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A Model Based Realisation of Actor Model to Conceptualise an Aid for Complex Dynamic Decision-Making

Keywords: Organisational decision making, Simulation, Actor Model of Computation, Actor Based Simulation.

Abstract: Effective decision-making of modern organisation requires deep understanding of various aspects of organisation such as its goals, structure, business-as-usual operational processes etc. The large size and complex structure of organisations, socio-technical characteristics, and fast business dynamics make this decision-making a challenging endeavour. The state-of-practice of decision-making that relies heavily on human experts is often reported as ineffective, imprecise and lacking in agility. This paper evaluates a set of candidate technologies and makes a case for using actor based simulation techniques as an aid for complex dynamic decision-making. The approach is justified by enumeration of basic requirements of complex dynamic decision-making and the conducting a suitability of analysis of state-of-the-art enterprise modelling techniques. The research contributes a conceptual meta-model that represents necessary aspects of organisation for complex dynamic decision-making together with a realisation in terms of actor model that extends Actor model of computation. The proposed approach is illustrated using a real life case study from business process outsourcing industry.

1 INTRODUCTION

Modern organisations constantly attempt to meet organisational goals by adopting appropriate courses of action (Shapira, 2002). Evaluation of the possible courses of action and selection of the best option are key challenges faced by organisations. It calls for the precise understanding of various aspects such as goals, organisation structure, operational processes, historic data and the stakeholders (Daft, 2012). The socio-technical characteristics (McDermott et al., 2013), inherent uncertainty and non-linear causality in business interactions (Conrath, 1967), and high business dynamics (Sipp, 2012) further exacerbate the complex dynamic decision making (CDDM) endeavour.

The industrial practice of organisational decision-making heavily relies on human experts who typically use 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 (Locke, 2011). As a result, CDDM tends to be a time-, effort- and intellectually-intensive endeavour. Furthermore, reports from leading consulting organisations such as McKinsey and Harvard Business Review (Kahneman et al., 2011, Meissner et al. 2015) often classify the current state of practice as biased, based on short-term emotion and imprecise for modern business context. This perceived poor state-of-practice of decision-making elicits a research question: What kinds of technological aids are needed for decision makers to arrive at precise, unbiased and effective decisions?

This paper argues that the success of decision-making largely depends on two key factors: (i) the ability to capture relevant information about organisation and (ii) the ability to perform what-if and if-what analyses of relevant information in a relatable form. The former ensures completeness of information and the latter ensures reduction of analysis burden on human experts.

A wide variety of Enterprise Modelling (EM) techniques have been proposed to capture the relevant information about organisation in a formal manner amenable to rigorous analysis (Authors Ref). However, they are found to be less effective and insufficient for a class of decision-making problems characterised by significant dynamism, inherent uncertainty, and emergent behaviour (Authors Ref). Being a socio-technical system, an organisation can be best viewed as a set of interacting units each
having own goals and operating with the intent of achieving them. Thus, behaviour of the entire organisation is not known a priori (and hence never specified as such) but emerges through the interactions of units each having well-defined behaviour (Hewitt, 2010). Behaviour of an organisation unit can be specified in terms of the many actor languages and frameworks available e.g., Erlang (Armstrong, 1996), SALSA (Varela and Agha, 2001), AmbientTalk (Van Cutsem et al., 2007), and Kilim (Srinivasan and Mycroft, 2008), ActorFoundry (Astley, 1998), Scala Actors (Haller and Odersky, 2009), Akka (Allen, 2013) etc. Though capable of catering to the specification of autonomous, intentional, and emergent behaviour, these languages do not provide support for uncertainty and temporal behaviour.

In this paper, we present an approach that extends the actor model of computation with uncertainty and temporal behaviour to serve as an effective aid for CDDM. In particular, this paper makes two contributions: i) a conceptual meta-model that represents necessary aspects of the organisation along with the inherent characteristics of CDDM, and ii) a realisation meta-model that concretises conceptual model by extending the core concepts of actor model of computation. Also, we illustrate the proposed approach demonstrating its efficacy with a case study from Business Process Outsourcing (BPO) domain.

