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SIMULATION OF PRODUCT CHANGE EFFECTS ON THE DURATION OF DEVELOPMENT PROCESSES BASED ON THE DSM

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1 INTRODUCTION

The effective management of product development projects is crucial for company success. Development projects are characterized by a strong informational coupling of tasks and numerous iterations. Investigations of current development processes showed that additionally unplanned product changes often extend the development process. Because of these various product changes, the project duration as well as the cost is difficult to estimate. Therefore, project managers need innovative models and methods to plan development projects.

This paper presents a simulation model that enables the prediction of probabilities for time and cost outcomes. The model allows the analysis of effects to these probabilities evolving from changes on single tasks as well as on changes to the parts of a product. The simulation model stems from the cooperation between the Institute of Industrial Engineering and Ergonomics at RWTH Aachen University and the Daimler AG and is verified on the software development process of a power-train control unit at the Daimler AG.

2 BACKGROUND

The study is based on a simulation model developed by Browning and Eppinger [1], which is based on the Design Structure Matrix (DSM) and uses Monte-Carlo simulation to create distributions of possible outcomes for process duration and costs. Later, it was refined by Cho and Eppinger [2] by improving iteration behavior, task overlapping and resource constraints. Lukas et al. [3] improved the model of [1] by adding a reduction of the iteration probability for each iteration and the depiction of alternative process paths. Lukas et al. also augmented the speed of the simulation by transferring the model from Visual Basic for Applications to Matlab.

None of these simulation models considers product changes, but project managers need to know which tasks and to what extent they have to be reworked in addition to how much the project will be extended. To model and to simulate product changes with these models means to estimate the extension of the duration and costs for each task and to manually change the input data before restarting the simulation. Therefore, the model by Lukas et al. is enhanced by the capability of simulating the effects of the changes to the parts of a product on the project duration and some additional functionalities.

3 ENHANCEMENT OF THE MODEL

In order to represent all aspects of the practical case at Daimler AG, the model structure (see Fig. 1) had to be adapted by using a product DSM and a Domain Mapping Matrix (DMM) [4] [5]. The simulation algorithm was adapted and refined where necessary to correctly represent real world behavior of the process. The model uses the following input:

- Duration and costs of tasks: In order to adequately represent practical data and still allow easy data handling, the duration and costs of each task are specified as triangular distributions.
- Workflow matrix (1): The workflow matrix can be used to specify the sequence in which tasks are performed. It can be also used to depict the probability for the selection of different process paths.
- Probability matrix (2): The probability matrix presents the probability of an iteration occurring after the execution of an activity.
- Rework matrix (3): The rework matrix defines how much of primary work has to be performed during an iteration. Analyses show that rework decreases according to an exponential function.

Therefore, a learning effect is implemented, causing an exponential reduction of the processing duration of activities with the number of iterations.

- Changes of probabilities (4): Each iteration during the development serves to refine results. With the augmenting quality, the probability for an iteration decreases with the number of iterations. This is applied by using the “changes of probabilities matrix”, which allows to reduce the iteration probability with every iteration.

If a product change is taken in account, the following input is also needed:

- Change vector (5): The product change applies to a specific time in the project and to one or more parts of the product. The change vector expresses the degree of change for each part.
- Product matrix (6): A product consists of many interdependent parts. Hence, if one part is changed, all the other parts depending on it have to be changed. The product matrix represents the proportion of the development time of a part that must be additionally performed due to a change.
- Process Product DMM (7): The DMM connects the product with the process view and indicates to which degree the particular activity is dependent on the development of a part.

