PREDICTING INDIRECT PROCESS COSTS OF ENGINEERING CHANGE BASED ON A TASK CHARACTERISTIC PERSPECTIVE

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Abstract

Today companies are capable to make precise predictions of engineering change costs incurred in producing departments. But implementing engineering changes is a work-sharing task. Besides production and assembly also non-producing departments are involved in engineering change management (ECM) processes. Activities performed in those departments lead to indirect process costs of engineering change (IPC). These costs result from planning, coordinating and supervising activities in ECM-processes and make up a huge share of total project costs. Today, there are no valid methods for estimating IPC. In practice, IPC are predominantly estimated on the basis of overhead rates. However, this does not lead to satisfying results. Hence, there is no transparency regarding IPC and IPC are frequently not considered in project calculations which may result in inadequate pricing decisions. In this connection particular attention must be paid to IPC. Therefore, we develop a model for predicting IPC in order to improve information and support managerial decisions.

Keywords: Decision making, Evaluation, Project management

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1 INTRODUCTION

The reasons for implementing engineering changes are various. In the automotive industry new technologies, changed regulations, modified customer needs or product defects force OEM to decide about engineering changes (VDA, 2010). Changes on OEM-level also affect suppliers in kind of further engineering changes resulting from changed specification or design needs of purchased items, parts, components or modules. In the customer-driven automotive industry, engineering changes cannot be avoided entirely (Hamraz and Clarkson, 2015). For suppliers “OEM-induced” engineering changes become a key competitive factor. They allow suppliers to meet the changing OEM-requirements and outperform rivals. Suppliers can only stay competitive in the market place if they are capable to follow new model introductions and product variety on OEM-level (Reddi and Moon, 2011; He et al., 2014). But there are substantial risks that have to be taken into account. Especially implementing unprofitable engineering changes is a major concern in practice. In this connection, numerous empirical studies indicate that engineering changes represents a significant cost factor (e.g. Ahmad et al., 2009; Jarrat et al., 2005) and that a lot of customer orders fail to be profitable (Wiltinger, 2011). E.g. the Automotive Industry Action Group reported “[…] for the North American automotive industry in total 350,000 ECs per year along with a processing cost (excluding materials and tools) of up to USD 50,000 per EC […]” (Hamraz and Clarkson, 2015, p. 25). Avoidance of unprofitable projects requires adequate pricing which again requires information about all costs incurred by project implementation. That information need to be available at early project stages. This in turn makes the prediction challenging. In early stages, just some of the cost relevant information are available. Detailed information (e.g. completely specified products, working plans, project structures) are usually not available. Nevertheless, precise predictions must be ensured. The reasons why that is important are shown in Figure 1. If the predicted costs are lower than the actual costs, the pursued profitability margin gets cut. This may even lead to unprofitable projects. On the other hand, higher predicted costs may lead to prices that are not competitive.