We envision an overarching research agenda\(^1\) for developing a business facing decision-making framework to improve precision of decision-making, reduce personal biases while considering decisions, consider short term and long term effects before arriving at decisions, and reduce the excessive analysis burden on human experts in decision-making process. We argue the presented contributions form a basis of such a business facing decision-making framework.

The paper proceeds as follows: Section 2 presents research motivation by highlighting necessary tenets of CDDM and reporting brief overview of state-of-the-art of EM techniques and actor language/frameworks. Section concludes by highlighting notable gaps that limit the adoption of EM techniques and actor languages/frameworks for CDDM. Section 3 presents the conceptual meta-model that has a potential to address CDDM problems. A meta-model that realises conceptual model by extending actor model of computation with relevant concepts such as uncertainty, temporal behaviour is described in section 4. The illustration of the proposed approach using a case study from BPO is highlighted in section 5 and a brief evaluation of proposed approach is presented in section 6. The paper concludes with a brief summary research progress and future plan to realise the overarching research agenda.

### 2 MOTIVATION

An abstract representation of decision-making is presented in Fig. 1. As shown in the figure, an Organisation interacts with its Environment to achieve its Goals. The Goals are typically assessed by evaluating the key performance indicators or Measures. The decision makers evaluate/predict Measures with respect to Goals and decide appropriate courses of action or Levers. In this formulation, the decision-making is finding best possible Levers for stated Goals in the context of Organisation and Environment. Essentially it is an iterative and refinement based method to explore available Levers, evaluate them with respect to Goals, Organisation and Environment, and finally decide most effective options. We argue the efficacy of such exploration depends on two key factors, i.e., ability to specify information about relevant aspects of the Organisation and ability to analyse available information in the context of the Environment where it operates.

The management literature advocates multiple methods such as Incremental method (Mintzberg et al., 1976) and Carnegie Method (Cyert et al., 1963) for guided exploration of Levers for stated Goals. However, they do not prescribe or recommend any technological aid best suited for their proposed methods as their focus in not pertaining to any technological aspects. We conducted a series of literature reviews and experiments to understand - *What kinds of modelling 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?

Our experiments such as (Authors Ref) and literature review such as (Authors Ref) indicate inadequacy of state-of-the-art of relevant enterprise wide modelling and analysis techniques and tools. An overview of our explorations is presented in this section. We first describe the key tenets of CDDM that we use for evaluating the state-of-the-art specification and analysis techniques. Subsequently we discuss the findings and illustrate the gaps by examining the state-of-the-art specification and analysis techniques.

2.1 Tenets of CDDM

We argue that an Organisation can be understood well by analysing what an enterprise is, how it operates, why it is so, and who are the responsible stakeholders (Authors Ref). This hypothesis is principally aligned with the Zachman framework (Zachman et al., 1987) and industry prevalent enterprise modelling (EM) techniques such as ArchiMate (Iacob et al., 2012)

CDDM puts some special demands on specification in terms of desirable characteristics of organisation that include reactive, adaptable, modular, autonomous, intentional, compositional, uncertainty and temporal. Essentially these characteristics represent associated dynamism to interact with Environment. Furthermore, industry practice of decision-making desires precise what-if and if-what analysis for apriori indication of a decision. As a result, a machine interpretable model forms the basis of analysis requirements. Table 1 enumerates specification and analysis requirements for CDDM.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-technical Characteristics</td>
<td>Why</td>
<td>Intention</td>
</tr>
<tr>
<td></td>
<td>What</td>
<td>Structural Specification</td>
</tr>
<tr>
<td></td>
<td>How</td>
<td>Behavioural Specification</td>
</tr>
<tr>
<td></td>
<td>Who</td>
<td>Stakeholders and Human actors</td>
</tr>
<tr>
<td></td>
<td>Modular</td>
<td>Must encapsulate internal goal, structure and behaviour.</td>
</tr>
<tr>
<td></td>
<td>Compositional</td>
<td>Multiple parts should be composed to a consistent whole.</td>
</tr>
<tr>
<td></td>
<td>Reactive</td>
<td>Must respond appropriately to its environment</td>
</tr>
<tr>
<td></td>
<td>Autonomous</td>
<td>Possible to produce output without any external stimulus.</td>
</tr>
<tr>
<td></td>
<td>Intentional</td>
<td>Intent defines the behaviour</td>
</tr>
<tr>
<td></td>
<td>Adaptable</td>
<td>Adapt itself based on context and situation</td>
</tr>
<tr>
<td></td>
<td>Uncertain</td>
<td>Precise intention and behaviour are not known a-priori.</td>
</tr>
<tr>
<td></td>
<td>Temporal</td>
<td>Indefinite time-delays between an action and its response</td>
</tr>
<tr>
<td></td>
<td>Machine Interpretable</td>
<td>Models that are interpretable by machine (i.e., support for simulation/execution)</td>
</tr>
</tbody>
</table>

