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EVALUATING THE FAILURES CRITICALITY IN COLLABORATIVE DESIGN WITH SUPPLIERS

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ABSTRACT

Innovation helps companies to increase their competitive position. Suppliers are an important source of innovation. Thus, successful collaborations with suppliers in New Product Development (NPD) can lead to competitive advantage and many companies try to involve suppliers in early stages of their design process. Potential benefits of Early Supplier Involvement (ESI) for collaborative design do exist only if this practice is managed effectively. However, such factors as low level of trust between buyer and supplier or inappropriate selection of the supplier can have negative impacts on ESI and lead to unsuccessful projects. It is obviously necessary to identify potential failures in collaborative design with suppliers impacting project performance. This paper describes the development of a criticality assessment of those failures obtained through literature results, collaborative work with 2 NPD project teams of a French company and an academic-practitioner consortium. The method proposed enables to tackle potential failures in future projects and to reduce costs by identifying improvements early in the development process when changes are relatively easier and less expensive.

Keywords: new product development (NPD), collaborative design, early supplier involvement (ESI), risk management

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1 INTRODUCTION

Most manufacturing enterprises widely recognize that New Product Development (NPD) is a core process that has a major role to play in achieving their competitive position (Clark and Wheelwright, 1995; Womack et al., 1990). Across all worldwide manufacturers, purchased materials account for over 50 percent of the cost of goods sold (Handfield et al., 1999). Suppliers have then a large and direct impact on the success of the NPD (Bidault et al., 1998). Thus, technology and international competition are forcing many manufacturers to make better use of the supplier's technological skills at the early stage of NPD in order to reach both more productivity for the R&D activities keeping in-house and an extended spectrum of technologies to include in the future final products (Brem and Tidd, 2012). A large range of papers has identified the benefits of Early Supplier Involvement (ESI) on product development performance measured by shorter time to market, improved product quality and reduced development costs (Bidault et al., 1998; Van Echtelt et al., 2008). However, potential benefits of ESI for collaborative design do exist only if this practice is managed effectively (Bidault et al., 1998; Monczka and Trent, 1997). Such factors as low level of trust between customer and supplier, inappropriate selection of the capable supplier, poor communication of co-ordinating mechanisms can have negative impacts on ESI and lead to an unsuccessful project (Eisenhardt et al., 1995; Wynstra, 1998). It is therefore important to conduct a broad analysis of the potential failures that can arise within a collaborative project of product development between customer and supplier. This analysis is similar to a risk analysis. An important work is dealing with risk analysis in existing literature. In engineering design literature, this work is more oriented on product and process development risk than on risk analysis concerning customer/supplier relationship. Thus, Wagner (2007) studied specification risk analysis for product development; Lough et al. (2007) focused on risk assessment in early design stages; Stamatis (2003) identified several types of risk analysis tools in the design and manufacturing process; Otto & Wood (2001) proposed risk assessment scales for NPD. In management science literature, existing work deals with supply risk management both in the academic discourse as in practical application (Hoffmann et al., 2012; Zsidisin, 2003). However, despite a wealth of research dedicated to risk analysis and risk management, previous studies have not fully explored the ESI context apart, for instance, from the study of Fliess and Becker (2006). These authors expressed their willingness to control the process of collaborative development with suppliers by trying to monitor the interfaces between the two partners among the development.

Managing ESI requires managing failures between customer and supplier occurring in this practice. A risk management analysis consists of several stages. Different authors mention different risk management stages, but basically the following stages can be identified: risk identification, risk assessment, risk management and risk monitoring (Hallikas et al., 2004; Mullai, 2009). In this respect, the failure management analysis in ESI includes the identification of the potential failures, the measure of their criticality regarding the performance of co-development project and the definition of their causes to implement the actions required to avoid them. In a previous work, we have conducted the first step by proposing a classification of the potential failures encountered in a co-development project (Personnier et al., 2012). This classification has been supported by evidences from literature and feedbacks from practitioners. In this paper, we are focusing on how to assess the criticality of the failures proposed in our classification. The aim is to reduce the likelihood of deviations regarding the objective the collaborative NPD with a supplier should achieve.

