A Simulation Based Aid for Complex Dynamic Decision Making

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Abstract. Modern organisations are large complex systems operating in an increasingly dynamic environment and are tasked to meet its goals by adopting suitable courses of action. Deciding an appropriate course of action calls for deep understanding of various aspects of organisation such as its goals, structure, business-as-usual operational processes and business dynamics. The state-of-practice of decision-making that relies heavily on human experts is often reported as ineffective, imprecise and lacking in agility. Dissertation presented in this paper aims to develop a suitable aid that will assist decision makers to arrive at effective decision with increased rigour, precision and agility for complex dynamic decision-making activities.

Keywords: Organisational decision-making, Simulation based decision-making, Socio-technical System

1 Introduction

Modern organisations constantly attempt to meet organisational goals by adopting appropriate courses of action [27]. Evaluating possible courses of action and selecting option that has the best potential to meet organisational goals are challenging task. It requires precise understanding of various aspects of an organisation such as goals, organisation structure, operational processes, historic data and the stakeholders of the organisation [12]. Comprehending relevant aspects in precise and meaningful manner to address complex dynamic decision-making (CDDM) is a challenge as it deals with large organisation with socio-technical characteristics [20], uncertainty and non-linear causality in business interactions [10], and high business dynamics [29].

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The industrial practice of organisational decision-making heavily relies on human experts who are aided with primitive tools such as spreadsheets, word processors, and diagram editors. Though adequate for capturing and collating the required information, these tools offer limited analysis support if at all [19]. This limited use of technological aids in analysing information make the decision-making activities time-, effort- and intellectually-intensive endeavors. Reports from leading consulting institutions such as McKinsey and Harvard Business Review [15, 22] often state this state-of-the-practice as biased, based on short-term emotion and imprecise for current business context. The problem is more critical for CDDM kinds of decision-making problems due their inherent characteristics.

Dissertation presented in this paper attempts to improve the situation by conceptualising and developing a simulation platform for organisational decision-making, precisely for CDDM. In particular, the research aims to improve precision, reduce personal biases, consider short term and long term effects, reduce the excessive burden on human experts and provide a-priori indication in shorter time window by introducing a simulation-based evaluation platform to the decision makers. The primary contributions of this research work are a) a language or meta-model to specify CDDM problems in a comprehensive manner, and b) a simulation platform for a-priori evaluation of decisions through *what-if* and *if-what* analyses. These two research contributions form the core enabling technology of an overarching solution[1] that aims to address organisational decision-making problem using a pragmatic *business facing* decision-making framework wherein the practitioners can capture enterprise using problem specific terminologies and pose their questions leading to decision-making using higher-level language abstraction.

This paper presents an overview of proposed research agenda, research progress and the plan toward the completion. The paper proceeds as follows: section 2 presents research motivation and objectives; methodology adopted for this research is presented in section 3; the research overview including the problem formulation, high-level approach and validation plan is discussed in section 4. Paper concludes with a brief summary on research progress, achievements and future plans.

2 Research Motivation and Objectives

Industry practice follows refinement-based methods such as *Incremental method* [24] and *Carnegie Method* [11] for organisational decision-making. These decision-making methods are essentially guided by set of decision questions that includes: *What are the overall goals? Are there any dependencies between these goals? What are the course of actions to achieve them? How do these course of action impact the goals? How they differ qualitatively and quantitatively?* The excessive dependency on human cognitive capability and limited utilisation of technological aids to answer these decision questions results into ineffective decisions.

[1] http://www.tcs.com/research/Pages/Model-Driven-Organization.aspx

Essentially, the decisions are often biased as the information syntheses are based on personal interpretation [15], limited to short term benefit due to cognitive limitation [22], and not precise enough due to lack of tool assisted analyses [19]. In contrast, the practitioners expect better decision-making approach and tool support that can improve precision, reduce personal biases, consider short term and long term effects, reduce excessive burden on human experts and provide a-priori indication about the efficacy of decisions.

This perceived poor view of the state-of-practice of decision-making (particularly for CDDM) elicits a research question: *What kinds of technological aids will help decision makers to arrive at precise, unbiased and effective decisions?* The dissertation presented in this paper focuses on technical aspect of this broad research question wherein the key objectives considered are:

1. Improve precision and effectiveness of the decisions with appropriate machinery to evaluate them a-priori.
2. Reduce excessive dependency of human experts to understand short-term and long-term implications.
3. Improve the agility of organizational decision-making, i.e., reduce the analysis time and effort, with automation.

