PROCESS TYPES AND VALUE CONFIGURATION IN MODELLING PRACTICE – AN EMPIRICAL STUDY OF MODELLING IN DESIGN AND SERVICE

Sommer, Anita Friis (1); Maier, Jakob (1); Mak, Jonathan (1); Moullec, Marie-Lise (1); Cassidy, Stephen (2); Clarkson, P. John (1)
1: University of Cambridge, United Kingdom; 2: BT Research Labs, United Kingdom

Abstract

The development of models, especially simulation models of both products and processes, has increased in industry and now offer substantial competitive advantages in decision support across many fields. Even so, little is known about the structures of applied modelling processes as the focus so far has primarily been on improving modelling tools and software, methodologies, and modelling outcomes. In this paper, we gain insights into the value creation activities in modelling practice through the analysis of activity structures from 12 different modelling processes across two large UK companies. The results show that modelling process structures can be divided into three distinct process types; ad-hoc modelling for decision support, new model development, and model change management. Existing research mainly considers new model development and therefore it is suggested that the other two types are also part of modelling practice, and therefore should be included in modelling process management. The process types are categorized from a modelling management perspective and a tentative modelling process management toolbox is suggested for further research.

Keywords: Simulation, Process modelling, Design process, Model development, Toolbox

Contact:
Dr. Anita Friis Sommer
University of Cambridge
United Kingdom
afs35@cam.ac.uk

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

The ability to model and simulate products and processes for decision support has during the last decade evolved from a being considered a future business potential to a real lever of competitive advantage across industries. Capable modellers are increasingly sought after in design practice to increase efficiency especially in two domains; product design (Aromaa et al. 2013) and process management (Schabacker et al. 2013). Hence, modelling in this empirical study is concerned with computer-aided development of virtual products and process models ranging in complexity from simple linear regression models to complex systems simulations. Modelling is, like other types of design, governed by several methodologies and standards (Eisenbart et al. 2011). Even though modelling research is rich in the application of modelling, there has been limited research on modelling methodology and the capture of the modelling processes (Tako 2014). This is despite the fact that understanding the modelling process itself is known to be highly relevant for improving existing modelling practice (Pidd 1999). Therefore, this paper focuses on exploring the modelling process itself, i.e. the network of activities leading to the development of a model and the relation between these activities. In current research on product development processes, a range of process configurations is identified ranging from sequential activity relations, through iterative processes towards chaotic-like structures (Buijs 2003). The appropriate choice of process model depends on the configuration of the process (Browning and Ramasesh 2007), and thus the modelling process model should be adapted to the process configuration. Therefore, it is relevant to explore the configuration of modelling processes to identify the types or the range of process configurations to support the choice of process model for managing the modelling process.

The paper is structured as follows. In section two, relevant research on modelling processes is introduced with an emphasis on structure in the modelling process. Section three describes the applied empirical methodology, and section four provides an overview of the study results. Finally, section five and six respectively contains a discussion and conclusion on the empirical findings and research proposals.

2 MODELLING PROCESS MODELS AND ACTIVITY STRUCTURES

Several modelling process models and methods have been proposed as prescriptive best practice (Law et al. 1991, Nance 1994, Robinson 2004, Albers et al. 2013, Schabacker et al. 2013, Subrahmanian et al. 1997). These include amongst others thorough descriptions of content in proposed major modelling activities (Eisenbart et al. 2011), practical advice to modellers (Pidd 1999), and detailed descriptions of model verification and validation (Sargent 2013). Hence, there are several suggestions for good modelling practice and methodologies. There are, however, only a small number of research studies describing modelling processes from existing modelling practice which include in-depth understanding of modelling processes (Tako 2014) and exploration of current modelling trends (Cameron and Ingram 2008). A key case study was conducted by Foss et al. (1998) to understand modellers, modelling activities, and to identify the process activity structures. The authors interviewed 15 modellers in the chemical process industry across different modelling types to derive a common process structure and a set of standard modelling activities. Ultimately, however, they could not reach one unified consensus across the interview results, and instead proposed a list of optional tasks that modellers alternate between during development. The list of main tasks includes; problem statement and initial data collection, modelling environment selection, conceptual modelling, model representation, implementation, verification, initiation, validation, documentation, and model application. The authors seemingly did not attempt to derive or categorize different process types, which may or may not have influenced their results. Furthermore, the authors emphasized the iterative and diverse nature of the activities, and called for a long-term cross-disciplinary research effort to explore and identify a model of the modelling process.

