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STRUCTURE-BASED SYSTEM DYNAMICS ANALYSIS - A CASE STUDY OF BENCHMARKING PROCESS OPTIMIZATION

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Abstract

In this paper, we present a case study in collaboration with MAN Truck & Bus AG which shows the application of the concept of structure-based System Dynamics analysis. The structure-based System Dynamics analysis approach uses structural Multiple-Domain Matrix models as a basis to derive System Dynamics models which are able depict the behavior of the examined processes. The implications from the behavioral models can be used to analyze the structure of the underlying process. For this case study the partner was interested in a process comparison of its own product benchmarking processes with benchmarking processes of other automotive OEMs. The tools and methods of the other OEMs were identified and analyzed. Based on a simulation-based comparison with the own tools and methods, potentials for further process improvements by integrating specific tools and methods of the other companies were identified. The results of the simulation were used as a decision basis for the industry partner to decide whether it is beneficial for the industry partner to incorporate particular tools and methods or not. Consequently benefits, challenges and further areas of research are identified.

Keywords: Design engineering, Conceptual design, System Dynamics, Engineering Design Process, Multiple-Domain Matrix

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1 INTRODUCTION

Process analysis is an ongoing challenge for a lot of systems engineers and the need for change increases constantly. This is because business environments are becoming more and more competitive (Hale, 1997). In this paper, we address this problem by developing a case study in collaboration with MAN Truck & Bus AG. To ensure its own compatibility the industry partner constantly triggers product and process improvements by benchmarking himself with competitors. For this particular case study the industry partner was interested in a process comparison of its own product benchmarking processes with benchmarking processes of other automotive OEMs (Original Equipment Manufacturers). The tools and methods of the other OEMs were identified and analysed. Based on a comparison with the own tools and methods currently in use, potentials for further process improvements by integrating specific tools and methods of the other companies should be identified. To create a holistic process simulation, the Structure-based System Dynamics Analysis of (Kasperek, Maisenbacher, et al., 2014a) is used: Based on existing descriptions of the MAN benchmarking processes structural models in form of Multiple-Domain Matrices (MDM) provide the basis to develop System Dynamics models of the MAN product benchmarking processes. The System Dynamics models, in turn, provide a simulation environment for the purpose of analysis and optimization by enabling the possibility to incorporate the others' tools and methods within the simulation. Structure-based System Dynamics Analysis was originally developed to analyze engineering design processes (Kasperek and Maurer, 2013). In this paper, we aim to determine if the approach is also applicable when analyzing and optimizing benchmarking processes. Specifically, we address the question whether our industry partner’s benchmarking processes can be improved by use of additional tools and methods identified within the other companies' benchmarking processes under consideration of dynamic influences such as influence on the overall process duration. The results of the simulation are used to decide whether it is beneficial for the industry partner to incorporate particular tools and methods or not. The incorporation of these tools and methods increases the quality of the benchmarking results as well as the process efficiency. For the case study itself we follow the sequence of the stages for conducting the case by Stuart et al. (2002): define research question, instrument development, data gathering and analyse data. As a first step of this case study available documentation of the MAN benchmarking processes was screened and protocoled interviews were conducted with the involved persons. The benchmarking processes of the other automotive OEMs were identified mainly based on protocoled interviews. As a second step sketches of the benchmarking processes were drawn which were then within a third step modelled in detail within structural models. The MDM models of the processes of the industry partner were used as a dataset to build up the System Dynamics models for each MAN benchmarking process. Particular tools and methods of interest of the other OEMs were then incorporated in the simulation models to measure their influence on the processes. Thereby the simulation models give insight into the underlying dynamics of the benchmarking processes and help to generate basic dynamic understanding; decision support through simulation experiments; and support the comparison of process configurations. To implement the System Dynamics models the software tool Vensim® was used. Consequently the decision of the industry partner which tools and methods to incorporate was prepared based on the simulation results and the expected influence on quality aspects.