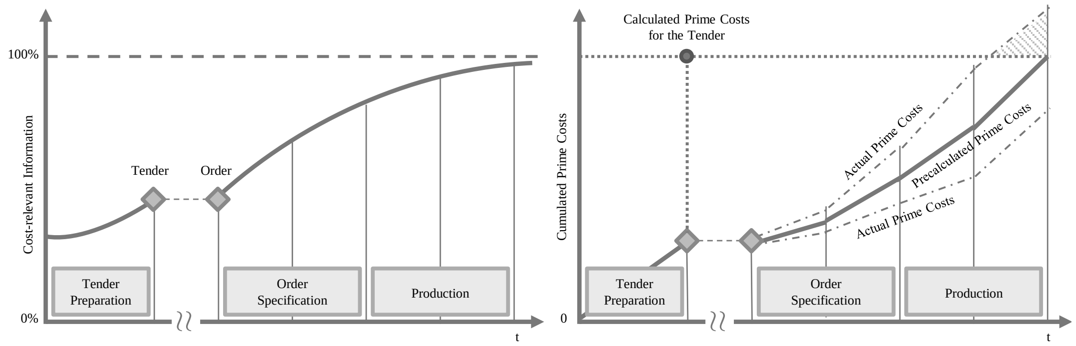

Figure 1. Change Cost Calculation

Today companies are capable to make precise predictions of all costs incurred in producing departments. But implementing engineering changes is a work-sharing task. Besides production and assembly also non-producing departments are involved in engineering change management (ECM) processes (Koh et al., 2012). Activities performed in these departments for implementing engineering changes lead to indirect process costs of engineering change (IPC). These costs result from planning, coordinating and supervising activities in ECM-processes and make up a huge share of total project costs (Becker et al., 2014). Today there are no valid methods for predicting IPC. In practice, IPC are predominantly estimated on the basis of overhead rates. However, this does not lead to satisfying results. Thus, attention must be paid to the prediction of IPC. Our research question asks:

How should a predictive model for ex-ante quantifying IPC be constituted?

Additionally, the following sub-questions can be derived:

- What are the causal factors of IPC?
- How should a causal predictive model for estimation of IPC be constituted?
- Which recommendation for predicting IPC can be derived for practice?

2 PRIMARY RESEARCH METHOD

For achieving the research objectives we follow a research process covering eight steps shown in Figure 2 (Shmueli/Koppius, 2011). In this connection we assume that prediction and explanation are explicitly equated according to the hypothetico-deductive model.
The research project is still in progress. **Goal of this conceptual paper is to give insights in the theoretical explanatory model which builds the base of the predictive model.**

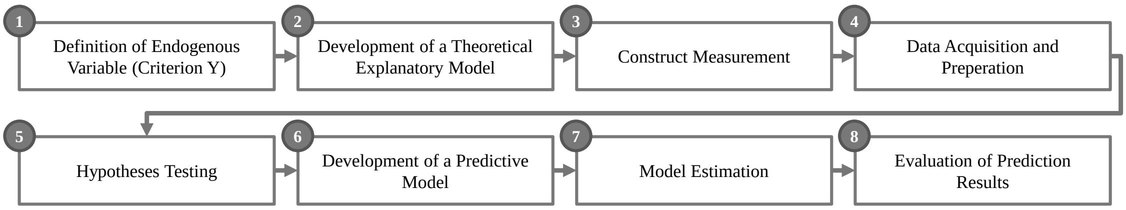

Figure 2. Research Process

2.1 Step 1: Definition of Endogenous Variable

The first step requires the definition of IPC as endogenous variable. IPC is defined as costs caused by activities performed in non-producing departments for implementing an engineering change project. We measure IPC based on department-specific activities that have to be executed in an ECM process to execute the department-specific tasks resulting from the engineering change project. Based on that, IPC of an engineering change s is the sum of the product of time spent t for executing necessary activities h contributing to task-execution in an ECM-involved non-producing department j and the appropriate cost rate c of the activity-executing employee e. The process-oriented measurement allows a comprehensible deduction of IPC resulting from additional activities caused by the implementation of an engineering change in the involved non-producing departments.

2.2 Step 2: Development of a Theoretical Explanatory Model

The second step requires the development of a theoretical model for explaining IPC. Theoretical foundation of the explanatory model is based on three major steps: Development of a Superordinate Theoretical Framework; Analysis of the Theoretical Base; Model Synthesis.

Development of a Superordinate Theoretical Framework:

The superordinate theoretical framework is based on contingency theory. Contingency theory claims that there is no best way to organize a company. Organizations' efficiency rather depends on a best possible fit of situational factors and formal organizational structure (Mintzberg, 1979). Based on that, contingency theory assumes that an organizations' situation determines the efficiency of an organization. If we assume the organizational structure to be constant, the situation of an organization influences organizations' efficiency directly as well as indirectly by influencing organizations' members' behavior which determines efficiency (Figure 3). The transfer of this basic idea on our study requires the development of study-specific conceptualizations of the constructs.

