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PREDICTION OF COMMUNICATION STRUCTURES BASED ON PRODUCT STRUCTURES

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ABSTRACT
Due to market pressure and increased collaborative work many companies face challenges arising from product and process complexity. The challenges include changes and iterations as well as cost and schedule overruns. Product and process of complexity are highly interlinked and can be tackled be structure-based models. It is commonly accepted that the process has to adapt to the product. Otherwise problems like quality and schedule issues arise. In this paper we test if the communication structure of a project can be predicted based on the product structure. We use the development of an electrically powered go cart as case study and derive communication and product structure independently for unbiased comparisons. We find that 86% of the communication relations can be predicted. Yet 44% of the predicted relations did not occur in the project.

Keywords: Product structure, communication structure, structural comparison

1 INTRODUCTION

Companies face challenges due to rising external complexity in engineering design. Reasons are shorter product life cycles, manifold costumer requirements, more solution options due to technological advances and combinations of products and services. Companies react by offering more products and introducing discipline-spanning collaboration. This increases internal complexity. If complexity is not managed successfully it leads to longer development times, cost overruns and wrong decisions with highly detrimental and long-term consequences. (Lindemann et al., 2009)

Product and process complexity are particularly important facets. Product and process of complexity are highly interlinked. It is commonly accepted that the process has to adapt to the product. Otherwise problems like quality and schedule issues arise. Baldwin and Clark (2000) formulated the fundamental isomorphism between product and process: Each relation among product components has to have a counterpart among process activities. Conway (1968) states, that the product architecture mimics the organization which develops the product. As process and product influence each other a misalignment between them will lead to quality, cost and performance deficits on the product side and to schedule and cost overruns on the process side.

Products and processes can be described by structural models such as matrices (e.g. DSM, DMM, MDM) and graphs (Browning, 2001). Therefore, structure-based methods are often used to describe and improve the alignment between product and process. As the process has to adapt to the product the product model is generally used to prescribe a suitable process which allows for designing a suitable organization.

In this paper we focus on the communication structure as one view onto processes which is also closely linked to the organization. We compare product and communication structures to determine if the communication structure can be predicted based on the product structure. Our hypothesis is that each link in the product structure represents a potential communication link during the project. Section 2 describes the setup of the case study, the methods for creating the structure models and the methods for comparing them. Section 3 presents the resulting structures and the comparisons. Section 4 discusses the results and section 5 gives summary and outlook.

2 METHOD

We base our research on a case study: a student project for developing an electrically powered go-kart. Eight students were supervised by four researchers. The project took half a year and covered the concept and development phases of the product life cycle. The project was thoroughly documented by development diaries, interviews, document versioning in an online repository and observation. The project and its documentation are describes in (Langer et al., 2010).

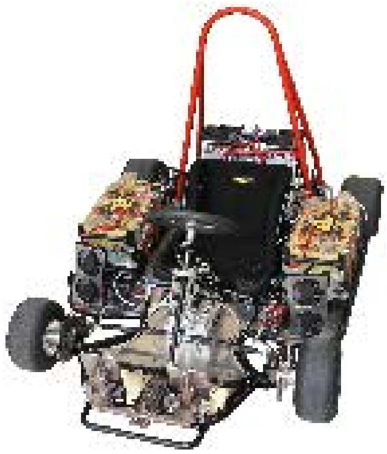

Figure 1. Case study project – development of an electrically powered go-cart

The cart comprises eleven subsystems: engine incl. recuperation (EM), cooling system (KS), wiring system and energy storage (ES), braking system (B), driver interface (FS), steering system (L), wheels and wheel mount (RR), package and integration (PI), auto body and safety (SK), sensor and electronics (SBR), and control system (R). We model both the product structure and the communication structure as DSMs of the subsystems.

2.1 Creation of the product DSMs

Three product DSMs model the geometry, energy and information relations among the major subsystems of the cart. The DSMs were modelled in interviews with the four supervisors of the project. Each interview took about half an hour. The final DSMs were cross checked by each supervisor after integrating all interview results.