2 BACKGROUND INFORMATION

2.1 Structure-based System Dynamics Analysis

The structure-based System Dynamics Analysis approach developed for engineering design processes (EDP), suggests the use of the underlying process structure represented in a Multiple-Domain Matrix (MDM) as a basis to develop a System Dynamics model of the EDP. This simulation model based on the process structure, sometimes also called process architecture, allows modelling and comparing various scenarios. (Kasperek, Maisenbacher, et al., 2014b)

For the comparison of the dynamic behaviour of EDP structures, the corresponding MDM need to be transformed in a System Dynamics model to assess the dynamic behaviour. (Kasperek, Maisenbacher, et al., 2014a)

The underlying system structure has to be transformed into a qualitative System Dynamics model first. Second, the qualitative model needs to be enlarged by additional information and mathematical equations for each element to model the boundary conditions. The mathematical equations that define each element are thereby functions of the input parameters of the particular elements. As soon as one quantitative System Dynamics model of the EDP is built, it is relatively easy to model different sequences of the process as most of the boundary conditions can be assumed to be the same for each sequence. The System Dynamics models of different process sequences can be simulated and to assess which of the examined process sequences offers the desired behaviour. One of the advantages of the structure-based System Dynamics analysis approach is the possibility to investigate the dynamic behaviour of systems based on the underlying systems structure. MDM is a simple and easy-to-use method for system understanding and analysis. In addition, the necessary information to create structural models is usually available early in the development phase (Kasperek and Maurer, 2013). Even though the current state of the approach already supports the decision of which components to consider for the structural and dynamic models, it remains one of the major challenges to choose which domains, interdependencies and elements should be incorporated in the model. Each particular decision has to be made under consideration of the expected benefit of adding complexity to the model. (Kasperek, Maisenbacher, et al., 2014b)

2.2 Benchmarking

The management method benchmarking is becoming more important due to the increasing amount of competitors and the resultant requirements companies are faced with. According to Sadagopan (2003) benchmarking is defined as "the process of comparing one's business processes and performance metrics to industry bests and/or best practices from other industries". Thereby best is generally measured in terms of quality, time and cost. The process of benchmarking involves the identification of the best firms in their industry or any other industry where similar processes exist and compare the results. (Sadagopan, 2003)
For this case study the specialized method process benchmarking is used. For this specialization the focus is on business processes with the goal of identifying and observing the best practices from one or more benchmark firms.

3 CASE STUDY

We follow the sequence of the stages for conducting the case by (Stuart et al., 2002), but do not treat "Stage 5: Disseminate" explicitly (see Figure 1).

Figure 1. The stages research process model adapted from (Stuart et al., 2002)

3.1 Stage 1: Research question

The first stage of the research process involves defining the research question. From the perspective of the industry partner the challenge can be stated as “how can potentials for process improvements of the own benchmarking processes by integrating specific tools and methods of the other companies be identified and analyzed?” This allows us to address the general question of interest from the research perspective: “Can structural models of benchmarking processes in form of Multiple-Domain Matrices, be used as a basis to simulate the dynamic behavior of these processes by System Dynamics?" If this question can be affirmed, the behavior of the benchmarking processes towards integrating specific tools and methods of other companies can be assessed. This would allow answering the challenge as stated by MAN Bus & Truck AG.

3.2 Stage 2: Instrument development

The second step in conducting the case research is the development of a research instrument and the selection of the appropriate field sites. The instrumental development should give focus but still have some flexibility (Stuart et al., 2002). For the MAN product benchmarking processes protocoled interviews with the affected managers about process steps, tools and methods were the primary data basis. For the product benchmarking processes of the other automotive OEMs also less or no process documentation was initially available. Based on an initial contact provided by MAN Truck & Bus AG also one or more protocoled interviews were conducted with benchmarking experts of each OEM. To be better informed and prepared the participants received the questions of the protocoled interview at least one week before the interview. Additionally the participants were asked to show existing documentation at the interview appointment as far as possible under the given confidentiality agreements. The questions for the protocoled interviews were grouped in three areas:

- General questions about the division: Allocation within the company, subdivisions and employees, work portfolio
- Information about the existing processes: Detailed view on the particular benchmarking processes
- General information about the work context: Further use of the results, specific examinations for special purposes, knowledge management

To give the participants a feeling for the desired form and degree of detail of their answers all questions were exemplarily answered for the MAN division.

