Toward Early Product Cost Optimization: Requirements for an Integrated Measure Management Approach

Matthias Walter[1], Christian Leyh[1], and Susanne Strahringer[1]

[1] TU Dresden, Faculty of Business and Economics, Chair of Business Informatics, esp. Information Systems in Manufacturing and Commerce, Dresden, Germany
{matthias.walter3, christian.leyh, susanne.strahringer}@tu-dresden.de

Abstract. In industry, product costs must be optimized to ensure long-lasting economic success. Cost optimization should already be performed during product development, in order to leverage its potential. Previous research has shown that information system support is greatly needed within early product cost optimization. Taking this on, we conducted interviews among discrete manufacturing industry experts, seeking to identify implementation challenges and, moreover, to develop a requirements model to overcome current challenges. To evaluate research results, we joined a co-innovation workshop at SAP SE, during which business domain experts from different industries successfully evaluated our approach. In summary, the concept introduces a promising solution to improve information system support during early product cost optimization.

Keywords: Product costing, product-cost optimization, product development, enterprise systems, emergent knowledge processes

1 Motivation

In times of globalization, demand rises for agility, innovation, and quality. Furthermore, shortened product life cycles and grown variety of product models have increased pressure on product manufacturers and their product portfolios [1]. In order to keep up with the global competition as such, optimizing costs throughout a product's life cycle has become a major driver for long-lasting economic success.

This circumstance becomes even more important for the discrete manufacturing industry; final products such as cars, trucks, and agricultural machines are assembled out of thousands of globally sourced components along a specific production routing. The complex manufacture of such products requires sophisticated planning, scheduling, and tracking of production processes. However, before a product goes to production, a significant effort is put into the product development. Product development includes several stages: an innovation phase to conceptualize new products, various research and development activities, feasibility and product tests, and production and resource planning. Such development cycles can last up to five years for products (esp. automobiles) within discrete manufacturing industries [2]. Moreover, summed-up figures for all-embracing product life cycles (Figure 1) can easily span across decades;

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for example, such a cycle covers almost five decades for automobiles, including the spare part warranties [3].

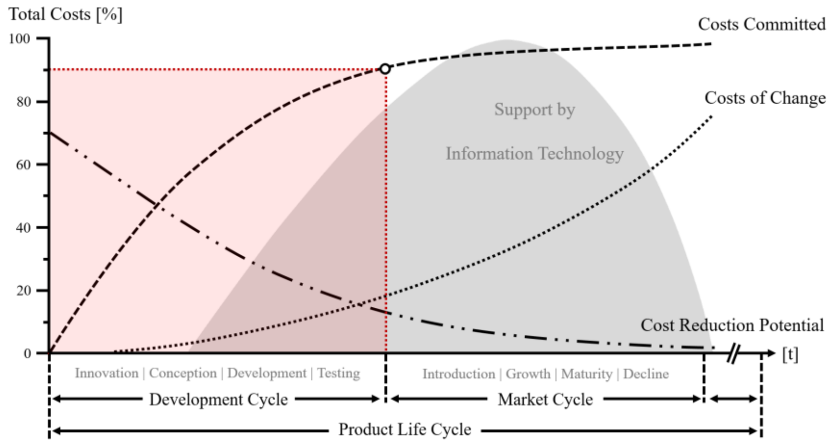

Figure 1. Cost commitments and reduction potential along product life cycle [3, 4]

To ensure long-lasting economic success of products in the upcoming decades, organizations try to optimize product costs for the overall product life cycle. At first glance, only 20% of the total product costs are incurred during product development cycles (Figure 1). However, at the end of the development cycle, 90% of the total product costs are already determined (by such factors as defining product variants, materials, production processes or sourcing strategies) [5]. This means that only marginal potential remains to optimize cost-efficiency once a product is in production. To leverage the potential to design a cost-efficient and therefore competitive product (e.g. by improving operations or material selections), optimization activities must be carried out as early as possible within the product life cycle, and therefore within product development.