This paper is organized as follows: the first section presents the background of our work, with our classification of failures in collaborative NPD with suppliers and an overview of existing criticality assessment in literature. It then describes the methodology adopted. Subsequently, based on a cyclical process between practice and analysis of literature, the development of the failure criticality assessment proposed and its application in a real setting are explained. Finally, some conclusions are drawn and we discuss managerial implications.

2 BACKGROUND

2.1 Classification of potential failures in collaborative design with suppliers

Our previous research work enabled us to draw an important list of failures observed in collaborative design with suppliers. Some of them were presented at the previous ICED conference (Personnier et al., 2011). In order to try to tackle those failures, a failure classification was defined (Personnier et al., 2012). The failures classes refer to key activities necessary to build and manage the collaboration between the two partners. The aim is to identify the critical activities during such collaboration. Table 1 presents this classification (23 sub-classes gathered in 6 classes) obtained thanks to a cyclic process combining literature results and empirical data. The practitioners mobilized for the development and validation of this classification are issued from the same companies mobilized for the elaboration of the failures criticality assessment presented in this paper.

Table 1. Proposition of a classification of failures in NPD with suppliers

Sub-classes	**Classes**
• Strategic alignment: motivation; goal convergence • Technological alignment • Relational alignment: mindset (industrial or culture); trust	① Alignment between both companies
• Criteria for the choice • Competences needed • Joint decision for the supplier choice	② Supplier choice and status
• Decision power distribution • Confidentiality agreement • Deliverables • Intellectual property • Detailed planning • Contract redaction	③ Contractual coordination
• Technical content • Optimisation of product cost • Specifications • Requirements • Supplier participation in the specification process	④ Specification process
• Roles and responsibilities • Project management • Internal collaboration	⑤ Procedural coordination
• Interpretation and understanding • Information sharing and lessons learned • Internal and external communication	⑥ Communication

The definition of each class of failures is given below.

① Alignment between both companies: The alignment can take the form of strategic alignment (motivation and goal congruence), technological alignment or relational alignment (Emden et al., 2006; Evans and Jukes, 2000). Relational alignment refers to alignment of mindsets (industrial or cultural) and to trust (Sako, 1992). Alignment of mindsets is not synonymous to 'similarity of mindset' as pointed by (Lam and Chin, 2005): "*With the mindset that certain conflict could be beneficial, clients and suppliers are apt to express their judgmental differences for improving decision making, which also fosters cognitive conflicts and thereby leads to better NPD performance*" (p.764).

② Supplier Choice and Status: This class refers to the question of how the supplier was chosen and for what skills (supplier status). The supplier status is one of the outputs of the "*Design-or Buy-Design"* decision-making process. It refers to the situation of supplier involvement decided by the project team; black box, grey box or white box engineering (Handfield et al., 1999). Once the supplier status defined, what are the relevant criteria for choosing the appropriate supplier? The supplier choice and its status in the collaboration might be characterized by a joint decision (Le Dain et al., 2010).

③ Contractual Coordination: This class is inspired from (Sobrero & Schrader, 1998). It refers to the negotiation between customer and supplier about issues to be included in the contract (confidentiality agreement, deliverables expected from both parts, intellectual property, detailed planning).

④ Specification Process: This class refers to the specific problems mentioned by (Karlsson et al., 1998) in their study of automotive suppliers related to the technical content, the requirements, the product cost, and the participation of the supplier in the specification process.

⑤ Procedural Coordination: This class is inspired from (Sobrero and Schrader, 1998). It refers to the coordination of the activities of the partners in the collaboration to achieve the objectives of the project. The authors argue that "*the higher the level of task uncertainty, the greater the need for procedural coordination*" (p.592).

