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AN INTEGRATED CONCEPTUAL MODELING FRAMEWORK FOR SIMULATION – LINKING SIMULATION MODELING TO THE SYSTEMS ENGINEERING PROCESS

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ABSTRACT

Use of simulation tools for industrial projects implies a need for aligning the engineering process and simulation modeling activities. Alignment of activities builds on the definition of a conceptual model, detailing modeling objectives, model contents, inputs and outputs, thereby relying on a project problem definition and candidate solutions. Modeling frameworks assist the analyst in defining conceptual models by identifying relevant activities to undertake, as well as suggesting good practices, and supportive methods. Surprisingly, current frameworks do not acknowledge the need for explicitly linking the set-up of a conceptual model to the engineering process. Hence, both project efficiency and effectiveness may be hurt. To address this gap, we propose an integrated conceptual modeling framework, which is tailored towards simulation use for logistic analysis purposes. Relevance of the integrated framework for project success is illustrated by a case example.

1 INTRODUCTION

Simulation is an essential part of an engineer's toolbox for supporting systems design. Its high relevance for testing and improving alternative designs is shown for numerous projects in (service) industry. Simulation use is linked to engineering projects by a conceptual model, i.e., a non-software specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model (Robinson 2008a). Basically, conceptual modeling starts from an understanding of the outcomes of the (earlier) phases in an engineering project, especially problem definition, and the identification and creation of alternative system designs.

Ideally, simulation use for engineering purposes starts from a clearly defined notion and coordination of engineering and conceptual modeling (CM) activities and their outcomes. Clarity in this respect contributes, among others, to improved communication and understanding among stakeholders and project team, including both engineers and analysts, improved knowledge capture, and reduced development risk. In turn, such contributions enhance qualities of a conceptual model in terms of its validity, credibility, utility, and feasibility, as well as contribute to modeling efficiencies.

So far, CM for simulation received little attention in simulation literature. However, some progress has been made in recent years, by the proposal of several modeling frameworks (Robinson et al. 2010). A modeling framework offers guidance for the analyst, through specifying and structuring key modeling activities, and suggesting good practices and supportive methods for executing them. Unfortunately, current frameworks do not explicitly link modeling activities to the engineering process. A reason for this may be in the fact that theory development on CM tends to be at an intersection of disciplines, especially operations research, statistics, engineering, and computer science (Van der Zee et al. 2010). Furthermore, the choice of domain, for example, industry, health care or the military may significantly impact the nature of CM. So far, literature has "confirmed" these intrinsic difficulties in doing research on CM by

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developing disciplinary approaches for specific domains, rather than focusing on interdisciplinary solutions, and/or exploiting similarities between domains.

In this article we seek to contribute to an interdisciplinary approach in guiding the analyst in building a conceptual model, by proposing a new modeling framework. We do so by relating an existing modeling framework for CM (Robinson 2008b), which has been developed from an operations research point of view, to the systems engineering process. Essentially, unhiding relevant links between the engineering activities and simulation modeling allows for adapting the modeling framework for its integrated use within an engineering context. Contributions of the new, adapted framework lie in a more effective and efficient CM. Model effectiveness may be increased by a closer – explicit – aligning of engineering project contents and organization with simulation modeling objectives and study set up, also see above. Modeling efficiencies may be improved by a (joint) exploitation of company resources or modeling means, like a common specification or diagramming language.

The remainder of this article is organized as follows. In Section 2 we explore the way simulation may be linked to an engineering project, by identifying and linking engineering and simulation modeling activities. Next in Section 3, we relate our findings to a well-accepted modeling framework for CM, addressing simulation use for logistic analysis purposes (Robinson 2008b). We suggest modifications of the framework to improve its integrated use within an engineering context. A set of integration principles is adopted to guide and underpin modifications. Use of the new, extended framework is addressed in Section 4 by means of a case example concerning the redesign of a planning system for a coffee manufacturer (Van der Zee et al. 2008; Pool et al. 2011). Starting from the case example we will discuss relevance of the suggested changes to the modeling framework for simulation success. Finally, in Section 5, we conclude with a summary of main findings.

2 LINKING SIMULATION MODELING TO THE SYSTEMS ENGINEERING PROCESS

The primary purpose of a simulation model is to understand how alternative system designs will or do perform. In turn, this understanding may be employed to support a decision maker on choosing the design that serves his purposes best. Qualities of a simulation model in terms of efficient and effective decision support rely on a series of modeling activities, especially conceptual modeling, model coding and experimenting. In this section we explore the way these activities are linked to the systems engineering process. Our focus is on the way engineering activities and their outcomes may be linked to simulation modeling activities. Figure 1 will serve as a guide in our discussion.