3.3 Stage 3: Data gathering

In case-based research, the data are the recorded and transcribed information from the interview, documents that the object of observation is willing to provide and other observations of the researcher. (Stuart et al., 2002)

3.3.1 Product benchmarking processes and existing tools and methods within MAN

Within the MAN Truck & Bus AG three major product benchmarking processes A, B, and C exist. A is focussing on free available information about competitors. B is focussing on automotive characteristics of the products of the competitors. C is focussing on detailed characteristics of particular parts of the automotive. The three processes are of different size and have different workloads. The left side of Figure 2 shows an overview of the processes.

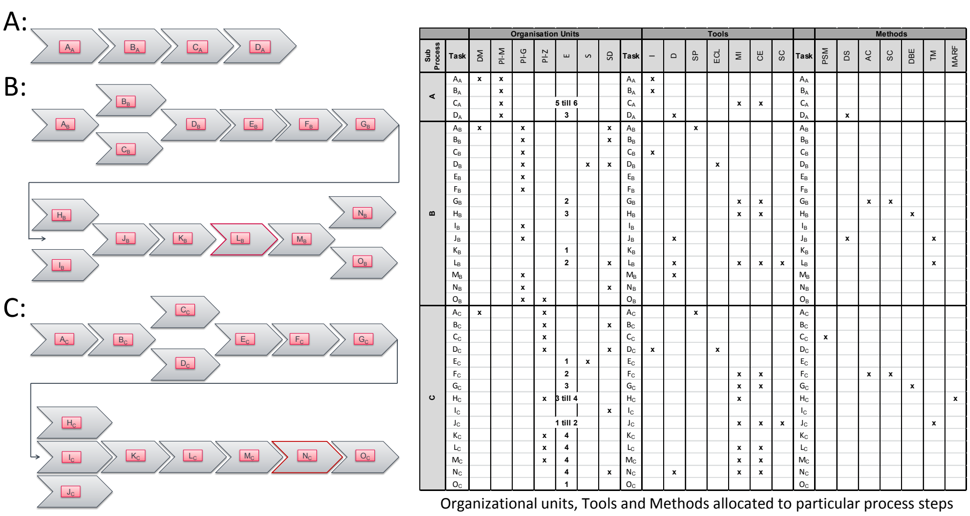

Figure 2. The three product benchmarking processes of the industry partner and allocated organizational units, methods and tools to process steps

Especially process B is also strongly influenced by other processes and divisions, so that various accompanied processes have to be taken into account to model the process sequence. Each step of the three processes was documented in detail by a written description of activities. Additionally organizational units involved in the particular process steps of the three processes as well as used tools and methods were documented within the interviews. The right side of Figure 2 shows the allocation of the organizational units, tools and methods to the particular steps. Thereby tools and methods are used to achieve the benchmarking objectives in an efficient and effective manner. Exemplary tools and methods are fact sheets to communicate results or test drive opportunities offered to important stakeholders. The names of the tools, methods and organizational units are abstracted due to confidentiality reasons.

3.3.2 Tools of the other OEMs and decision for focused tools

Based on the protocoled interviews various tools and methods were identified for their particular benchmarking processes. Even though tools were often labelled differently within the OEMs, most tools and methods were used in related constellations. For a better overview the identified tools were abstracted to categories of tools depending on the purpose of the tool. The categories were defined in clearance with the industry partner. The tools of each company were then allocated to these categories to allow for a comparison between the companies. As some categories of tools were not in the area of responsibility of the industry partner these categories were indicated and not further considered. Based on the comparison particular tools and methods of interest were selected by the industry partner based on the three categories: Conformance with process optimization targets; possible time to implementation, transferability to MAN context.

