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PROBLEMS AND ROOT CAUSES IN PRODUCT REALIZATION IN HIGH TECHNOLOGY ORIENTED INDUSTRIAL EQUIPMENT PRODUCTION ORGANIZATIONS

Caglar Ucler*, Ozalp Vayvay**

* Ozyegin University, Istanbul, Turkey, ** Marmara University, Istanbul, Turkey

E-mail: caglar.ucler@ozyegin.edu.tr

ABSTRACT

Build to order market in high technology is growing rapidly. Especially industrial systems in process industry are under narrow time constraints by the investors, despite the high level of complexity. This dualism results in mistakes, rework and loss of profitability. Consequently such product realization companies loose valuable time and in this rush they have difficulties in knowledge- accumulation and circulation. As a result innovation capability is restricted and the sustainability is jeopardized. In order to isolate key drivers of these problems, a technology oriented international organization was analyzed, where all business processes were captured in a network diagram. Then a process FMEA for the critical path was performed with consequent root cause analysis, indicating potentially the lack of proper IT & requirement management systems with 36.1% as the most critical root cause, followed by the lack of experience with 32.8% and high workload with 31.1%. Subsequently improvement areas in requirement management systems and human resources were indicated successfully.

Keywords: Product Realization, Business Process Management (BPM), Failure Modes and Effects Analysis (FMEA), Root Cause Analysis (RCA).

JEL Classification: M11, M15, O32

Yüksek Teknoloji Odaklı Endüstriyel Ekipmanlar Üretim Organizasyonlarında Ürün Gerçekleştirmedeki Problemler Ve Kök Nedenleri

ÖZET

İleri teknoloji alanında sipariş üzerine üretim pazarı hızla büyümektedir. Özellikle proses endüstrisi alanındaki endüstriyel sistemler yüksek düzeydeki karmaşıklık isterine rağmen yatırımcılar tarafından dar zaman kısıtları altında bulunmaktadır. Kendi içinde çelişen bu ikilik, hatalar, yeniden işleme ve karlılık kaybı ile sonuçlanmaktadır. Dolayısıyla bu tipte ürün gerçekleştirmesi yapan şirketler değerli zaman kaybının yanı sıra, acele ile çalışmaları sebebiyle bilginin birikiminde ve dolaşımında da zorluklar yaşamaktadırlar. Sonuç olarak inovasyon kapasitesi daralarak, sürdürülebilirlik tehlikeye girmektedir. Bu problemlerin ana sebeplerini izole edebilmek için teknoloji odaklı uluslararası bir organizasyon analiz edilerek, tüm iş süreçleri ağ diyagramı ile modellenmiştir. Daha sonra kritik yol üzerindeki süreçler için hata türleri ve etkileri analizi gerçekleştirilerek, sırası ile %36,1 ile uygun bilgi işlem ve gereksinim yönetimi sistemlerinin eksikliğinin, %32,8 ile tecrübe eksikliğinin, %31,1 ile de yüksek iş yükünün, potansiyel kök nedenler oldukları tespit edilmiştir. Ayrıca gereksinim yönetim sistemlerinde ve insan kaynaklarında iyileştirme alanları da başarıyla gösterilmiştir.

Anahtar Kelimeler: Ürün Gerçekleştirme, İş Süreçleri Yönetimi, Hata Türleri ve Etkileri Analizi, Kök Neden Analizi.

1. INTRODUCTION

Products have reduced life cycles in global, competitive markets (Afonso et al., 2008) and the marketplace is pulling increasingly the consumer pricing down (Cabano, 2009). Consequently firms apply different mechanisms for cycle time reduction in new product development (NPD) (Eling et al., 2013) to get a competitive advantage (Millison et al., 1992) resulting in a higher new product success (Cankurtaran et al., 2013). However the level of complexity is elevated for industrial products by multiple sites serving a global market with multi-products (Shah and Ierapetritou, 2012). Therefore either lack of time or focus on other priorities might result in several problems (Smith and Merritt, 2002) related to quality and reliability (Boersma et al., 2004). Additionally due to complex interactions, engineering changes in later stages can endanger the success of the whole project (Reddi and Moon, 2013). Then the caused rework result in the loss of profitability, and most importantly it leads to longer product cycles. Consequently, when running behind initial schedule, development time, cost and product performance are affected (van Oorschot et al., 2011). To overcome this, accelerated product development can be applied, but it also may result in a mismatch of the demand and may limit the innovation potential (Crawford, 1992).