Systems Engineering (SE) is an engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customer' and stakeholder's needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout the system's entire life cycle (INCOSE 2012). A primary purpose of SE is to guide the engineering effort – which may include contributions from several traditional engineering disciplines. In terms of project management it is complementary to project planning and control (Kossiakoff et al. 2009).

The SE process is visualized and described by Figure 1. In characterizing SE we chose to start from the INCOSE definition of SE and the engineering process - often referred to as the SIMILAR process (Bahill and Gissing 1998). Here "SIMILAR" matches the first letters of each subprocess (compare Figure 1). Reasons for choosing the latter definition are in the underlying consensus of many systems engineers and an easy mapping to alternative definitions, also see Bahill and Gissing (1998). Below we shortly characterize the SE process. For more details, see Bahill and Gissing (1998) and INCOSE (2012).

The SIMILAR process relates the early stages in a system's life, i.e. *concept*, to stating the problem and the investigating alternatives. By identifying customers' and stakeholders' interests in terms of their needs, and demands with respect to the problem, relevant system functions, value measures and constraints of the systems decision problem are established. The investigation of alternatives addresses the creation of candidate solutions to the design problem. Relevant tasks include idea generation, turning ideas into a (limited) set of alternatives through (detailed) screening using requirements as set in the problem definition, and cost analysis.