⑥ Communication: Communication problems might be the outcome rather than the cause (Maier et al., 2009). In this class, we consider the communication failures as symptoms of, for example, lack of information sharing and lessons learned, differing interpretation and misunderstanding between actors. Previous research has stressed the central role played by inter-firm communication (Dyer, 2000; Petersen et al., 2005)

2.2 Failures criticality assessment: Evidences from literature

Due to time and resource limitations it is not possible for firms to monitor all the risks they face. Companies are forced to make a scoring of risks to tackle the most critical ones (Hoffmann et al., 2012). A risk assessment is also necessary to anticipate and prevent accidents from occurring or repeating rather than simply responding to failure events (Lough et al., 2007). Several risk assessment techniques exist such as fault tree analysis, event tree analysis or event sequence diagram (Lough et al., 2007) but the most famous and the most used in product development is the Failure Modes and Effects Analysis (FMEA) (Lough et al., 2007; Wagner, 2007). FMEA represents a proactive risk analysis technique where potential failure modes are systemically identified before they occur (Lindemann, 2006; McDermott et al., 1996; Otto & Wood, 2001; Stamatis, 2003) and especially "*before it is too late to do anything*" (Baxter 1995, p. 294). According to Wagner (2007) who conducted a detailed study concerning FMEA and risk analysis, the nature of risks and quality issues with FMEA is very similar. FMEA follows the same procedure as the different risk management frameworks in product development, project management, and supply chain management. Thus, this author considers that the general idea and framework of an FMEA may be adapted successfully to NPD. Following Kaplan and Garrick (1981), a quantitative definition of risk consists of a set of triplets: the scenario i.e. when the failure happens, the probability of occurrence and the severity of the consequences. However, risks with a probability of occurrence of 100% are no longer uncertain and hence became problems that have to be tackled (Gluch, 1994). For this reason, a failure has to be regarded as a problem (Wagner, 2007). In FMEA, the failure criticality named Risk Priority Number (RPN) is evaluated via three parameters (Figure 1): the severity of its consequences, the likelihood of its occurrence and the probability that the failure is detected before the impact of the effect is realized (Wagner, 2007 based on Otto and Wood, 2001). Most authors suggest a 1 to10 rating for the assessment (Baxter, 1995; Lindemann, 2006; McDermott et al., 1996; Otto & Wood, 2001; Stamatis, 2003). The assessment scales can be based on existing failure data (McDermott et al., 1996, p. 27). According to Lough et al. (2007), risks assessment highly depends on the context. A definition of scales does not eliminate numerical subjectivity but attempt to reduce subjectivity by providing complete definitions for each ranking. The FMEA should also be applied within a team, between different departments or even companies. It establishes a common language, provides means for the communication, and reduces misunderstandings (Wagner, 2007).

RPN	=	**S**	x	**O**	x	**D**
Risk Priority Number		*Severity Rating*		*Occurrence Rating*		*Detection Rating*

Figure 1. FMEA Assessment according to Otto and Wood (2001, p567)

Based on this background, the research question can be raised: how to evaluate the failures observed in collaborative development with suppliers? To provide some clues to this question, two related questions must be addressed: How to adapt the three dimensions of criticality assessment to a context of collaborative development? And how is it possible to carry out this assessment within a project?

3 RESEARCH METHODOLOGY

This research results in a proposition for assessing the criticality of potential failures in collaborative NPD projects with suppliers with a view to improving the success of the collaboration. This ambition was consistent with the aim of engineering design research which is supporting industry by developing knowledge in the form of guidelines, methods and tools that can improve the likelihood of producing a successful product (Blessing and Chakrabarti, 2009). To reach this ambition, collaboration with six companies was set up to develop the failures criticality assessment presented in this paper. Yin (1994) states that when investigating events that may have little or no theoretical background, the researcher may select an exemplary case that provides the best example of a phenomenon. The companies selected fully meet this criterion. They seek to better use the supplier's technological skills at the early stage of their product development projects and thus expressed a willingness to improve their practices and hence reduce the risk perceived by their project teams regarding supplier involvement in their design activity.

