Toward overcoming accidental complexity in organisational decision-making

KULKARNI, Vinay, BARAT, Souvik, CLARK, Tony <http://orcid.org/0000-0003-3167-0739> and BARN, Balbir S.

Available from Sheffield Hallam University Research Archive (SHURA) at:

https://shura.shu.ac.uk/12463/

Citation:

Copyright and re-use policy

Toward Overcoming Accidental Complexity in Organisational Decision-Making

Vinay Kulkarni and Souvik Barat
Tata Consultancy Services Research
Pune, India
{vinay.vkulkarni, souvik.barat}@tcs.com

Tony Clark and Balbir Barn
Middlesex University
London, UK
{T.N.Clark, B.Barn}@mdx.ac.uk

Abstract—**This paper takes a practitioner's perspective on the problem of organisational decision-making. Industry practice follows a refinement based iterative method for organizational decision-making. However, existing enterprise modelling tools are not complete with respect to the needs of organizational decision-making. As a result, today, a decision maker is forced to use a chain of non-interoperable tools supporting paradigmatically diverse modelling languages with the onus of their co-ordinated use lying entirely on the decision maker. This paper argues the case for a model-based approach to overcome this accidental complexity. A bridge meta-model, specifying relationships across models created by individual tools, ensures integration and a method, describing *what* should be done *when* and *how*, and ensures better tool integration. Validation of the proposed solution using a case study is presented with current limitations and possible means of overcoming them outlined.**

Index Terms—**Organizational decision making, Enterprise modeling tools, Meta modelling, Method.**

I. INTRODUCTION

Modern enterprises are complex systems that need to respond to a variety of changes while operating in a dynamic environment. The cost of an erroneous response is prohibitively high and may possibly reduce subsequent options for change. Thus exploring alternative courses of action and arriving at best means of achieving organizational objectives is critical for business success[1,2]. Organizational decision-making processes evaluate possible alternatives by using the existing knowledge about the organization, its structure and available historic data, and finally predicts the best possible choice for a specific objective [1]. Large enterprises adopt an organizational structure involving multiple stakeholders for better management, control and decision-making [2,3,27]. These stakeholders play a specific role in a given organization structure and are responsible for specific functions related to strategic, tactical and operational aspects or a combination thereof. However, such structuring can

lead to undesirable side-effects such as scattered and fractured knowledge about goals, strategies, operational processes, *etc.,* [5, 6]. Coalescing these multiple heterogeneous distributed information fragments into a consistent integrated whole appears to be the key preparatory step in order to identify a holistic optimal response. Today the onus of executing this critical activity is largely on human experts who are expected to understand all relevant aspects and their relationships [1]. This is a huge challenge considering the size and complexity of modern enterprises [7,8]. As a result, decisions are arrived at based on partial information and tend, at best, to be optimal within that limited perspective. A sequence of such locally optimal responses may not lead to an optimal state for the enterprise as a whole.

Enterprise Modelling (EM) [18-26,29] aims to reduce dependence on human experts for organisational decision making by providing a wide spectrum of enterprise modelling languages[3]. However, the languages capable of modelling all relevant aspects (*e.g.*, the aspects suggested by Zachman in [29]) lack support for automated analysis. In contrast, languages providing automated support for qualitative and/or quantitative analyses are capable of modelling only one aspect of enterprise [9-11]. Therefore, a decision maker is forced to construct a tool-chain involving a large spectrum of EM tools and use them judiciously as advocated by a method. Paradigmatically diverse nature of modelling languages and non-interoperable nature of tools makes the task of constructing the desired tool-chain [12,17] an intellectually demanding endeavour [13] – the accidental complexity of organisational decision-making. It is one of the reasons why organisational decision making remains a time-, cost- and effort-intensive endeavour[1,4].

Given this context, this paper presents a model-based solution to reduce the accidental complexity. It begins with description of typical method industry practice deploys for organisational decision-making. Implementation of this method using three kinds of EM tools namely goal modelling [22], high level dynamics modelling [23], and operational processes modelling
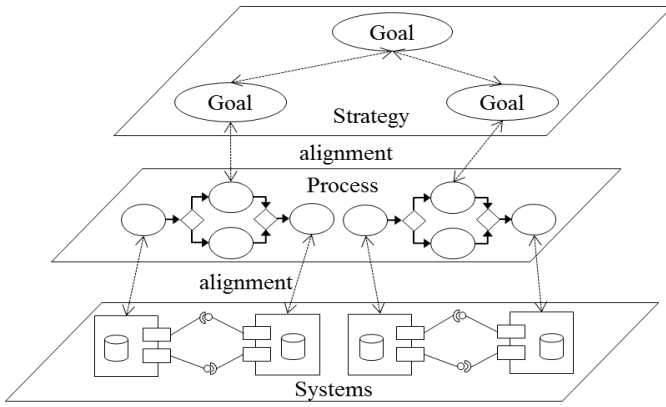

Fig. 1: Layers of organizational decision making

[21] is then described. We discuss limitations of such a tool-chain for effectively supporting organisational decision-making. We then present individual meta-models for the three tools, a bridge meta-model to integrate models created using individual tools, a method for step-by-step guidance for effecting integration, and argue how this leads to better integration of the three tools resulting in better traceability as well as change management. We evaluate the solution with a realistic example. The paper concludes by listing caveats and limitations of the proposed approach and future research to overcome them.

We look at the organizational decision-making problem from the practitioner's perspective. Our principal contributions are: a bridge meta-model for integrating goal and system dynamic models, and goal and business process models; a method for cogent use of goal modelling, system dynamic modelling, and business process modelling tools for effective decision-making; and evaluation of the proposed approach for industry use.

II. CURRENT PRACTICE

The general industry practice is to follow a refinement-based method (such as [16]) for organizational decision making [1,3] as shown in Fig. 1. It is guided by separation of the concerns principle, wherein at the onset the following questions may be asked: *What are the overall goals? Are there any dependencies between these goals? What are the means of achieving them? How do these means differ qualitatively and quantitatively?* Etc.

Typically, experts validate and rank solution alternatives based largely on past experience [1]. The limited details available at this stage means decision alternatives can at best be qualitatively differentiated [13]. However, decision makers need more certainty about the possible effects of choosing one alternative over the other, preferably in quantitative terms [14]. This leads to the next set of questions: *What are the measures? What are the levers influencing them? Are there any dependencies between the levers? etc.*

Experts use their experience in ranking alternatives. At this stage, the level of details available allows decision alternatives to be qualitatively as well as quantitatively differentiated. This gives

rise to options for strategies that organizations can use to achieve the desired objectives.

