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A SIMULATION MODEL TO PREDICT IMPACTS OF ALTERATIONS IN DEVELOPMENT PROCESSES

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Keywords: DSM, Process simulation, product development, process planning

1 INTRODUCTION

Product development is crucial for company success. Efforts aim to reduce development time and costs while ensuring higher product quality at the same time. However, as processes often proceed iteratively and concurrently, impacts of changes in single tasks or the process architecture can hardly be predicted.

The present work emanates from a cooperation between the Institute of Industrial Engineering and Ergonomics at RWTH Aachen University and the DaimlerChrysler AG. It presents a simulation model that permits to predict probabilities for time and cost outcomes and to analyse effects to these probabilities evolving from changes either on single tasks or on the process architecture.

The development process of a power-train control unit at DaimlerChrysler was analysed and simulated to verify the model. Results are presented at the end of this paper and show a good correlation with expectations and expert knowledge.

2 BACKGROUND

The work is based on a simulation model developed by Browning and Eppinger in 2002 [1]. The model is based on the Design Structure Matrix and uses Monte-Carlo simulation to create distributions of possible outcomes for process duration and costs. Also, a risk factor for comparison of different processes and process alternatives is presented.

In 2005, Cho and Eppinger [2] refine this model by improving iteration behaviour and considering task overlapping and resource constraints. Thus, processes can be modelled more realistically, but simulation complexity and necessary input data increase. As a consequence, Cho and Eppinger do not simulate process costs. Examination of the current development process showed that overlapping and resource constraints are not required for analysis, but investigation on costs was preferable. Therefore, only aspects of iteration behaviour were considered from this model and some additional functionalities were added.

3 PROCESS MODEL

In order to represent all aspects of the practical case at DaimlerChrysler AG, not only the simulation algorithm but also the model structure had to be adapted. Mostly known structures of the models above were used; additional information was included only where needed to correctly represent real world behaviour of the process:

- **Probability matrix:** All tasks and corresponding rework probabilities of the examined process at DaimlerChrysler can be seen in Figure 1. Entries in corresponding lines represent input data from other tasks; columns show output data of a certain task.
- **Duration of tasks:** As proposed in previous papers, task duration is specified as a triangle distribution. This adequately represents practical data and still allows easy data handling.
- **Costs of tasks:** Costs of tasks are not necessary for process simulation but will make an important contribution to possible conclusions. In the current example they are also provided as a triangle distribution.
- **Dynamic iteration:** The model supports an infinite number of iterations. To better reproduce real process behaviour it also permits to adapt rework probabilities during simulation.
- **Rework matrix:** The rework matrix defines how much of primary work has to be performed during iteration. Analyses show that needed work decreases according to a decaying geometric series. Therefore, only one value indicating the percentage of original work needed for a repeti-

tion of the particular task is used. This value is set to 100% for all tasks if no rework matrix is given.

- **Changes of probabilities:** Iteration during development serves to refine results. Hence, it can be assumed that the quality of results augments with every iteration and, consequently, probability for new rework decreases. This phenomenon was taken into account using the "change of probabilities" matrix. Every time an iteration is performed the corresponding rework probability is reduced by the specified fraction. For first approaches the model also allows to define changes globally for all tasks at a time.

		A	B	C	D	E	F	G	H	I	J	K	L	P	Q	R	S	T
Define module function	A	0	.1	.2	.1	0	0	.15	0	0	0	.05	.05	.01	0	0	.001	0
Define electronic function	B	.8	0	.25	.5	0	0	.1	0	0	0	.025	.04	.01	0	0	0	0
Define software function	C	.8	.75	0	0	0	0	.33	0	0	0	.05	.1	.05	0	0	0	0
Define mechanical function	D	.5	.66	0	0	0	0	.05	0	0	0	0	.025	.05	0	0	0	0
Fix requirement specification	E	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Choose supplier	F	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Analyse target specification	G	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Develop mechanical function	H	0	0	0	.9	0	0	1	0	.4	0	0	.25	.2	0	0	.005	0
Develop electronic function	I	0	.9	0	0	0	0	1	.6	0	.6	.33	.25	.1	0	0	0	0
Develop software	J	0	0	.9	0	0	0	1	0	.8	0	.75	.5	.6	0	0	0	0
Test at HIL	K	0	1	1	0	0	0	1	0	.8	.8	0	0	0	0	0	0	0
Test at engine testbench	L	0	1	1	1	0	0	1	.9	.9	.9	0	0	0	0	0	0	0
Test drive	P	0	1	1	1	0	0	1	.75	.5	.8	0	0	0	0	0	0	0
Approve module	Q	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	0	0
Approve software	R	0	0	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0
Production test	S	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0
Job #1	T	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0

Figure 1: Probability matrix of power-train control unit development process.