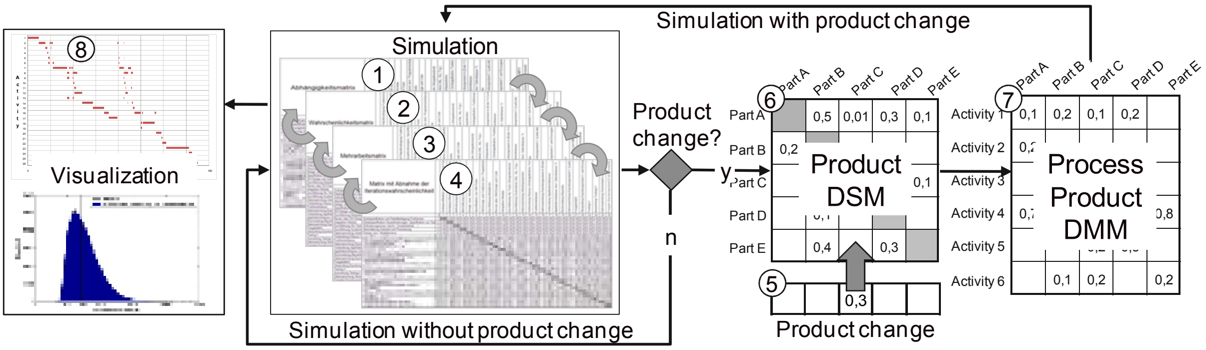

Figure 1: Model including process DSM, product DSM, change vector, DMM and visualization opportunities

Excel is used as an interface for the input in order to increase the applicability of the DSM method before the data is imported into Matlab for the simulation. The results of the simulation are visualized as a probability distribution (8) of a development project’s duration and costs according to changes on process or product (see Section 4). The transfer of the simulation results into a Gantt chart (8) allows conclusions regarding the resource allocation during the development project.

4 VERIFICATION STUDY

4.1 Simulation of the actual process

In order to verify the model, the development process of a power-train control unit at the Daimler AG was analyzed and simulated. All input data (see Section 3) were determined based on previous projects and further refined in discussions with process experts from Daimler AG. Simulation of the software development process without product changes reveals an average process duration of approximately 122 time units (TU). This correlates very well with the real development duration. The distribution is a lognormal distribution, which is skewed to the right due to the iterations. Figure 2 shows the complete distribution. The costs of the process show a similar distribution.

4.2 Simulation of product changes effects

The examined software of the power-train control unit contains five core functions represented by the parts of the product in the model. Along with the process data, these functions and their interdependencies, as well as the influence on the processing of the activities, were assessed by experts at Daimler AG. In a recent development process following the activity “approval test-drive”, 30 % of the function “A” had to be changed by the requirement to lower the CAN bus load. Using this information as an input, the simulation was performed. The interpretation of the simulation results shows that, according to the coupling of the functions, this change causes a redevelopment of 3.6 % of the function “B”, 3.5 % of the function “C”, 6.8 % of the function “D” and 3.4 % of the function “E” and, due to repercussions, a total of 32.9 % of the function “A”. These changes cause an extension of duration of the upstream activities and overall result in a 19 TU extension, on average, of the software development process and 19 % higher costs (see Fig. 2). These results show a good correlation with real data and expert knowledge. Aside from getting medium values for duration and costs, simulating offers important possibilities to managers. The risk of failure in duration and costs can be determined more precisely. The dispersion of the distribution increases with product changes due to the rework of the tasks and the increase of the probability of iterations. This means that, aside from extending the process, a product change increases the risk of even more iterations and with it the risk of higher costs and a longer duration for the development project.

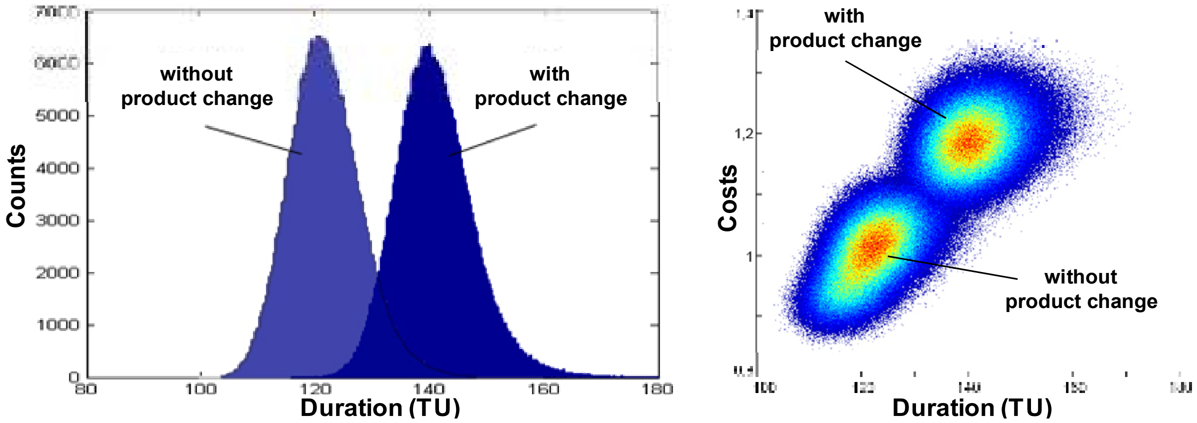

Figure 2: Simulation results for the duration of the software development process of a power-train control unit without and with a product change (left figure) and cost-time-distribution (right figure)

5 OUTLOOK

The use of overlapping tasks with an individual degree of overlap is necessary in order to easily transfer the project planning data used so far, which were displayed as Gantt charts, into the simulation model. The usability can be improved through the use of categories to describe the dependencies. It must still be investigated whether or not, and to what extent, these dependencies influence the simulation results.