However, decision makers need to find ways to effectively implement a given strategy, while utilizing existing operational processes and systems as optimally as possible [1,3]. This phase of decision-making is often characterized by negotiations and trade-offs [30], with decision alternatives being qualitatively as well as quantitatively differentiated [15,16]. Thus, organizational decision-making is an iterative process, with the analytical focus constantly shifting across the three levels of: identifying goals; finding levers driving them; and determining choice of strategies until the desired solution is obtained.

III. SUPPORT AVAILABLE FOR IMPLEMENTING THE METHOD

An enterprise can be understood well by understanding *what* an enterprise is, *how* it operates and *why* it is so. It further provides clarity on organizational responsibilities by understanding the *who* (i.e. responsible stakeholders for *what*, *how*, and *why*) aspect of the organization. Therefore, information about the *why*, *what* and *how* aspects of enterprise from the perspective of every stakeholder (*i.e.,* the *who*) can be considered as necessary and sufficient for the purpose of decision making [11].

There exist languages such as Archimate [18], EEML [19] and IEM [20] that enable specification of multiple aspects in an integrated manner. Archimate visualizes an enterprise along three Aspects - Structural, Behavioural and Information, and three Levels – Business, Application and Technology; and IEM visualizes enterprise along two Aspects - Information and Process. These structured representations help to improve documentation quality but lack precise execution / simulation semantics and hence are not capable of supporting machine-assisted analysis techniques for decision-making. As a result, these frameworks are vulnerable to multiple interpretations and demand heavy involvement of human experts – a time-, cost-, and effort-intensive endeavour.

Modelling languages such as BPMN [21], i* [22] and stock-n-flow (SnF) [23] are machine processable but support modelling of one aspect only, for example, the process aspect can be modelled using BPMN, high level goals and objectives can be modelled using i*, and high level dynamics can be modelled using SnF. Amongst these machine processable languages, i* supports only qualitative analysis whereas BPMN and SnF support only quantitative analysis. There are language-specific peculiarities / limitations too: SnF modelling tools such as iThink[5] and Simantics[6] come with a rich simulation machinery supporting what-if simulation, however, the language is best suited for creating generic models which explode in size when specialized; several BPMN tools such as ARIS[7] and Bizagi[8]
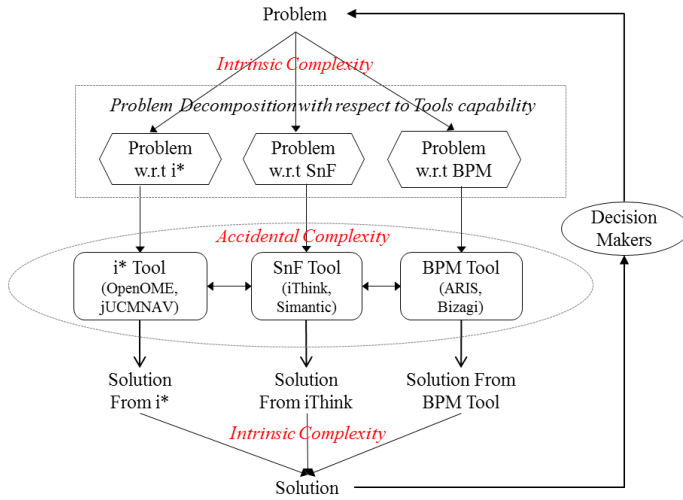
---

[5] http://www.iseesystems.com/Softwares/Business/ithinkSoftware.aspx

[6] www.simantics.org/

[7] http://www.softwareag.com/corporate/products/aris/default.asp

Figure 2: Organisational decision-making using existing modeling and analysis tools

Fig 3. Conceptual meta model of current practice of decision making

support what-if simulation but only in terms of time and resource parameters. Moreover, the three languages being paradigmatically diverse, it is difficult to integrate individual specifications in a meaningful manner [5,6 and 9], for example, support available for specifying relationships across these aspects in AnyLogic[9] is little more than setting up navigation links from one specification to the other.

Limited work is reported on integration of multiple languages each catering to one aspect of enterprise. The Unified Enterprise Modelling Language (UEML) [24] initiative aims to integrate existing Enterprise Modelling Languages using a meta-modelling framework. This is an ongoing initiative [25] with first version of the UEML demonstrating integration of IEM, EEML and GRAI [26] supported by MOOGO[10] and METIS[11].

Thus it can be said that in the absence of a single language capable of specifying all aspects of enterprise necessary for decision making [5,6,9], the only recourse available is to use a wide spectrum of modelling and analysis tools covering the necessary modelling and analysis needs. For example, one can choose the combination of i*, SnF and BPMN for modelling respectively goal, strategy, business process aspects of the organization. However, as each of these tools can model only a partial view, decision maker needs to break down the problem into sub-problems each addressable using one tool as shown in Fig 2. Partial solutions obtainable from separate tools need to be judiciously integrated into a consistent whole. Overlapping specifications, inability to set up relationships across specifications, and non-interoperable nature of tools are principal contributors to this accidental complexity. Today, industry
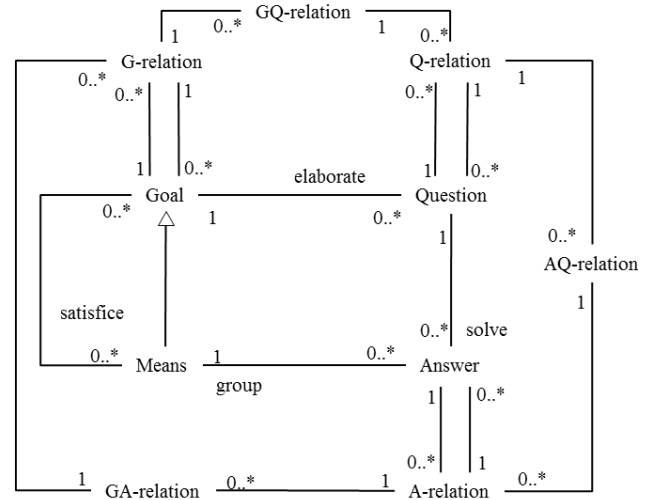
practice relies upon an expert team comprising domain and tool experts to overcome the accidental complexity. Apart from being time-, cost- and effort-intensive endeavour this approach hasn't met with much success[12] either.