2.1 Exploration of specification and analysis techniques

In (Authors Ref) we evaluated the suitability of EM techniques in the context of CDDM using Systematic Mapping Study methodology (Petersen et al., 2008). The evaluation 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. In particular, we found the EM techniques that support necessary aspects of CDDM (such as Zachman Framework and ArchiMate) are not machine interpretable and thus not amenable for rigorous analyses. In contrast, specification approaches such as BPMN (OMG, 2011), i* (Yu, 2006) and Stock-n-Flow (SnF) (Meadows and Wright, 2008) are capable of sophisticated analyses and simulation. For example, the process aspect can be analysed and simulated using BPMN based tool, the high level goals and objectives can be evaluated using i*, and high level system dynamics can be simulated using Stock-and-Flow (SnF) tools such as iThink. However, they are not capable of representing all necessary aspects.

Detailed review synthesis led us to explore multi-modelling and co-simulation environments involving multiple EM techniques to address CDDM. The exploration was conducted using two activities: a) a literature review on multi-modelling and co-simulation environments such as DEVS (Camus et al., 2015), AA4MM (Siebert et al., 2010), AnyLogic (Borščhev, 2013), and b) an experiment on multi-modelling and co-simulation approach by combining i*, Stock-and-Flow and BPMN tools. The research finding, experimental setup and experiences are presented in (Authors Ref). Both the literature review and experiment on multi-modelling and co-simulation approach have produced evidence that indicate a multi-modelling and co-simulation based approach using multiple EM techniques are capable of representing necessary aspects and they collectively support the analysis needs. However, they are largely prone to intrinsic complexity (as discussed in (Authors Ref)) and accidental complexity (as discussed in (Authors Ref)). Moreover, they are not capable of expressing many
socio-technical characteristics such as autonomy, uncertainty, temporal behaviour and adaptability.

The inadequate support for socio-technical characteristics in EM techniques (as in individual or within multi-modelling setup) opens up a scope for exploring the languages and frameworks that are based on the actor model of computation. A literature review on actor language and frameworks discloses their suitability in the context of CDDM. Essentially actor languages and frameworks are capable of specifying and analysing a range of socio-technical characteristics.

The key concepts and core capabilities of prevalent actor languages and frameworks (such as Scala Actor and Akka) are represented using a meta-model (termed as AMModel) as depicted in Fig. 2. The concept Actor, a named entity, encapsulates State, Behaviour and internal Actors. A State can be specified using attributes and the Behaviour is defined using set of Event specifications. The behaviouralSpec of Behaviour influences State of an Actor and is capable of representing four kinds of behaviour namely ReactiveBehaviour, AutonomousBehaviour, AdaptableBehaviour and EmergentBehaviour. The ReactiveBehaviour reacts by responding to Events, AutonomousBehaviour triggers internal Events, AdaptableBehaviour describes the adaptability of an Actor using set of rules and EmergentBehaviour specify the emergent behaviour of an actor model (Agha, 1985).

The proposed AMModel is capable of representing the what aspect using the structure and composition, how aspect using behavioural specification and the who aspects using the Actor itself. It is also capable of representing characteristics such as modular using the notion of Actor, compositional using contents association (See Fig. 2), reactive using ReactiveBehaviour, adaptable using AdaptableBehavior and EmergentBehaviour and autonomous using AutonomousBehaviour. However, it is not capable of describing the why aspect and other characteristics such as intentional, uncertainty and temporal behaviour.