Existing research also explores empirical modelling processes for specific purposes. One of these is the modelling cycle Ferri (2006) which has the purpose of illustrating how pupils model from a cognitive perspective moving from situational models to mathematical models. This provides relevant insights into the thinking associated with modelling but does not propose how these thinking patterns relate to activities or structures in modelling practice especially not in industry. Indeed, a general trend in current literature is towards regarding the inherent iteration patterns to the modellers thinking and expertise. One of the most recent empirical research papers on modelling processes which repeats and strengthens this assumption is by Tako (2014) which describes a discrete-event simulation. Focusing on positioning the modelling process in a business context, Balci (2012) conducted an empirical study on modelling processes in the business system context. The study identified an iterative process configuration and applied a waterfall model with iterations as illustration, relating other business processes to different activities in the modelling process. Similarly, Sargent (2013) proposed an iterative process for verification and validation of developed models during modelling based on empirical findings.

In the identified empirical studies on modelling processes, the underlying assumption seems to be that modelling is based on variations of one process type. To the authors' knowledge, research has so far had little focus on exploring different modelling process types through empirical studies on process configuration. Our exploration is based on the assumption that different process types have emerged in practice dependent on the context of the modelling effort, and that these have distinguishable process structures. Hence, we aim at identifying modelling process structures and suggest appropriate process model(s) for the grouping(s) of processes based on similar contexts. In order to develop a process model, the structure of the process must be known, i.e. what are the activities within the process (at the necessary level of detail), how are these activities connected, and what is the behaviour of these links and activities (Wynn and Clarkson 2005). This behaviour can also be viewed as the configuration of the process, and thus be used to distinguish different types of processes depending on different behaviours (Buijs 2003). Therefore, rather than aiming at deriving one best-practice process model, the suggested more appropriate aim is first to search for the process type(s) by determining the process configuration(s) (Buijs 2003, Cunha and Gomes 2003). A categorisation of process configuration based on relations between process activities is proposed by Stabell and Fjeldstad (1998). This categorisation allows us to analyse the distinct process configurations by determining the dominant value creation logic. The categorization is described in more detail in the following subsection.

2.1 Value Creation Logic and Process Configuration

The research study on process configuration by Stabell and Fjeldstad (1998) views process structures from a value creation logic perspective, distinguishing processes by their activity structure and the relationships between these activities. Stabell and Fjeldstad suggest the existence of three types of configurations for value adding processes. This includes value chain logic, value shop logic, and value network logic (see Table 1).

Table 1. Overview of process value configurations

	Value chain	**Value shop**	**Value network**
Value creation logic	Transformation of inputs into products	(Re)solving customer problems	Linking customers
Primary technology	Long-linked	Intensive	Mediating
Primary activity categories	• Inbound logistics • Operation • Outbound logistics • Marketing • Service	• Problem-finding and acquisition • Problem-solving • Choice • Execution • Control/evaluation	• Network promotion and contract management • Service provisioning • Infrastructure operation
Main interactivity relationship logic	Sequential	Cyclical, spiralling	Simultaneous, parallel
Primary activity interdependence	• Pooled • Sequential	• Pooled • Sequential • Reciprocal	• Pooled • Reciprocal

The value chain logic consists of a linear activity structure similar to operations and manufacturing value flows. Value shop logic is iterative and problem-based like product development, while the value network is simultaneous and parallel for value creation in networks such as service provisioning.