IV. PROPOSED SOLUTION

Current industry practice of organisational decision-making can be abstracted to the meta-model shown in Fig. 3. A high level goal is elaborated in terms of a set of specific questions to be answered qualitatively and/or quantitatively. A specific question can have multiple answers each a better fit than others in a specific context. A set of answers along with the specific contexts identify a high level means for achieving a specific goal. Thus, we can impose an order on carrying out these tasks leading to a method. A means of achieving a goal can be seen as a 'goal' for a more refined level of decision-making. This enables the method of decision making to take place at multiple levels of detail leading to decisions at varying level of coarseness.

Interference of goals, questions and answers further complicate the decision-making process. Interference could be of multiple kinds. For instance, answering a question may result in some other question[s] becoming null-and-void, or an answer to a question may necessitate some other question[s] to be answered, or a partial order may be imposed on questions. On similar lines, addressing a goal may amount to some other goal[s] being addressed, or the way a goal is addressed may necessitate some other goal[s] to be addressed in a certain way, or a partial order may get imposed on addressing goals. Also, qualitative and/or quantitative nature of an answer may make a goal infeasible in practice therefore leading to its re-definition through a negotiation process. Thus, the focus of a decision-making process
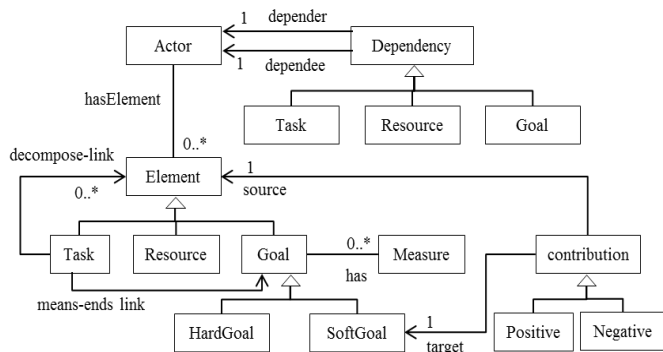
Fig. 4: Meta model of core i*

Fig. 5: Meta model of essential Stock-and-Flow concepts

keeps shifting from goals to questions to answers with multiple loop-backs to goals/questions/answers.

Existing practice relies entirely on human experts for doing the right things, in the right order, and the right way. Typically, the available help is limited to documented guidelines and best practices for using a tool independently. Though human centricity cannot be removed, there is a definite need to reduce excessive burden on human experts. We propose meta-model maps as a solution for an integrated use of existing EM tools. We consider a tool-chain comprising i* (for goal modelling), iThink (for SnF modelling) and Bizagi (for BPMN modelling) tools. We present individual meta-models for the three tools and a bridge meta-model to establish relationships that cut across specifications created by individual tools thus enabling automatic validation of related models for consistency and well-formedness. Significantly, this is an advance over state of practice where tools like AnyLogic[9] provide only navigable links from one specification to the other. Bridge meta-models enable logical integration of models created using i*, iThink and Bizagi models which can add further value if the three models are refined in terms of additional links to an ontology.

A. Individual meta-models

Meta-model of core i*: The i* model describes the intentional characteristics of the organizational entities or Actors [22]. How an Actor is achieving/can achieve its goals by leveraging its beliefs and abilities in a static context is the primary focus of i* model. The meta-model for describing i* model consists of four basic elements – *Actor*, *Goal*, *Task* and *Resource*. An Actor is an agent-oriented concept [28] that represents an active intentional entity; Goal represents the intentional desires of the actor; Task is an activity that an actor performs for achieving its desires; and a Resource is an intentional object that describes the finished product or service [22]. There are two kinds of goals namely *Hardgoal* and *Softgoal*. The former can be expressed quantitatively whereas the latter only qualitatively. *Strategic dependency* is an inter-actor relationship that describes dependence of an actor on other for Resource or achieving Goal or accomplishing Task. *Strategic rationale* is a relationship between *Elements* of an Actor. It can
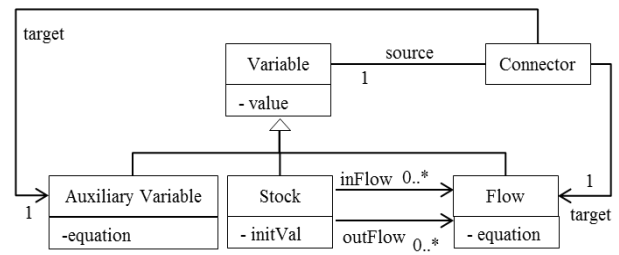
be one of the three kinds namely, *decomposition* link, *means-ends* link and *contribution* link. The decomposition link decomposes a Task into multiple Elements (*i.e.,* Goal, Task or Resource); the means-ends link identifies task providing means for achieving a goal, and the contribution link encodes impact of an element towards achieving a Softgoal in positive or negative sense. For instance, *Make*, *Some+*, and *Help* links denote positive contribution whereas *Break*, *Some-* and *Hurt* denote negative contribution to the target Softgoal. There are two kinds of decomposition links namely, AND-decomposition and OR-decomposition. Thus, meta model shown in Fig 4 constitutes a language to: Decompose a goal successively into sub-goals; Specify alternate means of achieving leaf-level goals; Encode their influence on Softgoals; and Capture interference amongst goals in terms of a dependence relation. Given such specification, propagation algorithms [31,32] exist to establish how well a goal can be (/ has been) achieved in qualitative terms.

Stock-and-Flow meta-model: The Stock-and-Flow model [23] describes high-level aggregated view of the system that emphasizes dynamic interactions between the constituent parts of the system over time. This also considers the impacts of feedback loops in system interactions. The meta-model comprises two principal elements namely *Stock* and *Flow* where Stock is a reservoir that represents state value of a system element and Flow is the element that controls change rate of a Stock. The value of a Stock changes over time based on the rate of in and out Flows. *Auxiliary Variable* is a temporary variable for computation purpose. *Connector* represents a function having Variable as its domain with Auxiliary Variable and Flow as the range. The *inflow* and *outflow* respectively represent positive and negative impact of a variable on a Stock. Fig 5 depicts stock-n-flow meta
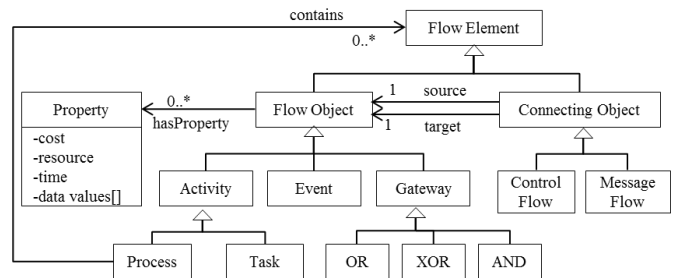

Fig. 6: Meta model of essential business process model elements

model.