In the next section, we describe the necessary concepts of CDDM that satisfy the tenets described in table 1 in terms of a meta-model. Then we discuss an extended form of actor model that realises this meta-model.

3 CONCEPTUAL MODEL

We define a meta-model to represent the relevant aspects of an organisation along with the characteristics described in Table 1. The proposed meta-model, termed as CMMModel, is depicted in Fig. 3. In the figure, an OrgUnit represents an Organisation which is an autonomous self-contained functional unit having high coherence and low external coupling. It has a set of Goals that represent its intention, Measures that describe the key performance indicators of OrgUnit, and Levers that represent possible courses of action with a potential to change an OrgUnit in terms of structure, behaviour and/or intentions. The goalSpec of Goal element uses Measure (and thus historical and current Data of an OrgUnit). The Measures are expression over Data and the leverSpec of Lever element describes the change specification or defines configuration parameters. An OrgUnit interacts with environment through a set of Events.

Internally an OrgUnit contains Data, Behaviour, Structure and Participants. Data represents the current and historical States of OrgUnit, i.e. current

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Footnote:

2 Meta-models are drawn using xModeler tool (http://www.eis.mdx.ac.uk/staffpages/tonyclark/Software/XModeler.html)
The structure of an OrgUnit is described using multiple contained OrgUnits and Participants. The contained units can interact with each other to delegate responsibilities or can participate in a hierarchical composition structure to accomplish higher level goals. The Participant, a specialised OrgUnit, represents the resources of the OrgUnit. Proposed meta-model advocates five kinds of Behaviour namely ReactiveBehaviour, AutonomousBehaviour, StochasticBehaviour, TemporalBehaviour and AdaptiveBehaviour. The ReactiveBehaviour represents external interactions using (external) Events and AutonomousBehaviour represents the internal behaviour using (internal) Events. The behaviouralSpec of StochasticBehaviour describes associated uncertainty of raising an Event and responding to an Event, and the behaviouralSpec of TemporalBehaviour describes the temporality of Event specification. The behaviouralSpec of AdaptiveBehaviour describes adaptation rules. We introduce a concept ‘Time’ to represent time aspect of an OrgUnit. There could be a central ‘Time’ element for an Organisation or each OrgUnit may own a ‘Time’ element.

Conceptually, the elements OrgUnit, Event, Data, and nesting capability of OrgUnit specifies the what aspect. Goal specifies the why aspect, Behaviour specifies the how aspect and Participant specifies the who aspect of an Organisation or OrgUnit. Event helps to capture reactive nature, the intent is captured using Goal, the modularity is achieved through the concept of OrgUnit, autonomy is possible due to the concept of AutonomousBehaviour, Events and Time, and composition can be specified using nesting relation. Also, OrgUnit is adaptable as it can construct and reconstruct its structure using AdaptiveBehaviour; modular as it encapsulates Data, Structure and Behaviour; intentional as it has its own goals; and compositional as it can be an assembly of OrgUnits. The StochasticBehaviour and TemporalBehaviour are capable of representing associated uncertainty and temporality.

Thus we argue this meta-model conceptually covers all the specification needs stated in table 1 and a machine interpretable specification realising this meta-model can serve the analysis need.

The proposed meta-model is grounded with a set of existing concepts. The modularisation and reactive unit hierarchy are taken from component model concepts. Goal-directed reactive and autonomous behaviour can be traced to actor behaviour (Agha, 1985). Defining states in terms of a type model is
borrowed from UML. An event driven architecture is introduced for reactive behaviour and the concept of intentional modelling (Yu, 2006) is adopted to enable specification of goals.

4 REALISATION MODEL

In this section we propose extensions to the actor meta-model (AMModel) of Fig. 2 to realise the proposed conceptual model (CMModel) of Fig. 3. The extensions are presented using a meta-model (termed as EAMModel) in Fig. 4. As shown in the figure, the concept of Actor (described in AMModel) is primarily extended with the concepts of Goal, Measure, Lever and Time. The extended Actor is represented as ExtendedActor in EAMModel. The concepts Goal, Measure, Lever and Time associated with ExtendedActor of EAMModel conforms to Goal, Measure, Lever and Time concepts introduced in CMModel.