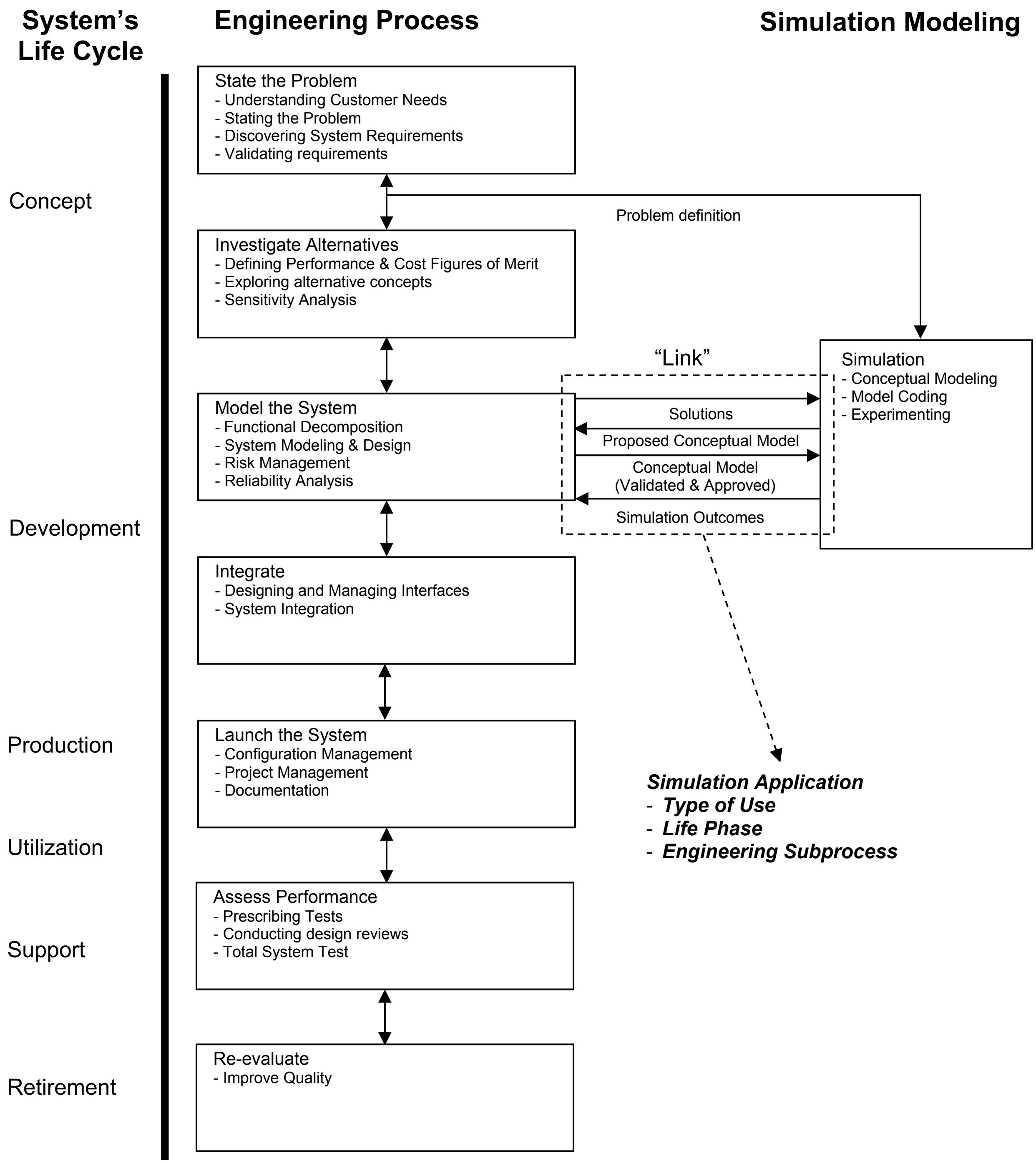

Figure 1: Relating Simulation Modeling to the Systems Engineering Process (Bahill and Gissing 1998)

System development builds on modeling and integration. Starting from the alternative design solutions found in the previous subprocess, models for these designs are developed for the purposes of (1) helping to manage the system throughout its entire life (preferred alternative), and (2) analyzing estimated benefits and shortcomings (candidate alternatives). Many types of models may be considered, like, analytic equations, block diagrams, flow diagrams, simulation etc. System integration concerns the linking of subsystems, thereby stressing the careful design of mutual interfaces.

Actual system use, i.e. *production, utilization and support*, is addressed by system launch and performance assessment. System use starts from its implementation, which suggests activities like buying and/or making, and next installing preferred subsystems. Successful implementation of a design solution requires careful planning, execution, and monitoring and control (performance assessment). Finally, *system retirement* is linked to system re-evaluation. The SIMILAR process is assumed to be highly iterative, allowing previous subprocesses to be rerun if process outcomes indicate the need to do so. Iteration is especially linked to the subprocess re-evaluation.

In developing a complex system, simulation use may be linked to nearly every step within the engineering process (Kossiakoff et al. 2011). Some possible uses are: understanding customer and stakeholder needs, mapping customer and stakeholder needs to engineering parameters, identifying requirements that have a sizing effect on major system elements, analyzing and detailing individual parts of the system, performance estimation and design verification, verification and validation of real system elements by offering a test environment, system operation, training and maintenance (Fuchs 2009). Typically, uses may concern specific phases in a systems' life cycle and engineering subprocesses. For example, a simulation environment for real-life testing of subsystems requires such subsystems to be readily available. On the other hand, whereas operator training assumes much system detail to be known on a company (specific) system, introductory education on system use may rely on far less detail, as, for example, only insights on system basic behavior are addressed. Hence, in the latter case, simulation may be an adequate vehicle for learning, already in the concept phase. Note how engineering progress suggests the availability of more detailed input for a simulation model, and – hence – the possibility of developing more precise simulation models in terms of their appearance and behavior.

Engineering and simulation activities are linked by a conceptual model, detailing modeling objectives, model inputs, outputs and contents. The nature and detail of a conceptual model is determined by the choice of simulation use, and engineering progress, see above. This is illustrated by Figure 1, which shows how simulation use is related to subprocess "system modeling". Once again, this is only one of the many possible applications of simulation along the system life cycle.

Simulation conceptual modeling activities are informed by the outputs of engineering activities. The net result of CM activities is a conceptual model, which is to be validated and approved within the overall project context. Note how latter activities imply a need for aligning engineering and modeling activities. Note that many iterations may be required in order to arrive at a conceptual model that is agreed upon by all parties involved. A main reason for this is the complexity of most engineering solutions, which sets high demands on building mutual understanding among stakeholders of both system designs and their corresponding models. Such understanding typically relies on the exchange of (graphical) model and design specifications, which may follow, for example, a step-by-step approach, considering designs at various levels of detail and/or part-by-part.

The approved conceptual model is the starting point for model coding, i.e., implementation of the conceptual model. Simulation outcomes are produced by executing the coded model according to the choice of experiments, as included in the conceptual model, and experimental design, i.e. choice of warm-up period, number of runs, and run lengths. Note how simulation is typically used in an iterative way, as simulation outcomes may underpin the definition of alternative design solutions. In turn, these changes in simulation set-up should be reflected in the conceptual model.