Interdependencies between primary activities can distinguish the value creation logics. Sequential interdependency is when activities follow a certain order, where one activity requires the input of the previous activity. Coordination is conducted through planning and integration of activities. Pooled interdependency is when two or more activities share the same resource. In such cases, coordination is achieved through standardization allowing for similarity in activities and resource requirements. Reciprocal interdependency is when the output of one activity is the input of others making them mutually dependent, and here, coordination is accomplished through mutual adjustments. The value chain logic mainly consists of sequential interdependencies, and coordination can mainly be viewed as integration between activities to maximize efficiency. The value shop logic comprises pooled, sequential, and reciprocal interdependencies, but the focus here is on effectiveness rather than efficiency. Therefore, coordination is both a matter of planning and mutual adjustment. In the value network configuration, the activities are both pooled and reciprocal and value is obtained through organisation and facilitation of exchange.

Based on the literature review we apply the notion of value creation logic to modelling processes in order to determine distinct differences in order to distinguish modelling process types and determine the choice of an appropriate process model. Existing empirical studies show that the modelling process most often initiates with a problem statement or problem assessment activity. They also show that modelling is a highly iterative process. As such, we would expect all modelling processes to have value shop logic. However, our empirical findings surprisingly show that this is not always the case.

3 METHODOLOGY

Inspired by Foss et al. (1998) we conducted an empirical study interviewing experienced modellers across a range of modelling areas and process contexts. We follow a similar methodology to the case study approach (Yin 2009, Eisenhardt 1989), supporting theory development through empirical evidence. We chose to interview experienced modellers across different modelling domains in industry, aimed at deriving applied modelling processes based on a broad yet professional practical knowledge base. At the time of writing 14 interviews (see Table 2) have been conducted across two companies: a large telecommunications company and a large industrial company in aerospace manufacturing, both in the UK. Two of the models in question were developed collaboratively between two modellers (no. 2 and 7, and no. 13 and 14). Hence, the case study includes examination of 12 unique modelling processes through 14 interviews. Even though the interviews are not evenly distributed across the companies they are evenly distributed on modelling process context i.e. whether they are modelling a product design or a process. Since we do not aim to draw any comparative conclusions, but rather explore a wide set of modelling processes, we believe this distribution is appropriate for our purpose.

Table 2. Profiles of participating experienced modellers

No.	Experience	Modeller’s area of responsibilities	Industry	Process Context
1	30 years	Data Analytics	Telecommunication	Service
2	18 years	Network Optimisation	Telecommunication	Design
3	20 years	Dynamic Organisation research	Telecommunication	Service
4	15 years	Data visualisation	Telecommunication	Service
5	12 years	Resource Optimisation System	Telecommunication	Service
6	16 years	Resource systems and models	Telecommunication	Service
7	6 years	Network Optimisation	Telecommunication	Design
8	5 years	Service Delivery	Telecommunication	Service
9	20 years	Organisational modelling	Telecommunication	Service
10	30 years	Network transmission modelling	Telecommunication	Design
11	22 years	Organisational modelling	Telecommunication	Service
12	7 years	Structural systems modelling	Aerospace	Design
13	14 years	Preliminary design modelling	Aerospace	Design
14	5 years	Preliminary design modelling	Aerospace	Design

The choice to interview industrial modellers as opposed to academic modellers may have affected the case study results. The customers of in-house modellers are often internal customers, and may be highly influenced by company strategies and policies without necessarily having to account for the modelling resource consumption in their own areas. This approach was chosen deliberately since large companies increasingly have modelling teams to support R&D and strategic decisions for senior management, and thus the context is appropriate notice for our findings. The interviewees are divided evenly between service process modelling and modelling in the design domain. The interviews lasted between 1-2 hours and were conducted based on a semi-structured interview guide and an interview grid, which was filled out during each interview. All interviews were audio recorded. During the interview, after having explained the content of a specific modelling process, the interviewee was asked to visually present their modelling process. They were asked to write their modelling activities on post-it notes from beginning to end, place these on a large piece of paper and draw the appropriate lines in between symbolising the relationships between the activities. This assignment was easy for most of the interviewees whereas a few had difficulties being constrained to this format. This part of the interview was also audio recorded to support data analysis. The resulting activity processes were photographed and analysed along with the audio files to identify the underlying value creation logic based on the presented framework by Stabell and Fjeldstad (1998).