3.3.3 MDM modeling

The domains of the MDM were adapted based on the suggested meta model of (Kasperek, Maisenbacher, et al., 2014c). The initially suggested resource domain was detailed into tools and methods. The left side of Figure 3 illustrates the meta model for the benchmarking processes.

Meta model of the product benchmarking processes

		Task	Org.Unit	Tool	Method	Time
		A B C	Dc Pl E	a b c	1 2 3	Hours/Months
Task	A B C	is followed by	is conducted by	needs	needs	lasts
Org.Unit	Dc Pl E			uses	uses	
Tool	a b c				is necessary for	
Method	1 2 3					
Time	Hours/ Months					

Detailed MDM for benchmarking process A

		Task				Org. Unit			Tool							Method		Time
		A_A	B_A	C_A	D_A	DM	PI-M	E	I	D	SPA	MI	OT	CE	IA	1	2	Hours
Task	A_A		x			x	x		x									2
	B_A			x			x		x		x		x					60
	C_A				x		x	5 to 6				x		x		x		32
	D_A						x	3		x					x		x	80
Org. Unit	DM																	
	PI-M								x	x	x		x		x			
	E									x		x	x	x		x	x	
Tool	I																	
	D																x	
	SPA																	
	MI															x		
	OT															x		
	CE															x		
	IA																	
Method	1																	
	2																	
Time	Hours																	

Figure 3. Meta model of the product benchmarking processes and detailed MDM for benchmarking process A

As suggested by (Kasperek, Maisenbacher, et al., 2014c), tasks (process steps), organizational units, tools, methods were chosen as domains and time as additional attribute. A detailed description of the domains can be found in (Kasperek, Maisenbacher, et al., 2014c). Based on this meta model the detailed MDMs for the particular processes A, B and C were created. The task sequences based on the previously developed process models, while the organizational units, tools, and methods were assigned based on the results of the protocoled interviews. The right side of Figure 3 shows the detailed MDM for process A.

3.4 Stage 4: Analyze Data

Especially for process B and C the granularity of process steps was quite high. After consulting the industry partner particular sequences of process steps were concentrated to one aggregated step with respect to the desired focus of the study. For eased System Dynamics modelling not all dependencies indicated within the meta model of the MDM were incorporated in the System Dynamics (SD) models: According to matrix theory, particular subsets of MDMs can be deducted indirectly by matrix multiplication (Maurer, 2007). The subsets *Org.unit uses tool, Org.unit uses method* as well as *tool is necessary for metho*d (both indicated in blue in the left part of Figure 3) were not directly modelled in SD as the corresponding information could be incorporated in the model by other interdependencies. The three subsets can be calculated out of the following other subsets *task is conducted by org. unit, tasks need tools* and *tasks need methods*. As an example the underlying assumption is: If a *task is conducted by an org. unit* and also a particular *tool is needed for this task*, then it does not have to be modelled which *org. unit needs which tool* as org. units and tool for the particular task are already defined. In the calculation case more relations are calculated than actually really exist. This is due to the fact that the calculation shows all potential relations and this number differs from the measured number of real relations. Consequently the meanings of these calculated subsets are slightly different: *Org.unit* **might** *uses tool*, *org.unit* **might** *uses method* as well as *tool* **might be** *necessary for method*. The mapping of the number of calculated relations to the measured number of relations offered values from 50% to 80% with a mean of 64% and a standard deviation of 11%. The benefit of the calculated dependencies is that they don't have to be directly modelled within the System Dynamics model as these dependencies are indirectly already incorporated in the model by the direct relations on which the calculations are based on. For this case study the effect of eased modelling was weighted higher than the loss of accuracy of the model.