3 AN INTEGRATED FRAMEWORK FOR CONCEPTUAL MODELING

In the previous section we showed how the conceptual model serves as the primary linking pin between engineering activities and simulation modeling. By capturing the essence of the simulation model it largely determines simulation success. In turn, this makes CM a highly relevant activity. In this section we will shortly review literature for guidance for the analyst in doing so (Section 3.1). Next, we will show how a well-accepted modeling framework – that has been developed starting from a disciplinary, operations research, focus – may be tailored towards its use within the engineering process (Sections 3.2, 3.3).

3.1 Guidance for the Analyst – Modeling Frameworks

So far, little guidance for the analyst in doing CM is available in literature. Recent research, however, identified modeling frameworks as an attractive means for supporting the analyst on CM, in addition to principles advocating evolutionary design, or suggesting effective model pruning (Robinson 2008a). Essentially, a modeling framework boils down to a procedural approach in detailing a simulation model in terms of its elements, their attributes and their relationships.

So far, several modeling frameworks have been developed, see Robinson (2008a), and Robinson et al. (2010) for overviews. Frameworks may be distinguished according to their domain and scope. For example, Arbez and Birta (2010) address the general case, i.e., discrete event dynamic systems. Alternative frameworks tend to be tailored towards the business or military domain, see, for example, Pace (2000), Guru and Savory (2004), and Kotiadis (2007). Furthermore, proposed frameworks differ in scope. Whereas some frameworks only address model contents, others also consider the problem context, project and modeling objectives, and/or the experimental frame, i.e., model inputs and outputs.

3.2 An Integrated Modeling Framework

In our research we chose to adopt and modify the modeling framework by Robinson (2008b). His framework addresses use of discrete event simulation for logistic analysis purposes. As such it's use may be linked to both "green field" settings, concerning early system life phases (concept, development, compare Figure 1), and "mid-life" updates – being advocated as a net result of a system re-evaluation.

Reasons for choosing Robinson's framework are (1) its wide acceptance within the field (2) its addressing of a main stream of research within the simulation community, and (3) its wide scope, covering problem context, modeling objectives, model contents and experimental frame (compare Section 3.1). To familiarize the reader with the concept of a modeling framework in somewhat more detail, we first discuss the modified framework in terms of modeling activities, see Table 1 (right hand side). Next we discuss its actual use within the project context by considering triggers forcing a need for adapting the conceptual model. In Section 3.3 we will motivate the way the new modeling framework has been adapted relative to the original framework by Robinson (2008b).

3.2.1 Modeling Framework – Defining Activities

The modified modeling framework distinguishes between 5 steps in defining a conceptual model (Table 1, right hand side). The first step links the conceptual model to the output from preceding engineering phases, especially problem definition and candidate solutions (compare Figure 1). Firstly, they clarify the engineering problem being faced by decision makers and stakeholders. Secondly, the analyst should get familiar with alternative solutions as they result from, for example, general idea generation techniques like brain storming, or more specific techniques like bottleneck analysis or value stream mapping as in lean manufacturing approaches. Furthermore, clarification of the subject matter may be a net result of consulting subject matter experts, either inside or outside the companies involved in the project.

The second step is meant to determine both modeling and general objectives. Modeling objectives relate to the project problem definition. Typically, they address a "reduced" objective, suggesting to analyze logistic performance of a given set of candidate solutions. Here performance measures build on the functional and requirements analysis and value modeling activities (see Section 2, and Figure 1). The use of a reduced problem definition and/or a restricted choice of solutions may be linked to simulation being used for analyzing just part and/or aspects of a system. This may be motivated by, for example, project resources, availability of alternative quantitative tools, or performance criterions for which simulation offers no or little support. General project objectives add to the modeling objectives by considering the way model use (visualization, interaction, flexibility) and changes to the model (flexibility, re-use) are facilitated. Furthermore, the project time frame set may influence feasible model detail, and choice and length of experiments.