Although the simulations of several processes performed so far produced a very good approximation to the actual process durations and costs, further evaluation is still necessary to validate the model. For a more realistic model, interfaces between processes should also be analyzed. 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 method of including input and output relations without needing to simulate all connected processes could improve practical usage.

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1. Challenges in product development projects
2. Development of a simulation model for the estimation of duration and costs of product development projects based on the DSM
3. Application of the simulation model in the automotive industry
4. Identification of potentials for process optimization by systematic parameter variation

Challenges in product development projects

Product development projects are characterized by:

- **Iterations:**
  - Planned iterations ensure the quality
  - Unplanned iterations are correcting wrong information and create rework
  - Rework is hard to estimate: 13-70% (on average: 33%) of the total project time at Intel was rework (Osborne 1993)
- **Complex information dependencies:**
  - Many information dependencies are simplified, not documented or even unknown
  - Iterations are not presented
- **Unplanned product changes:**
  - Change of requirements due to the changes of legal regulations or frameworks
  - Change of requirements due to product optimization
  - Product changes occur in parallel, depending development projects

Challenges of planning in product development projects:

The estimation of duration and costs of product development projects is difficult due to iterations, complex information dependencies and product changes.

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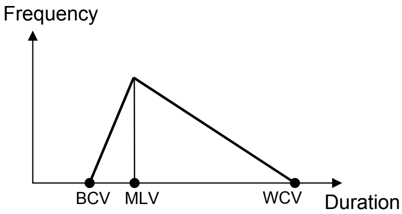
Development of a simulation model

Characteristics of the simulation model:

- Estimation of duration and costs of product development projects
- Based on the DSM and DMM
- Monte Carlo Simulation, implemented in MATLAB
- Model implies approach by Browning & Eppinger (2002)
- Application of multiple iterations and product changes possible
- Variances of activity duration and costs are considered
- Learning effects during execution of iterations
  - Decreasing iteration probability
  - Decreasing rework
- Various possibilities for result visualization and analysis
  - Probability distribution for duration and costs
  - Dependency between duration and costs
  - Gantt-Charts
- Risk management by analysing simulation results and comparing different project scenarios
- Identification of potentials for process optimization by systematically varying the parameters

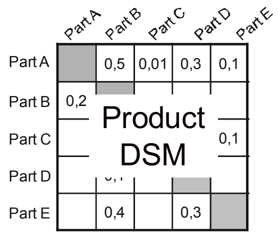
Required inputs for the simulation model

- Activity duration and costs as triangular distribution
- Workflow matrix: Information dependencies between activities
- Probability matrix: probability of an iteration
- Rework matrix: amount of work that has to be performed in an iteration loop
- Changes of probabilities: the probability of further iterations decreases with each iteration
- Learning effect



Additional input for product change:

- Point of product change
- Change vector: degree of change applying to one or more parts or functions of a product
- Product matrix: dependencies between parts or functions
- Process product DMM: dependencies between the parts or functions and the activities



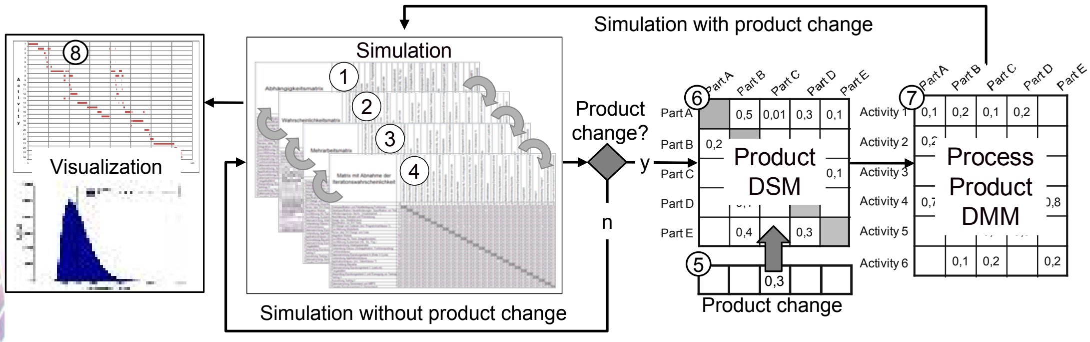
Probabilities of iterations in the Design Structure Matrix

50 % probability that an iteration from „Define mechanical functions“ to „Define electronic function“ occurs.