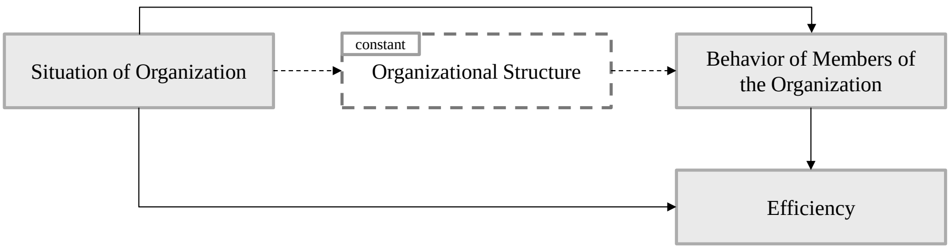

Figure 3. Contingency Theory

Starting with the construct "situation" we constitute that an organization's situation is determined by the tasks that it has to perform. Here we follow Perrow who points out that „ […] the work done in organizations, is considered the defining characteristic of organizations" (Perrow, 1967, p. 194). It is the task that determines the „ […] actions that an individual performs upon an object […] in order to make

some change in that object"(Perrow, 1967, p. 195). Following a task-related definition of engineering change projects we assume that the engineering change project (as superordinate task) c.p. determines the organizations' situation and directly as well as indirectly influences the organizations' efficiency.
The indirect effect on organizations' efficiency results from the influence of organizations' members' behaviour which themselves influence efficiency. For the indirect effect, we assume that a direct relation between the engineering change project and the behaviour of organizations' members is supposed to be no adequate representation of reality. The engineering change project as superordinate task has a collective character rather affecting overall organization-level than individual-level. Thus, we assume that organizations' members' behaviour is actually influenced by the sub-tasks resulting from the project as superordinate task and occurring in the different ECM-involved departments. Thus, the situation organizations' members face in their real working day is determined by department-specific sub-tasks. These actually influence behaviour and finally efficiency.
To model this relation of "project–sub-task– behaviour –efficiency" we use the concept of macro-micro-macro-modelling (e.g. Coleman, 1990). Basic idea is that collective variables cannot be explained solely on macro-level. An explanation requires an additional recourse on micro-levels, i.e. individual behaviour -level. The following Figure 4 shows the basic concept. Instead of explaining an endogenous variable only on macro-level the concept of macro-micro-macro-modelling prefers explanations by additionally considering the effect of exogenous variables on macro-level on the situation and finally the behaviour of individuals on micro-level. Thus, macro-micro-macro-modelling requires a hypothesis that links the exogenous variable on macro-level with that on micro-level.

