Managing Concurrent Engineering Across Company Borders: a Case Study

Dr Kamel Rouibah
Department of Quantitative Methods and Information Systems
College of Administrative Science, Kuwait
krouibah@cba.edu.kw

Abstract

Concurrent engineering (CE) requires designers to share information that can be incomplete or contradictory early during product development (PD). Information share is even more important when it crosses company borders to include customers and suppliers in the development of complex product. This exploratory research focuses on CE during early supplier involvement (ESI) when the product development process involves more than one company. A review of CE and ESI related literature finds lacking efforts that address the two issues: how to structure the process of customer /supplier collaboration, and where the supplier is involved in the customer' engineering process. This paper reports the findings of a case study conducted within two European companies (customer/supplier) about the issues. This paper found: (a) difficulties to implement CE across company borders; (b) engineers tend not to view their work in terms of creating and altering documents, nor even in terms of processes but in terms of assigning values to specifications and the relationships among specifications. This view is well supported by parameters. This parameter approach is useful to allow information-sharing, data communication and to control data validity. The paper discusses those findings as well as the implications relevant to those seeking to incorporate the information knowledge available from suppliers into the engineering design process. But it is neither aimed to justify the obtained results nor to describe any existing model that may help to understand such results.

1. Introduction: concurrent engineering in the early supplier involvement for complex product development across company borders

Market demands are moving manufacturing from mass production to mass customisation. To quickly responding to customer needs, companies are developing product in a collaborative process. Collaboration aims to improve product development efficiency (product cost and quality) and effectiveness (development cost and quality).

Pressure to achieve these goals resulted in significant changes in the way that engineering design is practiced. First the traditional sequential design-and-manufacture process is being substituted by a parallel activity known as concurrent engineering [13]. This concept calls for the involvement within the preliminary phases of design process, for all parties (work-group member's close co-operation) who can bring to bear expertise upon a design. For example, once the designer completes a set of drawings, manufacturing engineers may need to redesign the parts for ease of manufacture. Collaboration between work-group could span the company borders to include both customer and suppliers early in the product development process [4, 6, 14]. This collaboration is recognised as a complex process [9]. Much cost could be saved in the early phase of collaboration[1]. Second due to the advances in information and communication technologies, new and more powerful forms of enterprise organisation are emerging. The current trend for companies to focus on their core competencies is leading to closer forms of co-operation between customer and its suppliers namely through the establishment of different company networks [11]. In this setting, the role of supplier is evolving from the provision of components to a role that includes the provision of design information and knowledge [3]. Designers now have to rely heavily upon suppliers for information and expertise throughout the engineering design process.

The effects of these changes are many-fold, particularly upon the nature of customer-supplier relationships. These changes include the way information is handled. Indeed, some studies about engineering activities during complex product design [3, 7, 8] have shown that a very high share of engineering hours are spent on organisational matters rather than on *productive tasks* (figure 1). Approximately 25% are consumed while waiting for decisions or information from others work-groups. There are several reasons advocated, but the most important cause identified is the inadequate involvement of supplier in the customer' engineering process.

[1] Prasad [13] reports that approximately 80% of a product's life-cycle development cost is driven by decisions made in the first twenty percent of the program effort.

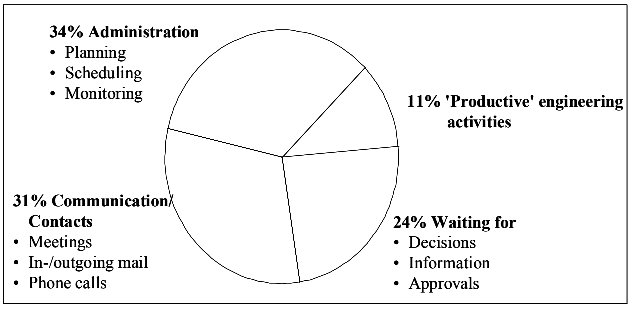

Figure 1. Productive engineering activities is a small rate of engineering activities [7]

Identifying where suppliers are involved in the customer' manufacture processes will enable: (a) all involved parties to work in a concurrent manner instead of serial; (b) to reduce engineering changes (ECs) earlier by means of early and intensive communication with the suppliers and (c) to structure and control information shared between the work-group member's close co-operation. EC refers to changes or modifications in form, representation, design, material, dimensions, functions, etc., of a product or component after an initial engineering decision has been made [10]. EC results from the fact that engineering is an iterative rather than a purely linear process.

Supplier involvement in the customer processes should therefore be managed carefully. One aspect of this research is to identify where the suppliers are involved in the engineering process of the customer, and how to inform suppliers and concerned parties about ECs impact as early as possible.

Hopefully this paper brings insight into the issues. This paper contributes to the CE and ESI literature by addressing the two above issues via a case study. This is focused on the design specifications that are usually provided in the early stage of product development, in the manufacture industry. This is a novel research in the area of ESI, product development, and competitive advantage that shows how customer-supplier interface works. The reminder of this paper begins with a brief literature review. The next section lays out the research methodology. The subsequent section describes the case study and the findings of the paper. The paper concludes with a discussion of the implications of this study and orients future research directions.

2. Literature review and unanswered questions

Our literature review uncovers the three following observations relevant to our purpose stated above.

First, from the recent literature review, this research has found that the subject of early supplier involvement (ESI) is a new and important research area both for the research community and practitioners [3, 6, 9, 14, 17, 18]. It appears that the customer-supplier interface now plays a key role in the design and development of complex and new products. For example, Culley *et al.* [3] have found that 86% of the surveyed companies take account of the "information and knowledge" previously obtained from suppliers. Moreover, significant benefits can be achieved if suppliers are involved in development process as early as possible [9, 12, 14, 18]. For example in the automotive industry, a critical element of Japanese practices is to involve suppliers, from the early stages, in the design of components for a new vehicle [2]. Therefore, customers have required the suppliers to be more involved in product development, thus shifting the responsibility of design and engineering to outsider specialist [14]. While the benefits of ESI are advocated, recent investigation in manufacturing industries has revealed that this approach is not widely practised in industries and its implementation has been a great challenge to researchers and practitioners [6, 9, 12].