2.2 Creation of the communication DSM

The communication DSM was derived from the coordination protocols of the students. They noted each coordination activity outside the regular team meetings. For each activity they documented date, partner, content and result of the activity. The protocols were checked for consistency among the involved partners. The list of interactions was later transformed into a DSM. The DSM was formed by entering a link between the partners if at least on communication occurred.

2.3 Comparison of the DSMs

For comparing the product and communication DSMs Δ-DSMs (deWeck, 2007) were computed. The relations in the product DSMs were split into two groups: relations, which go in line with at least on communication event, and relations, which go in line with no communication event. The three product DSMs were summed. The result was subtracted from the communication DSM to determine the communications links which are not covered by product relations.

3 RESULTS

3.1 The product and communication DSMs

The DSMs model the relations among the eleven subsystems of the cart. Figure 1 shows the four DSMs: product DSM (geometry), product DSM (energy), product DSM (information), and communication DSM.

The geometry DSM comprises 64 relations. The relations are symmetric apart from four relations. The asymmetry indicates potential modelling errors but can be explained by space limitations which only work in one direction. The energy DSM comprises 42 relations. The relations are symmetric apart from twelve relations. The asymmetry is due to the energy flow. The information DSM comprises 29 relations. The relations are symmetric apart from seven relations. The asymmetry is due to the information flow. The communication DSM comprises 52 relations. The relations are symmetric apart from fourteen relations. The asymmetry indicates potential modelling errors but can be explained by the communication events which only transferred data from one student to the other.

a)

	EM	KS	ES	B	RR	L	FS	PI	SK	SBR	R
EM	■	X	X		X			X	X	X	
KS	X	■	X					X	X		
ES	X	X	■	X		X	X	X	X		
B			X	■	X	X	X	X	X	X	
RR	X			X	■	X	X	X	X	X	
L			X	X	X	■	X	X		X	
FS	X		X	X		X	■	X	X	X	
PI	X	X	X	X	X	X	X	■	X	X	
SK	X	X	X					X	■		
SBR	X		X	X	X	X	X	X		■	
R											■

b)

	EM	KS	ES	B	RR	L	FS	PI	SK	SBR	R
EM	■	X	X	X	X			X	X		
KS	X	■	X								
ES	X	X	■	X		X	X	X	X		
B	X			■	X	X	X	X			
RR	X			X	■		X	X			
L				X	X	■	X	X			
FS				X		X	■	X			
PI	X	X	X	X	X	X	X	■	X		
SK									■		
SBR		X	X	X						■	
R											■

c)

	EM	KS	ES	B	RR	L	FS	PI	SK	SBR	R
EM	■	X								X	X
KS		■									
ES		X	■							X	X
B				■			X				
RR					■					X	X
L					X	■	X			X	X
FS							■			X	X
PI								■			
SK									■		
SBR	X		X	X	X	X	X			■	X
R	X		X	X	X	X	X			X	■

d)

	EM	KS	ES	B	RR	L	FS	PI	SK	SBR	R
EM	■	X	X		X	X	X	X		X	X
KS	X	■						X	X	X	
ES	X	X	■	X		X		X		X	X
B	X		X	■	X	X				X	X
RR	X			X	■					X	
L		X		X		■	X				
FS	X					X	■			X	
PI	X	X	X	X	X	X	X	■		X	X
SK		X							■		
SBR	X			X			X	X		■	
R	X			X				X		X	■

Figure 2. The four DSMs (to be read row influences column): a) product DSM (geometry), b) product DSM (energy), c) product DSM (information), and d) communication DSM

3.2 Overlapping of the DSMs

Table 1 shows the prediction statistics of each product DSM. The first column shows the number of correctly predicted links. The second column shows the number of communication links which were not predicted (false negatives). The best prediction is made by the overlapped product DSM followed by the geometry DSM. The worst prediction is made by the information DSM.

