it is important to recognise the issues that contributed to the disruption of the ongoing development project (See Figure 2).

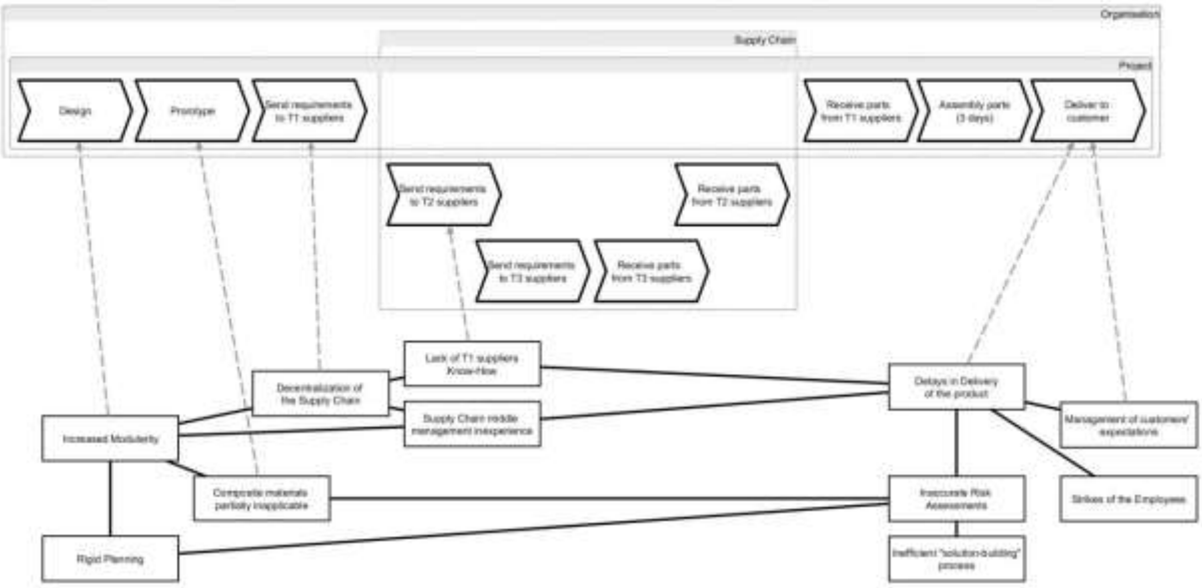

Figure 2. Issues network

The main technological innovation of the product compared to its predecessors was the introduction of a new composite material that should have presented several improvements: faster cruising speeds, cost savings, increased comfort and fewer delays due to mechanical problems. However, when the development team moved from the prototype to the realization of a complete product, the application of the composite material resulted to be mostly unfeasible. At the same time, the supply chain resulted to be much more efficient in normal situations, yet more vulnerable to disruptions.

When it was clear that the technological issues related to the employment of the composite material became obvious, the development team started to redesign the product and to change the original plan. However, both understanding the problem and changing the design required extensive time and resources. These efforts became even more relevant for a set of reasons: the risk assessments prior to the development of the project were inaccurate, there was a lack of planning in terms of how to build a

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solution in case a severe event happened and, finally, the company did no longer have the possibility to directly manage all the suppliers and had to rely on the new actors of the supply chain in order to solve the issues at hand. Ultimately, the company had to manage the customers' concerns about the quality of the product and to justify the potential delays in the delivery of the products. The information that is possible to extract from the Boeing 787 Dreamliner case has mostly been described in the previous sections and the only way to proceed further with the analysis would be by inferring in the model at the core of this research more pieces of information that have not been explicitly described in the contribution by Tang *et al*. For instance, by considering the insights gathered from the Swiss Cheese Model, it should be possible to "retrace" the logical links among Active Failures, Preconditions and Latent Failures that occur among the parts of the network of the issues (See Figure 2). However, the network of issues presents both failures and events that were part of the cause of the project disruption. For instance, the strikes of the employees might be in general mistaken as an external event, while it is possible to identify them as an Active Failure because of internal company and supply chain issues. The case mentions that the cause of these strikes were generated by the increased fear among the employees to become jobless because of increased externalisation. It is likely, that the organised strikes, that lead to the cancellation of some order by the customers, was caused by an increasing dissatisfaction among employees (See Figure 3).

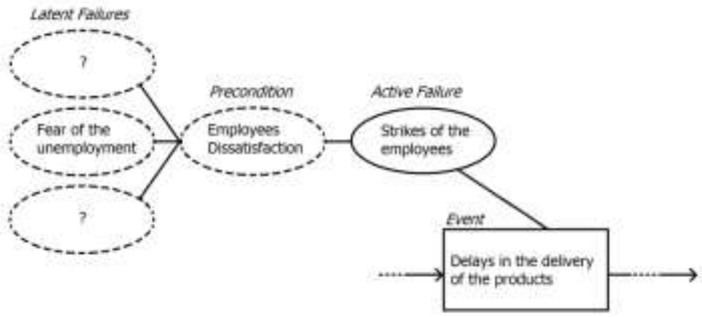

Figure 3. Example of logical chain of failures

In this context it might be correct to assume that the Precondition of the employee strikes could be the dissatisfaction of the employees and that the Latent Failures could be more than one (externalization of the supply chain) and that, therefore, the labour risks were even more miscalculated. If one would consider this deduction as correct, then a strict original plan could be considered overly optimistic and that to proceed with such a radical change in the supply chain with unhappy employees would alone become source of a potential disruption, even without the technical issues related to the difficulties in the adoption of the new materials. While the representation of this example (See Figure 3) is possible alone, it would be overly optimistic to depict in the same representation the entire causal chain of the events related to the disruption, all the relations among the different failures and all the specific impacts that these failures had on the ongoing development project. The next paragraph is presenting a potential solution to this problem.