Second, although organisational aspects of ESI have received much attention (such as supplier selection & evaluation, types of involvement, problems in managing supplier involvement, criteria to successful supplier involvement, integration procedures, availability of frameworks, communication procedures, controlling the process of cooperation), relatively several issues are still unsolved. One of the key issues is the need to understand, in practice, the mechanism by which suppliers are incorporated into the engineering design process and the way their information is handled during design activities. This has been raised by recent studies [3, 9, 14, 18]. For example, Takeishi [14] quoted "*managers have continually struggled with the question of where to set the boundary between what work takes place inside vs outside a company, what kind of relations to build with supplier, and how to manage the division of labour with them*". Culley et *al.* [3] did find one-third of the surveyed companies had access formal guidelines to aid respondents in decisions such as "*when to involve suppliers in the engineering design process? What their level of involvement should be?"*. Identification of the supplier involvement may help to set priorities so that suppliers' involvement becomes more manageable and economical. Even though ESI is recognised as an important subject, it is extremely difficult to perform early at the product development stage [1, 5, 9]. There are several typologies that differentiate between different forms of supplier involvement on the basis of product characteristics [11, 17]. Although valuable, these typologies have some shortcomings. Especially, they did hot address much details of how the collaboration and the involvement must be managed. Huang and Mak [9] reviewed a number of methodologies to support ESI. But they did find them unsatisfactory and piecemeal recommendations. Existing typologies only provide guidelines regarding the phases of supplier involvement of a development project (e.g. from the *concept phase* until the *end* vs only in the *detail engineering phase*) and the extent of involvement (e.g. the supplier only receives *functional specification*s vs almost *complete blueprints*). Among difficult issues facing the manufacturing in achieving effective & efficient supplier involvement during product development identified by

Wijnstra *et al.* [18] are the identification of *processes* and *tasks* that need to be carried out. The German national research project GIPP [1] tried to identify where different suppliers are integrated in the engineering process of the customer. GIPP models the interface between the customer and its suppliers through establishing links between the Bill of material (BoM) and the associated components at different levels of detail (see figure 2).

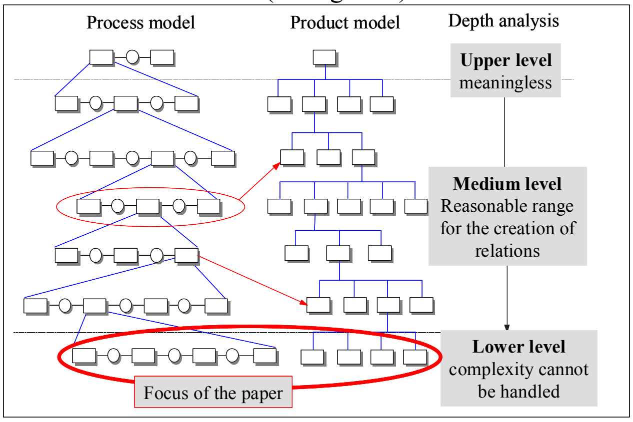

Figure 2. Relations between product and process model according to GIPP [1]

GIPP holds that the upper level is not useful and therefore not taken into account. The medium levels can be considered as the reasonable range for the establishment of supplier involvement, whereas the lowest level is too complex to be handled. The lowest level is exactly the main scope of this paper. It is the only meaningful one for the identification of the actual need for communication between customers and suppliers. However, our findings are different from the GIPP, as it will be explained in section 5.

Third, identifying where suppliers are integrated in the customer' engineering processes is also an open issue in the area of engineering change management community. This is useful to quick react to engineering change (EC). The change in one components or parts (at supplier side or customer) may affect other parts or components (at the customer or supplier side). Whilst it is necessary to identify the impact of change on both sides, recent literature on EC only addressed the issue within a single company [10, 15]. Efforts are lacking to manage ECs during customer/supplier relationship. Therefore there is a need to understand how the concurrent engineering changes could be achieved across company borders and what are the associated problems.

SGP (the customer) is in the process to reorganise its engineering processes towards the future product business taking into account concurrent engineering (CE) issues. In such a move, SGP pursue the goal to involve its supplier Knorr early in its future engineering process. The paper describes such effort, associated problems during analysis and new findings. The study is performed given the fact the decision to outsource has been made and is out of the scope of this study. In addition, it assumes that SGP/Knorr have already defined the product development process/ interface and the strategy. Before describing the case study, the next section lays out the used research methodology.

3. Research methodology / data collection

To answer our research question, we have undertaken an exploratory research, part of an European project. This was focused on a detailed study of a bogy design that is manufactured by two European companies: SGP Siemens transportation (the customer) and Knorr-Bremse (the supplier). The two companies have different profiles (table 1).

Table 1. Company profiles

	SGP	Knorr
Employees involved in (PD)	30	14
PD organisation	Project	Project
Development time	1,5 – 2 years	1-6 months
Complexity	High	High
Variants	Many	Many
Series	100 - 300	5-100
Reuse of information	High	Medium
Computer skill	Medium	Medium
End customer	Siemens TS	Transportation

SGP, located in Graz (Austria), is a world's leading manufacturer of rail bogies. The company belongs to Siemens AG. It has 600 staff and employs 170 people in the engineering activities, where more than 2000 bogies are manufactured yearly. The bogie design and production centre is the largest manufacturer of bogies for passenger in the world. SGP produces bogies for electric mainline traffic and shunting locomotives, and trailer bogies for high-speed applications, such as for German high-speed trains ICE 2 and ICE 3. Also SGP manufactures bogies for mass transit, light rail applications, and for all metro and suburban. Examples are bogies for Taipei Metro and Bangkok and MTRC Hong Kong. Examples of light rail bogies are delivered for Frankfurt (Germany), St. Etienne (France), St. Louis (USA), and airport link in Malaysia.