The participation of practitioners and researchers in the development of the failures criticality assessment was performed in the two following manners: At first, an exploratory-qualitative academic-practitioner workshop was set up with 8 participants from 6 companies working in purchasing or R&D departments (Table 2) and the 3 authors of this paper. The target of practical applicability of the results of this study justified the use of an academic-practitioner collaborative work (Hatchuel, 2001). These practitioners were selected because they are directly in contact with the suppliers integrated in product development. Secondly, a close collaboration with Company C4 was carried out. The first author collaborated with two NPD project teams, currently in charge of two specific co-development projects with suppliers. Each team is a cross-functional team of fifteen people including project purchasing managers, designers, and quality and project managers. The first author conducted 4 workshop meetings of two hours with each of the two project teams within a period of 3 months to collect data about criticality assessment of failures and apply the resulting proposition. Multiple data-collection methods were used including verbal and written feedbacks.

Table 2. French companies who attended the academic-practitioner workshop

Company	Job position of the participants	Industrial sector of the company
C1	Purchasing manager	Automotive
C2	Brand labelling purchaser	Energy management
C3	Packaging director	Cosmetics
C4	- Corporate purchasing director - R&D manager	House solutions
C5	- Commodity manager - Supply quality manager	High-Tech optics
C6	CEO	Selective sorting for health, security and environment

The research with the companies was conducted over two phases:

- *Phase 1: Development of the criticality assessment*

From literature review results on criticality assessment, the 3 dimensions (severity, occurrence and detection) were adapted by the researchers to the specific case of collaborative NPD with suppliers and a first framework was obtained. This framework was presented during the workshop we organized with the practitioners. They were asked to give their opinion about the definition proposed for the 3 dimensions. By taking into account their feedbacks, we devised a failures criticality assessment. Then, we discussed this proposition of assessment with the 2 project teams at Company C4. This collaborative work with the companies led to a preliminary proposition.

- *Phase 2: Application of the preliminary proposition*

The preliminary proposition was tested with the two project teams of Company C4. The first project team is in charge of the development of a new roller shutter motorization with a collaborative development of the external connector supplying the power to the motor. The second one is in charge of the development of a touch panel in collaboration with a supplier. The preliminary proposition of assessment was applied to these two case studies during workshop meetings conducted by the first author who was thus able to observe the difficulties encountered. The team members were asked to assess the criticality of failures issued from the failures classes presented Table 1. This assessment has been performed as a cross-functional team exercise to benefit from group discussions and create a common language (Wagner, 2007). Corresponding scales for each criticality dimensions were also discussed and built together with the two project teams. All remarks were taken into account for the elaboration of the final criticality assessment.

4 DEVELOPMENT OF A FAILURES CRITICALITY ASSESSMENT

4.1 Framework for a criticality assessment of the failures adapted from literature

The departure point for the development of an assessment of the criticality of failures occurring in collaborative NPD with suppliers was an adaptation of the classical assessment (Figure 1) to the specific case of collaborative NPD with suppliers. We thus proposed the three following dimensions:

The *Severity*: According to Oehmen (2005) who reviewed the work of Hall (1998), Smith and Merrit (2002) and Stamatelatos (2002), the *severity* of a failure embodies the severity of the impact. The definition applied to our situation is thus the importance of the impact on the project performances. Indeed, the goals of product development are to achieve the targets of high product quality, low product and development cost and short development time (Ulrich and Eppinger, 2003). Some authors also consider the innovation in project performance (Koufteros et al., 2007; Gemünden et al., 2005). Therefore, the impact of a failure due to the supplier integration in NPD will be regarding the main performance project pillars which are cost, quality, time and innovation. Regarding this notion, Le Dain et al. (2011), who studied the performance of the relationship between customer and supplier in NPD, talked about *efficacy*. Moreover, to be coherent with Ouchi's theory of governance mechanisms (1980), these authors introduced the notion of *efficiency*. Indeed, according to Ouchi (1980), when the relationship with the supplier is more complex than a traditional subcontracting, only assessing the *efficacy* is not sufficient. Our research considers collaboration with supplier for a product development. The notion of *efficiency* of the supplier who has to use its project resources in an appropriate manner to achieve the objectives should thus also be considered. Consequently, in order to be efficient, the collaboration has to be managed in an appropriate way which requires appropriate communication means, information sharing, mutual understanding and cultural aspects regarding both the country and the industrial culture. Moreover, in literature, authors mention the willingness of building a long term relationship with the supplier during a NPD (Bruce et al., 1995). Notions such as trust, willingness to collaborate and motivation are considered. Therefore, concerning the *severity* of the failures, three notions were considered. The first one is the *efficacy* regarding the project performance. Secondly, as this study focuses on collaborative NPD with suppliers, the impact of the failures on the *relationship with the supplier* has to be considered i.e. will this failure impact the relationship with this supplier only regarding this project or will it impact the long term relationship? Thirdly, there is a notion of *efficiency* in the way of working between the two partners.

