Successful Risk Management Approaches in Product Development Organizations: A Case Study Experience

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Abstract--This article discusses experiences from case studies conducted at product developing departments in four multinational companies. All organizations are outstanding product developing companies with a long and successful historical background within product development. Therefore it is interesting to understand how these companies deal with risks in their product development processes. The aim of the paper is to find out if the Design for Six Sigma (DFSS) concept supports the need of industrial companies to deal with risks in their product development projects. The results show that DFSS promotes the company needs to some extent. There is a great method support in DFSS regarding how to consider technical risks. On the other hand, all companies included in this study would need more support to highlight the holistic perspective concerning cross functional collaborations, increased communication and avoiding sub-optimizations in development project, a requirement that is not sufficiently supported.

I. INTRODUCTION

New product development is a real challenge, with great bets and quite low odds of picking a winner. However, it is the betting performance and the betting rules that make the difference between winners and losers, and in product development the biggest and most difficult challenge is the possibility to affect the outcome. Since product developers' actions and behaviors can be conformed the outcome can be influenced, and to some extent controlled [1].

Management of a product development project is actually about the management of risks [1]. Risk management is a vital part in early development steps dealing with what to include, exclude or change in the project scope and has to be a joint consideration between corporate management and the design organization [2]. In the beginning of a product development project everything is unclear, and all that exists is the risk of future problems. Progressive organizations therefore navigate through the project following risk indications towards a more concrete project outcome [3]. There should be a balance between the risk level, the uncertainty of the project outcome and the project's time schedule. Also the decisions based on fact in the project should increase accordingly as the project progresses [1]. A complete avoidance of risks in a new product development process is impossible if not avoiding innovation at the same time. Therefore risk management in product development is about dealing with risks, not avoiding them [1], [4]. Consequently, risk management in product development of today should be more than just conducting a risk analysis at project initiation. It is a permanent process that has to be continuously performed and communicated in the organization.

The functional, technical risks that can be monitored and with a correct adoption controlled by a risk analysis, for instance an FMEA, represents only one part of risks that has to be managed in a development project [5]. Besides that aspect, risk management is about ensuring cross-functional collaboration that fosters smooth hand-overs and continuous checkpoints during ongoing projects. Minimizing the occurrence of surprising risks concerning planned or expected product properties, production difficulties or insufficient availability of material is also expected from the risk management method. [6] Another aspect of risk management considers the transformation of knowledge and experiences between ongoing projects, as well as from previous performed projects. Further, many risks that appear within one project are also relevant in other parallel or future projects.

A product development concept considering the holistic view of the PD process with the purpose to develop successful products is Design for Six Sigma (DFSS) [3], [7]–[9]. Risk management is according to Yang and El-Haik [6] all what DFSS is about. In the DFSS context they considers losses due to lack of project limitations, weak business cases, bad cross functional communication, and errors in understanding customer needs to be included in the construct risk management [6]. It is about being aware of and preventing the occurrence of risk to secure the fulfillment of a new product's functional and non-functional robustness attributes. Concrete methods in Design for Six Sigma fostering risk management are for instance: simulations [10], [11], Design of Experiments (DOE) [6], [7], [11]–[14], reliability analysis [3], [13], life-span calculations [10], [11], [13], measurement system analysis [7], [13] and Design for manufacturing [12], [13], [15]. Certainly, also technical risks are dealt with in Design for Six Sigma, through the application of Failure Mode and Effect Analysis (FMEA) [3], [6], [8], [10], [11], [13]–[16] or similar risk analysis method [3], [15].

The research question to be answered in this article is if the Design for Six Sigma concept supports the need of industrial companies to deal with risks in their product development process. The reminder of the paper is structured as follows; the applied research method is described in section II, followed by a description of empirical case study experiences in section III. Thereafter, section IV contains the discussion of case study findings from a risk management perspective. The article ends with conclusions in section V.

TABLE 1 – SUMMARY OF CASE STUDY COMPANY DATA

Company	Organizational size	Origin	Product category
Alpha	Medium-sized	Part of a large global multinational corporate group, founded in Sweden.	Develops and produces simple business to business products with a high technological level.
Beta	Large	Multinational company founded in Sweden.	Develops and produces complex consumer products with a high technology level.
Gamma	Medium-sized	Swedish company.	Develops and sources simple business to business products with a low technological level.
Delta	Large	Multinational company founded in Sweden.	Develops and produces complex consumer products with a high technology level.

II. METHOD

The experiences in this article are based on a multiple case study conducted at four multinational mass-producing companies. All organizations included in the study are outstanding in product development and are further described in Table 1. The organizational sizes are specified in accordance with the definitions of the European Commission [17].