In fact, innovation requires the circulation of Ba (Nonaka et al., 2008) and shared knowledge (Lima and Carpinetti, 2011). Knowledge sourcing, transformation and exploitation build up the innovation value chain (Roper et al., 2008, Ganotakis and Love, 2012). When reworks are done in a fast manner, the capture of the associated knowledge can get difficult and local solutions do prevent the diffusion of the information. In fact knowledge management is tightly related to business process management (Cao et al., 2013), which lack is further narrowing down the innovation potential. This inhibits the sustainability.

Consequently the main problems in product realization have to be isolated in order to redesign the processes (Tenner and DeToro, 1996), avoiding such costly errors. A method is proposed herewith incorporating the usage of business process management (BPM) practices to represent the as is situation with a consequent process Failure Modes and Effects Analysis (process FMEA) accompanied by a Root Cause Analysis (RCA). Thus the structure of this paper is as follows: First BPM, FMEA and RCA are explained, and then their application on a technology oriented process equipment manufacturer is presented in detail. After results and discussion the paper is finalized with conclusions.

2. METHOD

BPM is a structured approach to improve operational activities continuously (Zairi, 1997: 64). Business processes are tasks, i.e. activities with inputs and outputs to achieve specific organizational goals (Cao et al., 2013). Therefore a process map is generated, showing activities as well as their relations, utilizing systems thinking in how an organization is actually working (Cronemyr and Danielsson, 2013). Interview techniques and analysis of available documentation can be conducted to finally represent the whole workflow in a model

(Weske, 2007:347), i.e. in a network diagram. This shall indicate additionally also the process owners as well as the boundaries and control mechanisms (Tenner and DeToro, 1996). Analysis techniques of project management such as critical path method (CPM) can be applied on this diagram, which gives the project completion time via the longest path through the network (Larson and Gray, 2011), delivering also the critical business processes on this path. All in one BPM aims organizational optimization using process monitoring and enhancement, which requiring involvement of the top management, clearly defined roles, adequate technical, well-trained people and appropriate culture (Jeston and Nelis, 2006: 299).

FMEA is a structured method first introduced by the US Military as the Failure Mode, Effects, and Criticality Analysis (FMECA) for the reliability evaluation of systems (DOD, 1980). Today, it is widely applied by multidisciplinary teams in automotive (BSI, 2009), aerospace (SAE, 2009) and other industries. FMEA is systematically identifying and assessing potential failure modes of products or processes, that failures can be prevented in advance with given recommended actions (Sankar and Prabhu, 2001; Mikulak et al., 2008). People, materials, equipment, methods, and environment are taken into consideration in the process FMEA (Mikulak et al., 2008). Each potential failure mode is assessed according to its effects, Severity (S = 1 for not dangerous to 10 for highly dangerous), causes, Occurrence (O = 1 for no occurrence to 10 for highly occurrence), control systems, Detectability (D = 1 for most detectable to 10 for least detectable), and consequently the Risk Priority Number (RPN) is calculated as the multiplication of S, O, and D (Prajapati, 2011).

RCA is used to determine the underlying causes of problems, complaints and undesired events (Vorley and Tickle, 2008). It involves data collection, identification of the problem, root cause identification and generation of recommendations (Rooney et al., 2004) for prevention or mitigation of problems (Vorley and Tickle, 2008). A cause-and-effect diagram is used to illustrate the problem with its associated causes, which is also called the Fishbone or Ishikawa diagram (Gupta, 2004).