Business process meta-model: Business process model describes the behaviour of the system or organizational unit. Business process meta model essentially describes the flow of activities and events [21]. The core element, Flow Element, is specialized into two kinds – Flow Object and Connecting Object as shown in Fig 6. The Flow Object is further classified into three kinds of elements – Activity, Event and Gateway. Activity describes the primitive or composite task of an organization. A complete and meaningful composition is termed as Process. Event is a meaningful phenomenon that occurred within or outside organization. Gateway is an element that helps to specify different kinds of join points namely, AND, OR and XOR. The Connecting Object describes the control flow and data flow of Flow Objects.

B. Bridge meta-model

Goal and Means are two key concepts that emerge from Fig. 3. A Goal is a condition or state that an organization would like achieve and the Means is a plan or a strategy that may satisfy a Goal. As decision-making process takes place at multiple levels, a Means at one level is a Goal for its lower level. This Goal-Means pattern of organizational decision making is depicted in Fig 7 with "DM::" prefix. We use this pattern to establish the relationships across the meta-models of Fig 4, 5 and 6.

In the i* meta-model (see Fig. 4), as *Goal* describes the condition or states of organizational elements we associate this Goal (represented as i*::Goal) with (DM::Goal) using an "isA" relationship. The i*::Task represents the possible means that satisfies the i*::Hardgoal using *means-ends link*. Further, an i*::Task can be decomposed into many i*::Elements (*i.e.,* i*::*Task*, i*::*Resource* and i*::*Goal*) using *AND/OR decomposition link*. Thus we infer an i*::*Goal* can indirectly be decomposed into many (sub-) i*::Goals, (sub-) i*::Tasks, and i*::Resources where these (sub-) i*::*Elements* qualitatively contribute to a (parent-) i*::*Goal*. Similarly a set of i*::Elements
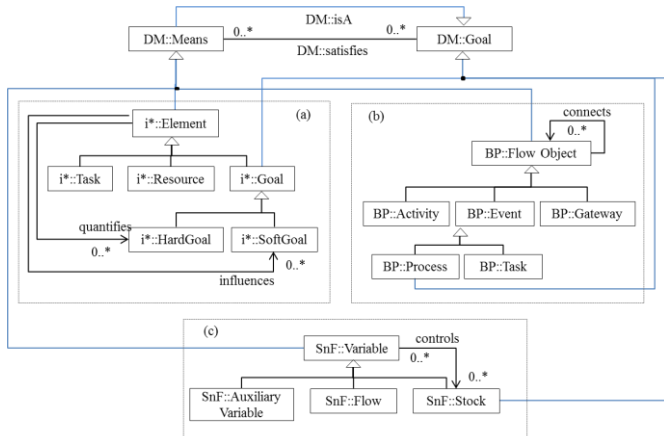

Fig. 7: Bridge meta model of i*, SnF and business process for organisational decision-making

influence an i*::Softgoal using *contribution-link*. In organizational decision making context we visualize this relation as i*::Elements qualitatively influencing to i*::Softgoal. With this conceptualization, we relate i*::Element to DM::Means. This conceptualization is summarized in Fig. 5a. The intermediate i*::Goals which are not in root or leaf of i* specification act as DM::Means. This realizes the DM::Means "isA" DM::Goal relationship.

In the Stock-and-Flow meta-model, the SnF::*Stocks* represents the state affairs and SnF::*Flows* represents the possible means for changing the state of a SnF::*Stock*. As shown in Fig. 4, the SnF::*Variables* (in particular SnF::*Stock* values, SnF::*Auxiliary Variables* and SnF::*Flow* of other SnF::*Stocks*) can determine the inflow and outflow of a SnF::*Stock*. Thus, we infer that SnF::*Stock* represents DM::*Goal* and SnF::*Variables* represents DM::*Means*. This conceptualization is shown in Fig. 7b.

A Business Process model essentially deals with the BP::*Activities* and their orders. Business process specification and meta-models that describe business process models are not capable of specifying the intentional aspect of an organization. We visualize a BP::*Process* as the intent of the process specification. Thus we conceptualize BP::*Process* as the DM::*Goal* and the specification of BP::Tasks, BP::Events and BP::Gateways of a BP::Process are the DM::*Means*. This conceptualization is depicted in Fig. 7c. The existence of sub-Process within a BP::Process is the realization of DM::Means "isA" DM::Goal relationship.

Table 1: Guideline for using specific models

Model	Question Type	Example
i* model	1. Question on high-level business strategy that depends on qualitative analysis. 2. Questions that are based on static algorithmic computation	What could be the possible means to secure a leadership position for an organization?
Stock and Flow	1. Questions on operational strategy that involves quantitative and temporal analysis 2. Questions that are based on aggregated behaviour of an organization	What could be the impact of high attrition of an organization? What is the impact when attrition is 10% and 15% respectively?
Business Process	1. Question on individualistic behaviours 2. Question on operational data or infrastructure	Probability of schedule slippage for a kind of delivery project

C. Application

Organisational decision-making process starts with a high level goal. The questions on high-level goals and their answers identify high level means for achieving the goal. Further questioning on identified Means (considering them as Goal) result into further elaboration and decomposition. Recursive application of this question-answer iteration over goals and means leads to a meaningful decision as illustrated in Fig. 1. We use i*, SnF and business process models to represent the relevant part of the organization for answering specific questions. The guiding principal for using i*, SnF and business process model is illustrated in Table 1.

Essentially, a decision making process starts with i* model for representing, analysing and elaborating enterprise goals and their high-level means. We find the forward evaluation and backward evaluation of i* model [31,32] to be capable of answering questions related to exploration of alternative means and their qualitative comparison. The focus of a decision-making process needs to shift from i* model to SnF model in order to perform precise quantitative and temporal analyses. The focus needs to shift to business process model for answering questions pertaining to operationalization details. This shift of focus necessitates creation of relevant destination models guided by the source model and the specific analysis need. A fixed point of this iterative process is the creation of i*, SnF and BPMN models that are necessary and sufficient for data-driven simulation-based solution to the specific decision-making problem. Table 2 is a compilation of mappings between the various meta-models namely, i*-SnF, i*-BPMN, and SnF-BPMN. We use Goal-Means pattern and associated mappings described in Fig. 7 as the basis for defining these mapping rules.