The company situation at Alpha and Gamma is a bit specific. Company Alpha is actually part of a large global group where the studied unit to a high extent is autonomous and therefore is described as a medium-sized company on its own. Routines and project models are in general consistently identical for all sub-units in the group and some general resources can be benefited from the company group. For instance, part of the early technical development is shared among the sub-units.

Company Gamma is a stand-alone company closely connected to a large multinational Swedish company. Development projects at the large company often override the development projects and company Gamma and they are commonly interconnected. In those cases, company Gamma acts as a supplier of sub-components to the larger company.

The case studies were performed with two investigators to increase the confidence of the findings [18]. Each case study lasted between four and six weeks, during which the investigators were full-time present in the organization. The time was divided between shadowing and semi-structured interviews. When needed the data collection was supplemented with documental studies. By following a case study protocol, information about the enterprises' product development organization were collected through a total of 41 days of observations and 73 interviews, see Table 2 for company details.

TABLE 2 - SUMMARY OF DATA COLLECTION METHOD AT EACH COMPANY

Company	Number of interviews	Days of shadowing
Alpha	18	4
Beta	23	13
Gamma	16	9
Delta	16	15

Shadowing is a holistic data collection method with emphasis on direct study of contextualized actions which can provide insight in day-to-day workings of organizations [19]. It is a nonparticipant specialization of direct observations, with reservation for all direct observations being partly participatory, that is less complex since it does not require observations and actions in parallel [20]. Shadowing was performed to learn company internal constructs, and organizational structures and dependencies. Doing so, company generic concepts and examples could be used during the interviews and thereby the risk of the respondents not understanding what is being asked for was decreased [21]. The shadowing observations were performed individually by the investigators to minimize the observed informants' discomfort, while being shadowed, and avoid unnecessary attention when taking part in meetings and other interactive forums.

Interviews were conducted to get a complete picture as possible of the organizations' product development processes. Therefore, respondents representing different organizational levels, as well as line segments, were selected. Also, roles in both the project- and the line organization were interviewed; see Table 3 for affiliation details. By doing so the investigators managed to cover most roles involved in the development process, even customers in two of the cases. Some of the interview respondent representations in Table 3, indicated by stars, were shadowing informants which happened to end up in an informal discussion just as Czarniawska [20] describes the shadowing method, and thus provided interview resembling material.

TABLE 3 – SUMMARY OF RESPONDENT AFFILIATION PER COMPANY (EVERY * INDICATES A CASE WHERE AN INFORMAL DISCUSSION DURING SHADOWING HAVE BEEN INCLUDED TO THE INTERVIEW MATERIAL)

Position in the organization	Alpha	Beta	Gamma	Delta
Continuous improvement		3*		1
Controlling			1	1
Customer	1		1	
Customer satisfaction		2		
Market	2	2	1	1
Middle line management	2	3	2*	3
Production	3			2
Project management		2	2	2*
Purchasing	2		3*	1
Quality	2	2	3	1
Technical development	3	4*	1	2*
Technical project management		2	2**	
Top management	1	1		1
Whole-product responsibility	2	1		
Design		1		1

According to Eisenhardt's [22] recommendation the interviews were conducted through double representation by a team of two people. This was done to increase the validity of the interview experiences with one investigator moderating the interview whereas the other one was responsible for taking notes. Audiotaping assures more accurate reproduction than any other method [21], but often inhibits the respondent's answers and behaviors [23]. Also, the benefits of taping are reduced in objective, data- focused situations [23]. Therefore, the interviews in three of the case studies were not recorded. In the fourth case, which initiated the multiple case studies, the interviews were recorded as a try out, resulting in a huge amount of data material for each interview. This extensive material was hard to validate with the respondents and the recorder also made the informants careful and reserved and thus hard for the investigators to receive honest and explicit answers. Therefore, for the latter case studies it was decided not to audiotape. Interview summaries created based on the distanced investigator's notes and observations according to Eisenhardt's [22] recommendations resulted in more active and relevant feedback in the validation process. Since the respondents' native language is Swedish, this is also the language used during the interview implementation. Thus all case study material presented in this article has been translated to English which easily could have caused connotation and change of meaning in the material [24]. The Swedish interview notes were validated by a double review process where both the interview moderator and each respondent proof read the material. To maintain validity, the investigators personally performed the translation of interview experiences. Also, respondent experiences are preferably presented through examples, rather than quotes, whose correctness are validated by the second investigator in the study.

A complete and validated set of case study material was imported into a software analysis tool supporting qualitative material which simplifies cross referring and linking between clustered descriptions and the original interview summaries.