During the analysis, the authors noticed the emergence of modelling process types and chose to categorize these as an aspect of the results, which proved to suggest similar categories to those introduced by Foss et al. (1998): Ad-hoc Modelling for Decision Support (MDS), New Model Development (NMD), and model change management (MCM). The three process types were found to differ on a range of management factors, which led to propose that these are three archetypal modelling processes. It must be noted however, that the sample size of this case study is not sufficient to draw a rigorous scientific conclusion for other cases. Rather, it provides valuable insights based on empirical evidence that can be tested for generalizability through further studies.

4 ACTIVITY STRUCTURES AND VALUE CREATION LOGIC

As mentioned in the methodology, three process types are derived through the case study data: Ad-hoc Modelling for Decision Support (MDS), New Model Development (NMD), and model change management (MCM). Each of these modelling types will be presented in the following subsections including examples from practice. An overview of the collected results is provided in Table 3, including ID name, process type, model type, purpose, outcome, and activity structure for each model. The ID name refers to a name for the modelling process given by the authors to anonymise the cases.

4.1 Ad-hoc Modelling for Decision Support

One of the twelve cases, ID-name Rep-perform, is not concerned with the development of one model. Rather the modeller is engaged in on-going ad-hoc modelling of a series of small, similar one-off models to support senior management decision support. The process is initiated by a senior managers request, often in the format of an email, with a problem statement formulated as a question. This type of modelling is considered distinctively different from new model development since models are quickly put together and then discarded after the results have been derived in a linear process configuration. Furthermore, the timeline for this process type is short, and senior management expect answers to their questions within a fortnight.

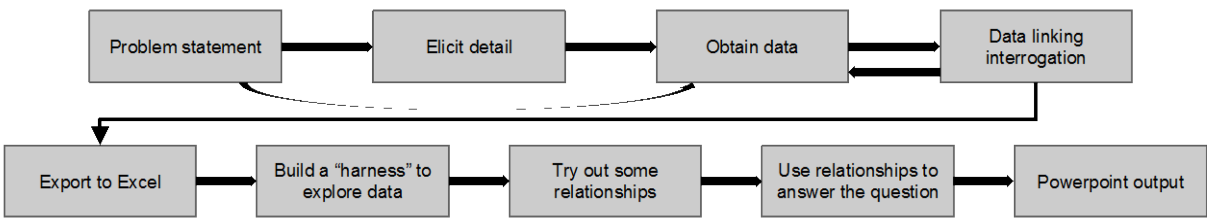

Figure 1. Case RepPerform – Process derived from modeller's drawings and interview analysis

The modeller drew the MDS process (Figure 1) as a linear development process. When asked for possible process iterations the modeller drew an arrow going back from data linking to obtaining data, since additional data had to be sourced when data quality proved insufficient. The requests do not include an internal budget for modelling but are covered as a headcount in at departmental level.

Table 3. ID name, process type, model type, purpose, outcome, and activity structure for each model.

ID Name	**Process type**	**Model Type**	**Purpose**	**Outcome**	**Dominant Structure**
CostOpt	NMD	Regression model	Decision support for cost reduction by predicting complaints outcome	Advice on field action	Cyclic
Resource -Mod	NMD	System Dynamics model	Model resources to understand relationships	Relations between resource variables	Cyclic
FaultsOpt	NMD	Statistic linear regression	Forecast faults for tactical decision support	Dash Board with recommendations	Cyclic
PatchOpt	MCM	Heuristic search technique	Optimize geographical patches	Tools and updates	Linear
Resource -Opt	NMD	Agent-based and heuristic-based logic	Capacity planning and scheduling according to skills	Automated scheduling of field resources	Cyclic
Tele-Network	NMD	Heuristic based model	Identify/ Optimise network design	Complete model of specific telecom network	Cyclic
Rep-Perform	MDS	Linear regression models	QQ-plots for senior management decision support	Performance effects	Linear
Hydra-Mod	NMD	System dynamics model	Model service performance for management decision support	Performance effects	Cyclic
Cable-Mod	MCM	Least squares	Optimize cable performance	Prediction of noise	Linear
Res-Perform	MCM	Regression, event-based simulation model	Resource performance relations for senior management decision support	Graphic interaction	Linear
Aero-Structure	NMD	Process workflow, multiple model types	To model the workflow of the structural analysis of an aeroplane engine	Complete structure systems model	Cyclic and Network
Aero-Prelim	MCM	Process workflow, multiple model types	To improve a preliminary design model of aeroplane engines	Updates of the model	Linear