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	0.5	0	0	.1	0	0	0	.025	.04	.01	0	0	0	0
Define software function	C	.8	0.75	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								1	0	.8	.8	0	0	0	0	0	0	0
Test at engine testbench								1	.9	.9	.9	0	0	0	0	0	0	0
Test drive								1	.75	.5	.8	0	0	0	0	0	0	0
Approve module								1	1	1	0	0	1	1	0	0	0	0
Approve software								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

75 % probability that in an iteration loop „Define electronic function” creates rework for „Define software function“.

Development of a simulation model
The Concept Model



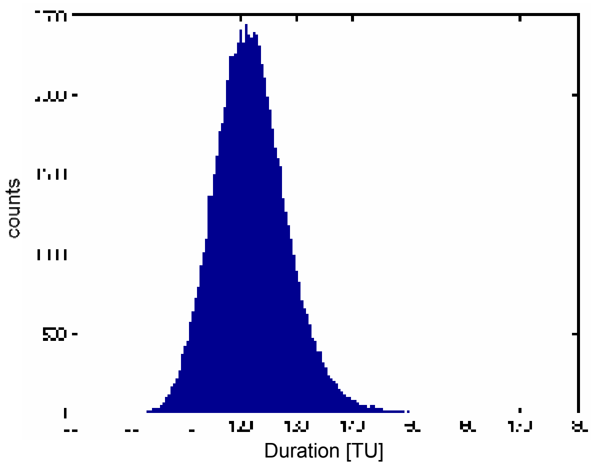
Elements of the simulation model:

1. Workflow matrix
2. Probability matrix
3. Rework matrix
4. Changes of probabilities matrix
5. Change vector
6. Product matrix
7. Process Product DMM
8. Visualization (Gantt-Charts, probability distribution, duration-cost-dependency)