Despite the immense potential of early optimization, which is evident among literature [4, 5, 6], we have shown that early cost optimization requires better software support [3]. Although information technology and product-costing methodologies have evolved over time, we could still highlight a clear gap in the expedient use of such technological capabilities and methodologies within the discrete manufacturing industry in our previous research [3]. In essence, the current status quo in the application domain suffers from non-transparent, inconsistent, and inefficient processes, caused by using spreadsheet software to calculate and manage product costs during product development cycles [3, 7, 8]. Not surprisingly, practitioners commonly agree that this practice has a negative impact on enterprises' profitability, and hence they demand solutions to overcome current hurdles.

Continuing our long-term design science research project [9], we now follow up our problem-centered initiation [3] with the definition of objectives that a future artifact has to accomplish. Therefore, we further explore implementation challenges and requirements for enhanced information system (IS) support during early product cost optimization [10, 11]. Following recommendations by Österle and Otto [12] for design-oriented information system research, we conduct collaborative research with practitioners among the discrete manufacturing industry to ensure both scientific rigor and practical relevance simultaneously [13]. Therefore, our elaboration focuses the following research questions:

Q1: Which main implementation challenges can be identified with respect to the enhancement of software support within early product cost optimization?

Q2: What are the most relevant requirements, from a practitioner's perspective, regarding software support for early product cost optimization?

To answer these questions, the paper is structured as follows. First, the next section provides research background and presents related work on IS support for optimization during early product development phases. Subsequently, we outline the methodology on how we conducted collaborative research. The following section states the key findings and implementation challenges, which are then transformed into an evaluated requirements model. The paper concludes with a discussion of research results and highlights the need for future development of rigorous artifacts following our proposal.

2 Related Work

The immense potential of early cost optimization is already recognized in existing literature. Authors such as Horváth [14] stress that product-cost optimization activities have to shift from operative functions (such as production, purchasing, etc.) to an activity that takes place within product development, and thus into a phase where no support is provided by information systems like ERP systems [4]. As product development in general is less structured than the production phase, research focuses on leveraging this potential by providing specific costing techniques and methodologies that serve dedicated contexts [15, 16, 17]. In their review of research directions toward cost-focused product development, Mörtl et al. [5] present a comprehensive framework for guidance among the variety of methodologies. Particularly relevant is the role of IS support: though recent research found a variety of software tools in relation to cost estimation and cost analysis, such tools were mainly introduced in individual companies, specific industries, or even worse, not yet used in industry at all [5]. This finding seems valid, as modern technological approaches like artificial intelligence are aimed at solutions for highly specialized and complex optimization scenarios [17].

However, as explored by Schicker et al. [7] and supported by our research [3], this practice leads to a status quo in which no IS support is available that addresses industry's requirements toward early product costing in an integrated approach. Thus, early product costing and its optimization are mainly dominated by spreadsheet software, leading to various disadvantages such as high manual efforts, high degree of information inconsistency, and lack of transparency [3, 7, 8]. As a result, the pure support of dedicated costing methodologies is not sufficient to satisfy industry's requirements toward an integrated IS support for early product cost optimization.

What should certainly be highlighted is the process perspective on cost optimization as part of product development. Traditional IS research focuses on the support of well-structured business processes with regards to their predetermined and repeatable characters [18]. Nevertheless, various publications contrast the upcoming importance of ad-hoc activities in modern business environments. These ad-hoc activities are initiated without being planned in advance and, therefore, could be described as loosely defined processes [18]. As a result, the degree of process specification can be stated in relation to the overall extremes (Figure 2).