Table 1: Modeling Framework Integration

Original modeling framework		Integrated modeling framework	
Activity	**Details**	**Activity**	**Details**
1. Understanding the problem situation	• Identify clients and subject matter experts • Understand the problem situation, preferably by interviewing clients and subject matter experts	1. Understanding the problem and candidate solutions	• Identify decision makers and stakeholders • Understand the subject matter (problem, solutions, requirements), preferably by interviewing decision makers, stakeholders and subject matter experts
2. Determine objectives - modeling objectives	• Define modeling objectives starting from the aims of the organization. Objectives can be expressed in terms of three components: Achievement, i.e. what the clients hope to achieve, measures of performance, and the constraints within which the clients (modeler) must work (e.g. budget, design options, available space).	2. Determine objectives - modeling objectives	• Agree on the set of candidate solutions for which performance has to be estimated. • Derive performance measures from the overall project problem definition.
- general project objectives	Consider: • Time scale – for doing the study. Relate to choice of model detail • Flexibility – ease of changing the model • Run speed • Visual display • Ease-of-use/interaction • Model/component reuse	- general project objectives	Consider: • Time scale – for doing the study. Relate to choice of model detail • Flexibility – ease of changing the model • Run speed • Visual display • Ease-of-use/interaction • Model/component reuse
3. Identify the model outputs	• Check modeling objectives for relevant performance measures • Establish model outputs helping to identify potential bottlenecks in systems operations • Determine format for representing responses	3. Identify the model outputs	• Check modeling objectives for relevant performance measures • Establish model outputs helping to identify potential bottlenecks in systems operations • Determine format for representing responses
4. Identify the model inputs	• Select quantitative and qualitative model data that can be changed, in order to represent candidate solutions. Such data may be partly identified by modeling objectives • Determine range over which model inputs may be varied • Consider factors not being directly controlled within the system	4. Identify the model inputs	• Select quantitative and qualitative model data that can be changed, in order to represent candidate solutions • Determine range over which model inputs may be varied given the set of candidate solutions • Consider factors not being directly controlled within the system
5. Determine model contents: scope and level of detail	• Determine model scope: - Identify the system boundary - Identify all components in the real system that lie within the model boundary - Assess whether to include components • Determine model detail (attributes) for all components included • Identify assumptions and simplifications concerning model scope and detail, and assess their impact on model outputs • Document model scope and detail, including a justification for their inclusion to the model	5. Determine model contents: scope and level of detail	• Determine model scope: - Identify the system boundary, starting from problem definition and candidate solutions - Identify all components in the real system (being part of candidate solutions) that lie within the model boundary - Assess whether to include components • Determine model detail (attributes) for all components included • Identify assumptions and simplifications concerning model scope and detail, and assess their impact on model outputs • Document model scope and detail, including a justification for their inclusion to the model. Relate format for documentation to stakeholder and project engineers' needs (known model formats, reference models)

Determining the model outputs concerns the third step within the modeling framework. Two categories of outputs are to be considered. The first category is linked to measurements underlying performance criterions as in the modeling objectives. The second category of outputs concerns those outputs assisting in unhiding bottlenecks in system operations. For example, flow time performance may be explained by resource utilization and product waiting times. Next to the choice of outputs a decision has to be made on their format for reporting. Outputs may be reported as numerical data (mean, maximum, minimum, standard deviation etc.) or graphs (bar charts, run charts, pie charts etc.).

Candidate solutions as they result from engineering efforts are the basis for defining model inputs (step 4). The set of solutions considered is to be fitted in a frame distinguishing experimental factors, i.e. system elements which distinguish candidate solutions from each other, and their range, i.e., values found for experimental factors as they typify alternative solutions. Next to, inputs in direct control of the system engineer, other factors may be included which may influence system behavior. For example, several product demand scenarios may be considered, given market uncertainties.

The final step concerns determining model contents. Essentially, it specifies relevant model components and their detail, including underlying assumptions and simplifications. Specification of model components can be done according to several formats, for example textual, tables, and graphical – using diagramming techniques. Ideally, component specification goes together with an explicit (textual) justification of their inclusion in the model. Typically, visualization of model contents may be of high relevance for conceptual model validation and acceptance. Ideally, the jargon introduced, as well as its visualization, appeals to the (implicit) reference models of both stakeholders and industrial engineers. Ideally, decision variables (experimental factors) are clearly identified, and related to system set-up and workings.

3.2.2 Modeling Framework – Triggers for Its Use

Above we defined the new framework in terms of its key modeling activities. The framework set-up may suggest CM to be a one-time exercise, to be executed following a sequential ordering of modeling activities. Unfortunately, conceptual models are seldom defined in this way. Usually, they are produced in an iterative way. Among the various reasons for this are: shortages of data, improved stakeholders insights, problem definitions being revised etc., also compare Robinson 2008b. In our quest to tune engineering and modeling activities we are interested in those situations where engineering activities trigger modeling activities and vice versa.