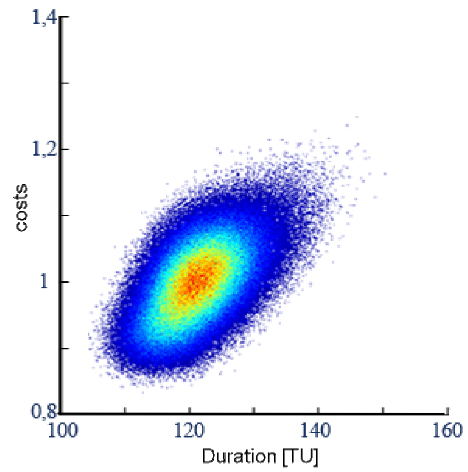
Simulation without product change

Example: Development of software for a power-train control unit

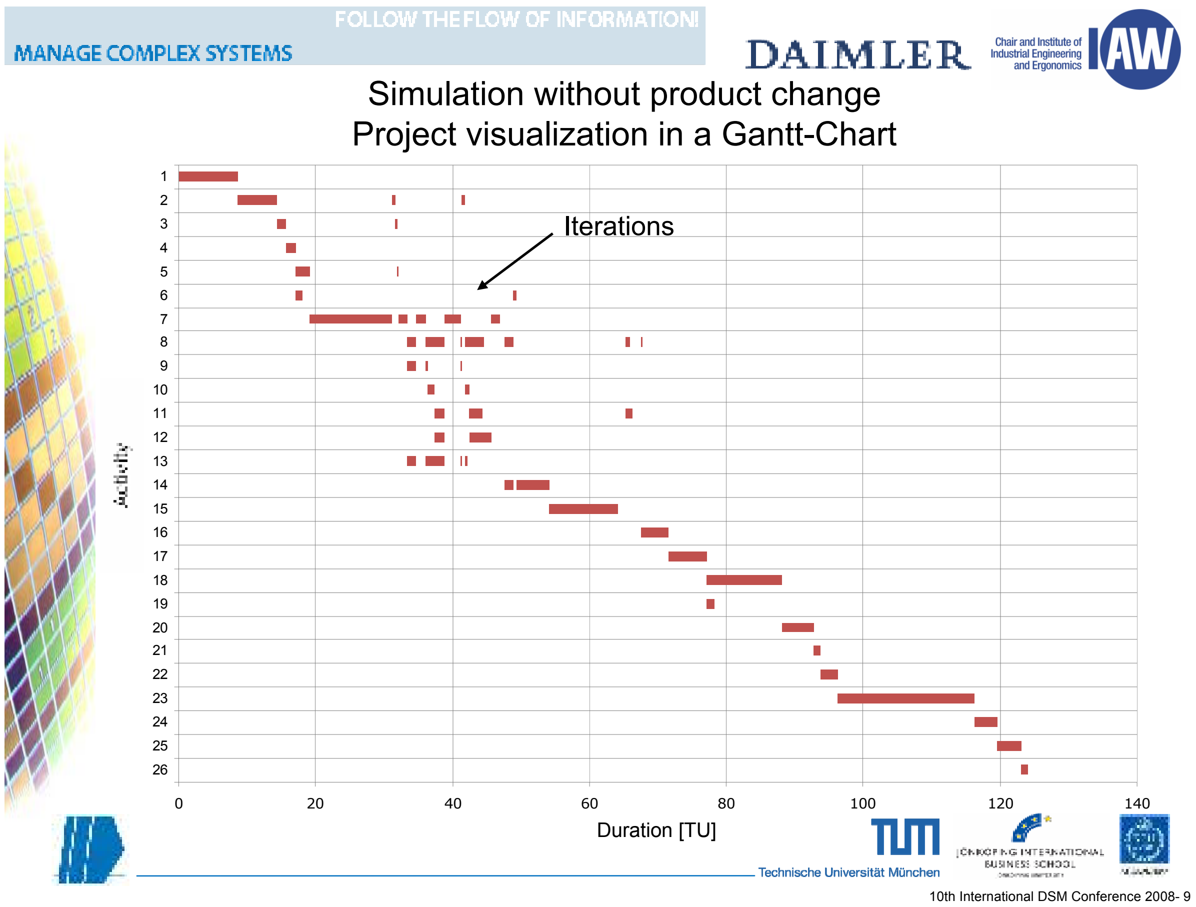
Probability distribution for duration



Dependency between duration and costs



Average:	121.9
Modus:	121.2
Variance:	40.8
5% Percentile:	112.1
95% Percentile:	132.8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Simulation without product change
Project visualization in a Gantt-Chart
Iterations
Activity
Duration [TU]
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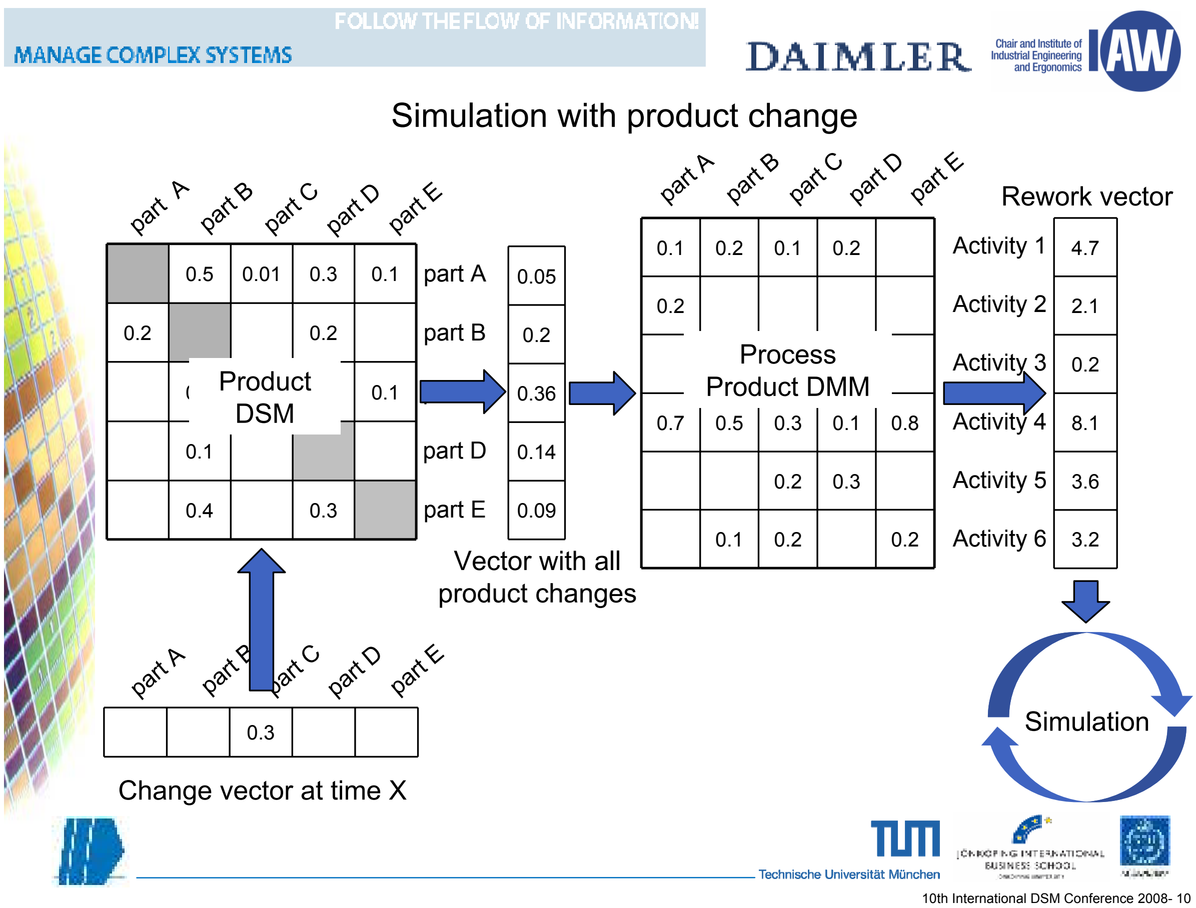
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Simulation with product change