Figure 2. Degree of process specification [adapted from 18]

To ensure both scientific rigor and relevance, early product cost optimization must be classified regarding its degree of process specification, as each process type has its own constraints and requirements. This classification is important because our previous research highlights the need for process flexibility within early product cost optimization [3]. To classify early cost optimization, we refer to Markus et al. [19], who see the development of a new product as an example of emergent knowledge processes (EKP) in general. Such EKP are characterized as organizational activity patterns with the following attributes:

a) An emergent process of deliberations with no best structure or fixed sequences
b) Unpredictable process actor set in terms of job roles, prior knowledge, and work context
c) Dynamically-evolving information requirements that include general, specific, and tacit knowledge distributed across actor sets [19]

In terms of these process characteristics, IS for the support of EKP "cannot target specific user roles, depend on training, or assume motivation to use the tool," "must accommodate complex, distributed, and evolving knowledge-base," and "support an unstructurable, dynamically changing process of deliberations of tradeoffs" [19]. In the context of our design science project, this justificatory knowledge serves as a foundation to guide further research activities, and is therefore our kernel theory [20].

Based on this justificatory knowledge, Marjanovic [21] has researched the IS-supported coordination of such EKP within an industry context. She summarizes her research with the conclusion that the coordination of a knowledge-intensive process cannot be fully predefined. Thus, automation of such processes—as known from work-flow technology—is neither desirable nor possible at all. What is instead required for IS support is a fundamentally different coordination support toward situated decisionmaking. Moreover, those requirements are not all thoroughly supported by familiar classes of current system types [21].

Following those research results on EKP and the information system design theory proposed in [19], we look to analyze the problem domain of cost optimization processes during the product development phase, in context of its degree of process specification to state implementation challenges; in addition, with the help of practitioners, we intend to develop a requirements model that serves for further artifact development.

3 Research Methodology

The purpose of this paper is to elaborate upon implementation challenges and to develop a requirements model toward early product cost optimization. By doing so, we follow the recommendation for a design science research process by Peffers et al. [10] and aim at developing an object-centered solution. Product costing has a long history of methodologies relying on expert knowledge (e.g. analogous models [22]), and even in current research authors like Mörtl et al. [5] state that industrial practice is the most important source of information for cost reduction projects. Therefore, the access to knowledge from practitioner communities is fundamental for our research. At the same time, such knowledge ensures that our research is relevant to practice, as argued in Rosemann et al. [23]. To capture tacit knowledge among the discrete manufacturing industry, we joined a co-innovation session at SAP SE, where potential and current SAP customers discuss business concepts and software requirements for the development of a new software for product life-cycle costing framed by an agile development process [24]. Following the recommendations of Österle and Otto [12], we applied research techniques that have been proven to capture the tacit knowledge of individuals within design-oriented IS research:

1. Interviews with domain experts from industry
2. Analysis of interviews
3. Elaboration of a common requirements model
4. Requirements model evaluation by domain experts

As a first step, we conducted eleven semi-structured interviews with international business domain experts who came from different industries and possessed diverse competences within the area of early product costing (Table 1). These experts declared specific interest in our research during earlier collaboration phases [3, 24] and moreover, have a high level of domain expertise.

Table 1. Expert interviews (step 1): Industry and competence distribution of participants

Industry	*Participants*
Automotive	7
Machinery Construction	3
Food Industry	1
Overall	*11*

Area of Competence	*Participants*
(Product) Controlling	7
Product Engineering	1
Consulting	2
Information Technology	1
Overall	*11*

These interviews were then analyzed to identify implementation challenges and possible artifact requirements. To do so, we systematically coded interview protocols. By the exploration of code structures, we were able to derive specific requirements for our research. In the third step, we combined the collection of requirements into an aligned requirements model, which includes significant experts' requirements for an approach toward IS support for early product cost optimization.

Table 2. Evaluation (step 4): Industry distribution of participants

Industry	*No. of Participants*	*Avg. Working Experience*	*Median of Working Experience*
Automotive	12	9.6 Years	6.0 Years
Machinery Construction	4	3.5 Years	3.5 Years
Consulting	2	4.5 Years	4.5 Years
Overall	*18*	*8 Years*	*5 Years*

Finally, this requirements model was presented to a separate group of business experts (Table 2) as part of a co-innovation focus group. As there were only two overlapping participants with the previous group of expert interviewees, the goal of this focus group was to evaluate in detail a) our understanding of interview results and b) the requirements model. To strengthen the results evaluation, we independently conducted iterative analysis on each requirement within the model. During each iteration, we presented the requirement description in relation to a practical example on how a potential artifact instantiation could work. Since we were interested in different evaluation perspectives, we conducted the evaluation again with experts from different industry roles and with varying domain expertise (Table 3). During each step of our evaluation, the focus group participants had to rate requirements with a score from 0 to 10, in which each business expert rated the requirements independently of one another for the whole requirements model.