- **Workflow matrix:** The workflow matrix can be used to specify the sequence in which tasks are performed. This matrix is primarily used during simulation to determine which tasks can be started and which ones still have to wait for needed input data.
  More interesting is the possibility of alternative process paths. In this case, percentages for the occurrence of different alternatives must be provided. During simulation, alternatives are randomly chosen according to their probabilities and work for tasks belonging to paths not chosen is automatically set to zero. Thereby, use of the model increases significantly, particularly in weakly defined and variable development processes.

All input data was estimated using values from finished projects. Discussions with process experts from DaimlerChrysler AG were then used to further refine and validate values.

4 SIMULATION RESULTS

4.1 Simulation of the actual process

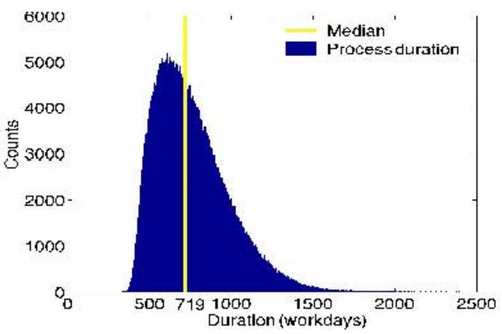


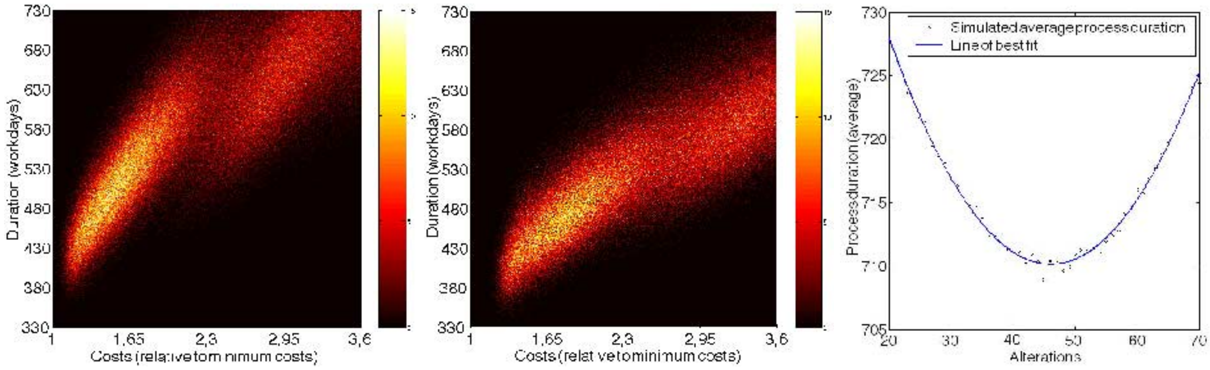
Figure 2: Simulation results for the power-train control unit development process

Simulation of the actual process revealed a medium process duration of approximately 760 workdays. This agrees very well with the real development duration of about three years. Due to the right-skewness of the probability distribution, the median is only 720 workdays. Figure 2 shows the complete distribution; costs of the process show a similar behaviour. Aside from getting medium values for duration and costs, simulating these values offers important possibilities to managers. For example, time and costs objectives can be determined more precisely using a defined residual risk. Also, earliest termination dates or minimum costs requirements can be compared to practical values revealing efficiency parameters.

4.2 Changes in task times and costs

Along with analysing actual process values and defining management goals, the process simulation also permits to analyse process behaviour due to changes in input data. For instance, impacts on the

process due to acceleration of individual tasks by higher efforts and costs, or effects of changes to rework probabilities due to longer task duration and thus more thorough execution, can be examined.
Plots a and b on the left side of Figure 3 show changes to process time and costs outcomes if duration of tasks H-J (See Figure 1) could be reduced by 1/3, augmenting costs of this tasks by 1/3. It can be seen that the second distribution shows a lower deviation on time but a higher variance in costs. In both plots a secondary local maximum can be identified in the upper right corner. This evolves from the possibility of an additional iteration of the whole process resulting in the higher duration and costs of the process.
Plot c represents changes of process duration by continuously increasing duration of tasks H-J by 1.5% and simultaneously decreasing corresponding rework probabilities by 1.05%. With these presumptions increasing task duration could lead to significantly lower process duration of only 710 workdays on average.