The Behaviour of an Actor in AMModel is extended with two additional behavioural types namely StochasticBehaviour and TemporalBehaviour wherein the StochasticBehaviour and TemporalBehaviour of EAMModel conform to the definitions of StochasticBehaviour and TemporalBehaviour of CMModel respectively.

We argue, the extended actor model (i.e., unified version of AMModel and EAMModel) is capable of realising the conceptual model represented in CMModel. The concept ExtendedActor of AMModel is capable of representing OrgUnit, Organisation and Participants as the concept ExtendedActor is an encapsulated, modular, autonomous, composable entity.

Actor of AMModel (and thus ExtendedActor of EAMModel) is capable of representing its current states using attributes of State entity. ExtendedActor definition is further capable of representing traces using historicalTraces association to State entity. Thus the unified meta-model (of AMModel and EMMModel) is capable of representing Data of CMModel.

Similarly, the Actor described in AMModel is capable of representing reactive, autonomous and adaptable behaviour using ReactiveBehaviour, AutonomousBehaviour and AdaptableBehaviour. ExtendedActor in EAMModel further introduces the StochasticBehaviour and TemporalBehaviour. Thus we argue they collectively represent all necessary behavioural types described in CMModel.

Finally, the extensions Goal, Measure, Lever and Time to the conventional actor meta-model help in realising conceptual model that is necessary for CDDM.

We have conceptualised a language termed as Enterprise Simulation Language (ESL) that implements the concepts of conventional actor model as depicted in Fig. 2 along with the extension proposed in Fig. 4. We have developed a prototype implementation of ESL using DrRacket³. We have also developed a prototypical simulation engine to iterate over the “apply Lever – Observe Measure – Analyse the feasibility of Goals” loop as depicted in Fig. 1. The simulation machinery comprises of Spreadsheet, DrRacket based ESL execution engine and Python wherein Spreadsheet is used for specifying Lever configuration, ESL engine for simulation, and Python for visualising Measures and Goals.

We illustrate the proposed realisation model and simulation capability of its implementation using an

³ https://racket-lang.org
industrial case from BPO domain. The next section presents the case study and observed results.

5 ILLUSTRATION

Consider the business process outsourcing (BPO) domain. Customers outsource business processes for a variety of reasons such as reducing Cost (C), increasing Efficiency (E), bringing about a major transformation, i.e., Delight (D). The outsourced processes can be classified into three buckets based on maturity of BPO verticals. For instance, Transcript Entry process of Healthcare vertical is one of the early adopter of BPO and has derived almost all potential benefits accruable from outsourcing (termed as Sunset or SS). On the other hand, IT Infrastructure Management process being a late adopter of BPO has a large unrealized potential to be tapped (termed as Sunrise or SR). And there are processes such as Help Desk, Account Opening, Monthly Alerts etc., that fall somewhere in between the two extremes as regards benefits accrued from BPO (i.e. Steady or ST). Thus, BPO demand space can be viewed as set of customers where each customer is characterised by one of the type described using a 3 x 3 matrix of Fig 5.

A customer invites bids from the vendors for a specific BPO outsourcing project. Typically, factors such as Quadrant (i.e. ranking as per independent agency such as analysts), FTE Count Range (i.e. full time employees to be deployed on the outsourced process), Billing Rate Range (i.e. per hour rate of full time employee), Organisation Size (the number of employee) and Track Record (i.e., familiarity with the processes being outsourced), influence who wins the bid. Other soft issues such as Market Influence (i.e. perception of the market as regards delivery certainty with acceptable quality), the rapport with the vendor etc., also play a part in bid evaluation. In addition to these known factors there could be some uncertainty in bid evaluation criteria (in other words, bid evaluation criteria can’t be fully known a-priori).