Table 1. Prediction of communication relations by product links

DSM	Communication relations with product link	Communication relations without product link
Product (geometry)	38 (73%)	14 (27%)
Product (energy)	26 (50%)	26 (50%)
Product (information)	15 (29%)	37 (71%)
Overlapped product	45 (87%)	7 (13%)

Table 2 shows the prediction statistics of each product DSM. The first column shows the number of correctly predicted links. The second column shows the number of wrongly predicted links (false positives. All DSMs have about the same proportion (ca. 45%) of wrongly predicted links.

Table 2. Relation of product relations and communication links

DSM	Product relations with communication links	Product relations without communication links
Product (geometry)	38 (59%)	26 (41%)
Product (energy)	26 (62%)	16 (38%)
Product (information)	15 (52%)	14 (48%)
Overlapped product	45 (56%)	36 (44%)

4 DISCUSSION

The validity of our results depends on the quality of the DSM models. The product DSMs were created in interviews and later cross-checked by the project supervisors. Therefore we assume their quality to be high. A better creation approach might have been a workshop with all supervisors to facilitate discussions and clarifications among them. The communication DSM has following drawbacks:

- Incompleteness by the approach: Several communication events are not modelled. Especially, the contents of the team meetings have not been considered. The false positive communications may have occurred during the meetings.
- Incompleteness during data creation: The student may not have documented all communications. One indicator supporting this is that most events have only been documented by one of the partners.

Thus, the conclusions must be confirmed by future research. Nevertheless we believe to gain valuable insights from our observations. We draw following conclusions from the results in section 3:

- Product DSMs are capable of predicting the communication DSM. We conjecture that this conclusion can be extended to product and communication structures in general.
- Overlapping multiple product views increases the predictive capabilities of the product DSMs. For future applications a trade-off between predictive capability and effort of modelling has to be done.
- The geometry DSM has the better predictive capabilities then the energy DSM, which in turn is better than the information DSM. The geometry relations can be used as base data for predicting communication links.
- Predictions on each view produce the same percentage of false positives.

5 SUMMARY AND OUTLOOK

This paper shows that the communication structure of a development project can be predicted by the product structure. We show the case study of the development of an electrically powered go cart. While the product DSM is of high quality some problems arise from the creation of the communication DSM. Nevertheless we show that our hypothesis holds. The predictive capability increases when the product DSM integrates additional views. The percentage of false positives is independent of the system view.

Based on the available data additional researches are possible:

- Determination of the correlation between structural properties of the product DSM and the occurrence of communication.
- Determination of the correlation between structural properties of the product DSM and the frequency of communication.

Future research will address following points:

- Confirmation of the findings in similar projects.
- Reduction of the number of false positives.

- Identification and integration of additional product views to increase the number of correct predictions (i.e. to decrease the number of false negatives).
- Extension of the prediction to the frequency of communications.

ACKNOWLEDGEMENTS

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INVEST ON VISUALIZATION

Prediction of Communication Structures Based on Product Structures

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INVEST ON VISUALIZATION

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- Interaction of product and communication structures
- Development of an electrically-powered Go-kart
- Observations and Findings
- Conclusion and Outlook

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Initial Situation and Problem

- **Situation**
  - Market pressure and collaborative work leads to rising product and process complexity
  - Not managed complexity leads to longer development times, cost overruns and wrong decisions with long-term consequences.
- **Problem**
  - Fundamental isomorphism (Baldwin & Clark, 2000): Each relation among product components has to have a counterpart in the process
  - Conway's law (Conway, 1968): the product architecture mimics the organization which develops the product
- **Hypotheses**
  - Each link in the product structure represents a potential communication link during the project
  - Models of the product structure can be used to predict the communication structure

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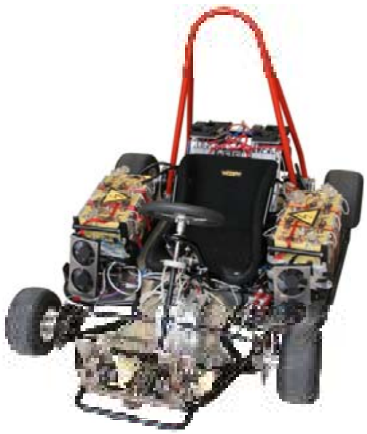
Method and Case Study