3 Research Methodology

This dissertation adopts Design Science Research (DSR) methodology proposed by Hevner in [14] for conducting research activities. Primarily, it follows three DSR cycles namely *relevance cycle*, *design cycle* and *rigor cycle* using the five research activities: *problem statement conceptualisation*, *exploration of state-of-the-art and state-of-the-practice of organisational decision-making*, *conceptualization of proposed approach*, *implementation of conceptualized approach*, and *research validation*. The iterative execution of two activities - a) *problem statement conceptualisation* and b) *exploration of state-of-the-art and state-of-the-practice of organisational decision-making* form the relevance cycle. The problem statement conceptualisation activity considers practitioner's views and industrial reports. The *exploration of state-of-the-art and state-of-the-practice of organizational decision-making* uses two methods - *literature review based exploration* and *experiment based exploration* to understand the capabilities and limitations of existing approaches and tooling infrastructures in the context of CDDM. Literature review based exploration adopts evidence-based secondary studies, such as *systematic mapping study* (SMS), [25] and experiment based exploration uses synthetic but close to real life case studies.

The *design cycle* comprises three iterative activities namely *conceptualization of proposed approach*, *implementation of conceptualized approach*, and *research validation*. This research adopts meta-modelling approach to arrive at suitable conceptual model and language processing paradigm for implementation artefacts. The research validation is based on *Artificial* and *Ex-Post* [26] evaluation strategy. It is *Ex-Post* as the evaluation to be performed after design and development of research artefact, and *Artificial* as the synthetic case studies illustrating scenario from industry and academia to be considered for validating research artefacts.

Finally, the *rigor cycle* that establishes the connection between research outcomes and knowledge-base to be performed using meta-analyses on multiple *Ex-Post* evaluations from research validation activities.

4 Research Overview

4.1 Problem Statement

A conceptual representation of decision-making is depicted in Fig. 1. As shown in the figure, an *Organisation* has a set of *Goals*, it publishes set of key performance indicator or *Measures*. The decision makers analyse, observe or predict Measures and decide appropriate courses of action or *Levers* incase they find that the Goals are not achievable or not achieved. The key activity of the decision-making is to select appropriate Levers for the stated Goals. It is an iterative exploration and evaluation of the available options to find best possible option that has potential to achieve Goals. The efficacy of such exploration depends on two key factors: (i) the ability to capture relevant information about Organisation and its environment, and (ii) the ability to perform *what-if* and *if-what* analyses, e.g., what will happen in terms of Measures and Goals if specific Lever is applied to Organisation or which Levers can leads to specific Measures, etc.

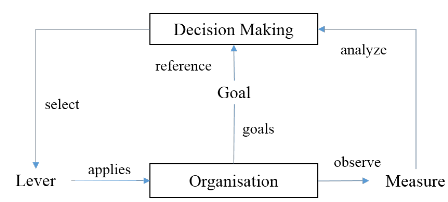

Fig. 1. Organisational decision-making

This dissertation argues that an Organisation can be understood well by analyzing *what* an enterprise is, *how* it operates, *why* it is so, and *who* are the responsible stakeholders [6]. This hypothesis is principally aligned with the Zachman framework [35]. The enterprise architecture frameworks, such as ToGAF[2], further advocate the need for a holistic view of an organisation for comprehensive understanding. Thus an ability to establish the relationships between various aspects constitutes a requirement.

Decision-making can progress either *top-down* or *bottom-up*. The former is a refinement process wherein the decision-maker begins by specifying enterprise at a coarser level of granularity by ignoring details. Bottom-up decision-making is a converse of top-down with abstraction replacing refinement. Therefore, ability to be cognizant of *abstraction* and *refinement* relationships across levels is a critical requirement on enterprise specification.

CDDM puts some special demands on specification in terms of desirable characteristics of organisation that include *reactive*, *adaptable*, *modular*, *autonomy*, *intentional*, *compositional*, *uncertainty* and *temporal* as described in Table 1.

[2] https://www.opengroup.org/togaf/

Table 1. Specification and analysis requirements for CDDM

	Requirements	Description
Aspects	Why	Intentional Specification
	What	Structural Specification
	How	Behavioural Specification
	Who	Specification on stakeholders and responsible human actors
Socio-technical	Modular	Must encapsulate internal goal, structure and behaviour.
	Composable	Multiple parts should be composed to a consistent whole.
	Reactive	Must respond appropriately to its environment
	Autonomy	Possible to produce output without any external stimulus.
	Intentional	Intent defines the behaviour
	Adaptable	Adapt itself based on context and situation
	Uncertainty	Precise intention and behaviour are not known a-priori.
	Temporal	Indefinite time-delay between an action and its response
Analysis	Visualisation	Support for visualization
	Machine Interpretable	Models that are interpretable by machine (i.e., support for simulation/execution)
	Quantitative	Simulation based quantitative analysis
	Qualitative	Simulation based qualitative analysis

Furthermore, industry practice of decision-making desires precise *what-if* and *if-what* analysis for a-priori indication of decision. As a result, ability to assess a decision in qualitative and quantitative manner forms the basis of analysis requirements. A-priori assessment of decisions is suggestive of simulation capability. Table 1 enumerates specification and analysis requirements for CDDM.