It is common observation that BPO outsourcing projects come up for renewal after few years (typically 3 to 5 years). Customer may renew the contract with the existing vendor on modified terms (typically advantageous to the customer) or may opt for rebidding. Factors influencing the renewal decision are reduction offered in FTE Count, Billing Rate, number and degree of escalations, perception that the external agent has as regards ability to meet the project requirements, inherence uncertainty, etc. Contracts that fail to get renewed become candidates for later bidding. Fig 5 shows a high level schematic of BPO space. The events of interest illustrating the interactions between customer and vendor, and the state transition of outsourcing project are depicted in Fig 6.

The demand space exhibits temporal dynamism. For instance, new processes emerge as candidates for outsourcing and some of the existing processes no longer need to be outsourced as, say, technology advance eliminates the need for human intervention.
in the process thus making it straight-through. Thus the BPO space can be viewed as an event-driven system where events have a certain frequency and are stochastic in nature. The frequency and stochastic characteristics typically vary from process to process. While operating in this uncertain space, a BPO vendor needs to make decisions of the following kind: Will continuation with the current strategy keep me viable ‘n’ years hence? What alternative strategies are available? How effective will a given strategy be? By when will a given strategy start showing positive impact? Will I be growing at the expense of competition or vice versa? and so on.

Answers to the above questions are essentially linked to the evaluation of portfolio basket i.e., 3 x 3 matrix of Fig. 5, of the organisation in terms of revenue accruable and expense in terms of FTEs.

5.1 Realisation using Actor Model

We model BPO scenario using our extended actor model (i.e., the unified meta-model of AMModel depicted in Fig. 2 and the EAMModel depicted in Fig. 4). The key elements demand, vendor and outsourced projects are modelled as ExtendedActor as shown in Fig. 7. The demand ExtendedActor comprises of nine attributes where each attribute represents a bag of outsourced projects of specific type from the demand classification i.e., [SR, ST, SS] X [C, E, D]. Each outsourced project ExtendedActor represents a specific demand classification using its State attributes and implements the state-machine depicted in Fig. 6. The increase (or decrease) of specific type of outsourced project in demand space is specified by instantiating (or destructing) specific outsourced project ExtendedActor.

Vendors ExtendedActors has a set of State attributes to represent portfolio baskets (i.e., flattened out 3 x 3 matrix), Resources, Traces and other attributes such as Revenue. The portfolio basket represents the bags of outsourced project ExtendedActors, The State attribute Resource contains a bag of ExtendedActors that represent the FTEs and the State attribute Traces is historical data about the values of State attributes of vendor such as Revenue at specific time. The characteristics of a vendor such as Quadrant, Billing Rate, FTE count, Market Influence and Delivery Excellence are also represented using State attribute of vendor ExtendedActor. In this formulation, one vendor is marked as ‘We’ and rest are classified as competitors.

This example considers two competitors – Competitor 1 and Competitor 2 as depicted in Fig. 7.

The table in Fig 7 shows the initial characteristics of ‘We’ ExtendedActor. We make these characteristics configurable to attenuate their values, thus these State attributes also act as Lever in this example. As shown in the figure, a vendor is equipped with a set of negotiation levers namely, the range of Billing Rate (employees billed against the outsourced process), range of FTE Productivity (percent reduction possible in number of full time employees), range of FTE Reduction (reduction possible during renewal of a contract), range of Billing Rate Reduction (reduction possible in billing rate during renewal of a contract), Influence Relation and Delivery Excellence. The Influence Relation is a qualitative characteristic that is quantified using four weighted labels namely ‘Excellent’, ‘Good’,
‘Normal’ and ‘Not Good’. Value of Delivery Excellence attribute is a probability distribution. For instance, ‘We’ ExtendedActor is confident of delivering ‘Excellent’ quality on 60% of Cost kind of BPO projects won. The values for ‘Good’, ‘Normal’ and ‘Below Normal’ quality for this kind of BPO projects are 30%, 10% and 0% respectively.

There are many Measures that are of interest to the stakeholders of ‘We’ vendor. Fig. 7 depicts three key Measures namely Revenue (i.e., the State attribute Revenue), Customer Count (i.e., total number of outsourced projects contain by ‘We’ vendor) and Realisation (i.e., average Revenue earned by each Resource per hour) for illustration purpose.