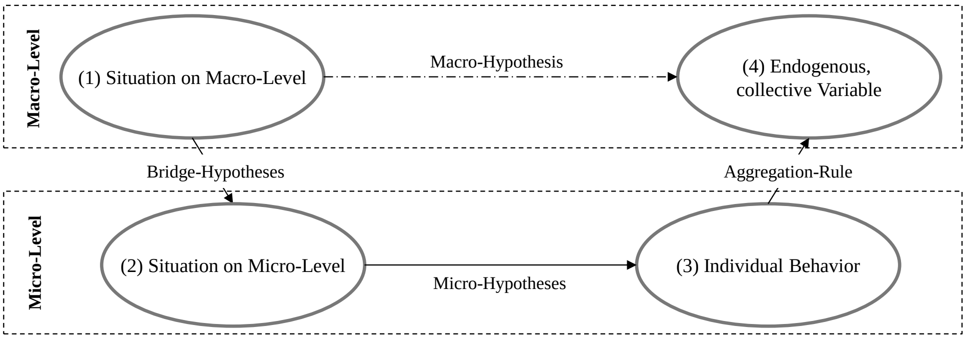

Figure 4. Macro-Micro-Macro-Model

Transferred to our study we understand the engineering change project as collective phenomenon affecting the entire organization (macro-level). The efficiency also refers to the entire organization and is seen as collective variable. As discussed above, we assume that a direct relation between the engineering change project as superordinate task on macro-level and the individual behaviour offers no satisfying representation of reality. Thus, we assume that department-specific sub-tasks (resulting from the superordinate task) determine organizations' situation and thus influence employees' behaviour.
If we take a closer look at the construct "behaviour of organizations' members" we first understand that organizations' members are seen as those employees in ECM-involved departments performing actions upon an engineering change project and therefore contribute to fulfil the superordinate task. behaviour is understood as the effort expenditure mobilized by an employee to fulfil the department-specific sub-task. The magnitude of effort expenditure is measured as time spent for task-execution. This is a common measurement for effort used in relevant empirical studies (e.g. Locke and Latham, 1990). Time spent is an empirically observable reflection of effort. All other reflections, e.g. cognitive or physical effort, are not considered. Thus, the conceptualization of organizations' members' behaviour is directly linked to the measurement of IPC. Time spent can be transferred in costs easily by multiplying time with personnel cost rates.
Finally, we have to conceptualize the construct "organizations' efficiency". Organizations' efficiency is conceptualized as IPC caused by implementing an engineering change. Based on the conceptualizations we derive the following working hypotheses: Under the assumption of constant organizational structures the engineering change project as superordinate task determines organizations' efficiency directly as well as indirectly by determining the situation on department-level and influencing time spent by employees to fulfil department-specific sub-tasks. While the behaviour of the employees is conceptualized as time spent for task-execution which can be directly transferred into IPC (with

appropriate cost rates) we can derive the following simplified working hypothesis: Under the assumption of constant organizational structures the engineering change project as superordinate task determines IPC directly as well as indirectly by determining the situation on department-level (Figure 5).

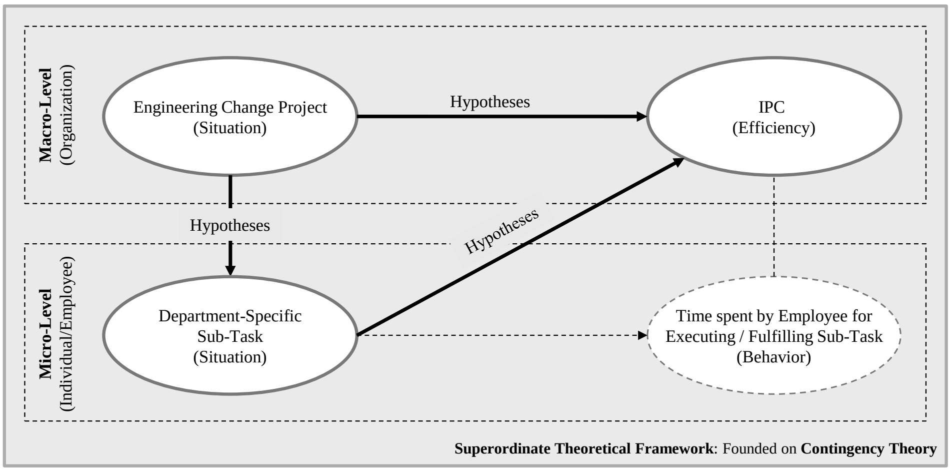

Figure 5. Superordinate Theoretical Framework

Formally explanations of the relations postulated by the superordinate theoretical framework requires appropriate theories. Based on five appraisal factors we have identified the following theories (theoretical base) used as foundation for the research hypotheses: Organizational Information Processing Theory and Attributional Theory of Achievement Motivation.

Analysis of Theoretical Base:

First, we discuss **organizational information processing theory (OIPT)** and its implications for the explanatory model. OIPT has its origins in contingency theory (Galbraith, 1974). OIPT have been frequently used and tested in literature concerning R&D / NPD-project-performance (e.g. Langerak et al., 2008). While R&D- resp. NPD-projects and engineering change projects are quite similar, OIPT and the findings presented in literature are also applicable for this study. OIPTs' basic assumption is that organizations' efficiency depends on a fit between information processing requirement of a task and information processing capability of an organization (Galbraith, 1974). Based on the task-related understanding of engineering change projects in this study we constitute that efficiency depends on a fit between information processing requirement of an engineering change project and information processing capability of the organization. Misfits between information required and information processed lead to reductions in efficiency. While we assume organizations' information processing capability to be constant, information processing requirement of an engineering change project is hypothesized to influence efficiency. Greater information processing requirement have a negative impact on efficiency. Thereby, efficiency is conceptualized as IPC caused by implementing an engineering change. For this study, we assume that project complexity and project novelty determine information processing requirements of an engineering change project (Ahmad et al., 2013). "[…] the greater the […] [novelty] and complexity, the greater the amount of information that must be processed among decision makers during project execution in order to achieve a given level of performance" (Ahmad et al., 2013, p. 336). Literature presents a strong theoretical foundation for this relation. Based on that, we postulate the following macro-hypotheses: The higher the complexity (or the novelty) of an engineering change project, the higher IPC caused by implementing that project.

This is beside others founded on the idea that ECM-involved departments encounter greater task difficulty and take more time for task-execution with a higher degree of complexity and novelty (Griffin, 2002). Thus, we have an additional explanation for the relation between project complexity and novelty and sub-tasks. Since greater information processing requirements of a task makes that task more difficult it can be stated that an increase in project complexity or project novelty lead to an increase in task difficulty. Both, a higher level of complexity and novelty increase difficulty of department-specific sub-tasks. This is assumed to be true for all ECM-involved departments. Since that we hypothesize: The greater the complexity or novelty of an engineering change project, the greater the difficulty of the department-specific sub-tasks in the ECM-involved departments (Figure 6).

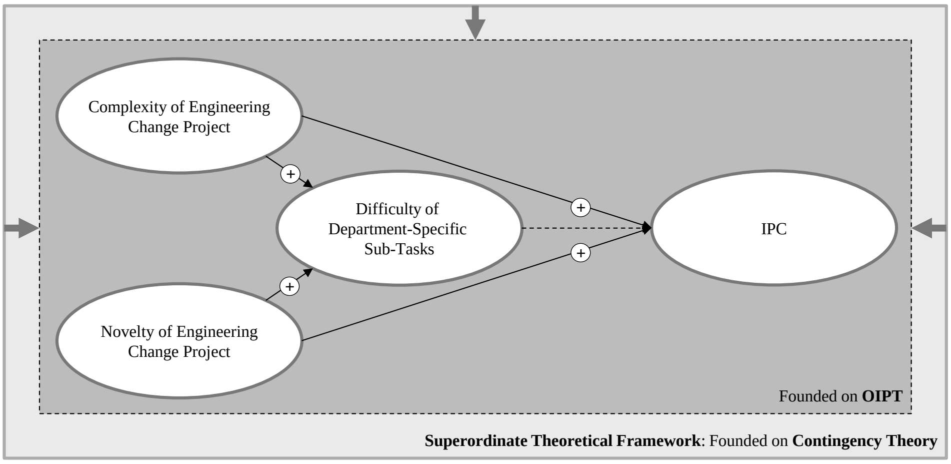

Figure 6. Postulated Relations

Second, we discuss **attributional theory of achievement motivation (ATL)** and its implications. In general, attributional theories try to explain the effects of attributions on behaviour and outcomes. Thereby attribution is a causal explanation of a specific behaviour or outcome (Weiner, 1986). One major filed of research in attributional research addresses achievement motivation. Here, researchers study behaviour aiming at successful task-execution while achieving the required quality standards of action results ("[…] achievement goal […] success […] with some standard of excellence"(McCllelland et al., 1953, p. 110)). One of the most important attributional theories focusing on achievement motivation and performance driven behaviour is Weiner's attributional theory (Weiner et al., 1971). This theory is fundamentally based on Heider's naïve psychology theory which was the first to propose a psychological theory of attribution (Heider, 1958). Heider argues that all people are naïve scientists having a desire to understand the causes of behaviour. Based on that Heider constitutes that people attribute behaviour and outcomes to the following causal factors: competence / professional skill of an individual, task difficulty, effort an individual mobilizes and random factors (Heider, 1958). Furthermore, Heider describes that if a task is successfully executed / fulfilled the magnitude of (actual) effort expenditure which was necessary for task-execution can be explained by equation (2) if the causal factors are known and the influence of random factors approach zero:

$$Effort = \frac{Task\,Difficulty}{Personal Skills} \tag{1}$$

Thus, given that skills and effort have a compensational relationship, people with low skills need to mobilize more effort to execute a task than people with high ability. This relation has been discussed and advanced several times. Especially the work done by Kukla (Kukla, 1972) and Brehm (e.g. Brehm and Self, 1989) are of superior importance. Both approaches constitute, that effort is proportionally mobilized to the extent of task difficulty. But if task difficulty is so high that goal attainment seems to be impossible, no more effort will be mobilized and the person will quit task-execution. While Heider was the first to propose a theory of attribution, Weiner (e.g. Weiner et al., 1971) developed a theoretical framework especially for performance driven behaviour. For that purpose, they picked up Heider's basic ideas. Weiner did not identify additional causal factors. His contribution is that he classified Heider's causal factors on the basis of the dimensions of locus of causality and stability (Figure 7) (Weiner, 1986).

		Locus of Causality	
		Internal	External
Stability	Stable	**Personal Skills**	**Task Difficulty**
	Variable	**Effort Expenditure**	**Random Factors**

Figure 7. Assumptions of ATL

This classification is important in kinds of predicting behaviour and outcome. Especially stable causes allow good predictions under given assumptions. Based on the postulated relation in the equation effort expenditure (time spent) can be explained on the basis of skills and task difficulty if a task is successfully fulfilled. For that purpose, we use the following assumptions: influence of random causes approach zero; employees see personal skills as well as task difficulty as stable causal factors (Weiner et al., 1971); tasks are not too difficult and therefore goal attainment is always possible; there is no need to quit task-execution; required quality standards of action results is always achieved. If we assume that skills are constant, we can postulate the relation: The more difficult a department-specific sub-task, the higher the time spent by the task-executing employee to fulfil that task. Because time spent can be transferred in IPC by multiplying time spent with cost rates of the task-executing employees, we constitute: The more difficult a department-specific sub-task, the higher IPC caused in that department (Figure 8).

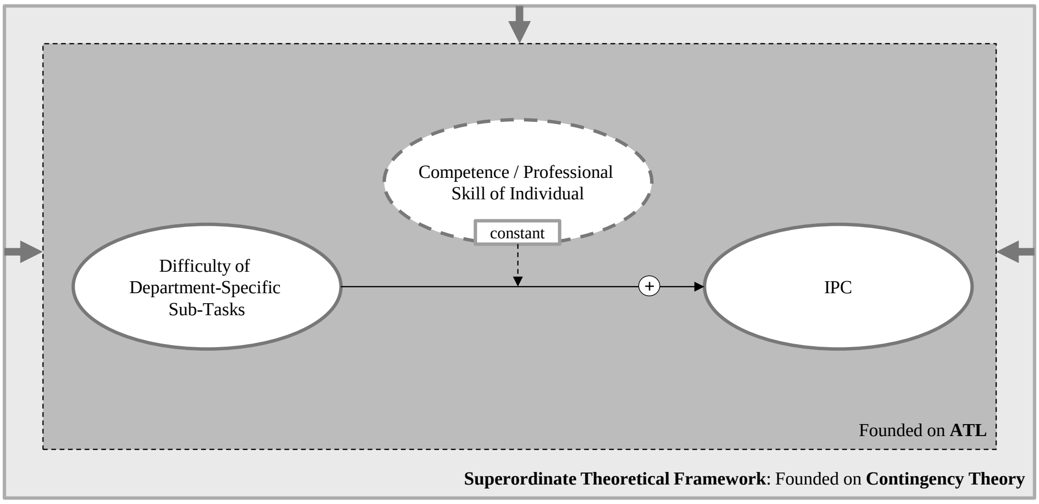

Figure 8. Postulated Relations

Model Synthesis:

Based on the theoretical discussions we derive the following hypotheses (Figure 9):