part A part B part C part D part E
Product DSM
Vector with all product changes
Process Product DMM
Rework vector
Activity 1 4.7
Activity 2 2.1
Activity 3 0.2
Activity 4 8.1
Activity 5 3.6
Activity 6 3.2
Simulation
Change vector at time X
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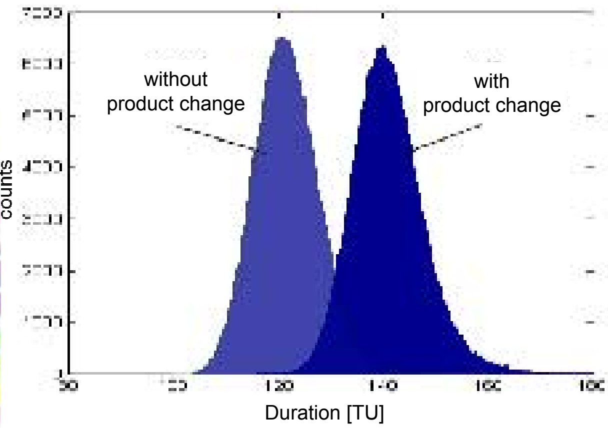
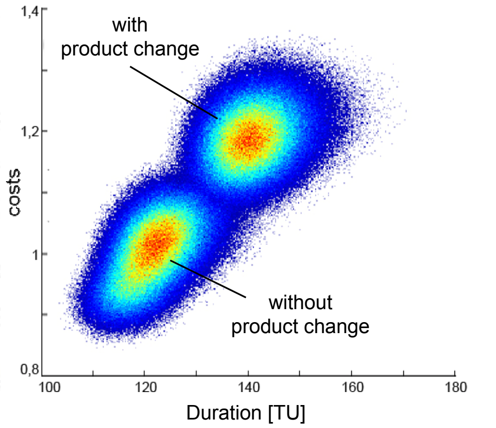
Simulation with product change

Example: Change of product requirement „lower CAN bus load“

Probability distribution for duration



Dependency between duration and costs



	without	with product change
Average	121.86	140.48
Median	121.51	139.97
Variance	40.78	47.72
5% Percentile	112.05	130.22
95% Percentile	132.80	152.50