One can model different kinds of vendor by setting appropriate values to the initial setting. The ‘Competitor’ ExtendedActors are modelled on the same lines as ‘We’ ExtendedActor.

This example considers a central Time to synchronise the entire business-as-usual (i.e., Behaviour). Time triggers two events namely ‘Month’ and “Year” to the demand and vendor ExtendedActors. Demand ExtendedActor raises RFP events for outsourcing project. Each RFP event is characterized by the kind of process being outsourced (i.e. SR or ST or SS), the objective for outsourcing (i.e. C or E or D), size of the process in terms of FTE count, and the desired billing rate. Interested vendors respond to the RFP event by picking suitable values from their characteristics at random. Bid evaluation function is a weighted aggregate of the various elements of RFP response and a random value to capture effect of inherent uncertainty. The vendor with the best evaluated value wins the outsourcing project which gets executed as defined by the characteristics of the particular vendor. Essentially, an outsourcing project ExtendedActor moves from Demand ExtendedActor to a vendor ExtendedActor (i.e., from demand basket to vendor portfolio basket) as shown in Fig. 7. The existence of an outsourcing project within a vendor impact vendor’s State attribute (and thus Measures) as outsourcing project consumes the resources and contribute the revenue, the customer count and other measures. It also impacts the track record and market influences over the time.

The decision to renew existing contract is modelled on similar lines but with a different set of characteristic attributes influencing the decision. Essentially the autonomous outsourcing project ExtendedActor raises Renew event after 3 to 5 years timeframe. Here too, the evaluation is cognizance of incomplete and uncertain knowledge renewability criteria.

5.2 Simulation and Results

We use the simulation environment developed using DrRacket and Python to run the system for 10 years. In the interest of space, two decision questions from many scenario playing are discussed in this paper. Decision questions are – i) Will continuation with the current strategy keep me viable ‘n’ years hence with respect to the competition? And ii) What
will be my position if we decide to change my characteristics?

An overview results of simulation run is shown in Fig 8. As can be seen, the current revenue of ‘We’ (represented using shades of ‘blue’ disks) is 438.98 MUSD from 90 customers with a realization of nearly 15.5 USD per hour per FTE. Corresponding numbers for competitor 1 and competitor 2 respectively are < 319.97, 78, 13.33 > (depicted using shades of ‘violet’ disks) and < 352.32, 79, 15.1 > (depicted using shades of brown disks). In short, at present ‘We’ vendor is doing much better than competition.

‘We’ vendor set a goal to deliver <750, 200, 17> after 5 years and <1000, 290, 18> after 10 years (depicted using green disk). As can be seen, by continuing to operate the same way the ‘We’ vendor will be delivering <587.58, 160, 13.5> after 5 years and <857.51, 215, 14> after 10 years (as directed by red line in Fig. 10) thus missing both the targets by a considerable margin. More importantly, competitor 2 will be overtaking ‘We’ vendor after 5 years and both the competitors will be significantly ahead of ‘We’ vendor after 10 years.

Clearly, ‘We’ vendor cannot afford to continue with its current way of operation. Further detailed analysis, involving model elements not described in this paper for want of space, shows that much of current revenue of ‘We’ vendor is loss making through what if scenario playing. It is possible for a stock or an individual variable to have a value that is a probability distribution, however, the structure of the stock-n-flow model must remain unchanged. Thus, systems dynamics modelling provides only a partial support for specifying and processing the inherent uncertainty within a system. Moreover, it is best suited for an aggregated and generalized view of a system where individual details get eliminated through averaging, and sequences of events are grouped as continuous flows. This generalized approach and ignorance of individual characteristics that significantly influence the system over time often leads to a model that is somewhat removed from reality. Though not designed to specify specialized behaviour, it can be done using systems dynamics modelling. But this is an effort-intensive endeavour, and more importantly leads to model size explosion (Authors Ref). For example, modelling of 4 competitors each having special characteristics leads to roughly 4 times increase in the size of systems dynamics model.