The supplier Knorr-Bremse is a leading European brake company system. It main business includes design and manufacture of brake, pneumatic- and onboard-systems for railway vehicles. Knorr, based in Germany, has several sites. One of them is located in Austria. Knorr-Bremse understands itself as a system vendor not only as a supplier of components. According to Knorr' high management, it is very important to establish and maintain close co-operation with manufacturers like SGP to improve the knowledge of railway vehicles and consequently the quality and function of its products, especially SGP as the centre of competence for bogies within Siemens Traffic Systems. It is believed that the close co-operation will be beneficial for both SGP and Knorr-Bremse.

Both SGP and Knorr are from the so-called engineering-to-order environment. In this setting, they co-operate to design a complex product. Processes generated are characterised by high uncertainty, frequent changes and disturbances, many iterations due to design interactive nature, and multiple levels of data maturity[2]. Engineer-to-order [19] has a considerable amount of design input. Each product is new and carries the implication of a large number of engineering changes (ECs).

3.1. Procedure of data collection

Data collection is longitudinal and made by one member of the project staying on site for 12 months on a full basis. The first 6 months were critic because the major findings of this research were discovered. Research activities included: analysing engineering business process of SGP (including information about milestones, design life cycle, supplier involvement, standard product structure); studying existing documents; interviewing and observing how engineers are performing their engineering activities with regard to the research objectives. SGP's engineering processes for conceptual and embodiment design phase have been analysed by means of the business process modelling tool ARIS Toolset® of IDS Prof. Scheer GmbH.

Interviews and meetings were first internal to SGP. They were held with 13 engineers from SGP, including the head of Product Management of bogie division. Engineers have different background ranging from CAD engineers, CAE engineers and design project managers. All of them are very close to the daily technical work. This on-site has enabled first hand observations of and participation in department meetings and discussions. Interviews and meetings were then extended to involve 5 engineers including the head of purchase department from Knorr. Finally collected data were analysed and new ideas were tested and refined in collaboration with other member of the project including 3 engineers from another supplier of SGP, 3 engineers from an information and communications technologies company (including the director, a head of unit and a senior consultant), 4 engineers from a leading European vendors of PDM solutions (including a project manager and 3 software developers), and the help of three researchers from two European universities.

About 20 meetings and several semi-structured interviews were held to collect data and to discuss the outcomes. All the meetings lasted from 4 to 8 hours. Among these workshops and meetings, two were critics.

3.2. Description of raw data

As stated above, SGP and Knorr cooperate to design passenger railcar bogies. Since the company with the responsibility for the entire system bogie is also responsible for the planning and control of the engineering processes related to the system it was decided to concentrate during the engineering process analysis on SGP's engineering activities and to identify within these processes those activities which require the involvement of Knorr supplier. In the future engineering process definition of SGP, the functions and organisational units of the suppliers to be involved is assigned as "external functions to be carried out" and "external units to be involved" directly to the particular engineering activities and events of SGP. Thus, the SGP engineering becomes a CE process backbone, which directly triggers and controls the involvement of the corresponding suppliers (see figure 3).

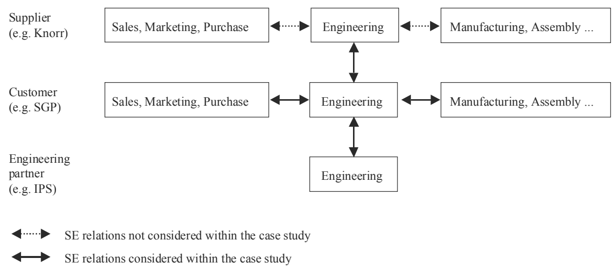

Figure 3. Concurrent engineering environment for the research

The case study is focused on the analysis of a bogie design. Figure 4 shows the bill of material of such product. Designing a bogie is a very complex process that passes through several phases: sales & marketing, conceptual design, system embodiment design, component design and detail design. Only three components (running gear, drive unit, and brake system) have been selected for this case study. SGP manufactures the *running gear* and the traction *drive unit*, whilst the bogie components of the *brake system* are designed by Knorr supplier at three different sites. The bogie engineering process requires a maximum of customer/supplier-interaction. A one hundred engineers from Siemens SGP and Knorr-Bremse co-operate to design and develop a new bogie.

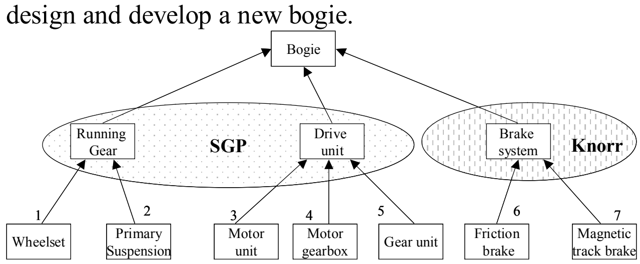

Figure 4. BoM of a Bogie (at level 2)

4. Motivations and difficulties of the case study

4.1. The challenge for ESI and co-operation between SGP/Knorr

In recent year, cost-reduction efforts at SGP have increasingly let to discussion on what should be done in order to achieve product development efficiency and effectiveness. Particular emphasis was therefore placed consistently on the following:

[2] We use the term maturity to denote the degree of consensus over and stability of data. A mature value is unlikely to be changed or deleted, and will have the required tightness or tolerances.

1- the integration and the selection of the best supplier with latest machinery; as consequence an extensive supplier assessment and qualification system has been set up especially for this purpose;
2- the establishment of a tightened customer/supplier-relationship with more efficient ways of communication and product data interchange; however the technical co-operation in and between different SGP engineering department and suppliers is not sufficiently supported as far as communication and information sharing;
3- the move from project based to product based.