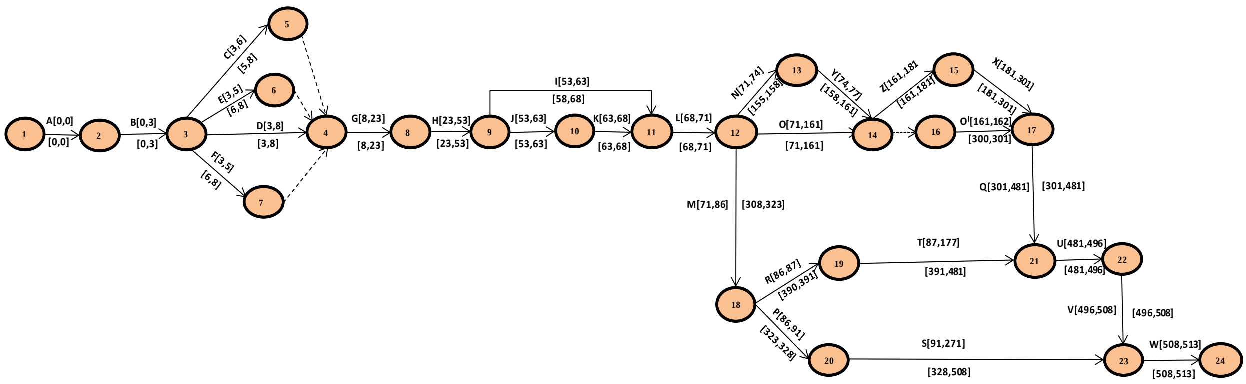
The Case Study

A technology oriented, international production company in the process equipment market was selected. In order to isolate the key processes a survey was conducted to employees across all departments, where all major tasks were isolated with their inputs, outputs, connection to other individuals, historically associated problems and duration. This resulted in the allocation of 27 main processes (see Table 1), which were crosschecked with the quality manual. Consequently a network diagram was prepared for these processes indicating the work flow starting from purchase order (PO) to delivery by including early/late start and early/late finish dates (see Fig. 1). This also delivered the critical path was determined.

Table 1 Activity list for main processes

Process Name	Owner
Product Order	Customer
Pre-assessment	Sales
Assessment by Sales	Sales
Assessment by Quality	Quality
Assessment by Design	Design
Assessment by Production	Production
Quotation Preparation	Sales
Negotiation	Sales & Customer
Paper Work	Sales
Job Number Creation and Production Scheduling	Production
Commercial Items	Sales
Design Dossier Initialization	Design
General Mach. Calculation	Design
CAE & Design Optimization	Design
Joining	Production
Plate Order	Design
Plate Procurement	Procurement
Production Identification and Dossier Duplication	Design
Piping Order	Design
Equipment Order	Design
Piping Procurement	Procurement
Piping Assembly	Production
Equipment Provision	Procurement
Equipment Installation	Production
General Drawing	Design
Production Drawing	Design
Vessel Production	Production

Fig. 1 Network diagram with processes on nodes including ES, EF, LS and LF Times



Historical failure modes derived from the questionnaire together along with other potential modes on the critical path were summarized by an expert group in a FMEA sheet (see Fig. 2). Recommended actions were determined for failure modes with RPN scores higher than 150 as:

1. A control mechanism is due, preferred information technology (IT) supported system
2. CRM implementation such as sales force or MS CRM, establishment of an Inside Sales Group
3. CRM or a similar tracking system inside sales group to track progress (as internal customer of design)