4.2 New Model Development

Seven of the twelve modelling processes are concerned with development of new models (CostOpt, ResourceMod, FaultsOpt, ResourceOpt, Telenetwork, Hydra-Mod, and Aero-Structure). The models are generally large simulation models built for long-term usage by modellers, internal users, and/or external business customers. These modelling processes are part of model development projects lasting around 1-2 years before first release. The NMD process is characterised by high degree of iteration and uncertainty related to both the nature of the customer need, model architecture, choice of modelling technique, and available data as presented in Figure 2 with the example of TeleNetwork.

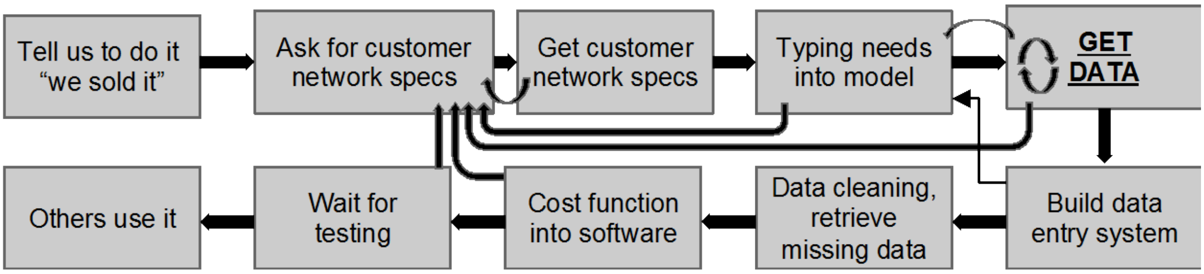

Figure 2. Case TeleNetwork – Process derived from modeller's drawings and interview analysis

The NMD processes are most similar to modelling processes described in existing literature and do indeed fit the value shop logic, which was not the case with the MDS-process. The modelling tasks were not explained in similar ways by the modellers. However, consensus was found on three points:

- New model development is initiated by a customer request.
- The request has to be analysed and amended together with the customer.
- The process requires several iterations across model development activities.
- The process ends with a final model capable of answering customer/business questions in a certain business domain.

An interesting finding is that the modelling process of Aero-Structure (one of the seven NMD processes) has a more complicated structure than the value shop logic. The purpose of the model is to model an aero engine's structural properties, which involves more than 30 engineers, each with the modeller's own local model across the design organisation. The purpose of the model is two-fold in this instance because it not only answers for business questions but also combines the knowledge from all these engineers. Hence, engineers join and support the modelling process not only to derive answers for their own questions but also to be connected to the knowledge and models in the other design domains. Hence, the modelling process takes on both a value shop logic but also a value network like structure in that engineers share in a joint model on a larger scale.

4.3 Model Change Management

The final process type MCM covers modelling processes continuously improving and/or developing new features in existing models. Four of the processes were of the MCM type. These are based on a request or pool gathered from existing model users and are continuously taking on a maintenance-like pattern. The modellers involved in MDM drew predominantly linear process models and describing relations fitting with the value chain logic (see figure 3). The MCM process is shorter than NMD processes but significantly longer than the MDS process lasting around 1-3 months. Furthermore, they were not managed as modelling projects but rather on-going maintenance and support by a support team.