Table 2: Mapping Rules

| Source meta model	Target meta model
i* Model Element	*SnF Model Element*
Goal	Stock
Goal that quantify or influence other Goal- i.e., Goal belongs to i*::Element that "isA" DM::Means	Stock with a Flow. The kind of quantification and influence decides the Flow type, i.e., inflow or outflow
Goal that describes the computation of other Goals	Auxiliary Variable
Task	Flow
Task with parametric behaviour	Flow with an Auxiliary variable. Auxiliary variable is connected to Flow using Connector.
Resource	Auxiliary variable
Positive Contribution (association)	Inflow
Negative Contribution (association)	Outflow
AND-OR decomposition (association)	Connector
Dependency (association)	Connector
i* Model Element	*Business Process Model Element*
Goal	Process
Goal that quantify or influence other Goal- i.e., Goal belongs to i*::Element that "isA" DM::Means	Sub-Process
Task that performs by organization	Task
Task that happens outside of an organization	Event
Resource	Properties of a Process or sub Process
AND-OR decomposition (association)	Gateway
Dependency (association)	Connecting Object
SnF Model Element	*Business Process Model Element*
Stock	Activity (Process, Sub process or task)
Flow	Task
Auxiliary variable	Task with an Event
Inflow (relationship)	Connecting Object
Outflow (relationship)	Connecting Object
Connector	Connecting Object
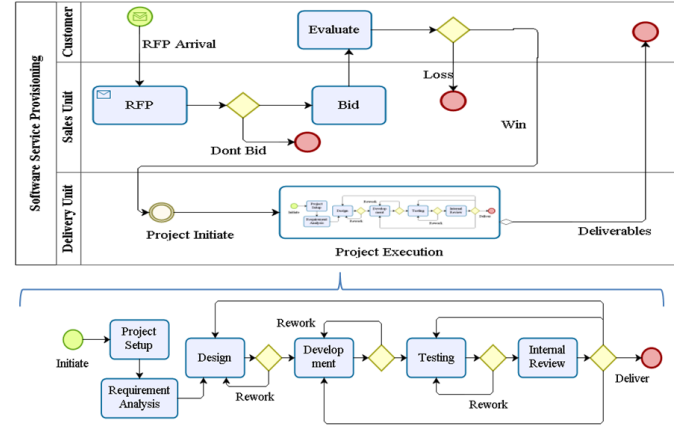
Fig. 8 Responsibility of Sales and Delivery Units

Business process Model Element	SnF Model Element
Task	Stock with an inflow Flow
Event	Auxiliary variable with Connector
Gateway	Auxiliary variable with Flows
Control Flow between Task and Task	outflow
Control Flow between Event and Activity	Connector

V. VALIDATION

A. Case Study

Consider a software service-provisioning organisation that earns revenue by developing bespoke software for its customers. The organisation bids for software projects in response to request for proposals (RFPs). Once a bid is won, the organisation initiates and executes projects using a tried-and-tested process leading to successful delivery. This business as usual (BAU) scenario is driven by a set of goals that are accomplished through a set of business processes implemented by agents conforming to a given organization structure. The organisation internally comprises of four units namely, Sales, Delivery, Resource management and Account where each unit has dedicated responsibilities for achieving the overall goal of "Secure Leadership Position". Business process model of Fig 8 depicts the responsibilities of Sales and Delivery units.

B. Decision-Making

The decision-making process starts with an i* model having a root goal "Secure Leadership Position". The root goal is elaborated through a question-answer based method into more Goals (each more precise than the root goal) with several alternate Means of achieving them made explicit. For example, we consider questions such as: *What are the various strategies the organization can consider for securing leadership position? How can they be measured? What are the influencing factors for implementing a candidate strategy? Who will be responsible for implementing a candidate strategy?*

Fig 9 shows elaborated i* model where "Improve Customer Satisfaction", "Increase Business Volume" and "Improve profit Margin" constitute first-level elaboration of the root goal "Secure Leadership Position" (which is marked with blue colour). Further questions lead to further elaboration, for example, "Increase Win Rate" is identified as a Means for realizing elaborated Goal "Increase Business Volume"; the "Increase Customer Satisfaction" sub-goal is dependent on Softgoal "Project Delivery" which is further influenced by a Softgoal "Resource Demand" where "Resource Demand" could be managed by two Means ("Increase Resource Strength" and "Increase resource Skill"). The "Improve Profit Margin" is dependent on the Softgoal "Profitability" which is then refined into sub-goals ("Revenue" and "Expenses") along with identification of possible means for achieving the two. The model depicted in Fig. 9 is essentially an instance of meta-model depicted in Fig. 4. The leaf level Means, marked with green colour in Fig. 9, influence intermediate sub-goals and through these sub-goals the root goal as conceptualized in Fig. 7a.

Iterative analysis of this i* model provides a qualitative insight into the possible impact (*i.e., influence* and *quantify* relationships of Fig. 7a) of a Means on various sub-goals that eventually percolates to the root goal. Table 3 depicts the impact of three leaf Means (i.e., "Increase Win Rate", "Increase Resource Strength" and "Increase Resource Skill") on selected sub-goals and goals. Table also depicts the analysis results of using Means "Increase Win Rate" and "Increase Resource Strength" together. For instance, The Mean "Increase Win Rate" will: i) positively impact "Improve Business Volume", "Revenue", "Expense" and "Late Delivery" goals, ii) Negatively impact "Improve Customer Satisfaction" goal, and iii) is inconclusive about "Profitability" goal. Thus, nothing conclusively can be said about the impact of this Means on the root Goal.

Table 3. Qualitative Analysis using i* model

| | Means | Goals and sub-goals (Symbols: Satisfied ✓, Partially Satisfied ✔, Partially Denied ⚡, Conflict ✎) | | | | | | Root Goal |
		Increase Business Volume	Revenue	Expenses	Profitability	Late Delivery	Improve Customer Satisfaction	Secure Leadership Position
1	Increase Win Rate	✓	✓	✓	✎ SnF1	✓	⚡	✎
2	Increase Resource Strength	-	-	✓	⚡	⚡	✔	✎
3	Increase Resource Skill	-	-	✓	⚡	⚡	✔	✎
3	M1+ M2	✓	✓	✓	✎ SnF2	✎ BP	✎	✎

Table 3 clearly identifies which decision points are left unaddressed. Moreover, decision maker would like to have a quantitative feel for some of the qualitatively arrived at decisions.