Table 3. Evaluation (step 4): Competence distribution of participants

Industry	*No. of Participants*	*Avg. Working Experience*	*Median of Working Experience*
(Product) Controlling	10	9.6 Years	8.5 Years
Product Engineering	1	6.0 Years	6.0 Years
Consulting	2	4.5 Years	4.5 Years
Information Technology	5	6.0 Years	6.0 Years
Overall	*18*	*8 Years*	*5 Years*

4 Results

4.1 Key Findings: Challenges within Early Product Cost Optimization

In the first step, we identified major challenges and characteristics regarding the early cost optimization process, with the purpose of providing necessary context information for elaborating the requirements. By interviewing business domain experts from different types of organizations (Table 1), we learned that the product development cycle (Figure 1) is structured into dedicated phases which are very often linked by strict gates (e.g. quality gates or management approvals). Though this finding indicates a structured process for product development in general, we did learn that product cost optimization does not follow such a determined process. In truth, early product optimization (as part of the product development process) evaluates and compares numerous alternative optimization concepts to each other—in terms of product designs, production processes, and production resources—in various back-and-forth iterations to find an optimal solution (in relation to financial figures like total costs, IRR, RoS, RoCE, etc). Thus, while the overall product development process tends to be well structured, optimization processes are executed separately from these established processes.

Moreover, the development of these alternative concepts requires in-depth knowledge about such concepts, including production resources and processes, price trends, customer requirements, and technical feasibilities. Consequently, the individual participation of experts in the optimization process is not predetermined; rather, it is a question of required skills and knowledge towards specific optimization measures (e.g. procurement department will be included in a make-or-buy analysis for a specific component). This variety of knowledge is then transformed into a common cost estimation that predicts a product's total costs throughout its life cycle. The optimization results must be transparent and traceable among all phases, due to their importance and impact on businesses' future profitability. For that reason, the interview participants reject black-box optimization approaches as elaborated in [17] during the product development cycle.

Since spreadsheet software has been identified as a tool of choice for early product costing in general (see section 2), it is not surprising to find this software in place for the management and execution of early product cost optimization across industries. Again, according to the experts' opinions, cost optimization suffers from a lack of transparency in regards to progress and responsibility management. Though ideas abound for cost improvements, no suitable IS support exists to capture and follow up on this tacit but important knowledge. Moreover, experts claim that the high manual effort to maintain and link emergent information as part of optimization management is exacerbated by spreadsheet software; this is also valid for the evaluation of optimization measures with regard to their impact on the entire product cost calculation. This is particularly critical, as costing experts suffer from time pressure during product development [3] and therefore are not able to realize all available optimization potentials.

In total, we identified six major implementation challenges for IS support in early product cost optimization (Table 4). The next step is to work out suitable design requirements for potential solutions.

Table 4. Implementation challenges for IS support within early cost optimization

No.	*Implementation Challenges*
1	Highly unspecified optimization processes
2	Unpredictable integration of business experts from the organization
3	Demand for process transparency and traceability
4	High efforts to coordinate and manage optimization processes
5	Manual efforts to evaluate and implement optimization measures
6	Lack of comprehensible documentation of solution approaches for optimization

4.2 Requirements Model: Approach towards Early Product Cost Optimization

Markus et al.'s [19] theory of EKP (see section 2) exhibits a high degree of correspondence with the early optimization of product costs (see section 4.1). Particularly, a strong similarity is indicated between the emergent process structures and the unpredictable integration of business experts to context-related tasks [21]. Slightly weaker is the correlation for user's information requirements [19], as optimization is carried out within an environment of business experts only. Consequently, early product cost optimization can be characterized as a type of EKP and is therefore neither an ad-hoc process nor a well-defined process, and instead shares characteristics of both extremes (Figure 2). In order to contextualize this conclusion, our approach should follow requirements as specified by Markus et al. [19], which essentially combine the accommodation of complex, distributed, and evolving knowledge with the ability to support dynamically changing processes of deliberations (see section 2).