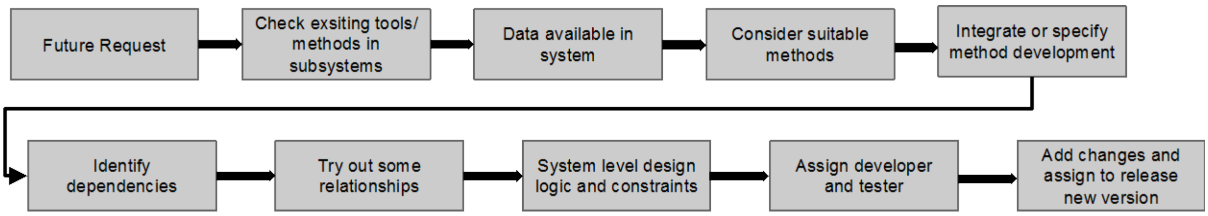

Figure 3. Case AeroPrelim – Process derived from modeller's drawings and interview analysis

4.4 Contexts of three modelling process types

Based on the empirical study, three emerged that could be classified as archetypes of modelling processes, each having unique process configurations. From a contextual point of view, it makes sense to categorise modelling in these three types since they differ in time and resource consumption - directly influencing company investments. Hence, the least investment is required for ad-hoc modelling. However these types of models are often short lived and do not contain the same rigour or capacity as a full simulation model. On the other hand development of a full model entails going through the NMD process, which requires substantial investments and can last years to fully develop. Finally, having developed a simulation model it often requires maintenance and regular upgrades, which should be considered as an on-going investment balanced towards the value derived from using the model. Hence, the three process types can be roughly positioned at different places in a modelling life-cycle (Table 4). MDS is the modelling process prior to new model development, whereas MCM is the modelling effort necessary to maintain an active model.

Table 4. Proposal of three modelling process archetypes categorised from their context

Process Type	Requestor	Modelling Organisation	Time scale	Predominant Value Logic	Company Investments
Ad-hoc modelling for decision support	Senior manager	Individual modeller	1-2 weeks	Value chain	Minimum
New model development	Internal customer	Group of project stakeholders	1-2 years	Value shop	Substantial
Model change management	Internal customer	Maintenance team	2-3 months	Value chain	Balanced

5 DISCUSSION

The study showed that even though modellers are responsible for providing significant decision support, the modelling process is far from rigorous and controlled. Even so, the emergent modelling processes do contain repetitive patterns in three distinguishable contexts, leading to suggest three distinguishable modelling processes. Thus, the results imply that application of three modelling processes is a viable solution to increase modelling rigour and process visibility. Thus, the main managerial implication of this work is the opportunity to improve rigour of modelling processes through the introduction of context dependent process models. Due to the role of models as key decision support tools, the modelling processes itself must be transparent and of a high quality standard. The largest risks in continuing to accept modelling as a 'one-man-job' without management directions is a wide spread on model quality and models remaining expert dependent, i.e. only operable by the modeller. This study shows that there is indeed a middle ground between implementation of a one best-practice modelling processes and not having any prescribed processes. Based on company contexts a set of appropriate modelling processes can be determined leading to increased control and transparency once implemented in the modelling community of the company. Further research should explore the impact of modelling management with regards to introduction of context dependent modelling processes.

The derived proposals aim to offer inspiration for further research, as opposed to attempting to draw generalizable conclusions. More research is needed to determine whether the three process types are indeed widely represented in modelling practice, and if so, which kind of value configuration they possess. The three types are in close alignment with modelling types suggested by Foss et al. (1998), the main difference being that even though Foss et al. (1998) mentions these modelling types in their methodology, they surprisingly do not consider unique modelling processes for each modelling type. Whether this is due to a lack of an emerging pattern in their data remains at this point unclear. However their initial categorisation of modelling types from empirical findings does support our suggested groupings, and larger quantitative studies are recommended for generalizable results.

Existing research on modelling focuses primarily on applications supporting NMD type processes as highlighted in section 2. However, little if any research aims at supporting MDS and MCM modelling processes even though researchers have identified these in industry alongside NMD type processes. Thus, inspired by product development research (e.g. Koen et al. (2002)), we propose the format of a modelling process management toolbox containing the three process standards and appropriate shared and unique template documents and tools. This is illustrated in figure 4. For MDS and MCM the process models have value chain logic whereas the NMD based on value shop logic fitting our empirical findings. The NMD model is based on an iterative model inspired by a toolbox for inclusive design developed by researchers in health care design at the Engineering Design Centre at University of Cambridge (Waller et al. 2013) and the unified software development process (Jacobson et al. 1999). The content for MDS and MCM are inspired by empirical findings combined with existing best practice on modelling tasks (e.g. Eisenbart et al. (2011)). Future research will aim at developing the process toolbox in collaboration with practitioners to fit the modelling processes types proposed through this paper. At this stage the toolkit remains an initial idea for further prescriptive research.