Fig. 2 The FMEA sheet

Process FMEA

Project : xxxx | Participants : xxxx | Rev: 4 | Date: 21.01.2016

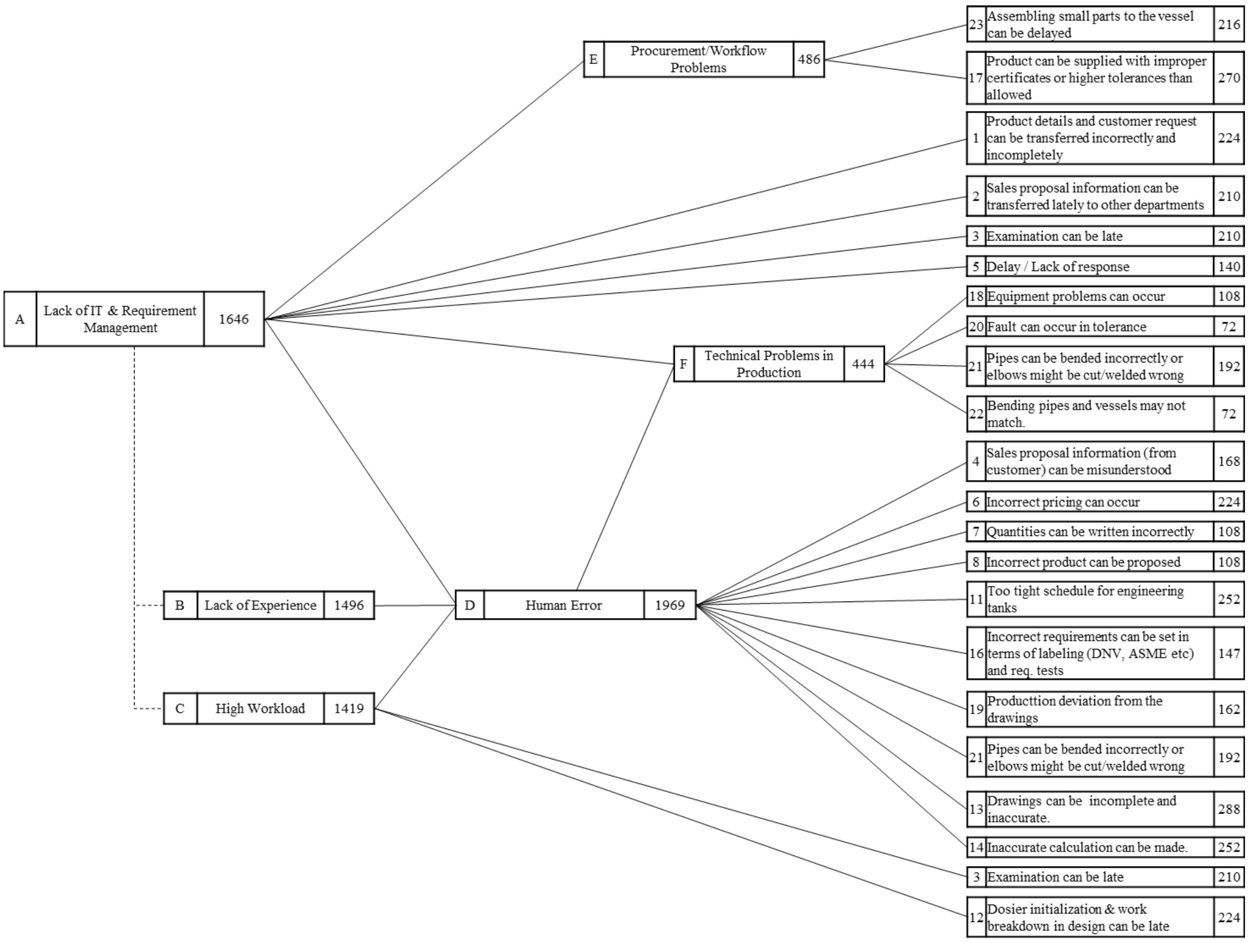
Item/Function	Tracking Nr.	Potential Failure Modes(s)	Potential Effect(s) of Failure	Severity	Potential Cause(s)/ Mechanism(s) of Failure	Probability	Current Process Controls	Detectability	RPN	Recommended Action(s)
Pre-Assessment	1	Product details and customer request can be transferred incorrectly and incompletely	Offer to customer is delayed; this can lead to wrong pricing having a big impact on profit.	8	Human Error	7	Verified by a sales personel	4	224	A control mechanism is due, pref. IT supported system
Pre-Assessment	2	Sales proposal information can be transferred lately to other departments	Late proposal, loss of recognition & loss of business	5	Human Error	6	Verified by a sales personel	7	210	1. CRM implementation such as salesforce or MS CRM 2. Establishement of an Inside Sales Group
Assessment by Design	3	Examination can be late	Late proposal, loss of recognition & loss of business	6	High workload	7	Verified by a design personel	5	210	CRM or a similar tracking system inside sales group to track progress (as internal customer of design)
Assessment by Sales	4	Sales proposal information (from customer) can be misunderstood	Iteration due in qutation process that the customer satisfaction decreases	7	Overlooked of requirement	4	Verified by a sales personel	6	168	minor recommendations section: presales engineer or application engineer group to support the process alternatively within a matrix org. the design department , someone from the dd can take this responsibility, however the workload asessment has be done accordingly.
	5	Delay / lack of response	Late proposal, loss of recognition & loss of business	7	Overload or mistake (forgotten)	4	Verified by a sales personel	5	140	
Quotation Preparation	6	Incorrect pricing can occur	Loss of business with the customer, unsatisfaction	8	Human Error and overlooked of requirement, lack of downstream req. Management tools	4	Verified by a sales personel	7	224	Presales engineer or application engineer group to support the process alternatively within a matrix org. the design department , someone from the dd can take this responsibility, however the workload asessment has be done accordingly.
	7	Quantities can be written incorrectly	Loss of business with the customer	6	Human Error and overlooked of requirement	3	Verified by a sales personel	6	108	
	8	Incorrect product can be proposed	Loss of business with the customer	9	Human Error and overlooked of requirement	3	Verified by a sales personel	4	108	
Commercial Items (Contract negotiation)	9	Contract / Guarantee terms especially scope, pricing & payment and delivery schedule can be incorrect / missing	Late recurrent costs associated to job numbers, inconsistency in cost structures, long term strategic issues	5	Lack of guarentee related knowledge and simply not done	7	N/A	7	245	Simply make a work together with quality, design & sales
Job Number Creation& Production Scheduling	10	Job number creation can be overlooked.	Confusion between interrelated production processes	4	Human Error and overlooked of requirement	4	Created by production planning personel	2	32	