In our somewhat idealized view – as embedded in the framework – a problem definition and design solutions are provided as a net effect of executing engineering activities. In turn, simulation modeling activities result in the definition of a conceptual model – to be agreed upon, and, next, simulation outcomes (compare Figure 1). Hence, any change with respect to problem definition and design solutions may trigger CM activities. Furthermore, a change of project resources and time frame (compare Section 3.1) may force a reconsideration of the conceptual model. In turn, engineering activities are triggered by revisions of the accepted conceptual model – as deemed necessary within the modeling context, and (initial) simulation outcomes.

3.2.3 Modeling Framework – Data

Typically, a well-defined conceptual model relies on consistent data, shared by modeling and engineering activities (Fuchs, 2009).

3.3 Integrating Conceptual Modeling and Engineering Activities

The modeling framework as it has been developed by Robinson (Robinson 2008b) acknowledges the relevance of the engineering project contents and set-up for CM. However, it gives weak support as far as an explicit linking and aligning of simulation modeling activities to engineering activities is concerned. In this section we show that such integration may be facilitated by the proposed modified framework. Essentially, we do so by motivating changes to Robinson's framework, starting from a multifaceted perspective to integration of activities as proposed by Thomas and Nejmeh (1992). Where Thomas and Nejmeh link integration to relationships between software tools, we apply their perspective to the relationship between simulation modeling and engineering activities, as they underlie the definition of a conceptual model.

Thomas and Nejmeh (1992) suggest 4 perspectives on tool integration, i.e., presentation integration, control integration, process integration, and data integration. In Table 2, each type of integration has been defined, including its essential properties. Note how the definition of properties is tailored towards their use for assessing the relationship between simulation modeling and engineering activities. Outcomes of the assessment, i.e. changes to Robinson's framework, are displayed at the right hand side in Table 2.

Table 2: Underpinning Changes to the Modeling Framework Starting from Integration Perspectives

	Integration		Consequences for conceptual modeling	
	Perspective	**Properties**	**Activities**	**Detail**
Set up	Presentation integration "Improve the efficiency and effectiveness of user's interaction with the environment by reducing his cognitive load"	• Appearance and behavior: Ease of interacting with conceptual models given already known engineering models. • Interaction paradigm: To what extent do conceptual models appeal to similar metaphors and mental models being familiar to stakeholders, and engineers.	5. Determine model contents: scope and level of detail	Details: Document model scope and detail: Relate format for documentation to stakeholder and project engineers' needs (known model formats, reference models).
	Control (service) integration "Allow the flexible combination of an environment's functions, according to project preferences and driven by the underlying processes the environment supports.	• Provision and use: To what extent are activities required, used, and used in the appropriate way?	1. Understanding the problem situation 2. Determine objectives - modeling objectives 4. Identify the model inputs	Activity: Understanding the problem and candidate solutions Detail: Agree on the set of candidate solutions for which performance has to estimated. Derive performance measures from the overall project problem definition. Detail: Select quantitative and qualitative model data that can be changed, in order to represent candidate solutions Determine range over which model inputs may be varied given the set of candidate solutions
Use	Process integration "Ensure that tools interact effectively in support of the defined process"	• Process step: How well do engineering and modeling activities combine in defining a conceptual model • Event/constraint: How well do engineering and modeling activities facilitate an iterative creation of a conceptual model?	All: In principle no problem – if overlapping activities are redefined and redistributed (cf. control integration) All: Events triggering either engineering or modeling activities should be clarified.	• Revisions of problem definition and design solutions • Changes to an accepted conceptual model (deemed necessary within the modeling context) • Outcomes of (initial experiments) • Availability of project resources
Data	Data integration "Ensure that all information in the environment is managed as a consistent whole, regardless of how parts of it are operated on and transformed"	• Interoperability: Ease of sharing data for modeling and engineering purposes. • Non redundancy: How much data is duplicated? • Data consistency: How well are semantic constraints maintained concerning data that are manipulated for both engineering and modeling purposes? • Data exchange: Agreement on data format and semantics. • Synchronization: How well are changes to shared data communicated?	All	All activities rely on (efficient) maintaining of consistent information.