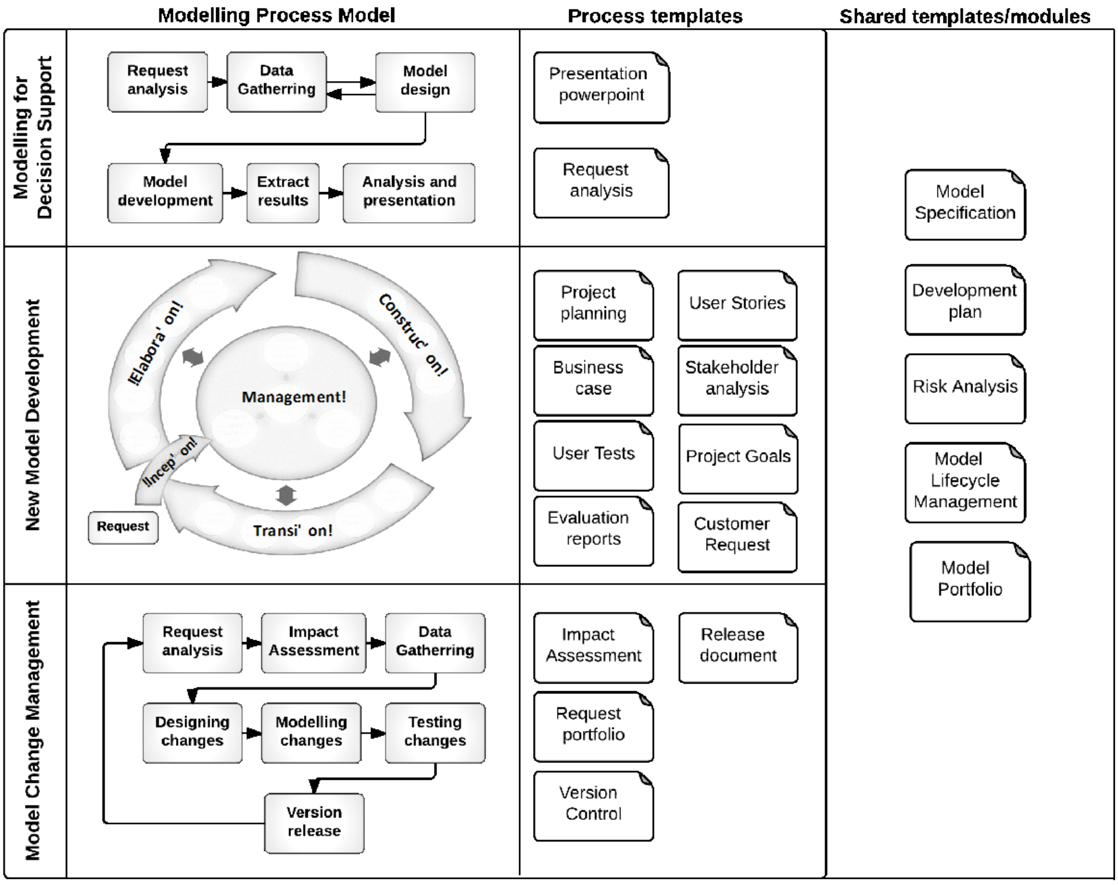

Figure 4. Toolbox for modelling process management divided by process type.

6 CONCLUSION

Through an empirical study, modelling activity structures have been explored across 12 different modelling processes across design and service modelling contexts. The paper contributes to existing research by proposing distinct management characteristics and process configuration for three modelling process archetypes: Ad-hoc modelling for decision support, new model development, and model change management. Based on the empirical findings it is proposed that the three process types should be distinguished and managed differently. Future prescriptive research is suggested to include the development of a toolbox to support management of the three process types.

REFERENCES

Albers, A., Klingler, S. and Ebel, B. (2013) Modeling systems of objectives in engineering design practice, Proceedings of the 19th International Conference on Engineering Design (ICED13), Seoul, Korea.