The *detection*: This dimension embodies the time frame of a risk (Oehmen, 2005) i.e. the probability that the failure is detected before the impact of the effect is realized (Wagner, 2007). This is thus the fact of discovering the failure more or less late in the project. Aggeri and Segrestin (2002) introduced a notion of latent period in the treatment of problems. This notion can be used for the time necessary to detect a failure. Therefore, our proposition for this dimension was to consider the moment when the project team is able to detect the failure. Is it at the early beginning of the collaborative development or later when many elements have been decided and validated in the project?

The *aptitude to cope with a failure*: The third dimension of a criticality assessment is the probability of the *occurrence* of a failure (Oehmen, 2005). However, contrary to failures considered in a product or a process FMEA, there is no significant experience which could enable us to statistically assess the probability of observing a failure during the collaboration with the supplier. One can assume that a factor influencing the occurrence of a failure is the project team's skills. The more they are appropriate, the less the failure is likely to occur. This is also linked to the treatment time of a problem (Aggeri and Segrestin, 2002) because if appropriate skills are not available, coping with a failure is more difficult and longer. Thus, the researchers wondered which measure could be associated with those elements. A notion of *aptitude to cope with a failure* was defined in order to be discussed with practitioners.

4.2 Feedback from the practitioners and key elements for rating scales

The framework for a criticality assessment of failures previously introduced in Section 4.1 was presented to the industrial partners. The results from both the academic-practitioner workshop and the collaborative work with Company C4 enabled us to improve the definition of the critically dimensions and to define the corresponding appropriate rating scales:

The first dimension is the *severity*. During the academic-practitioner workshop, the practitioners have suggested to evaluate the *severity* for each item of project performance (cost, time, quality and innovation). According to the framework proposed in Section 4.1, we suggested that the performance dimensions for a collaborative NPD with a supplier are not limited to these four dimensions of *efficacy*. Notions such as the *relationship with the supplier* and the *efficiency* of the collaboration are important elements enabling the success of collaboration with a supplier. As it was uncertain whether it was realistic or not to ask project teams to assess all those dimensions, two possibilities were proposed to C4 project teams. The first possibility was to only assess the *severity* according to the impact of the failures on *efficacy* (cost, quality, time and innovation) and to define an appropriate scale. The second proposition was to involve the two other dimensions (*relationship with the supplier* and *efficiency* of the collaboration). For this last proposition we proposed to assess each of the three dimensions *efficacy*, *relationship* and *efficiency* with three different scales or to have only one general scale involving elements of the three dimensions. At first the project teams reported that it was very time consuming to have three different scales. Subsequently, they agreed on the necessity of considering all those dimensions. Then, three corresponding scales were commonly defined.

Concerning the *detection* dimension, the practitioners agreed with the idea of a latent time more or less important necessary to notice a failure. They also suggested introducing a notion of visibility of the failure. The visibility of the failure is function of the presence of more or less obvious signals indicating the presence of the failure. In this respect, during the discussions to elaborate the rating scales, a project quality actor of Company C4 reported that "*in the worse case the failure is almost invisible and detectable very late*". Thus, in our discussions with all the companies, the *detection* was commonly defined as "*the latent period to observe the failure and the failure's visibility*".