6 CONCLUSIONS

The authors of the Boeing 787 Dreamliner case described in depth most of the aspects of the disruption that affected the company, but their perspective was mainly anchored to the supply chain management problems and what it meant in facing the adversities that were caused by the infeasibility of the original development plan. It is clear that the situation escalated not only from a singular cause and that it was created by a combination of different important issues that together became unsustainable and led to a critical situation: the current plan became at least partially obsolete and a set of important decisions became necessary due to the severity of the situation. This illustrates that when a disruption occurs, a detailed description of the problem can improve the understanding of the effects of a disruption beyond the simple distinction of its cause and effects. The representation through networks can give a detailed and comprehensive view on the severe events that unfold while keeping a proper amount of precision in its description. The analysis of the consequences of an already happened disruption might improve the capability of a company to respond to such events in the future. Moreover, the use of networks supports the possibility to compare one case with another in a simple

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yet effective way. For instance, by comparing different cases in a specific product development department and the related organisation, weaknesses in that department and organisations are recognised that might be dealt with during other important influences in the future. Moreover, for instance, such analysis might reveal potential organizational weaknesses or vulnerabilities and consequently support decision making processes in future changes of an organization. The model described in this contribution could support the understanding of the behaviours of disrupting and not only to identify the initial causes of the problem. By studying the Boeing 787 Dreamliner case, it is clear that the investigation model at the core of this contribution requires further improvements. For instance, as mentioned in the model section, the model should aim to describe both the detailed flow of the events that cause the disruption of the project while describing the complicated relations among the issues that occurred. The complexity of the complete description of a disruption that affects an ongoing development project might be as a whole too difficult to depict with a singular representation. Therefore, the full description of the events might require the combination of two different perspectives: a longitudinal perspective and a cross-sectional perspective (See Figure 4).

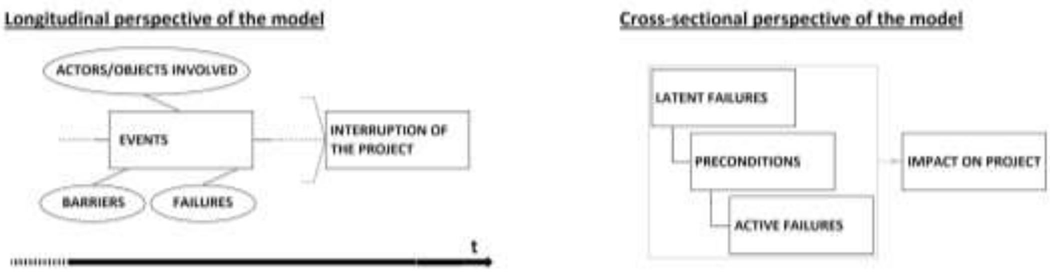

Figure 4. The two perspectives of the model

The longitudinal one is built with the purpose of representing the flow of events that lead to the interruption of the project. Every event can be enriched with some additional details: actors or objects there were involved, barriers that the company had put in place to avoid interruptions but were unsuccessful, the failures that lead to the specific event. The cross-sectional perspective aims to represent the impacts that the severe interruption had on specific parts of the development project. This perspective aims to clarify the cause-effect relationships among the failures, how they intertwine and, finally, how they impact the project plan. The longitudinal representation of the timeline of events that occurred has several ways to be depicted. Normally, models represent these type of phenomena in the shape of a tree. However, this might not necessarily be true in this model. While the disruption of the ongoing development project is clearly one of the final events represented in this chain of events, it might not necessarily be the only one. Further study of this perspective might lead to classify the behaviour of the interruptions on ongoing development projects. The cross-sectional perspective differentiates from the longitudinal one mainly because it does not imply time in its structure, it fact it describes an overview of the factors with a possible impact on an ongoing development project. For instance, latent failures might be implicit weaknesses in the organisation that become exploitable in specific conditions, therefore, they create preconditions that do not necessarily create real consequences in normal activities, but might only "activate" when an anomaly occurs. The two perspectives are not mutually exclusive alternatives, yet they complement and enrich each other. Consequently, they together belong to a single model since without one of them the other would lack important information relevant to understand the interruption that affected the ongoing development efforts.

7 DISCUSSION

The application of the model is limited in the proposed case since it employs secondary data that was not gathered for the specific purpose of the present research and, additionally, it focuses more on a specific part of the overall problem (the supply chain management issues). For this reason, some important information is lacking. Even though there was enough data to represent the network of the issues in detail, it is true that some information related to the GANTT had to be inferred, while the organisational structure of the company is mainly missing. Most of the cases that are present in the literature have similar problems and usually focus only on specific aspects of the disruption that affect

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ongoing product development projects; they lack a comprehensive view on the problems. Even if it is not always possible to solve the entirety of the consequences of these events within the development team, it is still important to analyse past problems in order to better prepare against future ones. It is consequently clear that the only way to improve further the model is to acquire direct empirical data on disruptions that companies faced in the past. With more information on the cases it might even be possible not only to represent the network of issues and its relation to the project phases, but also recreate

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