3.4.1 Qualitative System Dynamics modelling

Within this case study, the transformation method according to Kasperek and Maurer (2013) was used. Building a SD model out of an MDM can be divided into the development of a qualitative and a quantitative SD model. Each process step respectively aggregated process step was transformed into the SD composite construct of a rework cycle. In particular the standard rework cycle construct of (Reichelt and Lyneis, 1999) is used for each process step. Additionally the variable *Start task* defined to enable coordination between the rework cycles by modelling the condition that a subsequent rework cycle can only start of particular amount of work packages has already been processed error-free, thus reached the *work done* stock. To increase the comprehensibility of the SD model, the approach of (Kasperek, Lindinger, et al., 2014) is used. Thereby a composition panel for the allocation of organizational unit, tools and methods to the particular process steps is used. Within this panel the organizational unit, tools and methods are bundled to "Allocated Org. units", "Used Tools" and "Used Methods" for each particular process step modelled as a rework cycle. Figure 4 shows the qualitative SD model for process A. The other processes of the industry partner were modelled in a similar way.

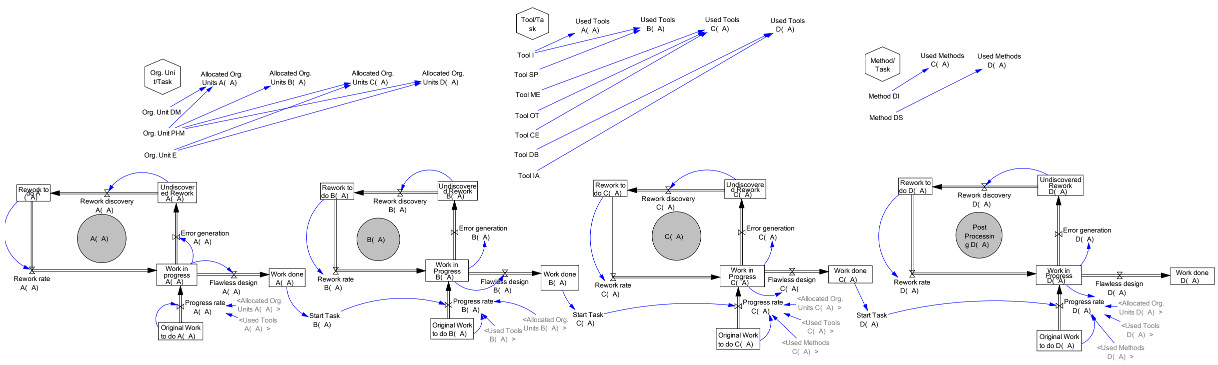

Figure 4. Qualitative SD model of process A

3.4.2 Quantitative System Dynamics modelling

As a first step of quantification the initial values of each stock were defined 0, except of the "Original Work to do" variables which represent the original amount of work packages for each process step. This amount was normalized and set to 100, representing 100% of the work packages.

As far as equations were implemented within the models, the same types of equations were used for each of the three MAN processes. The different values of the duration "T", the "progress rate" and the general amount of occurring rework ("flawless design") for each processes step of all three processes were estimated based on interviews and workshops. Within Table 1 the different equations implemented within the SD model are given.

The values of the progress rate were calculated by dividing the normalized "Original Work to do" by the estimated duration of the particular process step. The constant of 0.0078125 shown within the Table 1 is attributed to the chosen time step interval of the simulation. The term (100/T)*0.0078125 reflects the values of the progress rate for the last time step and ensures the "Original Work to do" stock not getting negative.

Table 1. Equations implemented within the SD model

Variable	Equation	Unit
Original Work to do	= - Progress rate	WP
Progress rate Fall 2	= IF THEN ELSE ("Start Task" = 1 :AND: "Original Work to do" – (100/T)*0.0078125 >= 0 :AND: "Allocated Org. Units" > 0 :AND: "Used Tools" > 0 :AND: "Used Methods" > 0, 100/T, 0)	WP / t
Work in Progress	= + Progress rate + Rework rate – Flawless design – Error generation	WP
Flawless design	= x * Work in Progress	WP/t
Error generation	= (1 – x)* Work in Progress	WP/t
Work done	= + Flawless design	WP
Undiscovered Rework	= + Error generation – Rework discovery	WP
Rework discovery	= 0.8 * Undiscovered Rework	WP/t
Rework to do	= + Rework discovery – Rework rate	WP
Rework rate	= Rework to do	WP/t
Start Task	= IF THEN ELSE ("Work done" > 90, 1, 0)	/

3.4.3 Simulation of the Engineering Design Process

Figure 5 shows exemplary simulation results for the first process step of benchmarking process A. As the same equations; even though with different implemented values; were used for each process step the principal characteristics of the graphs of this process step give an overview of the general simulation results.