SGP has acquired a lot of experience and knowledge over the past dedicates concerning ***project*** bogie design. Therefore, it is currently migrating from project business (i.e. one-of-a-kind bogie engineering and manufacturing) to product business (i.e. customer-independent bogie platform engineering with afterwards order-dependent product adaptation and manufacturing). Such a move is accompanied by the wish of SGP' high management to include its suppliers early in its future product business taking into account CE issues. A head of one department at SGP quoted "*successful concurrent engineering (CE) does not necessarily result in shortened engineering throughput times, but in a reduced time-to-customer, reduced product costs and improved product quality. Shortened engineering throughput times may be achieved through migration from project to product business by early involving suppliers*". In a project-based business, the company designed and manufactured rail-car bogies to customer order using a *one-of-a-kind approach*. Basing the business upon products (instead of project), the company will engineer customer-independent platforms, which will be adapted and manufactured by order. By moving toward a *product view* of meeting customer demand, SGP is trying to move toward a more economical model. The cost disadvantages when compared to mass production stem from: a) development costs, b) learning curve, and c) logistics costs. If there is only one of any product, its entire R&D expenditure needs to be factored into the price. When building a bridge, hydroelectric dam, or large structure, the total design costs are assigned to the single product. In a product environment, the required number of units to justify the R&D costs varies widely. Airplane manufacture can be profitable with a series run of about 100 units. Automobile manufacturers require many thousand units to cover the R&D expenses. The cost of manufacturing a given product decreases over time. This is referred to as the learning curve. In the manufacture of a complex product, the 10^{th} unit can cost 30% less to produce than the first. When a project delivers only a single item or a small group, this potential for learning is limited. A project view to meeting customer demand can limit the opportunities for reductions in the logistics costs. These can stem from lack of co-ordination in ordering inputs, production inefficiencies, and post manufacturing costs. Taking into consideration the move from project based to product based, it was therefore decided not to capture the current practice in the one-of-a-kind bogie engineering, but to draw up right from the beginning an engineering process representation, which can be used as a guideline for the re-organisation of the engineering domain with respect to CE issues. The decision to model right from the beginning the target-processes for SGP's future engineering in product business turned out to be very painful (see section 4.2.).

Another driver that encourage SGP and Knorr to early cooperate is related to barriers of provision of information to both sides. From the Knorr' view, early collaboration will reduce the interface problem. For instance the communication between SGP and Knorr will be improved and technical contacts will be established during early stages of new product development, which ensures less errors, better quality, less development time and consequently less overall costs and EC-cost. Understanding such early involvement and collaboration will give a deep insight in the engineering processes of SGP and will consequently lead to a better understanding of the requirements of SGP as a customer of Knorr. Today interaction between SGP and Knorr is serial and paper based, according to face-to-face communication (figure 5). This has many disadvantages (problem of data management, coordination of changes and communication) from the SGP's managers' view. Using documents lead to problem of data management (data inconsistency, data isolation and data redundancy) especially when there are lot of engineering changes. Paper based co-operation between SGP-Knorr is a task consuming when product data (geometric models, process models and workflow) and documentation notification must be exchanged frequently between several involved people from different companies (problem of change coordination). When fixing (releasing) requirements of a new product, key managers, other than the technical ones, from SGP and Knorr meet in a one location. This is usually conducted in a location other than the place where the people involved normally work. This process is too expensive including time of involved people. Other expenses include the costs associated with flying people to a remote site and putting them up in hotels and feeding them for several days. Once those managers return to their companies, it happens that the agreed requirements changes for several reasons: technical specialists feel they are out of feasibility or need tightness or final end-users change their requirements (problem of communication). Therefore, new meetings are required in order to evaluate the impact of changes accordingly additional costs are generated. For these reasons, engineers from both sides are willing to be more involved in a remote process that could be Internet based (figure 5) in order to overcome the previous mentioned problem (data management, coordination and communication).

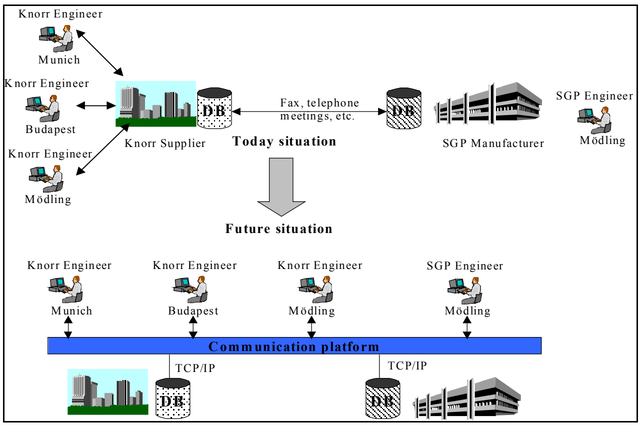

Figure 5. Current situation vs desired situation that drive the case study

The head of one department at Knorr summarised Knorr's goals regarding the future engineering co-operation with SGP within a CE framework by quoting "*In order to avoid sub-optimal solutions, and to avoid the frequent engineering change (ECs), future cooperation should not only be performed at component level (designed by each supplier), but at the entire product level with involvement of the supplying companies. At the time of order release the data for components with a long fore-run are not yet complete, and the cooperation could be done earlier* ***based on bids***". The involvement of suppliers (e.g. Knorr) in product development has therefore become a key issue in the engineering process of SGP. However such involvement raises some difficulties.

4.2. Problems encountered during process analysis

As already pointed out (see section 4.1) it was decided not to model the state of the art in engineering for SGP's project business, but to define right from the beginning the target processes for engineering in the future product business. The consequence of this decision, part of the whole project research, turned into a business process re-engineering activity with all generated difficulties.

- Parallel to the performance of the process specification and requirements definition, the future strategy as well as the organisational structure was discussed by SGP's managing board. A stable organisational structure which could have been used as a baseline for the process analysis was consequently not available. Both organisational structure and process representation were therefore subject to possible changes.
- Even though the overall vision regarding the future process is clear, the detailed common view on the particular sub-processes still has to be generated.
- The generation of this common view requires the participation of many persons, especially if the processes to be defined are supposed to support CE with the involvement of various internal and external actors to SGP and Knorr.
- When interviewing people it turned out to be problematic to make their implicit knowledge explicit, i.e. although the people knew what activities they have or will have to perform, and in what order, they find it very difficult to describe those activities in such terms so that they can be documented in graphical form.

5. Results of the case study

Through the analysis of SGP engineering processes and possible Knorr involvement, the following results were discovered.