4.2 Literature Review and Experiments

The problem definition triggers several research questions, such as: *What kinds of modeling abstractions and analysis techniques are available for specifying and analysing different aspects of an organisation? Are they capable of supporting expected characteristics of CDDM? What are the gaps?* A series of systematic mapping studies and experiments are conducted to find comprehensive answers to these research questions.

A literature review on Enterprise Modeling (EM) literature using SMS methodology was performed to evaluate their suitability in the context of CDDM [5]. The review concluded with a critical observation that the existing EM techniques are capable of satisfying the expected requirements of CDDM described in Table 1 in parts. The review synthesis led to an exploration on multi-modelling and co-simulation environments involving multiple EM techniques to address CDDM. The exploration is conducted using two approaches: a) a literature review on multi-modelling and co-simulation environments such as DEVS [9], AA4MM [28], AnyLogic [8], and b) an experiment on multi-modelling and co-simulation approach by combining i* [34], Stock-and-Flow [21] and BPMN [33] tools. The research finding, experimental setup and experiences are presented in [16]. Both the literature review and experiment on multi-modelling and co-simulation approach have produced evidences that multi-modelling and co-simulation based approach are largely prone to intrinsic complexity [17] and accidental complexity [16]. Moreover, they lack in expressing several socio-technical characteristics such as autonomy, uncertainty, temporal behaviour and adaptability.

The inadequate support for socio-technical characteristics in EM techniques (in isolation or within multi-modeling set up) opens up a scope for exploring the languages and frameworks that are based on actor model of computation [1]. A literature review using SMS methodology on actor language and frameworks discloses their suitability in the context of CDDM. Essentially actor languages (e.g., Erlang [3], SALSA [32], AmbientTalk [31], and Kilim [30]) and frameworks (e.g., ActorFoundry [4], Scala Actors [13], Akka [2]) are capable of specifying and analysing a range of socio-technical characteristics such as reactive, modular, autonomy, intentional, compositional and emergent behaviour. The identified limitations of actor languages and frameworks are: a) lack of support for the notion of time and uncertainty, b) explicit support for relevant aspects, their relationships such as abstraction and refinement relationships.

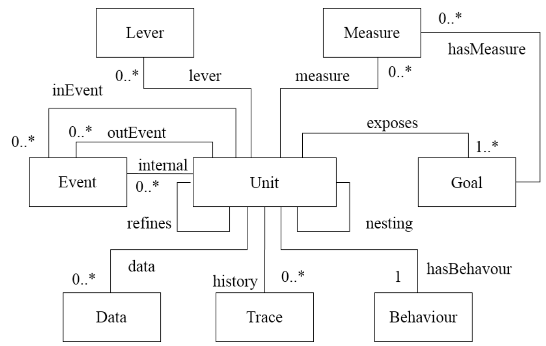

Fig. 2. Conceptual Model

4.3 Proposed Approach

This research proposes a conceptual model to describe CDDM and conceptualizes a decision-making platform by using the concepts and technology explored in previous section. The conceptual model and overview of proposed platform definition are described below.

Conceptual Model: An organisation can be viewed as something that responds to a set of events as it goes about achieving its stated goals. Oganisations consist of many autonomous units, organised into dynamically changing hierarchical groups, operating concurrently, and managing goals that affect their behaviour. The structure and behaviour of an organisation are described using a set of concepts as depicted in Fig. 2.

A *Unit* that represents organisation is an autonomous self-contained functional unit with high coherence and low external coupling. It exposes *Goals*

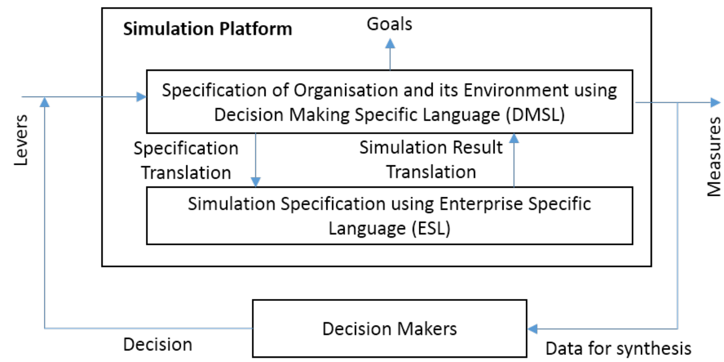

Fig. 3. Decision Making Platform

stating its intention. It interacts with environment through a set of *In-Events* and *Out-Events*. Internally it contains a *Behaviour*, a set of *Internal Events* and current and previous states of the organisation, i.e. *Data* and *Trace*.