- **Case study: development of a electrically powered gokart**
  - 8 students
  - 4 supervisors
  - 11 major subsytems



- **Modeling of the product structure as DSM**
  - Three perspectives: geometry, energy and information
  - Data acquisition by interviewing the supervisors
- **Modeling of the communication structure as DSM**
  - Data acquisition in development diaries of the students
  - Model creation by parsing the diaries
- **Comparison of the structures**
  - Application of Δ-DSM

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Product and Communication DSMs

product DSM (geometry)

	EM	KS	ES	B	RR	L	FS	PI	SK	SBR	R
EM	■	X	X		X			X	X	X	
KS	X	■	X					X	X		
ES	X	X	■	X		X	X	X	X		
B			X	■	X	X	X	X	X	X	
RR	X			X	■	X	X	X	X	X	
L			X	X	X	■	X	X		X	
FS	X		X	X		X	■	X	X	X	
PI	X	X	X	X	X	X	X	■	X	X	
SK	X	X	X					X	■		
SBR	X		X	X	X	X	X	X		■	
R											■

a)

product DSM (energy)

	EM	KS	ES	B	RR	L	FS	PI	SK	SBR	R
EM	■	X	X	X	X			X	X		
KS	X	■	X								
ES	X	X	■	X		X	X	X	X		
B	X			■	X	X	X	X			
RR	X			X	■		X	X			
L				X	X	■	X	X			
FS				X		X	■	X			
PI	X	X	X	X	X	X	X	■	X		
SK									■		
SBR		X	X	X						■	
R											■

b)

product DSM (information)

	EM	KS	ES	B	RR	L	FS	PI	SK	SBR	R
EM	■	X								X	X
KS		■									
ES		X	■							X	X
B				■			X				
RR					■					X	X
L					X	■	X			X	X
FS							■			X	X
PI								■			
SK									■		
SBR	X		X	X	X	X	X			■	X
R	X		X	X	X	X	X			X	■

c)

communication DSM

	EM	KS	ES	B	RR	L	FS	PI	SK	SBR	R
EM	■	X	X		X	X	X	X		X	X
KS	X	■						X	X	X	
ES	X	X	■	X		X		X		X	X
B	X		X	■	X	X				X	X
RR	X			X	■					X	
L		X		X		■	X				
FS	X					X	■			X	
PI	X	X	X	X	X	X	X	■		X	X
SK		X							■		
SBR	X			X			X	X		■	
R	X			X				X		X	■

d)

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Comparison of the Product and Communication DSM

Prediction of communication relations by product links

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Relation of product relations and communication links

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Quality of the Communication DSM

- **Incompleteness by the approach:**
  - Several communication events are not modeled
  - Especially, the contents of the team meetings have not been considered
  - The meetings of the students and the supervisors have not been considered
  - The false positive communications may have occurred during the meetings

- **Incompleteness during data creation:**
  - The student may not have documented all communications
  - One indicator supporting this is that most events have only been documented by one of the partners.

Findings

- Product DSMs are capable of predicting the communication DSM
  → Conjecture: this applies to any product and communication structures

- Overlapping multiple product views increases the predictive capabilities of the product DSMs
  → For future applications a trade-off between predictive capability and effort of modeling has to be done.

- The geometry DSM has better predictive capabilities then the energy DSM, which in turn is better than the information DSM.
  → The geometry relations can be used as base data for predicting communication links.

- Predictions by each view produce the same percentage of false positives.
  → This indicates that our approach has some systematic error in it.

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Future Work

- **Based on the available data additional researches are possible:**
  - Determination of the correlation between structural properties of the product DSM and the occurrence of communication.
  - Determination of the correlation between structural properties of the product DSM and the frequency of communication.

- **Future research will address following points:**
  - Confirmation of the findings in similar projects.
  - Reduction of the number of false positives.
  - Identification and integration of additional product views to increase the number of correct predictions (i.e. to decrease the number of false negatives).
  - Extension of the prediction to the frequency of communications.