This constitutes the next step of decision-making. The next step uses either SnF or BPMN models for answering specific questions that require quantitative analysis or justification. We use iThink and Bizagi for SnF and BPMN modelling and simulation respectively - which model to use when is described in Table 1. For example, the decision points SnF1 and SnF2 of Table 3 are addressed using SnF models as they require quantitative and temporal analysis on aggregated business operations to understand when overall "Revenue" may supersede the overall "Expenses". On the other hand, the decision point BP is addressed using business process model as it requires simulation of operational processes to understand the percentage of (individual) projects that may get delayed due to delays in "Project Setup", multiple iterations due to "Rework" in "Project Execution" business process (see Fig. 8), etc.
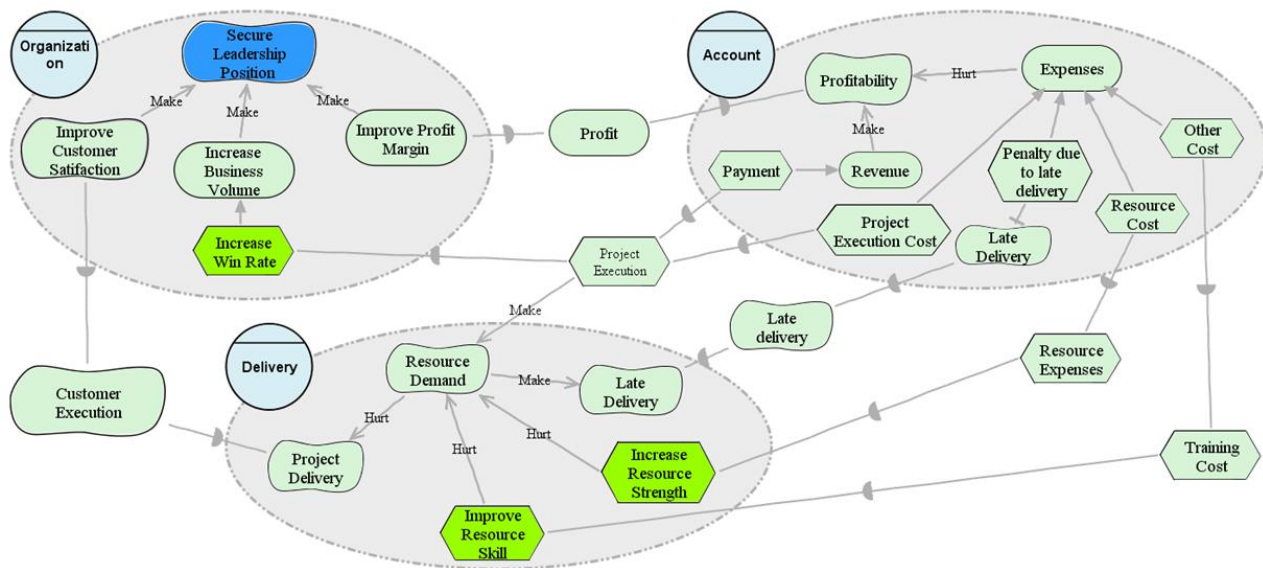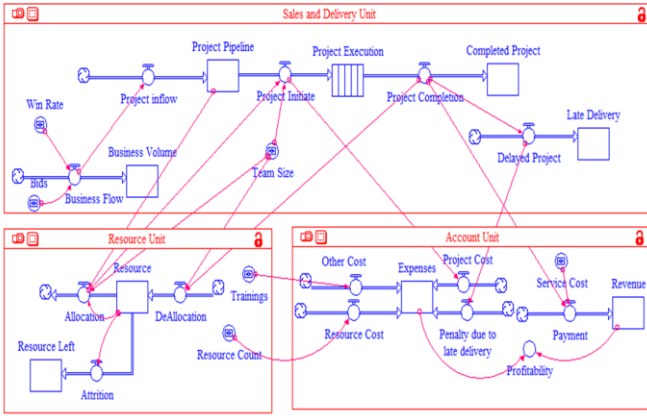

Fig. 9. Elaborated i* model

Fig. 10. Corresponding SnF Model

We construct a SnF model to answer SnF1 and SnF2 decision points and use business process model depicted in Fig 6 to answer BP decision point. The construction makes use of mapping rules described in Table 2 where the questions and context required to answer the questions determine the model to be constructed. Fig 10 depicts SnF model necessary and sufficient to answer SnF1 and SnF2 decision points.

Constructed SnF model (depicted in Fig 10) focuses on the "Profitability" goal of i* model depicted in Fig 9. The "Profitability" goal is represented using "Profitability" Auxiliary variable within Account Unit of SnF model. The "Revenue" and "Expenses" goals are represented using "Revenue" and "Expenses" Stocks in SnF model. The Tasks that contribute to "Revenue" and "Expenses" Goals using means-ends links are represented using inflow Flows. For example, "Payment" is represented using "Payment" Flow to "Revenue" Stock. The rest of the model is created by navigating back to the dependent Goals and Means. For example, the impact of "Increase Win Rate" Task of i* model is represented using "Win Rate" Auxiliary variable and subsequent Stock, Flows and Connectors; the path "Increase Win Rate" and "Increase Business Volume" is represented using "Win Rate" Auxiliary variable, "Business Flow" inflow and "Business Volume" Stock. The "Project Execution" Task of i* model is a complex activity and hence expanded further while constructing the SnF model. The expansion is illustrated using Stock-and-Flow path "Project inflow" Flow to "Completed Project" Stock. The project associated delays and the penalty due to late delivery is considered using "Delayed Project" Flow, "Late delivery" Stock and connectors. Simulation of constructed SnF model with suitable data leads to quantitative and temporal analysis of "Increase Win Rate" Means on "Profitability" Goal (i.e., SnF1). The result is shown using a graph in Fig. 11a. Similarly, impact of "Increase Win Rate" and "Increase Resource Strength" Means together on "Profitability" goal is shown in Fig. 11b. As can be seen from Fig 11, Profitability drops initially but improves over time leading to positive impact for both the alternatives. If unsatisfactory, one can keep on modifying value of the Auxiliary variable "Resource Count" to evaluate the impact of 'Increase
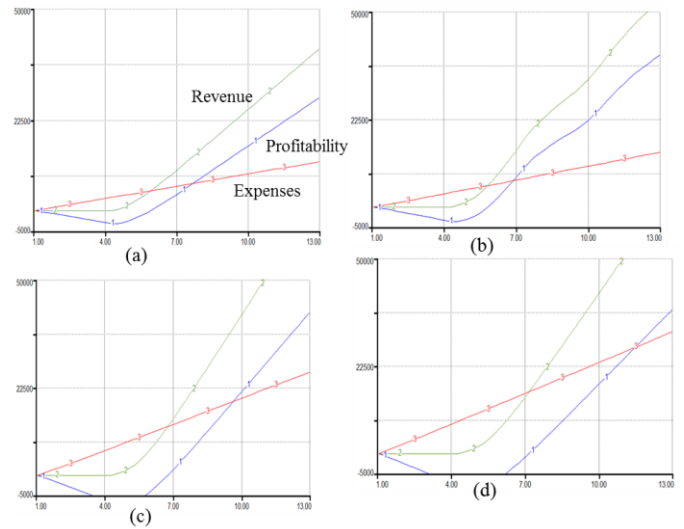