The analysis were conducted with an including, rather than excluding, approach screening the case study material for behaviors, solutions, problems and suggestions related to risk management regarding the two perspectives: what kind of product development risks do companies solve, and what kind of risks do they not manage to solve from the viewpoint of a complete product development processes. The risk management experiences from case study respondents and observed informants then were categorized into clusters to organize the content of each company's empirical description. The examples in the empirical experiences section composes word-paintings presented by the respondents and aims to replace quotes in the article. Finally, the two perspectives of good working methods and risk management needs in companies' product development organization were compared to the exiting support in the DFSS concept.

III. EMPIRICAL EXPERIENCES

Product developing organizations in general tend to have problems with prioritization and the case study companies in this project are no exceptions. The general situation presented in this initial part of the empirical experiences chapter is common for all four studied companies and is followed by company individual experiences.

The work in development projects is controlled by constraints regarding time, technology and cost to be able to deliver the product at a specific date according to budget and specification. Sometimes it is not even communicated which of the aspects from the triple constraint; time to market, quality or cost that is most important or even what is prioritized in a project. However, time and price always tend to override engineering-wise prioritizations. Frequently, the time aspect is determinant since there is a great loss of money correlated with every delay in unit of time. Therefore it happens that gates in the project model are consciously passed even without the fulfillment of all requirements, but with an enclosed working list of remaining activities to be

able to precede the project. Since most development projects are long term projects the probability of changes due to modified customer-, market- or legislative demands during the process is high and there is no generic structure of how to treat changed demands and prioritizations in ongoing projects. But every late change during a development project means a quality risk for the project since it is difficult to quality assure a new parameter without disregarding something else.

At its best the product development prioritizations would reflect the following-up measurements required from management and likewise be beneficial in the R&D organization. There is a forgiving attitude in both company Gamma and Delta's organizations where it is accepted to provide late deliveries and no one is ashamed of this behavior, which links to the fact that there are no goals of what to accomplish or when the development cost should have paid back. It should be apparent from management that a late delivery is not acceptable even though a decreased lead time for R&D projects not necessarily correspond to an improvement. The ability to meet delivery precision is still important. From perspective of the triple constraint more important than the development lead time is to consider the effectiveness of the project. The final solution should be in line with market and customers' expectations, and how much a product costs in the end should be evaluated to see if the development expenditures can be paid back.

Still, the four organizations in this case study are successful product developing companies which inter alia are due to their relations to risks in the product development organization. When it comes to the consideration of technical issues in development projects they all have well established systematic working methods by using FMEA. The method and its corresponding report are considered a living document which is regularly up-dated and adjusted risks are registered. This risk management structure for technical risks is described as an organizational generic method, applied in all companies' product development processes inheriting previous risk experiences but also a way of developing the companies' product- and method knowledge by learning from mistakes. Despite a mature and effectively control of technical risks in development projects the companies still have risk issues of non-technical nature to tackle. Organizational and leadership aspects cause troubles from several perspectives in companies' product development project. Examples of these risks have already been encountered with descriptions like the lack of a generic structure to manage late project changes or the non-communication of project prioritizations. These issues can be summarized in two categories; creating a holistic picture in the R&D organization and its connected product development project organization, and communication within and between projects.

A. Company Alpha

Company Alpha's organizational structure is composed of two segments separating the company's two product ranges with almost separated product development organizations. Only one of the segments has been considered in the study. Some roles involved in product development, however encapsulate both segments and thus those respondents represent experiences from both of the organization's segments.

Both segments at company Alpha have a product responsible role for each project range who is product recipient and task manager for the product development organization, providing product orders and requirement specification input to projects. Looking to the investigated segment, the project organization is almost nonexistent with technical developers doing some extra work as project managers. It is often the design department that drafts product solutions and presents a complete proposal for other involved functions in the end of the project, a solution that might not be optimal regarding other aspects than functionality. In development projects at company Alpha there is a big focus on product function which results in other aspects getting lost like the possibility of adapting product solutions to existing production- and assembly solutions.

Example: Co-workers at purchasing experience that the technical developers have unreasonable expectations on the other departments to fulfill their needs. They do not have any understanding of lead time and believe that everything they need can be bought from the closest supermarket.

Example: A business developer experiences the risk analysis in development projects to be very technically, or product engineering oriented. Many other important aspects fall away when the technical aspects of the risk analysis drive and control development projects. There is also a lack of interaction between development and production during component development. He often gets the feeling that the technical development creates a complete product solution draft which is delivered at the end of the project without considering any other aspects than functional requirements.