5.1. The engineering processes become unstructured at a very low of details

The initial approach adopted in this research, termed "*modular reference process*[3] *models*", consists in the specification of all process modules, which cover all processes of SGP and their interaction with the supplier. These processes are then stored in a process library. According to the specific situation, the appropriate process modules are retrieved from the library and combined to a complete process, which has to be finally implemented as workflow. The drawbacks of this strategy consist in (a) the necessity to pre-model any possible process module that may be required, (b) the difficulty to find and retrieve the most convenient process modules from the library according to the specific situation, and (c) the fact that the interfaces between the process modules have to fulfil the needs of any kind of possible combination. Engineering sub processes vary significantly.

To test the applicability of the "*modular reference models*", SGP's engineering processes for conceptual and embodiment design phases have been analysed by means of the business process-modelling tool ARIS Toolset. Through function decomposition of ARIS Toolset, a process hierarchy can be obtained which allows illustrating very complex processes in a modular and therefore more comprehensible way.

For the analysed design phases, current practice shows almost no supplier involvement at all. In addition, it has found that the entire amount of process modules cannot be predefined. Furthermore, the number of sub processes to be executed during a large engineering project (such as a bogie development) would require extensive human interaction related to the composition of the overall process based on the process modules.

During the analysis, it has found out that engineering processes can be considered structured and stable, i. e. timely invariant, at a very abstract level only. Such processes include the global process of bogie design, platform development, engineering, design system, determination of system parameter, etc. However, it was impossible to represent the engineering processes at an ***adequate level of detail***. The more detailed the analysis gets the more unstructured the processes become.

[3] Workflow Management Coalition (WfMC) defines a process as a formalised view of a business process, represented as a co-ordinated (parallel and/or serial) set of process activities that are connected in order to achieve a common goal.

Figure 6, which is part of the structured overview of the defined process model of a bogie design, illustrates the detailing problem. This figure is obtained after decomposing the *Global process*, the *Platform development*, the *Engineering*, the *design system* and *determination of system parameters*. The maximum level of detailing that can be achieved by means of structured engineering process representation of a bogie design is limited. The functions shown in a horizontal line, such as "optimise frame (components) according to internal requirement" are unstructured processes. They are highly interactive, i.e. frequent communication between the functions is required in order to achieve an optimal engineering result. This optimisation[4] process with involvement of suppliers consists of ad-hoc processes, which are performed according to the specific circumstances in a given engineering situation. These ad-hoc processes cannot be predefined in the form of reference processes. Therefore, the particular actions performed as part of the optimisation process are added in textual form to the engineering processes shown in figure 6.

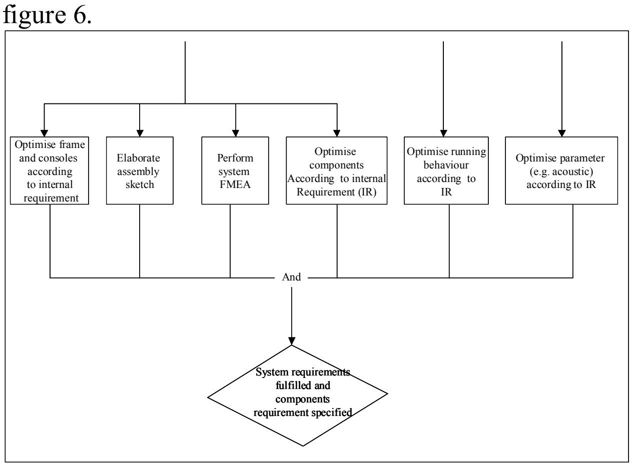

Figure 6. Maximum level of detailing that can be achieved by means of structured engineering process representation

As a consequence of the finding, it was impossible to: (a) identify for a specific engineering situation when and how suppliers (such as Knorr) are to be involved in the CE process of the customer, (b) model stable reference processes which may cover any possible engineering situation that include an interface between customer and suppliers, and could be implemented into a workflow management system.

Even this research found that formal design process exists, design process becomes harder to represent when the design becomes more detailed, which turns to making the supplier involvement harder to be achieved. This finding contract previous research such as of Culley *et al*. [3] who found that 65% of the surveyed companies had official design process models with the potential to aid and facilitate engineering designers in their decisions on supplier interactions.

Ad-hoc processes, depending on the specific circumstances in a given engineering situation, start to dominate the engineering activities. The characteristics of technical (i.e. non-administrative) engineering processes depend very much on "*the specific circumstances*" in a given engineering situation. In such a case, the occurring events, the activities to be performed, their sequence, and the required participants cannot be pre-defined. The process is therefore purely ad-hoc and would have to be specifically designed for each particular engineering situation. This is not feasible. This result supports the GIPP group finding [1, 5]. Decision on supplier involvement is taken in relation with these ad-hoc processes.

Moreover, as the early collaboration is done according to vague and rough data supplied by SGP and Knorr, many design iterations and engineering changes (ECs) are necessary to reach a design consensus. In order to improve the paper-based communication, engineers have expressed the need for a "rapid communication" in order to avoid delaying the project.

As the engineering process cannot be all represented as reference process models, a different approach to CE, was therefore initiated. It will be discussed in the next section.