- **H1a**: The higher the complexity of the engineering change project (PRO COM), the higher IPC.
- **H1b**: The higher the newness / novelty of the engineering change project (PRO NEW), the higher IPC.
- **H2a,j**: The higher the complexity of the engineering change project (PRO COM), the higher the difficulty of the department-specific sub-task in a ECM-involved department j (TASK DIFFj).
- **H2b,j**: The higher the novelty of the engineering change project (PRO NEW), the higher the difficulty of the department-specific sub-task in a ECM-involved department j (TASK DIFFj).
  H3,j: The higher the difficulty of the department-specific sub-task in a ECM-involved department j (TASK DIFFj), the higher IPC.

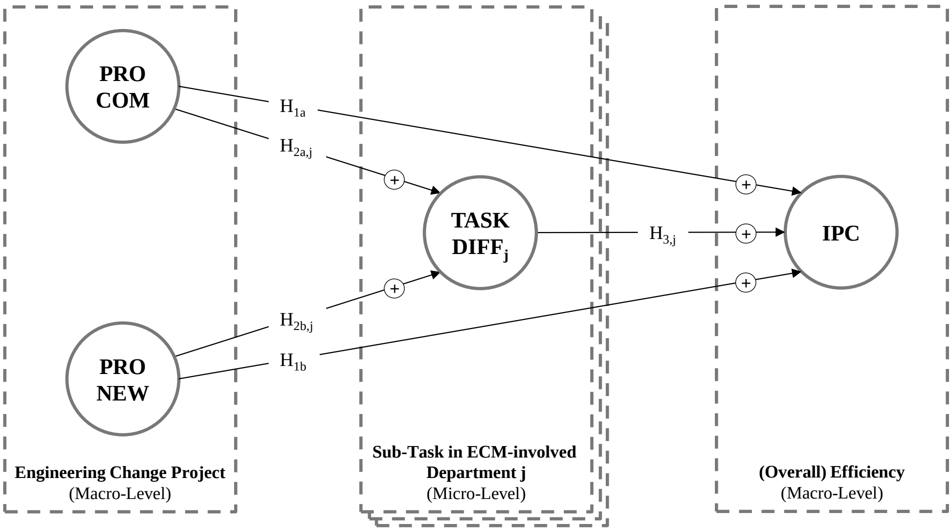

Figure 9. Research Model

2.3 Step 3: Construct Measurement

In step three formative measurement models for the exogenous variables are developed. Here we follow a procedure involving four major steps (see MacKenzie et al., 2011): develop a conceptual definition of the construct, generate items to represent the construct, assess the content validity of the items and formally specify the measurement model. The measurement of the construct PRO COM is exemplarily summarized in the following Figure 10.

Complexity of a Engineering Change Project (*PRO COM*)				**Formative Measurement**
Definition: A complex engineering change project is one with many, interdependant project elements.				
Item		**Score**	**Scale**	**Source**
pro com_1	Number of inhouse produced parts in the change object	ℕ = {0; 1; 2; …}	Metric	Novak and Eppinger, 2001, Swink, 2003, Lebcir, 2011, Puddicombe, 2012
pro com_2	Number of purchased parts in the change object	ℕ = {0; 1; 2; …}	Metric	Novak and Eppinger, 2001, Swink, 2003, Lebcir, 2011, Puddicombe, 2012,
pro com_3	Number of assembly groups in the change object	ℕ = {0; 1; 2; …}	Metric	Expert-Based
pro com_4	Number of physical interfaces in the change object	ℕ = {0; 1; 2; …}	Metric	Expert-Based
pro com_5	Number of product functions in the change object	ℕ = {0; 1; 2; …}	Metric	Griffin, 1997, Williams, 1999, Kim and Wilemon, 2003, Geraldi and Adlbrecht, 2007
pro com_6	Number of internal departments involved in the engineering change project	ℕ = {0; 1; 2; …}	Metric	Baccarini, 1996, Williams, 1999, Green, 2004, Swink et al., 2006, Geraldi and Adlbrecht, 2007, Qureshi, 2015
pro com_7	Number of external partners involved in the engineering change project (e.g. supplier, engineering service provider)	ℕ = {0; 1; 2; …}	Metric	Geraldi and Adlbrecht, 2007, Müller and Turner, 2007, Maylor et al., 2008, Vidal and Marle, 2008
pro com_8	Number of hierarchical levels in the engineering change project	ℕ = {0; 1; 2; …}	Metric	Baccarini, 1996, Williams, 1999, Green, 2004, Qureshi, 2015