Fig. 11. Quantitative analysis using Stock-and-Flow model for profitability

Resource Strength' Means in this combination - Fig. 11c and 11d depict such iteration. Such iterative loop helps to identify locally optimal solution. On the other hand the simulation of business process depicted in Fig 8 provides insight about BP decision point. Simulation result shows "Late Delivery" reduces to an extent with "Increase Resource Strength" with reduction in delays in "Project Initiate" task and reinitiating tasks that traverse through "Rework" loop. Thus we conclude the goal "Improve Customer Satisfaction" improves with "Increase Resource Strength" in M1 + M2 combination of table 3. Similarly one can explore M1+M2+ M3 option together with varying "Resource Count" to finalize the best possible option. There could be many such iterations over SnF and business process model simulations considering i* models as navigation aid for exploring options to reach a satisfactory answer for "Secure Leadership Position" goal.

C.   Evaluation

Though tasks that need to be accomplished are fairly well-known, organisational decision-making is today largely a human intensive endeavour. Enterprise modelling tools aim to provide automation support to one or many tasks, for instance, i* enables elaboration of high level goal into constituent sub-goals and alternate means of achieving a sub-goal, iThink enables quantitative simulation of a stock-n-flow model etc. However, there is no single EM tool capable of supporting all tasks. As a result, several EM tools need to use in a cogent manner – onus of which lies entirely with the decision maker. This is a cost-, time- and effort-intensive activity.

Recent tools and techniques such as AnyLogic and AA4MM try to solve this problem by adopting a multi-modelling and co-simulation approach. For example, AnyLogic offers Stock-and-Flow [23] and State Chart[13] based analyses using Discrete Event

---

[13] http://doc.omg.org/formal/2009-02-02.pdf

Simulation [34] as mediating protocol. The AA4MM [12] provides a multi-modelling and co-simulation framework that integrates multiple agents with heterogeneous models and different formalism-based simulation environment. Concepts of different formalisms are related with the DEVS [35] formalism and interactions with agents are established through an Agents and Artifacts (A&A) paradigm [36]. Although there is some success in managing accidental complexity, their focus is on integrating multiple tools by correlating their inputs and outputs. On the other hand, relevant initiatives for establishing interoperability of two languages, such as semantic integration of goal and process modelling [37] and integration of system dynamic and business process modelling [38], focus on the novelty of model to model transformation rather than applying them in organizational decision making problem.

Our proposed solution is a step towards reducing time, cost and effort of decision-making by helping human decision maker through better integrated use of existing EM tools. The method provides a discipline – *what* needs to be done *when* and using *which* tool. Along with the bridge meta-model, the method helps in creating optimal models as the fixed point of an iterative process. This certainty is a definite plus for practitioners especially considering size and complexity of modern enterprises. Table 4 encapsulates advantages of using the proposed approach over current state of practice.

Table 4. Improvement in state of practice

Tasks in organizational decision making process	Current practice	Automation using existing EM tools	integrated use of existing EM tools
Specify goals	Manual	Tool (i*)	Tool (i*)
Elaborate each goal into a set of questions	Manual	Manual	Manual
Specify questions	Manual	Tool (i*, iThink, Bizagi)	Tool (i*, iThink, Bizagi)
Identify possible answers for a question	Manual	Manual	Manual with tool-aided guidance
Find answer to a question in a specific context	Manual	Tool (i*, iThink, Bizagi)	Tool (i*, iThink, Bizagi)
Group a set of questions and a set of answers into a means	Manual	Manual	Manual with tool-aided guidance
Evaluate a means	Manual	Manual	Manual
Identify feasible means for achieving a specific goal	Manual	Manual	Manual with tool-aided guidance

VI. CONCLUSIONS AND FUTURE WORK

This research is being undertaken by research lab of organization in the business of offering software, processes and technology consultancy[14]. It is becoming increasingly apparent that coming up with the right decision and demonstrating its likely efficacy is much more important and harder than developing IT systems that support implementation of the decision. We described a typical method that industrial practice deploys for organisational decision-making. We identified

limitations of existing EM tools for effectively supporting this method and have presented a bridge meta-model to overcome some of these limitations. Our approach has been validated using a realistic a case study.

Our view is that existing model driven engineering technology suffices to implement the proposed solution and going forward we intend to focus on key research and practice issues of robustness, scalability and usability of tooling infrastructure. We anticipate that once these areas have been addressed, the ensuing a toolset will provide many benefits to practitioners such as: Goal modelling, stock-n-flow modelling and process modelling tools being used in a better integrated manner; reduction in the current excessive reliance on human experts for doing the right things in the right order and the right way and how an automated method can impart enhanced certainty to decision-making process.

Current SBVR[15] related technology provides unifying semantics to the three models and check them for conformance and so already provides a significant advance over current state of practice that relies on human experts. Our proposal of the use bridge meta models enhances this capability by providing a technical infrastructure that can also lead to better traceability as well as change management.

Our experience from this work indicates that the limitations of the proposed solution are rooted in modelling, model organising and model analysis capabilities of existing EM tools. Thus, the solution aims for better integrated use of existing EM tools without trying to overcome their fundamental limitations. Though the proposal reduces dependence on human experts to an extent, several challenges remain unaddressed.

Practitioners prefer ready-to-use solution for a specific problem. They demand seamless integration of tools wherein results of simulation performed using one tool can be fed as input to the other tool, results of co-simulation of multiple tools can be collated in a purpose-specific visualisation, etc. Paradigmatically diverse modelling language and non-interoperable tools are major impediments for such seamless integration. Thus we conclude by asking: Is a single language capable of specifying all the relevant aspects of enterprise in a simulatable manner the right answer?

REFERENCES

[1] Zur Shapira. Organizational Decision Making. Part of Cambridge Series on Judgment and Decision Making, 2002. ISBN: 9780521890502

[2] Parsons, Talcott, and I. Jones. Structure and process in modern societies. Vol. 3. New York: Free Press, 1960.

[3] Daft, Richard L. Organizational Theory and Design. Cincinnati, Southwestern College Publishing: 1996.