5.2. Engineers neither think in processes nor in documents but in parameters and their relationships

In order to overcome the problem of extensive human interaction required to compose the overall process from *process modules* the document-controlled workflow approach was considered an alternative approach. Predefined document types containing "sensitive" document sections retrieve the appropriate subset of process definitions, combine them and finally execute them as workflows. However, this approach requires the predefinition of not only the entire subset of processes but also of any document type and completion variant that may occur. Since the completion of a document depicts an event triggering a workflow, the entire set of documents used within the overall context of a business workflow must be somehow interconnected, i.e. it must be defined how to get from an event triggering a workflow (the document completion) to an event resulting from a workflow (the automatic provision of a new document to be completed). As far as engineering is concerned the most essential disadvantage of this approach consists in the use of documents. In SGP an engineering milestone checklist based on completed documents had been generated. Nevertheless it has been during the case study that the checklist was hardly used because of two main reasons: (a) the everyday business did not allow the engineers to invest the time required to complete the documents or, (b) the engineers were simply not keen on completing the

[4] Optimisation evolves many activities such as: check validity of requirements; define target values for parameters and derive new start values for iteration; communication and feedback inside engineering with involvement of external engineering unit and other internal organisation unit; determine components requirements; achieve consensus among involved engineering units with respect to the internal requirement.

documents since the related work was not considered directly productive, i.e. the document work did not bring them any further tangible value in their usual engineering business. In addition, meetings held between people from SGP and Knorr about bogie design co-operation are time and cost consuming (see section 4.1), and are subject to frequent requirement change. A representative of a large automotive supplier summarised document disadvantages by quoting *"future engineering will no longer have the time to wait for documents"*.

Based on the engineers' experience and taking into account previous disadvantages, engineers report they were less concerned about processes and documents. In a design setting, neither a document nor process view captures the essence of the customer-supplier collaboration. Engineers see their work as making engineering decisions during "*specific circumstances in a given engineering situation*", not as creating documents or as following processes. An internal SGP workshop revealed that the mentioned "*specific circumstances in a given engineering situation*" are defined by product parameters, especially they quoted the ***killer parameters***. Parameter captures well the way engineers work and think, and dominates most discussions and organised workshops. Depending on the type and the value of a specific parameter the engineers have to communicate with other company-internal and -external engineers as well as with experts from other disciplines such as operations planning or purchase. The term *killer parameters* had been mentioned various times during organised workshops within SGP. Parameters represent elementary engineering variables during engineering activities in the engineer-to-order environment. They represent the specific circumstances in a given engineering situation. Killer parameters are critical components attribute values, which must be kept within a certain value range or below a certain maximum value because otherwise extensive reworking of the entire bogie system design would be required. These parameters have an extensive impact on both self-manufactured and supplied components and should be managed carefully by the customer and supplier. Therefore, the management of *killer* parameters requires intensive communication with the suppliers in order to achieve a consensus regarding the components geometric and functional properties.

Bogie development process is dominated by iteration procedures, which start at the beginning of the System Embodiment Design phase and stop at the end of the Component Design phase. Although some parameter values may be predefined by a requirements list, start values have to be estimated for most of the parameters at the beginning of the engineering process. While the engineering activities proceed, the parameters are subject to numerous iterations. The corresponding parameter values estimated at the beginning become more and more precise and stable.

This new approach considers complex product development as a form of parameter processing. The engineering process is approached as a network of activities that uses and produces parameters (figure 7).

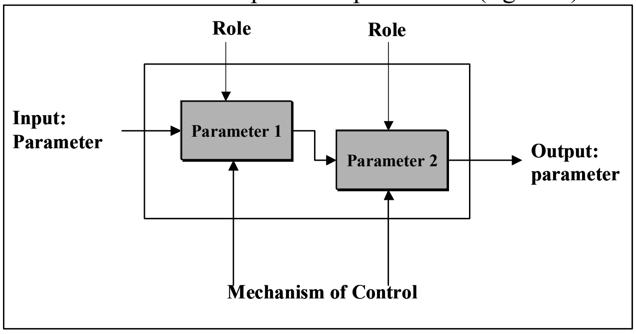

Figure 7. **Modelling engineering activities from a parameter perspective**

An activity can start when all required input parameters are available and ends when the target parameters are stable. The control mechanism to upgrading parameters is outside the scope of this case study and will be made in a separate paper.

Parameters often share complex relationships. These relationships might be represented by mathematical equations such as

max_axle_diameter = *f* (max_axle_load, bear_distance, track_gauge, axle_material);

wheel_motor_distance = *f* (gear_transmission_ratio, wheel_diameter_worn, max_axle_diameter, clearance_to_rail, gear_steps).

Parameters represent the smallest elements for basic co-operation between the customer and its suppliers. The collaboration is therefore more easily based on parameters and their relationships since the engineers (from SGP and Knorr) subscribe to product interface parameters. In case of a parameter value change, subscribed engineers (either at the customer or supplier sides) will be automatically informed in case of ECs. Not all parameters are required for the customer-supplier co-operation. Only a subset is required to satisfy such co-operation. For example, designing a bogy for passenger rail car requires 300 *killer parameters* as quoted by SGP' engineers. These parameters will be the subject of collective estimation and validation by the engineering from customer-suppliers relationship.

During the case study a list of engineering parameters and their relationship, relevant to bogie life cycle has been developed.

Using the parameter approach as a mean of collaboration across company border has led to the establishment of links (matrix) between parameters and parameters, parameters and final end-users requirements, parameters and components, parameters and people, documents and components (see figure 8).

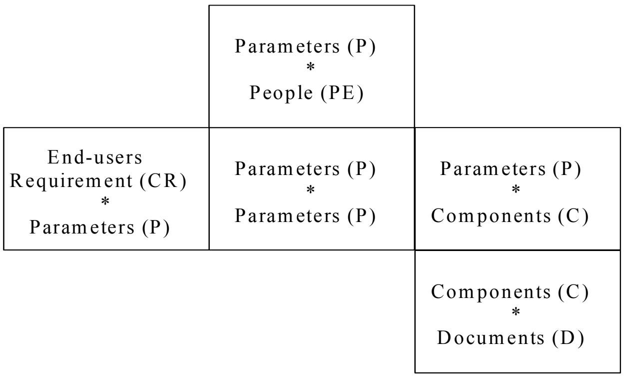

Figure 8. Dependencies between parameter/ components/ documents and people

Table 2 shows an example of parameters linked to product structure items or components (the table is not meant to show all parameters). Due to my confidentiality agreement with the two companies, the names of component types in the sample are limited.

Table 2. Dependencies between parameters and product structure items related to a bogie.