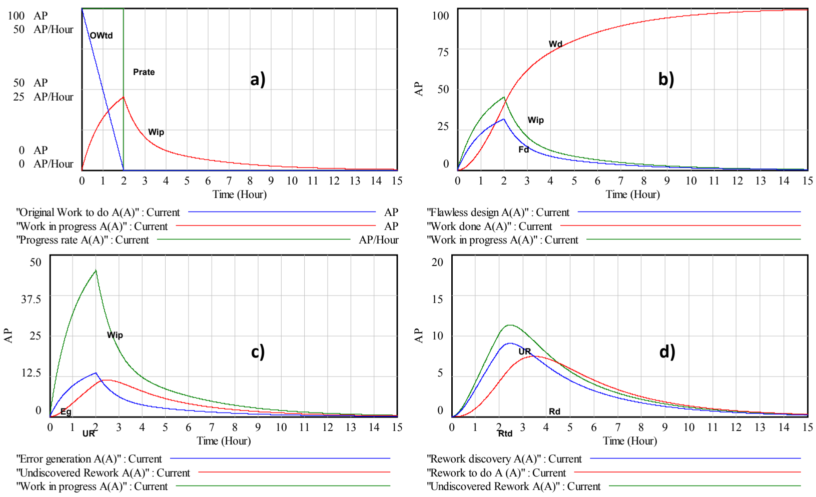

Figure 5. Exemplary simulation results of the first process step of benchmarking process A

a) shows the trends of „Original Work to do", „Progress rate" and „Work in Progress". The "Original Work to do" decreases with a certain "Progress Rate" and finally reaches 0. In the meantime "Work in Progress" increases and reaches its maximum when all original work has been done. Afterwards there is still work in progress due to rework, but decreases slowly.
b) shows the trends of „Work in Progress", Flawless Design" and „Work done". It can be seen that the trend of "Flawless Design" is scaled based on the trend of "Work in Progress" and can be also seen based on the corresponding equation indicated in Table 1. The difference indicates the amount of work packages which still have to be reworked ("Error generation"). The maximum of "Flawless Design" indicates the inflection of "Work done".
c) shows the trends of „Work in Progress", „Error generation" and „Undiscovered Rework". It can be seen that the trend of "Error generation" is also scaled based on the trend of "Work in Progress". The "Error generation" also influences the "Undiscovered Rework". Thus, it starts to decrease shortly after the "Error generation" reaches its maximum.
d) shows the trends of Rework discovery", „Rework to do" and „Undiscovered Rework". The "Rework discovery" indicates 80% of the "Undiscovered Rework" due to the assumption that 80% of rework are discovered immediately. The "Rework to do" indicates the amount discovered rework minus the amount of already reworked work packages.
To verify the simulation results of the three processes the results of each simulation were presented to the responsible MAN manager. Within a workshop it was shown which input from whom was incorporated in the model. After it was approved by the management that the models sufficiently enough represent the real processes, the model could be further used to identify optimization potentials

by incorporating tools and methods from the benchmarking partner within the own process simulations.

3.5 Process simulation with additional tools and methods

Based on the developed simulation of the existing processes B, C and the identified tools and methods of the other OEMs different adaptions of the processes by these tools and methods were simulated to identify potential optimization possibilities. Within the analysis of the benchmarking processes of the other OEMs comparable to process A, no additional tools and methods could be identified. Therefore process A was not further analyzed for the incorporation of other tools and methods.
As the changes to the processes were hypothetical their influences on the processes could not be measured. The influence of the additional tools and methods on the processes B and C was estimated within workshops with the corresponding managers. Within these workshops it was decided which parameters would be influenced by the particular tools and methods, as well as how this influence would be formed. This information was taken as a basis to simulate the influence of each additional tool and method. In most cases additional tools and methods were supposed to decrease the error rate within existing process steps. The analysis of the benchmarking processes had two goals: increasing the quality of the process outcomes as well as decreasing the process time. These two goals were to a certain extent contrary as additional tools and methods for increasing the quality of outcomes may also increase the process duration. Based on these goals three possible outcomes for the incorporation of additional tools and methods with respect to the process duration were identified:

- Tools and methods decreasing the duration of a particular process step by decreasing the error rate
- Tools and methods increasing the duration of a particular process step by increasing the amount of work to do
- Tools and methods increasing the overall process duration by adding an additional process step

Table 2 shows the values of the process step durations within process B. Process steps where additional tools and methods were implemented are indicated in yellow. The left part of the figure shows the initial values, the right part shows the simulation results of the incorporation of additional tools and methods. The very right column shows the delta of both simulations. Cells indicated with […] were calculated, but left out within this publication for confidentiality reasons.

Table 2. Simulated values of process step durations of process B before and after the incorporation of additional tools

Whole Vehicle Process							
Task	Original simulation values			Simulation values after adition of the chosen tools and methods			
	Point in time of "Start Task" [Weeks]	Point in time of "Work done" >=90 [Weeks]	Time per Task [Weeks]	Ponit in time of "Start Task" [Weeks]	Point in time "Work done" >=90 [Weeks]	Time per Task [Weeks]	Expenditure of time [Weeks]
A_B	0	3,46094	3,46094	0	3,46094	3,46094	
B_B	3,46094	15,1016	11,64066	3,46094	15,1016	11,64066	
C_B		13,2109	9,74996		11,0234	7,56246	-2,1875
D_B	15,1016	38,8281	23,7265	15,1016	38,8281	23,7265	
E_B	38,8281	45,8984	7,0703	38,8281	45,8984	7,0703	
F_B	45,8984	48,7422	2,8438	45,8984	48,7422	2,8438	
G^*_B	48,7422	55,9063	7,1641	48,7422	56,5313	7,7891	0,625
J^1_B	/	/	0	56,5313	59,0938	2,5625	2,5625
K_B	55,9063	65,7344	9,8281	59,0938	64,7109	5,6171	-4,211
L_B	…	…	…	…	…	…	
M_B	…	…	…	…	..	4,5	-0,3984
M^1_B	…	…	…	…	…	2,5625	2,5625
N_B	…	…	…	…	…	…	
O_B		…	…		…	…	
Time for the whole process			…			…	

4 PROCESS ANALYSIS

The incorporation of additional tools and methods offers several potentials for analysis with respect to process duration or quality. The potentials considering process duration were assessed based on the simulation results. Therefore, as shown in Table 2, the simulated process durations with and without the additional tools and methods were compared. The industry partner based its decision which tools and methods to incorporate on the effected process duration as well as quality aspects. A scheme was developed to show both aspects within one view. Table 3 shows the corresponding tools and methods sheet. This sheet consists of the process tasks, the potential additional tools and methods, the simulated

difference in time between task duration with and without the additional tool or method and the assumed effect on the quality. To allow a quick overview the simulated duration delta was also indicated with a colour scale from red (significant duration increase) to green (strong time saving).
The effect on quality was assessed based on the results of interview series with the involved managers and rated from (--) for an expected significant quality decrease to (++) for an expected significant quality increase. The particular lines of argumentation of the management for an expected quality increase or decrease were also documented. Based on the tools and methods sheet and the lines of argumentation, suggestions for which tools and methods to incorporate within the MAN processes on a short-term, medium-term and long-term perspective were given by the researches.