What must be further taken into consideration is singularity of EKP; according to Marin et al. [25], the execution environment is crucial for any implementation. Following recommendations and research results from the literature [18, 19, 21], we designed an adequate approach that provides the right degree of process specification towards a structured optimization approach without being too restrictive.

Based on the result of our expert interviews, we devised a requirements model that includes a processual perspective for early product cost optimization (Figure 3). To address all implementation challenges (Table 4), we propose a concept for a) the overall coordination of early cost optimization (Measure Management and Measure Reporting) and b) the specific process to guide a specific optimization measure from an initial idea (Identification) through its evaluation (Evaluation & Decision) to its final implementation (Implementation). In total, we derived 30 detailed requirements, which are presented in the next section.

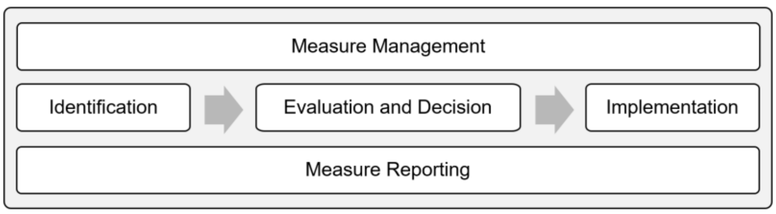

Figure 3. Approach to early product cost optimization

4.3 Requirements Model: Result Evaluation

To simultaneously answer the second research question and evaluate our interpretation of expert interviews, the focus group evaluated all requirements within our model. To highlight differences within the discrete manufacturing industry, we report the results separately for the participants from automotive and machinery-construction businesses (Table 2). In addition, the total values include results from the consulting sector as well.

Measure Management (Table 5, Measure Management) covers all-embracing requirements to provide an overall support enabling the coordination of various optimization measures within product development. Together with Measure Reporting (Table 5, Measure Reporting), it aims at managing measures efficiently by providing solutions for process transparency and traceability. On the detailed level, requirements focus the identification of optimization potentials (Table 5, Measure Identification). Once an optimization potential is identified, it is further developed into a specific measure. This measure is evaluated in regard of its feasibility and benefit. Based on its impact regarding total product costs and further financial figures, the measure is approved for future implementation (Table 5, Measure Evaluation and Decision). Finally, approved optimization measures are implemented into the main product development process (Table 5, Measure Implementation).

In general, business experts with different roles from different industries evaluated the established requirements model very positively. Moreover, no changes to the overall approach or to the single requirements were deemed necessary.

Table 5. Evaluated requirements for measure management

Measure Management	*Average Score*			*Std. Dev.*
	Overall	*Automotive*	*Machinery Construction*	*Overall*
Collect cost-optimization measures	7.78	8.25	7.50	1.72
Select measures for projects, calculations, versions, and cost items	8.06	8.42	7.75	1.43
Define responsibilities	6.78	7.08	7.00	2.44
Create achievement plans	7.06	7.45	6.50	2.29
Estimate measure impact	8.29	8.64	7.00	1.45
Rate measure maturity	7.59	8.00	7.00	1.82
Tag/flag measures	5.35	5.18	5.50	2.03
Change history	7.44	8.00	6.25	2.41
Control measure dependencies	5.63	5.90	5.25	2.06
Measure Identification				
Target costing	8.72	8.83	8.00	1.45
Internal benchmarking	7.44	7.67	8.25	1.86
External benchmarking	6.50	6.92	5.75	2.11
Measure-independent scenario simulation	7.67	8.00	7.50	2.16
Cost driver analyses	7.89	7.83	9.00	2.21
Best practice database	6.28	7.17	4.75	2.13
Checklist	6.00	6.83	6.00	2.58
Tool-generated optimization recommendations	6.83	7.17	6.25	1.92