It is the project's steering committee that evaluates the result at every project gate. But the result is also dependent on the composition of the steering committee, if they are capable to confirm the outcome or not. The project group works different depending on the choice of participant on a personal level, and the communication within a project diversifies a lot depending on the participants in the project. There is no organized information flow, most experiences are provided at informal discussions during coffee breaks. Further it is common during development projects that people work individually on their tasks, some collaboration between technicians can happen but no cross functional collaboration exists. Communication and interchange of experiences between projects is almost absent besides local initiatives

within the design department since the realization of those is up to each individual project manager.

Example: A business developer explains that knowledge transformation between projects is every individual project manager's responsibility. Distribution of knowledge between projects occurs but it is really weak. Also, collection of experiences is inadequate often performed with an inner circle of co-workers lacking external contacts with the product or market even though that is one check point in the development process. If the market organization is even approached regarding customer experiences it is done through a written survey with short response time.

Among co-workers at company Alpha an organized way of sharing experiences and increase the openness in the organization is requested. The way it is right now, the knowledge exchange is often forgotten and when it occurs the small group participating does not always have experience of the complete product system.

B. Company Beta

The R&D organization at company Beta consists of five segments. Moreover there is a project management office completely separated from these segments where development project managers and project coordinators are located together like another line organization. The organizational structure at company Beta is really complex and a visualized organizational chart of the company's R&D organization is non-existent. Also, there is an extensive meeting structure at the company and many co-workers in the project organization spend almost full work days in meetings. The transfer of information between organizational levels is quite unwieldy, a problem can be raised upwards from operational level to top management within a week but to distribute a decision downwards often takes several weeks. Co-workers on operational level and managers also perceive the functionality of information flow procedures differently.

Example: A project manager at company Beta believes that they are good at working in projects. The best thing is that the commercial project organization and technical project managers are located together in projects, and that they sit together similar to a line organization. He thinks that it creates networks and cross functional understanding that is necessary for keeping the holistic understanding of what is going on in a project.

The fact that there is a dedicated holistic product responsible in every project is agreed upon at company Beta. On the other hand there is a differing view regarding which role that has the complete product responsibility in development projects. One of company Beta's R&D line segments is dedicated the responsibility for the complete product system on a general level and according to specifications. Besides that there is a project manager in every development project that operates feature balancing

and launching which is responsible for considering the complete and specific product in a project.

Example: A middle line manager in the complete product system segment experiences that the distribution of responsibilities between the segment with product system responsibility and the project manager lacks understanding in the product development organization. She also experiences that the purpose with the line segment is unclear for many co-workers which makes them incapable to use the resources in an adequate way. However, the segment already lacks resources to fully support the development process causing the described structure not to manage to prevent product sub-optimizations.

Example: According to a whole-product responsible there are only two roles that have a holistic overview of the product system, the technical project manager and the commercial project manager. They follow a development project and even come along on test occasions of the complete product. He perceives that all other units focus on their component solutions and see the product as a system that administrates their components instead of regarding the holistic product and consider how it would be affected by its included components.

To coordinate connections between project- and line organization there is a matrix structure at company Beta. But even here the distribution of responsibility and decision making is a bit unclear. Both line- and project organization want to moderate decisions but currently it is the line organization that owns the development resources.

Example: A project manager claims that a projects ability to make good decisions and solve problems is reduced due to the line organizations ownership of development resources. Therefore, the projects become dependent on communication with line segments, which does not fully work and thus is a weakness in the system.

Example: From the line's perspective a middle line manager describes the line's responsibility to support projects. But he perceives that it is common that the line carries more of a project's delivery tasks and that the project not even tries to deliver on its own but just specifies requirements for the line. He does not think it is necessarily wrong to push tasks to the line, but the organization then has to be adjusted to that mindset; slimming the project organization and increase the amount of resources in the line.

In cases when projects run according to plan it is the line organization that makes decisions about product attributes and change of requirements, but in emergency situations decisions can be made by the project organization as well. Due to the unclear responsibility distribution in the matrix structure, line versus project, and the separation between the two organizations structures, many decisions are brought up to corporate management. To become more efficient

company Beta has to set a structure defining who has decision authorities and who does what to avoid too many decisions that are brought up to corporate management, which is the case today.

Example: A project manager describes that the line- and the project organization are almost two completely discrete worlds functioning very differently. Only a few co-workers have working experiences from both organizations. A lot would be gained if company Beta to a greater extent could move people between the line- and project organization. Then both organizations would get a greater exchange of experiences and a better understanding of how the different worlds are working.