Aromaa, S., Leino, S.-P. and Viitaniemi, J. (2013) Are companies ready for the revolution in design: Modelling maturity for virtual prototyping, Proceedings of the 19th International Conference on Engineering Design (ICED13), Design for Harmonies, Vol. 9: Design Methods and Tools, Seoul, Korea.

Balci, O. (2012) 'A life cycle for modeling and simulation', Simulation, 88(7), 870-883.

Browning, T. R. and Ramasesh, R. V. (2007) 'A Survey of Activity Network-Based Process Models for Managing Product Development Projects', Production and Operations Management, 16(2), 217-240.

Buijs, J. (2003) 'Modelling product innovation processes, from linear logic to circular chaos', Creativity and Innovation Management, 12(2), 76-93.

Cameron, I. T. and Ingram, G. (2008) 'A survey of industrial process modelling across the product and process lifecycle', Computers & Chemical Engineering, 32(3), 420-438.

Cunha, M. P. e. and Gomes, J. F. S. (2003) 'Order and disorder in product innovation models', Creativity and Innovation Management, 12(3), 174-187.

Eisenbart, B., Gericke, K. and Blessing, L. (2011) A framework for comparing design modelling approaches across disciplines, Proceedings of the 18th International Conference on Engineering Design (ICED 11), Copenhagen, Denmark.

Eisenhardt, K. M. (1989) 'Building Theories from Case Study Research', The Academy of Management Review, 14(4), 532-550.

Ferri, R. B. (2006) 'Theoretical and empirical differentiations of phases in the modelling process', ZDM, 38(2), 86-95.

Foss, B., Lohmann, B. and Marquardt, W. (1998) 'A field study of the industrial modeling process', Journal of Process Control, 8(5), 325-338.

Jacobson, I., Booch, G., Rumbaugh, J., Rumbaugh, J. and Booch, G. (1999) The unified software development process, Addison-Wesley Reading.

Koen, P. A., Ajamian, G. M., Boyce, S., Clamen, A., Fisher, E., Fountoulakis, S., Johnson, A., Puri, P. and Seibert, R. (2002) Fuzzy front end: Effective methods, tools, and techniques. PDMA Toolbook for New Product Development, New York: John Wiley and Sons.

Law, A. M., Kelton, W. D. and Kelton, W. D. (1991) Simulation modeling and analysis, McGraw-Hill New York.

Nance, R. E. (1994) 'The conical methodology and the evolution of simulation model development', Annals of operations research, 53(1), 1-45.

Pidd, M. (1999) 'Just modeling through: A rough guide to modeling', Interfaces, 29(2), 118-132.

Robinson, S. (2004) Simulation: the practice of model development and use, John Wiley & Sons Chichester.

Sargent, R. G. (2013) 'Verification and validation of simulation models', Journal of simulation, 7(1), 12-24.

Schabacker, M., Szélig, N. and Vajna, S. (2013) Suitable methods for process modeling and process optimization, DS 75-1: Proceedings of the 19th International Conference on Engineering Design (ICED13), Design for Harmonies, Vol. 1: Design Processes, Seoul, Korea, 19-22.08. 2013.

Stabell, C. B. and Fjeldstad, Ø. D. (1998) 'Configuring value for competitive advantage: on chains, shops, and networks', Strategic Management Journal, 19(5), 413-437.

Subrahmanian, E., Reich, Y., Konda, S., Dutoit, A., Cunningham, D., Patrick, R., Thomas, M. and Westerberg, A. W. (1997) The n-dim approach to creating design support systems, Proc. of ASME Design Technical Conf.

Tako, A. A. (2014) 'Exploring the model development process in discrete-event simulation: insights from six expert modellers', Journal of the Operational Research Society.

Waller, S., Bradley, M., Hosking, I. and Clarkson, P. J. (2013) 'Making the case for inclusive design', Applied ergonomics.

Wynn, D. and Clarkson, J. (2005) 'Models of designing' in Design process improvement, Springer, 34-59.

Yin, R. K. (2009) Case study research: Design and methods, London: Sage publications, INC.