Concerning the *occurrence* dimension, the practitioners have admitted the impossibility to define statistical failures' occurrence probability due to the newness of the subject. They also agreed that the notion of the *aptitude to cope with a failure* is more appropriate than the *occurrence* when failures encountered in product development with suppliers are addressed. In addition, they highlighted that this notion is actually linked to the *occurrence* but more in a predictive view. If the project team is able to cope with the failure then the o*ccurrence* will be low. However, they reported that skills of the project team are not always sufficient to cope with certain failures which also influence the treatment time. For example, the project buyer reported that sometimes the project team has the required skills to cope with a failure but is not sure of being able to mobilize them or to be able to mobilize them in a time short enough. Furthermore, this project buyer said that "*sometimes [they] need the intervention of the purchasing manager but it is difficult due to strategic aspect regarding the collaboration in course with the supplier*". In this case, they know which external skills they have to mobilize but they are not sure that it will be successful. Bearing this consideration in mind, the more general term "*aptitude*" was introduced which embodies "*the aptitude of the project team to cope with the failure thanks to its own skills or by mobilizing the necessary external skills*". The corresponding rating scale was defined.

4.3 Resulting proposition of a failures criticality assessment

The academic-practitioner workshop and the work with Company C4 led to a proposition of a failures criticality assessment (Figure 2). This assessment is named FPI (Failure Priority Index) and is composed of three ratings: the *Severity* (S), the *Detection* (D) and the *Aptitude* (A). As previously explained, the *Severity* is composed of three sub-assessments: the *Efficacy* impact (E) which embodies the impact of the failure on the project performance (cost, quality, time, and innovation); the supplier *Relationship* impact (R) and the *Efficiency* impact (Ecy).

FPI	**=**	**S (E*R*Ecy)**	**x**	**D**	**x**	**A**
Failure Priority Index		*Severity Rating*		*Detection Rating*		*Aptitude Rating*

Figure 2.Preliminary proposition of criticality assessment of failures in collaborative NPD with suppliers

Tables 3 presents the scales commonly defined with Company C4 project teams including the dimensions previously described. It was decided to use a 1, 4, 7, 10 scale as this is the usual way of assessing failures at Company C4 in their quality tools with: 1=no effect to 10=critical effect for the three *severity* scales and 1=very high to 10=low for *detection* and *aptitude* scales. Realistic scenarii issued from the discussions with the project teams were used for each assessment to make it clearer.

Table 3. Rating Scales

Efficacy Rating Scale	
1	This failure generates a minor impact on project performances and is surmountable
4	This failure can generate delays and overcosts but quality and cost aspects are not impacted
7	This failure does not enable to obtain a technical/performance optimum and can be detrimental for the project
10	This failure is likely to lead to a blocking of the project
Relationship Rating Scale	
1	This failure generates a minor impact on trust and on the customer/supplier collaboration within the project
4	Impact on the collaboration within the project due to this failure but the project teams will continue to work together after a common discussion
7	This failure negatively impacts motivation and trust toward the supplier and leads to difficulties to collaborate within the project with this supplier
10	This failure is likely to stop the relationship with the supplier and lead to an important loss of trust. Collaboration with the supplier is endangered within the project but also any eventual future collaboration.
Efficiency Rating Scale	
1	This failure does not prevent, with the implemented means, to successfully carry out the project within the first trial
4	This failure does not enable to have an immediate success with the project but can be overcome after a discussion between the teams
7	This failure leads to a misunderstanding between the actors but does not endanger the project. It is necessary to adapt the implemented means to cope with this failure (meetings, communication means…)
10	This failure generates numerous adjustments between the actors to cope with it and can endanger the project

Detection Rating Scale	
1	The signals indicating this failure are obvious and visible during the early stages of the project
4	The signals indicating this failure are small but visible during the early stages of the project
7	The signals indicating this failure are obvious but visible late during the advanced design stage or industrialization stage
10	The signals indicating this failure are very small and visible late in the project when an important amount of decisions have been validated
Aptitude Rating Scale	
1	The project team is autonomous to cope with this failure and self confident to deal with this failure
4	The necessary actions to avoid this failure require know-how of an external actor of the project
7	Avoiding this failure is within the skills of the project team but this one is not sure of being able to OR The project team knows how to avoid this failure but is not sure of being able to due to the treatment time
10	The project team is unable to avoid this failure because it is out of its skills and has no idea about how it could be possible to cope with it

5 APPLICATION OF THE CRITICALITY ASSESSMENT AND DISCUSSION

The criticality assessment was applied on the co-development projects conducted by the two project teams of Company C4. They used the failures classes proposed Table 1. As previously said, this classification was validated by the project teams in a previous work. Table 4 presents the criticality assessment for the failure "*No alignment in project expectations*". Actually, one project team reported troubles regarding the definition of common project expectations with the supplier. C4 was more interested with the supplier's R&D skills whereas the supplier was interested with mass production.