The problem is not a low employee turnover, it has increased during the last decade and there are many newly recruited people in the organization which sometimes results in a lack of competence. There is a need for different career opportunities in company Beta. One that fosters internal work changes, preferably between the project and line. And another one that increases the experience in the line by shorter phases where people are allowed to be experts on a particular phase and run it in many different projects. Such an improvement would foster both the project – line interaction and the need to optimize development projects according to continuity promoting the holistic perspective and reduce the numbers of handovers which currently increases the risk for sub-optimizations.

Example: A co-worker in the complete product segment experiences that problems often occur when parts are put together into one product. Simulations and visualizations are available on component- and part level, but not to make any simulation tests of the complete product. Therefore, sub-optimized solutions can accomplish outstanding results according to component simulation tests. The complete product segment frequently identifies sub-optimized component solutions during product system testing.

Sub-optimized solutions of course causes late product specification changes which are problematic for operative co-workers; the only thing they know is that changes will occur, but not when or how late in the process. Company Beta tries to improve towards a process with few changes. They has several co-workers employed at their business development department responsible for dealing with information about identified problems in previous and existing products. These employees represent complaining customers in development projects trying to ensure that problems do not re-occur in new product solutions. There is also a business management system used for transferring information in which all relevant information regarding development projects and previous experiences are reported.

Example: We have an awesome management system for information exchange in product development explains a business developer at company Beta. Everything is

documented and saved in well-organized systems, but there is so much information. She spends around 70% of her working time reading protocols and project information in the system instead of being part of the projects, just because she is expected to know what is going on. The management system is so detailed that one can work from home without meeting with people and still know everything. She questions if that is good or if the system is too good.

Nevertheless, the information transfer downwards the organization does not always work well. It is hard when people in the organization are replaced since it takes time for the project organization to get to know the teams in the line and understand who to communicate with. As it is right now, individual experience and continuity is needed to be able to do a good job since the employee turnover at company Beta has increased a lot during the last years.

Example: There are many handovers in a project whereof most are done beyond organized meetings tells a technical developer. Many things are solved through informal channels since many people are experienced and know who to talk to in order to avoid getting the project stuck. Only things that are not solved during internal meetings are handed over through organized meetings.

In the end of each development project white books are written to summarize lessons learned. Information and experiences from a project is also documented in the management system. The white books are really comprehensive and it is unusual that co-workers have time to consider the information included.

Example: A project office manager experiences that there is not really anybody reading the white papers before a new project initiation. Right now we rely on people's individual experience, that co-workers who get into projects are experienced people, and that they in turn know who else that is good to talk to.

There are also local exceptions of well-functioning knowledge exchange. For instance there is an unofficial structure between business developers at one line segment of communicating tips and problem experiences and providing feedback on current problems through E-mail and during group meetings. But how co-workers in general deal with upcoming problems in projects is often person-dependent.

C. Company Gamma

Company Gamma develops sub-components for a large company. The large company delivers complete product systems to the end customers. Thus, the two organizations have a business to business relation. Company Gamma has an organizational history of acting as a consultancy company below the complete product organization implicating an indirect second hand relation with the end-user of their products. Consequently, this relationship affects the

organizational behaviors in product development and thus the results of this study. The two companies with their existing relationship can be seen as two segments within a parent organization. Company Gamma has well-established and communicated company values and clear visions that have been experienced during participating observations. All co-workers are committed to, and familiar with, these values which foster the company's ability to conduct quick changes keeping all co-workers on track.

There is a history of an organizational structure without a responsible for the comprehensive range of products at company Gamma. That structure has resulted in a situation with an extreme selection of product varieties and even after a re-organization, when R&D was structured in logical range departments with a responsible at each department, it happens that the local responsible does not have the complete picture of all existing solutions. Similarly, it is common that co-workers on an individual level do not see the holistic picture for the component they develop, where and how the specific component should fit in the complete product system.

Example: We are a large organization, and therefore it is hard to know where you are in the value-chain, reports a project manager. As soon as you get to know the value-chain it is possible see the information flow, but on the other hand with a stricter system the flexibility and happiness in the organization will decrease. He does not believe that there is a need for more work instructions. A better holistic view would be good, and then it would be possible to deviate a bit without creating failures. As it is right now, it is very difficult to get the full picture. It easily becomes the whispering game, partly because of cultural differences in the organization. A holistic picture would also simplify the relevance assessment of a functional requirement in its context.

It is rather common that the most important property in a development project get lost during the performance of the project since no one considers what is best for the product. A total responsibility of the holistic product experience, including things that happen after the development process, is requested at company Gamma.