	11	Too tight schedule for engineering tanks	Confusion between interrelated production processes	6	Human Error and lack of requirement management	6	Created by production planning personel	7	252	Include design kick-off meeting with all related personal (CE environment)
Design Dosier Initialization	12	Dosier initialization & work breakdown in design can be late	Prevents CAE&Design Optimization process	7	Manual operation with High workload in design	8	Verified by chief in design	4	224	No streamlined process. IT push for requirement management would be good (ERP II or similar)
CAE&Design Optimization	13	Drawings can be incomplete and inaccurate.	Incorrect production is made or redesign during production	9	Lack of experience and/or control mechanism	8	Verified by engineer in design	4	288	Control procedure including cross check by production and or quality 3D model to 2D drawing PLM System with revision tracking and digital approval
	14	Inaccurate calculation can be made.	Incorrect production is made.	9	Lack of experience and/or control mechanism	7	Verified by engineer in design	4	252	Detailed internal procedures due for design acceptance
Plate Order	15	Plates can be ordered without customer or Notifying Body (TUV etc) confirmation of design	Incorrect procurement is made.	4	Human Error or by purpose with special approval of the director in order to be in time	3	Verified by procurement	2	24	
	16	Incorrect requirements can be set in terms of labeling (DNV, ASME etc) and req. tests	Confusion between interrelated production processes	3	Human Error lack of requirement management process	7	Verified by storehouse	7	147	
Plate Procurement	17	Product can be supplied with improper certificates or higher tolerances than allowed	Redundant raw material is kept in storages.	9	Overlooked requirements and Human Error	5	Verified by quality	6	270	Income inspection for all parts due. Requirement management to be on a solid system to transfer all req. data to quality
Vessel Production	18	Equipment problems can occur	Production delays	9	Disruption of machines, power failure.	4	Verified by production personel	3	108	
	19	Producttion deviation from the drawings	Incorrect production is made.	9	Carelessness	3	Verified by production chief	6	162	
	20	Fault can occur in tolerance	Unsuitable product is produced	8	Machine Error	3	Verified by production chief	3	72	
Piping Assembly & Joining	21	Pipes can be bended incorrectly or elbows might be cut/welded wrong	Reproduction of pipes & scrap	8	Machine Error, wrong interpretation of the drawings or wrong workmanship	6	Verified by production chief	4	192	training
	22	Bending pipes and vessels may not match.	Reproduction of pipes & scrap	6	Machine or user Error	3	Verified by quality	4	72	
Equipment Installation	23	Assembling small parts to the vessel can be delay	Production and delivery can delay	9	Delay of small part (valve...) procurement	6	Verified by procurement and production	4	216	Design gate meetings including design, production,procurement as well.