a b c

Figure 3: Time and costs outcomes of the original process (a) and the accelerated process (b) and change of average process duration through longer task duration and fewer iterations (c)

5 OUTLOOK

The analysis of this exemplary process reveals good accordance with practical experience. Nevertheless, for further validation the model will be adapted to other processes.
For a more realistic model interfaces between processes should also be analysed. Interaction of different processes can change output values significantly, but simulation of all coupled processes at the same time is often complex for the user. Therefore, a way to include input and output relations without needing to simulate all connected processes could improve practical usage.
In order to establish the method more widely, an improved user interface could be envisioned. A tool that helps to collect necessary data and to perform relevant analyses would allow easier usage. Thus, managers could be provided with important strategic information without needing profound computer skills or knowledge of design structure matrices.

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[1] Browning Tyson R. and Eppinger Steven Modeling Impacts of Process Architecture on Cost and Schedule Risk in Product Development. *IEEE transactions on engineering management*, 2002, 49(4), 428-442

[2] Cho Soo-Haeng and Eppinger Steven A Simulation-Based Process Model for Managing Complex Design Projects. *IEEE transactions on engineering management,* 2005, 52(3), 316-328

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9TH INTERNATIONAL DSM CONFERENCE

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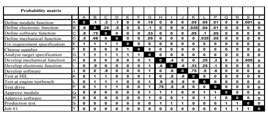
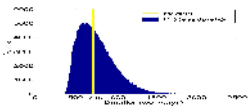
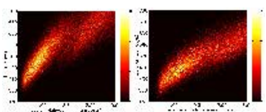






- Introduction – Traditional methods for project planning
- Development of the simulation model
- Simulation results
- Evaluation of process alterations
- Outlook
- Summary

Introduction – Challenge

Problem

Comparison and evaluation of complex development processes

- Estimation of duration and costs
- Calculation of risks
- Evaluation of sub-processes
- Quantification of potentials in process performance

Challenge

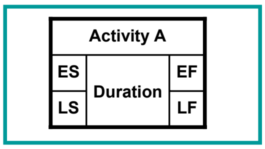
Estimation of duration and costs in early phases of product development projects is difficult, because of

- many parallel processes,
- complex project organization through:
    - integration of many organizational units (supplier, specialized divisions),
    - strong interdependency of activities because of multi-functional teams,
    - many iterations in the project (e.g. caused by changes in the specification).

Introduction – Traditional methods for project planning

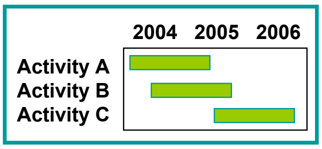
Traditional methods for project planning

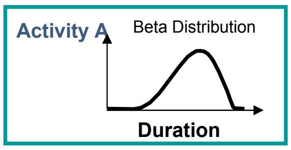
- Gantt-Charts
- CPM (Critical Path Method)
- PERT (Program Evaluation and Review Technique)



Poor applicability for CE-projects

- Not intended for iterations
- Not considered for coupled activities
- No integrated risk management
- Complex project representation



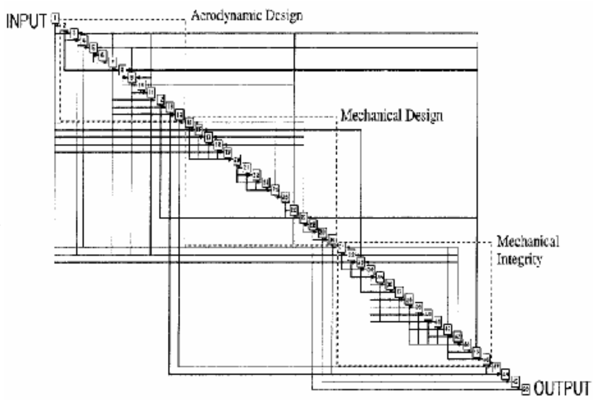


➡ **Traditional methods are not suitable to assist efficiently in the planning and management of complex product development processes.**

Introduction – Design Structure Matrix as a method to support planning of complex projects

Advantages of Design Structure Matrix

- Presentation suitable for complex and strongly interdependent processes
- Iterations presentable
- Compact form of representation
- Degree of dependence presentable
- Additional work generated by iteration presentable
- Suitable as a database for simulation models