Table 3. Exemplary tools and methods sheet for management decision

Whole Vehicle process			
Task	**Tool / new Task**	**Time delta [Weeks]**	**Quality increase**
C_B	Tool_ISC	-2,1875	+
M_B	Tool_C	-0,3984	o
G^*_B	Tool_C	0,625	o
K_B	Tool_VPNP	-3,5156	++
J^1_B	new task	2,5625	++
M^1_B	new task	2,5625	++
K_B	Tool_RIA	-0,6954	+
Whole Time [Weeks]:		-1,0469	+

The tools and methods sheet was accompanied by an additional document indicating the mines of argumentation why particular tools and methods have an effect on the overall quality of the processes.

5 DISCUSSION

The combined use of structural and dynamic models offers the possibility to depict different aspects such as process steps, methods and tools by using the domain notation of the structural complexity management approach. By coupling structural and dynamic models the structure-based SD approach offers the possibility to expand structural models by additional information and create a simulation of the behavior of the development process. Thereby the approach serves as a possibility to increase the understanding of the dynamics of benchmarking processes, serve as a tool for decision support and for benchmarking of different methods and tools. The initial data gathering and modelling by structural models supported the system thinking of all involved persons. The explicit representation of interrelationships and involved elements helped to increase the overall system understanding.
Nevertheless some process steps which were modelled within the structural models were not considered later as they were not necessary for further analyses. Further guidance is needed to identify which elements to consider for the structural representation of the investigated processes. The structural models proved very helpful for the development of the System Dynamics models as the interrelations necessary for the SD model were already available. The knowledge of the structural modelling community of the possibility of deducting indirect dependencies showed that particular interrelations did not have to be modelled as they were already indirectly incorporated in the models. This led to a significant simplification of the SD models. Even though this simplification is context dependent it might be also relevant for other SD modelling activities beyond the circumstances of this case study. The transformation of process steps into rework cycles proved its potential and supported the structuring of the SD models. The assignment of methods, tools and organizational units was also supported by the previously developed structural models by the overview of dependencies between the particular domains. The estimation of durations proved to be intuitive for the experts, while the estimation of error rates was difficult as the rework cycle view on the process steps was new to most of the assessors. The visualization of the simulation results made dependencies between process steps more transparent and thereby supported the anlysis of the MAN benchmarking processes. By increasing the system understanding, a basis for the decision which additional tools and methods to integrate and where was developed.

6 CONCLUSION AND OUTLOOK

This research shows the application of the structure-based System Dynamics analysis within a case study. Originally developed for classic engineering design processes we aimed to determine if the approach is also applicable when analyzing and optimizing benchmarking processes.

The case study was conducted in collaboration with MAN Truck & Bus AG. Three benchmarking processes were in the focus of the study. The industry partner was interested in a process comparison of its own product benchmarking processes with benchmarking processes of other automotive OEMs. Therefore tools and methods of the other OEMs were identified and analyzed. Based on existing descriptions of the MAN benchmarking processes structural models in form of Multiple-Domain Matrices (MDM) provided the basis to develop System Dynamics models of the MAN product benchmarking processes. The System Dynamics models, in turn, provide a simulation environment for the purpose of analysis and optimization by enabling the possibility to incorporate the others' tools and methods within the simulation. Transferring the possibility of deducting indirect dependencies known from structural models into the System Dynamics models significantly eased the modelling activity. Based on a simulation-based comparison with the own tools and methods currently in use, potentials for further process improvements by integrating specific tools and methods of the other companies were identified. The results of the simulation were used as a decision basis for the industry partner to decide whether it is beneficial for the industry partner to incorporate particular tools and methods or not. Therefore a scheme summing the simulation results and additional quality aspects was developed to support the decision. The transformation of process steps into rework cycles proved its potential and supported the structuring of the SD models. The assignment of methods, tools and organizational units was also supported by the previously developed structural models by the overview of dependencies between the particular domains. Nevertheless we identified the need for further tool support to automatically derive the System Dynamics models out of the structural models. This would significantly decrease the modelling effort. The identified possibility of making use of indirect dependencies while developing the System Dynamics models seems promising and should be further analyzed. Overall the structure-based System Dynamics Analysis approach could be successfully applied to benchmarking processes. It increased the understanding of the dynamics of benchmarking processes, served as a tool for decision support and for benchmarking of different methods and tools.

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