The proposed approach enables modelling of a system as a set of units each listening/responding/raising events of interest and interacting with other units by sending messages. A unit encapsulates state (i.e. a set of State attributes), trace (i.e. events it has responded to and raised till now) and behaviour (i.e. encoding of reactions). As the modelling abstraction supports ‘time’ concept, value of a variable and relationships between variables can change with respect to time. Consider the example of determining the impact of track record on bid win of organisation where the value of track-record variable changes over time thus affecting bid win factor. Since a process is an individual actor, simulator can determine the impact of successful contract completion, renewal with/without negotiation etc., for that specific process – systems dynamics model falls short here. A trace of events serves as a memory that can be queried to establish more complex relationships between levers. For example, successful completion of contract leads to improved track record as well as better rapport with the customer thus improving the bid win factor of future outsourcing bids everything else remaining the same. Thus, the abstraction provides primitives for creating models that closely mimic reality.

6 EVALUATION

For the kind of decision-making problem illustrated in this paper, industry practice relies extensively on Excel spreadsheets. Such an approach typically represents the influence of lever onto measures in terms of static algebraic equations. However, value of a lever and influence of a lever onto a set of measures can vary over time. This behaviour cannot be captured using excel sheet. There is no support for encoding stochastic behaviour either.

Stock-and-Flow models are also used for a class of decision-making. In this approach, the system behaviour is expected to be known a priori. Essentially the system is specified in terms of stocks, flows of stocks, and a fixed set of equations over system variables that control the flows. Value of a stock or a flow or a variable is a discrete number or a range or a distribution. The quantitative nature of Stock-and-Flow models and sophisticated simulation support enables decision-making through what-if scenario playing. It is possible for a stock or an individual variable to have a value that is a probability distribution, however, the structure of the stock-n-flow model must remain unchanged. Thus, systems dynamics modelling provides only a partial support for specifying and processing the inherent uncertainty within a system. Moreover, it is best suited for an aggregated and generalized view of a system where individual details get eliminated through averaging, and sequences of events are grouped as continuous flows. This generalized approach and ignorance of individual characteristics that significantly influence the system over time often leads to a model that is somewhat removed from reality. Though not designed to specify specialized behaviour, it can be done using systems dynamics modelling. But this is an effort-intensive endeavour, and more importantly leads to model size explosion (Authors Ref). For example, modelling of 4 competitors each having special characteristics leads to roughly 4 times increase in the size of systems dynamics model.
7 CONCLUSION

Effective decision-making is a challenge that all modern enterprises face. It requires deep understanding of aspects such as organisational goals, structure, operational processes. Large size, socio-technical characteristics, and increasingly fast business dynamics make this activity much more difficult task for decision makers. Inadequate support for representing necessary aspects of an organisation in a relatable form and inability to handle inherent uncertainty and temporal characteristics are the present lacuna in state-of-the-art technological aids that are used in decision-making.

This paper shows the gaps by evaluating technological aids with respect to the needs of complex dynamic decision-making. We began by outlining a conceptual model (i.e. CMMModel) that has potential to mitigate the identified gaps between the available technical capabilities and expected characteristics. We then argued that an extended form of actor model (i.e., AMModel and EAMModel) can address these needs. We validated the hypothesis through an industry scale case study from BPO domain. We have shown how the case study can be modelled in terms of the proposed realisation model that is an extension of actor model of computation for complex dynamic decision making. We have shown how simulation of this model helped in identifying the most appropriate of the available alternatives at each decision point. Thus, it can be said that the proposed approach can be used to define purpose-specific strategy and/or evaluate the most appropriate from a set of candidate strategies.

We acknowledge this paper does not discuss the language constructs of ESL but, principal objectives of paper were: establish the core concepts of CDDM, correlate the core concepts with actor model of computation, and propose the necessary extensions to actor model for supporting complex dynamic decision-making.

Our next step is to use the proposed extended actor meta-model and its implementation in the form of ESL for developing a business-facing decision-making framework that will improve the precision of decision-making, reduce personal biases while considering decisions, consider short term and long term effects before arriving at decisions, and reduce the excessive analysis burden on human experts in decision-making process.

REFERENCES

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