---

[14] www.tcs.com/about/research/research_areas/software/Pages/Model-Driven-Organization.aspx

[15] http:// www.omg.org/spec/SBVR/1.2/

[4] Raymond E. Miles, Charles Curtis Snow: Organizational Strategy, Structure, and Process. ISBN 080474839X, 9780804748391 Stanford University Press, 1978.

[5] David Chen, Guy Doumeingts, François B. Vernadat: Architectures for enterprise integration and interoperability: Past, present and future. Computers in Industry 59(7): 647-659 (2008)

[6] Fox, M.S. , Issues in Enterprise Modelling, Proceedings of the IEEE Conference on Systems, Man and Cybernetics , IEEE. 1993.

[7] McDermott, T.; Rouse, W.; Goodman, S.; Loper, M.; Multi-level Modeling of Complex Socio-Technical Systems. Conference on Systems Engineering Research (CSER'13). 2013

[8] David W. Conrath: Organizational Decision Making Behavior under Varying Conditions of Uncertainty. Management Science Vol. 13, No. 8, Series B, Managerial (Apr., 1967), pp. B487-B500

[9] Joseph Barjis. Enterprise, organization, modeling, simulation: putting pieces together. Proceeding of EOMAS, 2008.

[10] Joseph Barjis and Alexander Verbraeck. The relevance of modeling and simulation in enterprise and organizational study. In Enterprise and Organizational Modeling and Simulation, pages 15-26. Springer, 2010.

[11] Balbir S. Barn, Tony Clark, Vinay Kulkarni: Next Generation Enterprise Modelling - The Role of Organizational Theory and Multi-Agent Systems. ICSOFT EA 2014: 482-487

[12] Benjamin Camus, Christine Bourjot, Vincent Chevrier. Combining DEVS with Multi-agent Concepts to Design and Simulate Multi-models of Complex Systems. 2015. <hal-01103892>

[13] Caroline M. Sipp, Carayannis Elias. Real Options and Strategic Technology Venturing: A New Paradigm in Decision Making. Nov 27, 2012.

[14] Anderson, D.R., D.J. Sweeney and T.A. Williams An Introduction to Management Science: Quantitative Approaches to Decision Making. (South-Western Publishing)

[15] Cyert, Richard; March, James G. A Behavioral Theory of the Firm (2 ed.). Wiley-Blackwell. ISBN 0-631-17451-6. 1992.

[16] Mintzberg, H., Raisinghani, D., & Theoret, A. (1976). The structure of unstructured decision processes. Administrative Science Quarterly, 21, 246-275

[17] Julien Siebert, Laurent Ciarletta, Vincent Chevrier. Agents and artefacts for multiple models co-evolution. Building complex system simulation as a set of interacting models. Proc. of 9th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2010) , pp. 509-516

[18] Iacob M, et al. State of the art in architecture support, ArchiMate deliverable D3.1. Enschede, The Netherlands: Telematica Instituut; 2003.

[19] John Krogstie (2008) Using EEML for Combined Goal and Process Oriented Modeling: A Case Study. IDI, NTNU,Trondheim, Norway. Proceedings of EMMSAD 2008.

[20] Peter Bernus ; Mertins, K. ; Schmidt, G. (2006). Handbook on architectures of information systems. Berlin : Springer, 2006, ISBN 3-540-64453-9, Second Edition 2006

[21] OMG Document, Business Process Model and Notation, http://www.omg.org/spec/BPMN/2.0/, formal/2011-01-03, January 2011.

[22] Eric Yu, Markus Strohmaier, and Xiaoxue Deng. Exploring intentional modeling and analysis for enterprise architecture. EDOCW'06. 10th IEEE International, IEEE, 2006

[23] Donella H Meadows. Thinking in systems: A primer. Chelsea Green Publishing, 2008.

[24] F Vernadat., "UEML: towards a unified enterprise modelling language". In: Int. J. Production Research, 40 (17), 4309-4321. 2002

[25] Andreas L. Opdahl, Giuseppe Berio. A Roadmap for UEML. I-ESA 2006, 2006, France. pp.2, 2006. <hal-00488758>

[26] Guy Doumeingts, David Chen, Bruno Vallespir, P. Fénié, François Marcotte: GIM (GRAI Integrated Methodology) and its Evolutions - A Methodology to Design and Specify Advanced Manufacturing Systems. DIISM 1993: 101-120

[27] Halleux, P., Mathieu, L., Andersson, B., A Method to Support the Alignment of Business Models and Goal Models, BUSITAL'08, CEUR Workshop Proceedings, Vol. 336 (2008)

[28] Bresciani, P., Perini, A., Giorgini, P., Giunchiglia, F., Mylopoulos, J., Tropos: An Agent-Oriented Software Development Methodology, Autonomous Agents and Multi-Agent Systems (2004)

[29] John A Zachman. "A framework for information systems architecture." IBM systems journal, 26(3):276-292, 1987.

[30] Tim Hartnett. Consensus Decision Making. New Society Publishers, 2011

[31] Jennifer Horkoff, Yijun Yu, Eric S. K. Yu. OpenOME: An Open-source Goal and Agent-Oriented Model Drawing and Analysis Tool. iStar 2011: 154-156

[32] Jennifer Horkoff, Eric S. K. Yu. Finding Solutions in Goal Models: An Interactive Backward Reasoning Approach. ER 2010: 59-75

[33] Roland W. Ettema, Jan L. G. Dietz: ArchiMate and DEMO - Mates to Date?. CIAO! EOMAS 2009: 172-186

[34] Law, Averill M., and Kelton, W. David. Simulation Modeling and Analysis (1991:McGraw-Hill, Inc. New York)

[35] Zeigler, B., Praehofer, H., and Kim, T. Theory of Modeling and Simulation: Integrating Discrete Event and Continuous Complex Dynamic Systems. Academic Press, 2000.

[36] Ricci, A., Viroli, M., and Omicini, A. Give agents their artifacts: the A&A approach for engineering working environments in MAS. In Proceedings of the 6th international joint conference on Autonomous agents and multiagent systems, AAMAS, ACM (2007).

[37] E. C. S. Cardoso, P. S. Santos Jr., J. P. A. Almeida, R. S. S. Guizzardi, and G. Guizzardi, "Semantic Integration of Goal and Business Process Modelling, " IFIP: International Conference on Research and Practical Issues of Enterprise Information Systems (CONFENIS 2010), 2010.

[38] P. Fiona Tulinayo, Stijn Hoppenbrouwers, Patrick van Bommel, Henderik Alex Proper: Integrating System Dynamics with Object-Role Modeling and Petri Nets. EMISA 2009: 41-54