Example: Development of a gas turbine blade (source: Cronemyr et.al. 2001)

Introduction – Selected simulation approaches

Browning/Eppinger (2002):

- • Monte Carlo simulation of duration and costs
- \- Comparison of alternatives by variation of influence coefficients
- \- Only one iteration possible
- \- No resource constraints
- \- No overlapping possible

Cho/Eppinger (2005):

- • Forecast model for the duration of CE projects
- \+ Resources delimitation with parallel activities
- \+ Restricted overlapping possible
- \+ Multiple iterations possible
- \+ Learning curve for repeated iterations
- \- No change of iteration probability for repeated iterations
- \- No approach on costs

Development of the simulation model - Characteristics

- Model to simulate probabilities of duration and cost outcomes of CE projects on basis of the approach by Browning/Eppinger (2002)
- Monte Carlo simulation, implemented in Mathlab

+ Improved iterations
  - Multiple iterations
  - Dynamic iteration (probabilities can change during simulation)
+ Alternative process paths possible
+ Risk management possible by comparison of different project scenarios
+ Various possibilities for result analysis (e.g., probability distribution for duration and costs)
- No resource constraints

- Validation based on the development process of a power-train control unit

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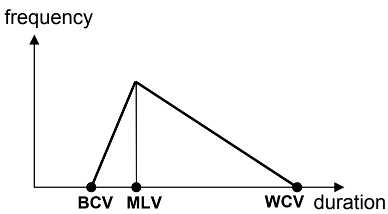
Process model – Input data

Probability matrix		A	B	C	D	E	F	G	H	I	J	K	L	P	Q	R	S	T
Define module function	A	0	.1	.2	.1	0	0	.15	0	0	0	.05	.05	.01	0	0	.001	0
Define electronic function	B	.8	0	.25	.5	0	0	.1	0	0	0	.025	.04	.01	0	0	0	0
Define software function	C	.8	.75	0	0	0	0	.33	0	0	0	.05	.1	.05	0	0	0	0
Define mechanical function	D	.5	.66	0	0	0	0	.05	0	0	0	0	.025	.05	0	0	0	0
Fix requirement specification	E	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Choose supplier	F	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Analyse target specification	G	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Develop mechanical function	H	0	0	0	.9	0	0	1	0	.4	0	0	.25	.2	0	0	.005	0
Develop electronic function	I	0	.9	0	0	0	0	1	.6	0	.6	.33	.25	.1	0	0	0	0
Develop software	J	0	0	.9	0	0	0	1	0	.8	0	.75	.5	.6	0	0	0	0
Test at HIL	K	0	1	1	0	0	0	1	0	.8	.8	0	0	0	0	0	0	0
Test at engine testbench	L	0	1	1	1	0	0	1	.9	.9	.9	0	0	0	0	0	0	0
Test drive	P	0	1	1	1	0	0	1	.75	.5	.8	0	0	0	0	0	0	0
Approve module	Q	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	0	0
Approve software	R	0	0	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0
Production test	S	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0
Job #1	T	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0

- Necessary:
  - Probability matrix
  - Duration of tasks



- Optional:
  - Costs of tasks
  - Rework matrix
  - Probability change matrix
  - Workflow matrix with possibility for alternative process paths

Process model – Input matrix

Probability matrix																		
		A	B	C	D	E	F	G	H	I	J	K	L	P	Q	R	S	T
Define module function	A	0	.1	.2	.1	0	0	.15	0	0	0	.05	.05	.01	0	0	.001	0
Define electronic function	B	.8	0	.25	.5	0	0	.1	0	0	0	.025	.04	.01	0	0	0	0
Define software function	C	.8	.75	0	0	0	0	.33	0	0	0	.05	.1	.05	0	0	0	0
Define mechanical function	D	.5	.66	0	0	0	0	.05	0	0	0	0	.025	.05	0	0	0	0
Fix requirement specification	E	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Choose supplier	F	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Analyse target specification	G	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
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Develop software	J	0	0	.9	0	0	0	1	0	.8	0	.75	.5	.6	0	0	0	0
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Test drive	P	0	1	1	1	0	0	1	.75	.5	.8	0	0	0	0	0	0	0
Approve module	Q	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	0	0
Approve software	R	0	0	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0
Production test	S	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0
Job #1	T	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0