Measure Evaluation and Decision				
Optimization concept development	7.11	6.75	8.50	1.59
Impact evaluation for alternative concepts	7.56	7.67	7.00	1.64
Concept documentation	6.50	6.67	7.00	2.54
Concept versioning	6.28	6.50	6.75	2.23
Measure Implementation				
Highlight measure impact	7.50	7.67	7.50	1.57
Costing structure integration	8.06	7.67	9.00	1.39
Optimization history	7.67	7.67	8.25	1.49
Link measure result to best practice database	5.72	6.58	5.50	2.76
Measure Reporting				
Optimization progress reporting	7.33	7.50	5.50	2.00
Target cost deviation tracking	8.22	8.17	8.25	1.40
Measure achievement reporting	7.39	7.50	7.00	1.42
Measure impact evaluation	7.39	7.50	8.50	1.74
Measure dependency reporting	5.39	5.83	5.25	2.00

5 Discussion

All in all, the evaluation scores for most requirements are nearly equal across the different industries and indicate a strong need for such an artifact. One reason for differences is the circumstances of production. Particularly within the automotive industry, we learned about long product development cycles lasting up to five years [3]. This circumstance leads to higher scores for requirements that improve the overall process transparency and traceability (e.g. change history or creation of achievement plans). Surprisingly, a requirement ranked as less important is the ability to enable knowledge externalization and harvesting (Best practice database for measures), which Marjanovic [21] describes as a major aspect for IS support in EKP. This finding supports our interpretation about the reduced necessity for information in early cost optimization (see section 4.2). Therefore, we should discuss and evaluate our results against common approaches that are described alongside best-practices for EKP.

Workflow systems are considered as process-oriented coordination technology [26]. Though workflow systems allow an effective coordination support with the ability to assign tasks to respective users within routines, these systems are only suitable for well-structured processes that have been defined in advance [21]. As such, workflow systems are not able to overcome implementation challenges 1 and 2 (Table 4).

In contrast to that analysis, Böhringer [18] describes a solution based on micro-blogging and activity streams as a possibility to overcome boundaries of structured workflows. This need to overcome boundaries of structured workflows also exists in the context of product costing [8]. Nonetheless, Böhringer [18] faces fragmentation of information because of provided flexibility, especially when knowledge is generated in relation to ad-hoc processes. Due to needing a holistic coordination approach towards different optimization measures, as expressed by implementation challenges 3 and 4

(Table 4), these artifacts also cannot solve our problem in the context of early product cost optimization.

Furthermore, implementation challenges 5 and 6 (Table 4) intensify the need for a much more specific IS support, which is capable of integrating with current product costing solutions in the area of product development. In essence, many solutions are available to manage knowledge-intensified processes, but these are not able to address our implementation challenges with a holistic approach, which is required to ensure usability and effectiveness [19]. This perspective receives support from industry, which highlights the need for improvement and offers collaboration for further research. Therefore, our requirements model for a specific type of EKP remains valid and should be instantiated as a software artifact to enable extensive evaluation.

6 Conclusion

Based on our earlier research [3], we were able to elaborate and evaluate a requirements model for the IS support of early product cost optimization with 27 business experts from the discrete manufacturing industry. This requirements model has its roots in theory about emergent knowledge processes [19]; it contains 30 requirements to address the industry's key implementation challenges. This evaluated requirements model serves as a solid foundation for the next steps in our design science research project. Following the recommendation of Peffers et al. [10], we further concentrate on iterations for development and design of a software artifact including further formative evaluations to address the limitation that our model lacks a broad empirical evaluation. The current evaluation scores for our 30 requirements will provide guidance on how to prioritize while designing the instantiation in our next step.

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