Main changes to the Robinson's framework are expressed in terms of a redefinition of activities and their detail. Presentation integration, in terms of user-interaction with the conceptual model, is supported by suggesting to relate the choice of model format and components to stakeholders' and project engineers' needs. This eases their mastering and understanding of model logic. In turn, this facilitates their participation in modeling (validation) and engineering activities (relying on better insights in system workings, as facilitated by the model), their agreement on the conceptual model, and acceptance of model outcomes.

Starting from the concept of control integration, also known as "service integration (Liu et al. 2010), we found considerable overlap as it comes to engineering and modeling activities. Especially, no clear division of tasks is found when it comes to problem definition, and solution finding. We solve this issue by linking both activities to the engineering process, see Section 2. As a net effect we clarified "understanding the problem situation", by linking understanding to the (reduced) problem definition and (restricted) choice of solutions – being the outcome of engineering activities. In turn, the identification of design solutions as a prime input to CM forces a tailoring of modeling objectives, and model inputs. Note, how this leaves a need for considering an efficient choice of experiments, aiming to do just those experiments that support relevant insights. Application of principles underlying process integration further support a redistribution of activities, see above. Next, iteration of CM activities is linked to a clear set of events that may be fit into the overall project organization.

Data integration (compare Section 3.2.3) has not been explicitly addressed by Robinson. Although we do not detail it here, we stress its relevance for project effectiveness and efficiency.

4 CASE EXAMPLES – BENEFITS OF AN INTEGRATED FRAMEWORK

To illustrate benefits of the integrated framework we consider a case study concerning the redesign of a planning system for a large coffee manufacturer, see Van der Zee et al. (2008), and Pool et al. (2011).

4.1 Project Characteristics

To introduce the case study we will shortly discuss the process of manufacturing "liquids", i.e. fluid coffee extracts, and their planning and control. Next, project set-up is considered. The first step for producing liquids, concerns the roasting of alternative types of green coffee beans. In a next step so-called "coffee blends" are extracted from these beans. Here each blend is related to a certain mix of roasted coffee beans. The liquid blends (liquids) are further concentrated in a number of steps to make them fit for use in coffee machines. The final production stage concerns the packaging of the blends.

At the start of the project the management acknowledged the need for a rigorous redesign of the current planning system. This was primarily motivated by the outcomes of the preceding and on-going "lean" projects on the production system's design. They resulted in significant changes and improvements to the organization of the operators, their working procedures and the machinery.

The development of a new planning system is a complex task, which heavily relies on the distributed skills and domain knowledge of managers, planners, and operators. Two teams are set up to develop the new planning system. The design team addresses the design of the planning system, whereas main focus of the second team is on its implementation. The design team consists of the logistics manager of the plant, a representative of the lean team, the head of the supply-chain coordination group, the head of the detailed planning and scheduling group, one expert in production planning, one expert in discrete event simulation, and a project leader. The implementation team consists of foremen, planners, process engineers, and the project leader.

4.2 Benefits of Framework Integration – Case Examples

4.2.1 Project Overview – Distinguishing between Engineering and Simulation Modeling Activities

The design team decided that simulation should be adopted as a principal tool for decision support on the new planning system. Starting from simulation's perceived relevance for project outcomes, the project was largely set up like a simulation study. The initial phase may be characterized as conceptual modeling, thereby starting from the idea that the principles underlying cyclical planning may be an important basis for planning systems redesign.

Effectively, CM activities boiled down to solution engineering, in terms of the definition of a planning hierarchy, tasks and organization. Planning system design relied on a joint participative effort of the design team, being supported by analytic tools. The output of the CM phase concerned a design for the planning system, which was sufficiently valid/credible for implementation. Pruned simulation models were used to test logic of the conceptual model for correctness and completeness. In the next phase of the project – in parallel to planning system implementation – a coded simulation model was used to fine tune the proposed planning system.

The above example illustrates how simulation modeling and engineering activities are easily mixed up. This may be true both from the stakeholder perspective as well as that of the engineer/modeler. In principle, this does not have to be wrong. For example, the project was quite successful. However, we found that being unclear on the respective nature and contributions of simulation and engineering may impact stakeholder understanding of methods (simulation) and its expected benefits. May be that is most clearly expressed by stakeholders' questions like "when are we going to simulate", thereby suggesting non-adequate notice of significance of progress made on planning system design – both apart from and as a precursor to simulation.