A Unit may make use of several contained Units in order to meet the promised goals. The contained units can interact with each other to delegate their responsibilities to others; a unit can also participate in hierarchical composition structure to accomplish wider goals of the organisation. A Unit has a set of Levers and Measures where levers are transformation function and the parameters that can be used for configuration purposes, and measures are meaningful state variables that are exposed to the environment.

Conceptually, elements Unit, Event, Data, Trace and nesting capability of Unit, collectively, specifies the *what* aspect, Goal specifies the *why* aspect, Behaviour specifies the *how* aspect and Unit, as individual, specifies the *who* aspect of an organisation. Event helps to capture reactive nature, the intent is captured using Goal, modularity is achieved through Unit, autonomy is possible due to the concept of Internal Event, and composition can be specified using nesting relation. Also, Unit is adaptable as it can construct and reconstruct its structure; modular as it encapsulates the structure and behaviour of an organisation; intentional as it has its own goals; and compositional as it can be an assembly of Units.

A set of existing concepts are adopted to come up with Unit abstraction. Modularisation and reflective unit hierarchy are taken from fractal component models [7]. Goal-directed reactive and autonomous behaviour can be traced to agent behaviour. Defining states in terms of a type model is borrowed from UML. An event driven architecture [23] supports flexible interactions between components, and the concept of intentional modelling [34] is adopted to enable specification of component goals.

Decision Making Platform: A high-level platform definition is depicted in Fig. 3. Platform supports two languages namely *Decision Making Specification Language* (DMSL) and *Execution Language* (EL). DMSL concretises proposed conceptual model to specify the CDDM instances. It specifies the organisation, possible levers, expected measures and the environment where an organisation operates. DMSL also specifies various aspects of organisations in relatable form, the socio-technical characteristics and the various relationships such as *abstraction* and *refinement* as described in Table 1. Execution language is executable specification to perform *what-if* and *if-what* analyses.

DMSL uses the concepts borrowed from actor model of computation, event-driven systems, declarative rules, goal specification, conventional class model, linear temporal logic and theory of uncertainty. As part of overarching research initiative, a language termed as *enterprise specification language* (ESL) is designed and prototyped by extending actor model of computation with the notion of *time* and *uncertainty*. This dissertation plan to use ESL as underlying execution machinery by supporting adequate mappings to translate DMSL to ESL. Proposed platform definition uses primitive statistical tools to interpret and visualize simulation results of ESL.

4.4 Validation Plan

The research outcome will be validated using two synthetic near real-life case-studies: a) a case study on *software service provisioning organisation*, and b) case study on *academic institution*. The case study on software service provisioning organisation (as illustrated in [16]) focuses on improving the revenue of an organisation by exploring possible levers such as project selection, recruitment strategy and investment of tooling infrastructure. The case study on academic institution explores the possibility of improving university ranking by deciding appropriate levers such as research collaboration, teaching and research ratio, PhD student intake, staff selections, etc.

5 Conclusion

The research presented in this paper is part of an overarching research agenda of an industrial research organisation that aims to develop a *business facing* platform as an aid to the decision makers to arrive at precise, unbiased, evidence based decisions. It also aims to reduce the excessive human dependency and improve the agility of the decision-making process. This dissertation focuses on the technical aspect of overarching research agenda by introducing a language to specify decision-making instances and simulation platform to evaluate the efficacy of the possible decisions.

Till date, the problem statement is defined by evaluating industrial reports and its relevance is validated though a list of publications [18, 17, 16, 6]. The research scope and contributions are identified using literature reviews and experiments on various options that have the potential to realise decision-making platform. The literature review on Enterprise Modelling technique is presented in [5] and experiments of multi-modelling option is presented in [16]. The hypotheses and conceptual model are presented in [16, 6]. Definition of DSML and exploration of candidate execution language are ongoing activities. As next step, this research will also focus on game theoretic approach, competition and collaboration aspects for better decision-making. A recommendation system for guided simulation using appropriate technique such as genetic algorithm to be explored in this research.

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