Example: A project manager in the customer organization talks about the value of having a project manager who could live with the product during its entire life-cycle to create a greater understanding. Today developers do not have time to follow-up or document development projects. The project responsibility is handed over to technicians and purchasers in connection with a gate before the product launch and start of production. Thereafter, the product responsibility is handed over a second time, to the marketing department, at the time for start of production.

Also, when it comes to the complete product system to which company Gamma delivers its products there are organizational roles in each department acting as a communicator between the two segments. It occurs that these people feel that they do not contribute with anything in the organization. Having the role as communicator between the segments, with understanding for the comprehensive product perspective and the specialized competence in company Gamma's range, they are needed to make projects run smooth.

Historically it has been hard for co-workers at company Gamma to distinguish between project and line. For instance they appointed a technical manager to work with processes but people in the organization believed it was a line manager who could answer challenging technical questions. As a part of the last re-organization, supporting roles to clarify the matrix organization were introduced. The project organization at company Gamma is divided in accordance with the line organizational structure with dedicated project managers to each product range. Prioritizations are the line managers' responsibility but they are often influenced by the individuals in the project organization, where the ones shouting out the loudest get their wish through. It is common that no one knows how many projects that are running, which makes it hard for anyone in the organization to prioritize. A project portfolio being a mixture of big- and small projects on different complexity levels the coordination is difficult. It is also a matter of time accuracy in development projects. For company Gamma it is necessary to relate to its parallel segment's process, but most often they gets involved to late when the product system is almost completely developed. Moreover, Gammas process is slower than the parallel segment.

Example: A purchaser tells that company Gamma historically has acted as a consulting company to their customer always folding according to the customer's orders which has resulted in a large-scale product range. He experiences that company Gamma needs to be involved earlier in the process, to be part of defining the functions and generate a solution. Once a designer in the customer's organization has sketched a solution it is too late, then he/she wants to have it like that."

Since an internal change of position within the global group is expressed as a personal development and career path the employee turnover in the organization is constantly high. That structure affects the organizations competence and increases the need for detailed routines and descriptions. Sometimes it happens that the continuous changes of co-workers result in lack of competence for a desired action in a line segment even though the competence still exist within the organization. It is often every individual's responsibility to make sure that the required information is maintained when a co-worker changes position or quits since there are no routines or instructions for handing over information or sharing knowledge. Documented handovers of information is required in development project deliveries but there are often more relevant information, difficult to document, that get lost. Therefore, to accomplish a good result when having a

problem it is necessary to know people in the organization who can guide you further to find the right knowledgeable individuals. There are many work instructions at the company, but a general description, like a process, that connects all the instructions and information together is missing. The existing management system is sometimes described by co-workers as a big black hole where new descriptions just are added without relating to or changing what already exists.

Currently there is no formal or structured way of working with knowledge transformation at company Gamma which makes it happen very rarely and at these occasions randomly. Several people within the organization describe the lack of a forum for performing experience and knowledge transformation. There is no introduction program available for personnel that have moved or changed job within the global group. Sometimes there are too high expectations on internal recruited people's ability, since they are used to work in the global group, resulting in an insufficient introduction and thus a lack of understanding for the holistic picture or the information flow.

D. Company Delta

Company Delta's R&D organization consists of three segments which during participating observations were experienced to be quite straight forward, separating the two product ranges and the non-technical product development issues from each other. The communication and information structure at company Delta is efficient and flexible by performing visual management and pulse meetings steadily on all organizational levels. Company Delta is a non-hierarchical organization meaning that every co-worker can ask for support everywhere. One of the organization's biggest strengths is the physically gathered company plant which provides top management and decision making close to R&D and the production line.

There are dedicated departments at company Delta responsible for the complete product picture, but with a strong line these organizational functions are often too weak in comparison to individual design departments. Most co-workers assume that there is someone in the organization that has the comprehensive picture but not everyone knows about the existing structure and who is the holistic product responsible which is necessary to make the line plan and perform their work based on fact instead of gut feeling. Also, to control the incoming deliveries on a company level but even from an internal departmental perspective it is necessary for Delta to secure the co-workers understanding of the holistic project view.

Example: A middle line manager describes the R&D process structured to perform technical development in the line organization. The R&D projects then just include gleaning the final product based on several different and technical components. Sometimes he perceives the component design departments being too strong, which makes them getting lost in their own pipes, and consequently sub-

optimizations occur. Further he expresses that the line is too powerful and that project managers at company Delta therefore has were little empowerment.

A project team at company Delta is built as a cross functional combination of roles and competences according to recognized best practice. However, since the line owns the problems and thus takes the responsibility of delivering a result to the project, the real project team consists of only one person, the project manager. It is often deficient attendance at project meetings and it is common that decisions, which concern a project result, are made by the line at technical meetings which easily make the project managers' decision authority get superseded.