4. Presales engineer or application engineer group to support the process, alternatively within a matrix organization the design, someone from the design department can take this responsibility; however the workload assessment has be done accordingly.
6. A control mechanism is due, preferred IT supported system

9. Simply make a work together with quality, design & sales
11. Design kick-off meeting with all related personal
12. IT would be good for requirement management (ERP II)
13. Control procedure including cross check by production and quality, 3D model to 2D drawing, product Life-Cycle Management (PLM) System with revision tracking and digital approval
14. Detailed internal procedures due for design acceptance
17. Income inspection for all required parts, requirement management to be on a solid system to transfer required data to quality
21. Training to employees
23. Design meetings including design, production, and procurement as well

After that possible root causes were analyzed and the failure modes were arranged respectfully (see Fig. 3). Within these groupings the cumulative total RPNs were computed in order to have a participation factor for the ranking of the causes. This was also used to isolate the most significant root cause. Therefore weighing factors to the failure modes on each path to the root cause were assigned by specialists in consensus. None of the failure modes did participate a root cause with a higher rate than 100% over multiple paths, i.e. the RPNs were distributed over associated paths with the factors.

Fig. 3 The root cause analysis



3. RESULTS AND DISCUSSION

The process FMEA delivered potential failures, which root causes were determined. All in one it was seen that the lack of IT and requirement management systems did contribute mostly with a cumulative RPN of 1646 to the potential failure in the product realization from PO to product delivery. This corresponded to a level of 36.1% of total, despite the existing web-based Material Requirement Planning (MRP) system. The reason therefore was assumed that the existing system was just embedding sequential workflow logic without enabling proper bidirectional information flow and collaboration. Moreover the requirement and thus configuration management were not supported by the existing system in terms of streamlined inbound information flow to all departments. This hindered the propagation of internal content generation that the high participation of this root cause was also evaluated as appropriate. Also the existing MRP was manually controlled, not combined to any CAD system or another knowledge capture system. This made it insufficient and error prone for the user.

Indeed human error did score very high with a cumulative RPN of 1969, but it was assumed to be a subordinate, leading to two further root causes; namely lack of experience and high work load, with cumulative RPNs of 1496 and 1419 respectfully. Additionally the hierarchic relation of human error to the IT & requirement management systems was also underlined, since such systems also reduce human error. Consequently the lack of experience was ranked with 32.8% as the second significant root cause. With respect to the average experience of 7 years in design (Robertson and Radcliffe, 2010), the average experience in the company was more than sufficient, but there was a bad split between very young designers and experienced designers, resulting that major mistakes, i.e. human errors, were potentially attached to the younger part of the team, where training is definitely due.

This also indicated that an appropriate control mechanism was missing, quantified in the recommended actions as well. Considering that PLM delivers tighter workflow, easier product carryover, and more efficient product data retrieval (Cantamessa et al., 2012), it is assumed that it will support the implementation of a gated design methodology. Technical problems on the workshop were assigned partially to the lack of IT and configuration management and partially to human errors. Given a suitable system is implemented; this would give an overview that the possibility to make a mistake would be reduced and especially the detectability would be increased.

This would also deliver a functioning mechanism suitable for higher utilization rates, i.e. higher workload, which was ranked in the third (3rd) and last place with 31.1% among the root causes. At this point it is important to say that both, lack of experience and high work load, could be positively affected by the introduction of an appropriate system for IT & requirement management, integrating the whole product life cycle, meaning the change of how the product realization is made, which can drive towards innovations (Iyer et al. 2006) fostering sustainability as well.

4. CONCLUSION

Companies try to keep their NPD cycle times short to remain competitive in the global market. This contradicts with the complex nature of industrial equipment for the process industry, where the integrators are further demanding highest technology in the shortest time possible. Thus mistakes, rework, and loss of profitability narrow down the knowledge accumulation /-circulation, which is limiting the innovation potential and endangering sustainability. Consequently there is need to further investigate the product realization process in high technology oriented companies to understand the main drivers of problems.

By using process management tools and techniques the methodology used here enabled the allocation of major root causes to understand and prevent potential failures. Therefore first all processes are to be isolated and mapped in diagrams to find critical paths, then process FMEA is to be incorporated to finally conduct a RCA. There are already many individual examples of business process management, process FMEA, and RCA in the literature; however this work differs in delivering a novel streamlined, integrated methodology as a managerial implication, which can be directly adapted to high-tech product realization organizations.

Furthermore the case study also did deliver key findings related to the process equipment production organizations. The lack of proper IT & requirement management systems was found with a cumulative RPN of 1646, corresponding to 36.1% as the most critical root cause. Then the lack of experience was with a cumulative RPN of 1496 achieving 32.8% the second important root cause, followed by the high workload with a cumulative RPN of 1419, i.e. 31.1%. The total high average experience didn’t change the metrics, since the experience was not homogenously distributed over associates, but there were groups with lots of experience and with minimum experience, who did not collaborate due to missing system architecture beyond basic MRP.

Thus further analysis in the life cycle from sales, through delivery resulted in the requirement of extensive PLM, which tools have to be adopted adequately covering all items in product realization, supporting product configuration, structured gated design, and a higher level tracking of all items as a managerial recommendation to the process equipment industry. Likewise the training and enhanced control of especially younger employees embedded in a system were further recommended. Consequently it was shown that the company transformation using IT tools for the integration of build-to-order production organizations shall also reinforce the innovation potential and thus have a positive impact on sustainability.

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