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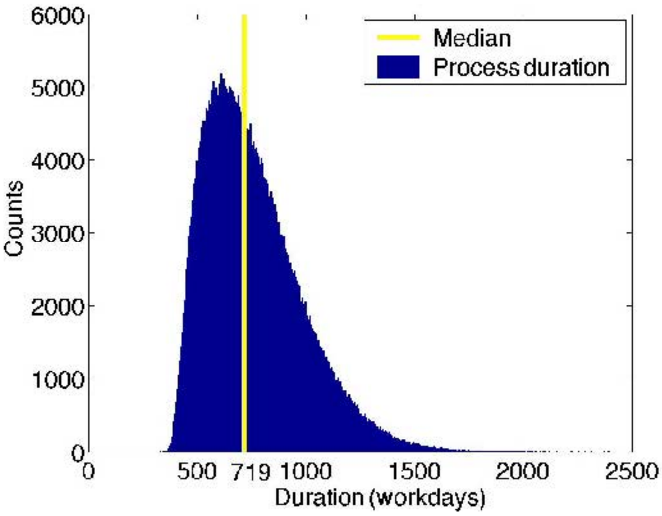
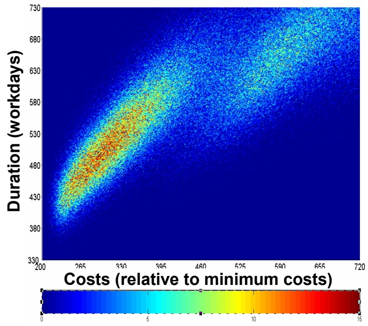
Simulation results



- Simulation results are given as a probability distribution
- Duration as well as costs can be analyzed
- Minimum duration can be determined
- Median can be calculated
- Probability of certain outcomes helps to determine chances and risks

Process alterations – Cost / duration dependencies

A



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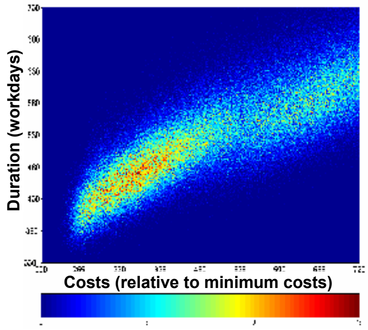
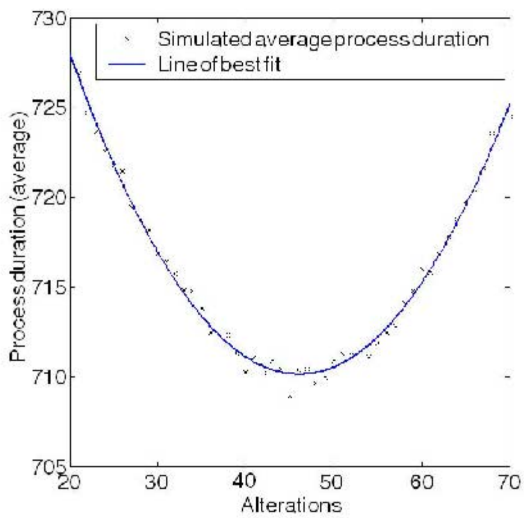


- Showing process duration over costs allows fast evaluation
- Picture B evolves from a process alteration:
  - Only tasks H-J altered
  - Duration: - 1/3
  - Costs: + 1/3
- Results:
  - Risk for higher costs augments
  - Risk for time deviation declines

Process alterations – Reducing rework probabilities



- Alteration can be performed incrementally to find optimal processes
- Assumption:
  - Augmenting development time reduces iteration probability
- Only tasks H-J are changed:
  - Duration augments by 1.5%
  - Iteration probability decreases by 1.05%
- Optimum for duration and iteration probability at ~45 alterations
- Average process duration can be reduced by ~6%!

Outlook

- Apply model to other processes for further validation
- Include possibility to represent interaction of different processes
- Examine further possibilities for analyses
- Add possibility of overlapping activities
- Complete tool including all simulation and analyzing features

Summary

- Product development is crucial for company success. Efforts aim to reduce development time and costs while ensuring higher product quality at the same time. However, as processes often proceed iteratively, impacts of changes in single tasks or the process architecture can hardly be predicted.
- This work presents a simulation model that permits to predict probabilities for time and cost outcomes of development processes and to analyze effects to these probabilities evolving from changes either on single tasks or on the process architecture. DSM matrices are used to represent processes and results are generated by Monte Carlo simulation.
- The development process of a power-train control unit at DaimlerChrysler AG was analyzed and simulated to verify the model. Results show a good correlation with expectations and expert knowledge and permit better process planning.