Example: A project manager describes the importance of close collaboration with the line organization to make projects proceed at all. She has to chat around and be alert to make sure that she get invited to important meetings and can look after her interests. As a project manager she can easily "get with decisions" that influence her project rather than making decisions of her own. Since a project manager does not own the economic development resources or the decisions, it is hard to require result from that position.

Project managers who participate in the problem solving process in the line appeared to be considerably more accepted in the line than those who just demand results. There are arguments against a strong project organization at company Delta with people claiming that it would result in losing the organizations modular construction system since the project organization would not foster the best solutions from a line perspective. Most probably the line would still communicate with each other regarding interfaces and the project managers would have to be liable for problem reporting and responsibility distribution in the line which increases the project managers' involvement in projects and requires a strong project organization that has respect in the organization.

Delays frequently occur in Delta's development projects due to difficulties with handovers. There are often problems with synchronization and integration between hardware- and software development which includes two different release processes whereof only one is in accordance with the company's development process. Moreover, the purchasing department wants to be part of development project as early as possible due to lack of understanding for their responsibility and its effect on the project, especially from the design department. With a respected project organization, cross-functional project meetings could facilitate the synchronization between functions and relative the development process.

Example: A top manager perceives that it can be too much cross-functionality in the development projects, too many meetings with many people would not be efficient either. He experiences that people during the last years have

increased their presence at meetings, which is risky since it decreases the utilization factor in R&D. It unclear whether the increased representation on meetings is due to watching for possible and relevant information or just to learn more about interesting projects and project solutions.

Weekly pulse meetings are organized at company Delta from where information is quickly distributed in the organization. These meetings summarize project status and project versus line coordination and are performed at several organizational levels in the organization but also in most departments independent of their job assignments, resulting in the possibility of distributing information through the entire organization within a day. One mentioned disadvantage is the space for individual interpretations that occurs with information spread by word of mouth which can cause ambiguity in the organization. On the other hand spoken information is possible to question immediately in contrast to written routines and newsletters on a server. People attending the pulse meetings also have time instantly after the meeting for further discussions and clarifications. For co-workers involved in many forums there is not time to attend all meetings, but with company Delta's open climate there are other ways to track projects such as calling or passing by someone in the project. However, this oral communication structure makes it hard for new employees to get in to the company since you have to know people to get into the right situations and be able to do a good job. Similarly collaborations between department and responses in a project are more individual than structural independent. Overall, the introduction of new employees at company Delta needs to be more efficient. Currently it is described to take between two and three years before a newly recruited employee fully is skilled in its work and the recruitment has paid back.

At company Delta a visual planning system is applied on group and department level considering both short-term and long-term planning. However, visual planning on group and department level operates quite different in different parts of the company; some groups are really mature whereas others are beginners. But the visual planning could be used more, for instance to share knowledge and experiences. At the project office a structure of internal audits is applied with project managers reviewing each other's project which is experienced as a good way to exchange experiences and learn from each other. Similarly the visual planning activity at several departments could be further developed to focus on learning outcomes instead of activity reporting. On the other hand there are also mature applications of the visual management system at company Delta concentrating the long term planning on integration activities indicating when someone else is dependent on the precision of delivery, and complemented with short-term activity boards on group level.

IV. DISCUSSION

Dealing with risks should be a continuous and natural part of product development including everything in between reliability analyses, designing for assembly and considering technical risks through one or several FMEA's. The studied companies are really good at considering several of these risks on their own. Company Beta for instance has a special organizational segment paying regard to production and manufacturing aspects of new developed solutions. FMEA is a risk management method used by all the studied companies. Most often the FMEA implementation is even regulated by laws, standards or specific product regulations. At company Beta and Delta FMEA is also applied in every product development project. In contrast to company Alpha and Gamma, Beta and Delta are large companies with additional resources within the product development organization and more complex products. Thus they have better pre-requisites to realize a comprising activity like FMEA that easily can consume hundreds of man-hours in a project.

In general all these successful product developing companies are good when it comes to considering technical risks. Nevertheless, it is still technical issues that cause problems in most product development projects. Due to the deep technical knowledge in all four organizations their development projects easily result in several excellent, but sub-optimized, technical component solutions. Several roles at the companies indicate the difficulty of considering the complete product system during development. E.g. component design departments sometimes get too strong which makes them getting lost in their pipe and consequently develops a sub-optimized component solution experiences a middle line manager at company Delta. Similarly a business developer explains a common situation at company Gamma where co-workers on an individual level do not have the understanding of how a specific component should fit into a complete product system. Even the business developer at company Alpha describes the feeling that technical developers often create complete solutions before synchronization with other roles. A purchaser at Delta also requests its involvement earlier in development projects since the project organization normally lacks the understanding of purchasing's effect on the project result. At company Beta a whole-product responsible describes that wrong decisions frequently are made in development projects since they did not consider the holistic product perspective. Thus, the technical risk management problems in product development seem to depend on problems with considering the complete product system perspective at every organizational level in the company during a development project.