Dependencies between component / parameters		max-axle-load	bear_dist	track_gauge	wheel_diameter_wor	clearance-to-rail
1	Brake equipment					x
1.1	Friction brake					
1.1.1	Wheel disc brake complete					
1.1.1.1	brakes pliers	x	x	x	x	
1.1.1.2	Spring-brake cylinder	x	x		x	
1.1.1.3	Hose line					
1.2	Magnetic rail brake			x	x	

5.3. Engineers use the concept of hardness grade to measure design stability

During product design, engineering data exist in multiple levels of maturity, within different departments in the customer-supplier relationship. In order to ensure engineering data validity all the time, it has been discovered that engineers of SGP use the concept of hardness grade, noted HG. It is originated from McKinsey and is related to cost reduction measures. McKinsey uses 5 HG. Engineers of SGP have later on adopted the terminology in order to show how secure and stable the value of a specific parameter during the design process. It also indicates where suppliers intervene during the bogie design. The McKinsey's hardness grade was frequently used by SGP engineers without any adaptation. During this research a HG definition was made and agreed inside SGP. Per opposite to the 5 HG of McKinsey, five HGs of parameter specification have been adopted during design process. The evolution of a parameter value through hardness grades controls the design process.

The 5 HGs are linked to the bogie life cycle and milestones (figure 9). For example, during HG 1 the parameter value has been estimated and depicts a start value for iteration. During HG 3 parameter values are specified based on more precise calculations in co-operation with other engineering groups of SGP; parameter values are checked and preliminarily approved by Knorr supplier; parameter values are checked and preliminarily approved by internal organisational units to SGP other than engineering; and finally parameter values are checked and released by the responsible project manager of SGP.

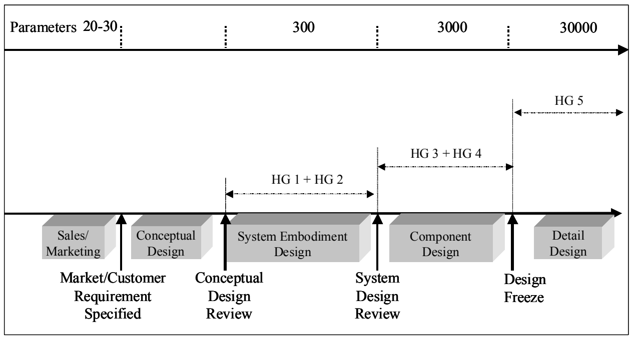

Figure 9. Design stages, milestones, parameters and hardness grades

Parameter values may be explicitly or implicitly predefined by external (final end-users) or internal requirements (by engineers). If parameter is predefined by external end-users then it is set to "hardness grade = 5". Otherwise, the parameter has to pass all hardness grade transitions from 1 to 5.

Whereas the hardness grade of a parameter already depicts one form of parameter state, the parameter has to pass various statuses within a particular hardness grade level prior to its upgrading. During bogie design, collaborative process of assigning values to parameters moves a parameter through several statuses within each phase of the product life cycle. Parameter values must be estimated, approved, and released. This forms the parameter life cycle.

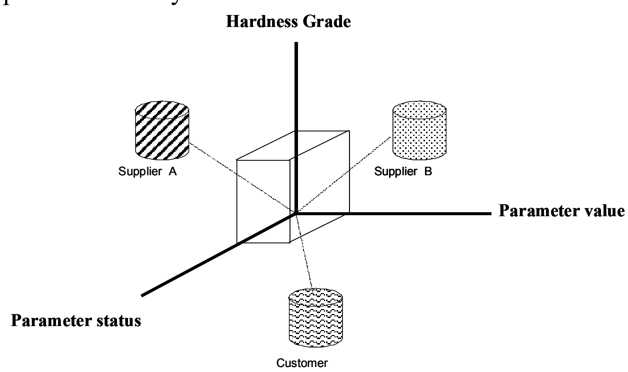

Figure 10. Three dimensions of a parameter

The above sections described new finding to co-ordinating engineering design activities and placed this within a framework of participants, parameters, and procedures. Before using this parameter approach, several steps need to be performed.

1. Identify the product interface collaboration between customer/supplier to meet the specific end-user demand.
2. Ensure engineering transparency through assignment of parameters without input/output interdependence relationships, to product life cycle (i.e. to each phase of design: system embodiment design, component design, etc.).
3. Obtain external end-users' specifications through interviews and marketing research.
4. Transform external requirements into internal functional requirements, and identify predefined parameters.
5. Link parameters to all components; parameters will now identify where suppliers and the main contractor collaborate.

6. Conclusion & perspectives

This paper, has described an exploratory research about CE during ESI and its consequences to design complex product in a collaborative mode. The case study has found unexpected difficulties to manage CE during early product specification stage. In addition, findings have shown engineers think in term of parameters and their relationships, instead of documents. Parameters represent the smallest elements where Knorr (the supplier) is integrated in the SGP (the customer) engineering processes. From the case study it appears the quality of the component design jointly developed by customer and the supplier depends very much on the specific circumstances in a given situation, which are well represented by parameters. Parameters represent the essence of the collaboration in the customer-supplier relationship.. This is different from the GIPP approach [11] that is based on establishing links between the BoM and the associated components. This finding constitutes a new approach to manage concurrent engineering and engineering processes across company borders. Furthermore, this paper proposes clear concepts that represent a new approach for workflow management and engineering change management across company based on parameters.

The parameter approach is being adopted by the SGP and Knorr to improve collaboration and communication early in the product development stages. From the case study, it turns up that both SGP and Knorr have agreed using parameters to increase the engineering transparency, as well as to reorganise their engineering processes. This approach would make engineers aware of the necessity to communicate and would therefore contribute to the engineering transparency and co-operation. The parameter approach in connection with the hardness grade definition is considered a very useful approach to better quality assurance in engineering. This approach could in fact provide significant support during the assessment of engineering change (ECs) effects and would furthermore allow the documentation of the engineering process. The direct access to product data across company borders is vital regardless of the actual type of project management organisation.

Beyond these benefits, this research suffers from limitations. First, according to six design methods [16], this approach best fits parametric design and permits configuration design. Second the approach described here is only applicable to product families (not one of a kind) where former product specifications can extensively be reused for new designs. Third, this approach is based only on two companies: SGP and Knorr. However, because companies are facing the same challenges, the findings of this paper are not SGP and Knorr concerned.