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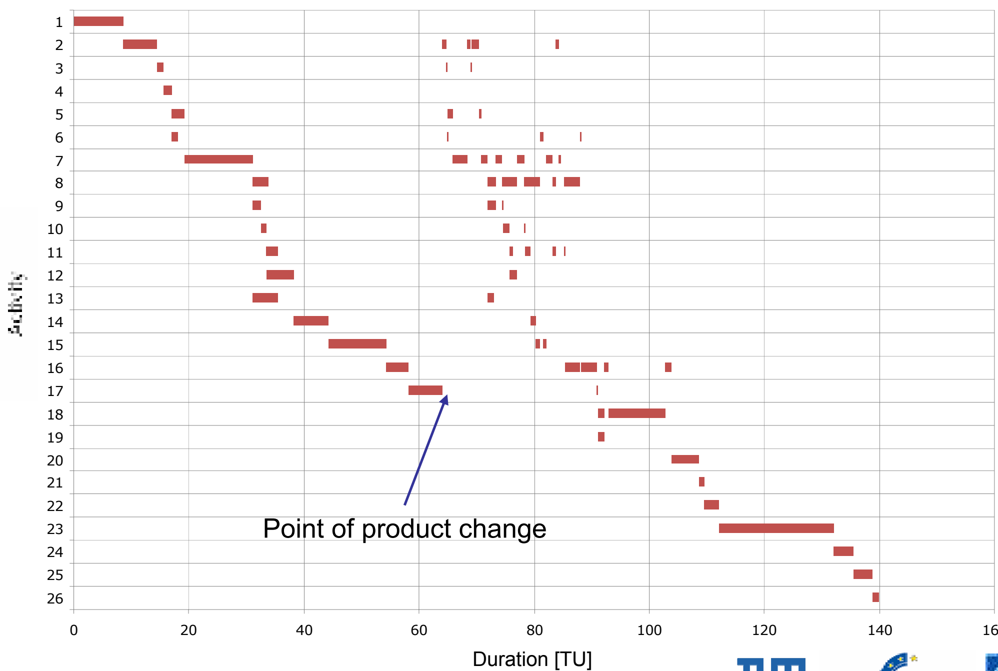
Simulation with product change: Project visualization in a Gantt-Chart



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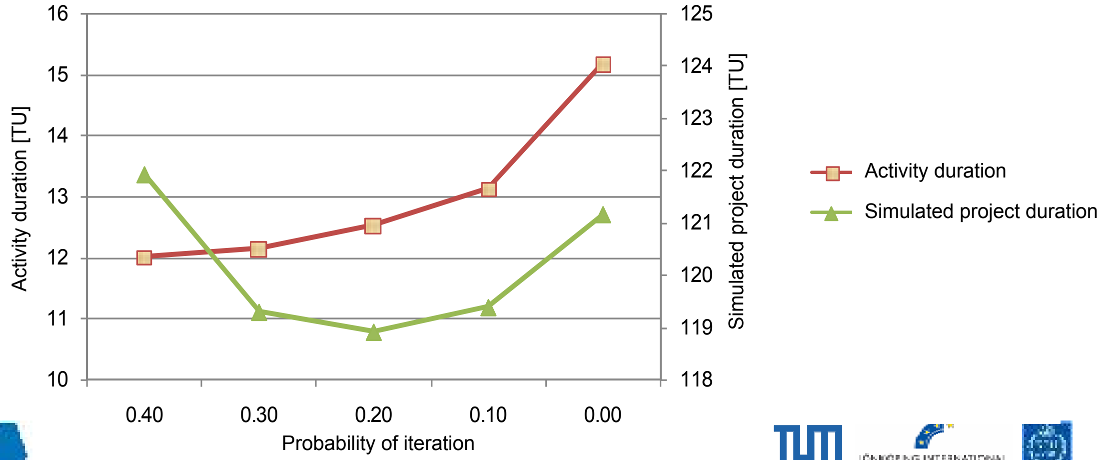
Identification of potentials for process improvement

Hypothesis: An extension of an activity's duration leads to better quality of its output (Turnquist 2003) and therefore to a decreasing probability of iterations. This can result in a reduction of the project duration.

Investigation of the iteration from “review over software design” to “software design and coding”



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Summary & Prospects

Summary:

- Iterations and product changes are the main influencing factors for unplanned extensions of projects
- Simulation model for the estimation of project duration and costs
- Using systematic parameter variation leads to a reduction of project duration
- Validation of the model by simulating various development projects

Next steps:

- Implementation of the possibility to overlap activities
- Realization of further validation studies
- Realization of the identified potentials for process optimization