Table 4. Test of the criticality assessment with a C4 project team

	Severity					
Failures	**Efficacy impact « E »**	**Supplier relationship impact « R »**	**Efficiency impact « Ecy »**	**Detection « D »**	**Aptitude « A »**	**FPI**
No alignment in project expectations	7	7	10	4	7	**13720**

No difficulties were reported with the *detection* and the *aptitude* and the respective scales (Table 3) were validated. In addition, the project teams reported that, by giving the same weight to each of the five ratings, the *severity* has a too high weight compared to the *detection* and the *aptitude*. A solution could be to first average the three *severity* components so that the *severity* has the same weight as the *detection* and the *aptitude*. A remark was also made regarding the high FPI obtained. As Otto and Wood (2001) reported, while the Risk Priority Number (the FPI in our case) remains quite linear for low ratings, the gaps between the RPN with high ratings get larger and larger. Although, it can be generalized that the RPN represents a means of comparison rather than an "absolute" value. There is no target RPN and failures might always occur. The question is how much risk the team, or the company, is willing to take (Otto and Wood, 2001). Moreover, as Pfohl et al. (2010) argue, "*supply chain risk management does not work simply by applying a number of methods. It rather is a philosophy that is supposed to be deeply rooted within the company and the supply chain*". Furthermore, the question of updating the criticality assessment during the project was raised. Risk management is a dynamic process (Wagner and Bode, 2008) and probabilities of unwanted events occurring can change over time, even as the impact these events can have (Hallikas et al., 2004). For this reason, several assessments of the FPI are recommended during the project. Accurate times have to be determined according to the company's NPD process. Indeed, monitoring those risks in due times is necessary. It can provide an early warning when risk levels are rising, giving companies time to react to these changing circumstances by altering their mitigation strategies (Hoffmann et al., 2012). Few authors stress the importance of monitoring risks pro-actively and on a regular basis (Dani, 2009; Hallikas et al., 2004; Norrman and Jansson, 2004). This is also a very time-consuming process and it is therefore not feasible for companies to realize for all their different supply risks (Hoffmann et al. 2012). The core challenge of risk management is to find the optimum balance between the cost of carrying risk and the cost of mitigating risk. Finally, the project teams mentioned that the minimization of risk should take place in the early stages of design and be a team exercise to achieve the desired objectives as also mentioned by (Lindemann, 2006). Risk management is tightly linked to the success of a product development process and the achievement of overall goals (Wagner, 2007).

6 CONCLUDING REMARKS AND FUTURE RESEARCH

This paper has introduced concepts for dealing with failures in collaborative NPD with suppliers. From a failures classification and literature results about risk management and criticality assessment, a proposal was made to rank those failures in order to be able to determine which ones have to be dealt with in priority during a collaborative NPD with a supplier. In a managerial point of view, this gives designers and engineers a chance to predict and prevent collaborative failures rather than reacting to them. The failures criticality assessment proposed will act as a traffic light drawing attention on the critical stages of the collaboration. In an academic point of view, the result of this paper gives a criticality assessment applied to this specific type of failures developed by including both academic and practitioner point of views. The main aim of this research work is to be able to prevent those failures from occurring during collaborative NPD with suppliers. That is why the next step is to develop a complete tool of failures analysis including the criticality assessment presented in this paper, preventive actions with leaders for each failure and an update of the criticality assessment to monitor the failures during the collaboration. Furthermore, as it is very ambitious and quite impossible to pretend being able to avoid all the failures, so as to enrich this prioritization obtained with the criticality assessment, a quantitative analysis is carried out to identify the most critical failures.

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