Results of this research have several implications for both researches and practitioners. From a research perceptive capturing parameter relationship is close to knowledge management. For example, one participant reacted to parameter approach by comparing the parameter relationship as knowledge capture used in other research areas and suggested to initiate further investigation to capture parameters and their relationship. Results also imply that outsourcing does not work effectively without extensive internal effort to SGP. To gain competitive advantage from ESI, managers should "*ask not what your supplier can do for you; ask what you can do with your suppliers*" as Takeishi [14] suggests. Consequently internal reorganisation must be initiated to comply to fully adopt such an approach.

As the product design addressed within this research spans the company borders, there is a need to further investigate the implementation of such approach in a new generation of software. However, this requires solving two specific issues in order to create trust between partners: the workflow inter-company, and the security of exchanging data across company. Indeed existing system such as PDM systems offer little flexibility to support engineering activities when the design spans the company borders. This research encourages development of new generation of PDM (called Collaborative Product Data Management cPDM) systems oriented to support the parameter-based approach and workflow across company borders. Furthermore, this research encourages future research to address the security aspects of data exchanged in the customer-supplier relationship. The move from a linear design to concurrent engineering design activities may trigger more radical changes in the design of information system that span company borders. Inter collaboration between companies (customer/supplier) is successful only if involved parties sense and feel that the value they provide is compensated with equal value received. Since the parameter based approach exists, how to access data of suppliers and customers? How could a company outperform competitors who also have cooperative relationships with their partners?

Acknowledgement

The project to which the above-described results refer is co-funded by the European Commission under the ESPRIT programme (project No. 26780 - *SIMNET: Workflow Management for Simultaneous Engineering Networks*. The project partners are:

- Siemens SGP Verkehrstechnik GmbH, Graz, Austria (Co-ordinator)
- EIGNER + PARTNER AG, Karlsruhe, Germany
- Knorr-Bremse Systeme für Schienenfahrzeuge GmbH, München, Germany
- Mission Critical SA, Waterloo, Belgium
- BETA at Eindhoven University of Technology, Eindhoven, The Netherlands
- TU Clausthal, Clausthal-Zellerfeld, Germany
- IPS Ingeniería de Productos, Procesos y Sistemas Integrados S.L., Valencia, Spain

The author wishes to acknowledge the Commission for its support and the SIMNET project partners for their contribution.

References

[1] Aich, Goldstein and Kretzschmar, 1997. Indexing and classification of development sub-processes in different development phases [in German], Association project "Business process design with integrated product and process models" (German Federal Research Office - Programme "Production 2000", Subproject 4 "Informatics- technical integration of process and product models", Final report of work package 4.1

[2] Clark K.B. and Fujimoto T., 1991, *Product development performance: strategy, organisation and management in the world auto industry*. Harvard Business School Press: Boston MA

[3] Culley S.J., Boston O.P., & Christopher A. 1999, Suppliers in New Product Development: Their Information and Integration. *Journal of Engineering Design*, Vol. 10, No. 1, pp. 59-75

[4] Eisenhardt K.M., and Tabrizi B.N.1995, Accelerating adaptive processes: product innovation in the global computer industry. *Administrative Science Quarterly* vol. 40, pp. 84-110

[5] Fleischer L.J.K, 1998, Supply chain involvement. Concurrent engineering effectiveness: integrating product development across organisation. Munich: Hanser Gardner Publication, 1998, pp. 113-139 [chapter 5]

[6] Graaf D.R. and Kornelius L., 1996, Inter-organisational concurrent engineering: a case study in PCB manufacturing. *Computers in Industry* (special issue), vol. 30, no 1, September, pp. 37-47

[7] Harmon, R. L. 1996, Das Management der neuen Fabrik.

[8] Holmes C., and B.,Yazdani, 1999, Internal drivers for concurrent engineering industrial case study. *5th International Conference on Concurrent Enterprising* (ICE'99), pp. 455-464

[9] Huang G.Q. and Mak K.L.2000, WeBid: A web-based framework to support early supplier involvement in new product development. *Robotics and Computer Integrated Manufacturing* 16, pp. 169-179

[10] Huang G.Q., and Mak K.L., 1999, Current practices of engineering change management in UK manufacturing industries. *International Journal of Operations & Production Management*, vol. 19, no 1, 1999, pp. 21-37

[11] Jagdev H.S., and Thoben K.D. (2001): Anatomy of enterprise collaboration. *Production Planning & Control*, 2001, vol. 12, no 5, pp. 437-451

[12] Lipparini B., 1994, Strategic partnership s in new product development: an Italian case study. *Product Innovation manage* 1994, vol. 11, pp. 134-145

[13] Prasad, B., 1996, *Concurrent engineering fundamentals: integrated product and process organisation.* Volume I (Upper Saddle River, NJ: Prentice Hall).

[14] Takeishi A., 2001, Bridging Inter- and Intra-firm boundaries: Management of supplier involvement in automobile product development. *Strategic Management Journal* vol. 22, pp. 403–433

[15] Terwiesch, C., Loch, C. H., 1999, Managing the Process of Engineering Change Orders: The Case of the Climate Control System in Automobile Development. *Journal of Product Innovation Management* 1999, Vol. 16, pp. 160-172.

[16] Ullman, D., 1997, *The Mechanical Design Process*, (New York: McGraw-Hill Company).

[17] Wijnstra F., and Pierick B.T., 2000, Managing supplier involvement in new product development: a portfolio approach. *European Journal of Purchasing & Supply Management* 6, pp. 49-57

[18] Wijnstra F., Weele A.V., and Weggemann M., 2001, Managing Supplier Involvement in Product Development: Three Critical Issues. *European Management Journal* Vol. 19, No. 2, pp. 157–167

[19] Wortmann, J.C., D.R. Muntslag, and P.J.M Timmermans, 1997. *Customer-driven Manufacturing*, Chapman & Hall