Figure 10. PRO COM Measurement

2.4 Step 4: Data Acquisition and Preparation

In a fourth step, real data for IPC as well as for the exogenous variables is collected in cooperation with an automotive supplier company. The company is a global leader in driveline and powertrain technology. We consider engineering changes using the example of transmission systems as one important product group of the company.

Some of the necessary data for the constructs is available in the company-internal change management database and the ERP-system. IPC is not directly available and is collected via a web-based documentation tool. The tool allows involved employees to document their working hours spent for performing ECM-activities.

After data collection, the sample is split into two disjunctive sub-samples – a training-sample and a test-sample. The training-sample is used for model testing and parameter estimation. The test-sample is used for evaluation of predictive accuracy (out-of-sample error).

2.5 Step 5: Hypotheses Testing

Step five includes hypotheses testing based on the training-sample. For this purpose as well as for model estimation we use partial least squares (PLS) path modelling. PLS is especially useful if the objective is prediction (e.g. Sharma et al., 2015). The model estimated from the sample is supposed to provide accurate predictions for new records from that population.

2.6 Step 6: Development of a Predictive Model

The empirically tested model (using the training-sample) build the base of the predictive model. This is because we understand that prediction and explanation are explicitly equated. We have to take further assumptions into account to use the tested hypotheses as base for the predictive model. First, we have to proof whether data for the exogenous variables is available at the time of prediction or whether the exogenous variables need a prediction for their part. The latter is problematic because it may cause an infinite prediction regress. Second, we assume that the system of causation observed in historical data will not change in future (time stability). Thus, we assume that the relations observed in the explanatory period are also true for the prediction period.

2.7 Step 7: Model Estimation

In step seven we estimate the parameters of the before developed predictive model. For this purpose, we use PLS. This is based on a pervasive belief in literature that PLS has some advantages when the goal is prediction based on empirical data (e.g. Henseler et al., 2009). The result is a predictive function resp. equation which allows the prediction of IPC based on ex-ante available exogenous variables.

2.8 Step 8: Evaluation of Prediction Results

In the eighth step, we use data of the test-sample to evaluate the predictive accuracy of the predictive function. The data of the test-sample represent unseen and quasi-future data which can be used for evaluating predictive accuracy (out-of-sample error). The developed predictive function is compared to alternative prediction methods to derive inferences about the suitability for predictive generalization compared to rivals. The following alternative prediction methods are considered:

- Nearest Neighbour-Approaches: Cost estimation based on historical IPC of a documented similar engineering change project in the training-sample.
- Mean Value-Approaches: Cost estimation using the arithmetic average (median) of IPC in the training-sample.
- Expert-Based Estimation: Cost estimation based on expert ratings.

Root means squared error (RMSE) is used as error measure. The most suitable prediction approach can be identified based on a comparison of the method-specific RMSE.

3 THEORETICAL AND PRACTICAL CONTRIBUTION

Our research results support cost accounting of engineering change costs. This is based on three kinds of practical recommendations that help companies to improve information about IPC and to make reliable predictions:

- Methodical recommendations for predicting IPC: Based on the evaluation results and the comparison one can identify the best-performing prediction approach. First results show that the predictive model can generate good prediction results.
- Recommendations for integrating prediction in ECM process and acquiring relevant data.
- Recommendations for integrating predicted IPC in project calculations.

The recommendations will help companies to create transparency of costs incurred by engineering changes and to improve managerial decisions. Furthermore, this study contributes to research on financial evaluation of engineering changes by focusing on IPC and their influencing factors.

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