Providing another risk supporting system as contribution within DFSS would thus be ineffective since it would not help the companies to avoid their sub-optimization problems and none of them would probably change from FMEA as their risk management method. On the contrary, support regarding how to co-ordinate the line- and the project

organization within development projects is needed in all the studied companies. Further, all four companies would benefit from recommendations regarding responsibility distribution and ways of communication between project and line. Company Gamma has a strong line organization that easily runs over the project organization. Often the project managers end up with decisions they were not part of making; to make development projects work smoothly project managers need to collaborate close with the line and adjust to the lines routines. The situation is reverse at company Beta where the line organization only knows that changes will occur during a project, but not when or how late in the process. Also several departments at both company Beta and Gamma perceive that they get involved to late in the development projects. In the specific and intimate relation between company Gamma and its customer a purchaser believe that company Gamma needs to be involved earlier in its customer's development process, to be part of defining the functions and generate a solution. If the designer once has sketched a solution of a product system it is too late, then he/she wants to have it like that.

Common for all the companies is thus the need for support to concentrate on the holistic product picture on a system level, avoiding sub-optimizations, and to coordinate the project and the line organization. As it is right now, the communication within and between the project- and line organizations is really depending on individual connections or who you happened to talk to. According to a technical developer in company Gamma it is important to find the right individual in the organization to accomplish a good result when having a problem in a project. A similar scenario is described by a developer at company Beta who claims that many things are solved the informal way since many people know who to talk to get the project continued. Also, experienced product developers are aware of their position in the process chain and which other functions that is affected by their work. The Design for Six Sigma concept claims to consider the holistic perspective of the product development process, but is there any concrete support for that available in the concept?

Regarding the technical risk perspective the DFSS concept provides support by presenting concrete methods like DOE [6], [7], [11]–[14], Design for manufacturing [12], [13], [15] and FMEA [3], [6], [8], [10], [11], [13]–[16]. The four studied companies already use several of these methods in their development organization. But every company is not as mature as these four and therefore the technical risk management method support in DFSS provides a useful contribution for product developing organizations.

Although DFSS is completely right regarding method support of technical risks, it also promises support regarding risk management due to difficulties considering a holistic perspective of development processes. Co-workers in all the studied organizations understand the importance of a holistic product system perspective in product development. Still there will always be hard to make co-workers keep the

holistic view during a development project. Holistic product responsibility in a development process is about not digging into details or sub-systems, which is difficult. Some of the companies in this case study have tried to find a solution with responsibility roles considering identified problems in the development process, or assigning a complete product responsible role. These solutions can definitely be perfectly well working solutions, but the implementation will take time. What is needed, independent of the chosen specific solution which often is company individual, is a customer representative in the development process. This role's assignment is to consider the product system from a customer needs perspective throughout the entire process.

All the studied organizations somehow want help with coordination and clarification of the relation and responsibility distribution between project and line. Either the line is too strong, or there is an almost nonexistent project organization, or there is an ambiguity regarding what is what. The indistinctness brings on difficulties with project handovers and inadequate communication. Also, interchange of knowledge between project and line is malfunctioning. Several respondents report the non-existent need for additional work instructions, systems, or documentation routines. There is already a heavy workload spent to document knowledge and experiences, and to consider written information. A useful DFSS contribution in this context would be to provide concrete methods fostering interaction, communication, and clear distribution of responsibilities, for instance by suggesting how to create short, efficient and interactive meeting places.

V. CONCLUSION

There is a great method support in the Design for Six Sigma concept considering technical risk management, for instance reliability analysis, design for manufacturing and FMEA. Most of these tools are applied by the studied companies and thus the DFSS concept is completely right. The concept also emphasizes the holistic picture in product development which is found problematic in all four of the introduced companies. Hence, the concept should provide support for how to deal with organizational risks like lack of communication, problems with cross functional collaboration or sub-optimizations. To foster communication and cross-functional collaboration the concept have to include concrete solutions of how to accomplish short and efficient forums for interaction. Since a product system's holistic picture is dependent on its customer needs routines for the holistic perspective have to be created by dedicating a customer focus responsible role in the product development organization.

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