Clearly, the idea of an unjustified all-in-one solution method should be avoided. A clear separation of engineering and simulation activities as in the integrated framework may help in "educating" the stakeholders' and modelers in the way simulation may fit in and support the engineering process. In turn this improves project overview, adequate use of methods, and the way stakeholders may contribute to and assess the project. Note how such "education" extends the notion of "managing stakeholder expectations" as suggested by Robinson (2008b), which essentially stresses outputs of the simulation study – as they may be expected by the stakeholders.

4.2.2 Aligning Engineering and Simulation Modeling Activities

Project progress is actively stimulated by the interdisciplinary design team. They formulate (and adapt) project objectives, and suggest/create solutions to questions faced in defining the planning system. Simulation is one of the tools for analyzing candidate designs (compare Section 4.2.1). While several planning system parameters may be considered decision variables, only a subset of these parameters, such as safety stock levels, are considered for simulation analysis. Choices are based on a jointly shared perspective on parameters' relevance for system performance.

As such the project set up typifies a broad class of projects. Advantages of framework integration are in a clarification of the interface between engineering and modeling activities (compare Figure 1). Inputs to CM are (a reduced) problem and (a restricted) set of solutions. The conceptual model serves as a linking pin, documenting an agreed upon format for model coding. Note how such an agreement is typically realized as a joint iterative effort bringing together a "customer perspective", as represented by an engineer starting from some problem and suggesting candidate solutions, and a "supplier", i.e., the analyst, seeking to serve the customer best, by trading off available resources and time for doing the simulation study, and decision support in terms of relevant insights that may be obtained in doing the study. Typically, such a trade-off is reflected in (a refined) choice of candidate solutions, model scope and its detail. Note how it may be wise to clearly identify reasons which force the need for a new iteration, see Table 2 (Process integration).

4.2.3 Model-Based Systems Engineering - a Common Language in Engineering and Modeling

System complexity forced a participative engineering approach in doing the project. Success of the approach heavily relied on a sound specification of candidate planning systems. For specifying candidate planning systems we made use of a reference architecture (Van der Zee and Van der Vorst 2005) allowing us to specify the overall system, i.e. the planning system and the (related) production system, using terminology appealing to all stakeholders. In terms of graphical overviews, and textual listings it offered insightful overviews of the planning system and its elements. As such it "organized" the creativity in the design process in a natural way. At the same time these specifications could be used for specifying conceptual model contents in a straightforward way.

A prime requirement for effective model use is stakeholder understanding. By suggesting the adoption of a common format for specifying both engineering designs and model contents, relevant gains are realized in terms of (1) modeling efficiencies and (2) stakeholder participation in solution creation, validation and testing. The choice for a single format is in line with the concept of model-based systems engineering, advocating the use of a common system model throughout the engineering process (Ramos et al. 2012).

5 CONCLUDING REMARKS

In this article we discussed the integration of simulation use in engineering projects. We considered the way conceptual modeling activities could be related to engineering activities. Based on four perspectives on integration (Thomas and Nejmeh 1998) we suggest changes to a well-known conceptual modeling framework (Robinson 2008b):

- Presentation integration suggests aligning formats for specifying engineering designs and simulation model contents. Familiar specifications may add to both modeling efficiencies, i.e., less modeling, and its effectiveness, i.e., solutions being created starting from joint understanding and acceptance. A joint reference architecture is of high relevance in realizing such benefits.
- Control (service) integration boils down to what extent activities are (1) required, (2) used, and (3) used in the appropriate way. We found how engineering and modeling activities may overlap. Such mixing up may both hurt project overview, and efficiencies. Note how this finding also relates to process integration, which among others, suggests a coherent decomposition of activities. Starting from both integration perspectives, the initial activity as suggested by Robinson, i.e., understanding the problem situation is clarified as "understanding the problem definition and candidate solutions". Furthermore, the definition of modeling objectives and choice of model inputs is related to the set of candidate solutions following from engineering activities.
- Process integration suggests a tuning of activities, next to a coherent decomposition of activities, see above. Starting from the idea of a conceptual model being a linking pin between engineering and modeling activities, triggers for a next iteration in conceptual model set up are captured.
- Data integration adds an overall perspective by suggesting a maintaining of consistent information.

The contributions in this article are meant to foster the discussion on the integrative use of simulation within engineering projects – where such discussion seems to be largely absent. We feel that starting from such a perspective may add to both modeling efficiencies and its effectiveness. Identifying, linking and aligning engineering and modeling activities – as suggested in this article – is to be considered instrumental in triggering a discussion, which may be, for example, further flavored by adding perspectives from computer science and statistics.

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