A Case Study Exploring Suitability of Bottom Up Modelling and Actor-based Simulation for Decision Making

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ABSTRACT

Traditionally, the top-down design method and analysis techniques, such as system dynamic model, have been used extensively for understanding complex systems. In top-down approach, a system is specified in terms of global state and the desired analyses are performed using aggregated macro-behaviour that represents the overall system. Essentially, the individual elements and their peculiarities are not differentiated with an assumption that the inherent dynamics of the overall system is precisely known to the system modellers. This paper, in contrast, presents a case wherein the system behaviour emerges from the individual elements and their interactions. The paper further demonstrates the usability of bottom up approach, actor based modelling abstraction, and actor based simulation technique to understand complex systems (with emergent behaviour) using a case study on decision making of a Research and Innovation (R&I) organisation.

KEYWORDS

Complex dynamic decision making; Enterprise modeling; Bottom-up modelling; Simulation; Actor-based simulation.

1 INTRODUCTION

Two design alternatives, named top-down approach and bottom-up approach, exist for specifying and analysing complex systems [1]. In top-down approach, a system is visualised in terms of global state and the behaviour is represented using aggregated macro-behaviour of the system elements. For example, the System Dynamics (SD) model [2] uses the concepts of *stocks*, *flows* and *information* to represent system state and system level nonlinearity, feedback loops and the time delays. The behaviour is described using differential equations. In principal, these modeling elements and equations represent generalized form of an overall system that approximates the peculiarity of individual elements. Conceptually, the top-down approach considers a reductionist view [3] to understand system using the mathematical rigour from operational research, optimization theory, and sophisticated AI algorithms. The bottom-up approach, in contrast, considers the micro-behaviour of individual elements and their interactions in precise form as oppose to the overall system behaviour. Conceptually, the bottom-up approach relies on emergentism [4] as advocated in actor model of computation [5, 6], and agent-based systems [7].

Traditionally, the top-down approach is popular choice (as compare to the bottom-up approach) for analysing and understanding the complex systems in the context of critical business needs such as decision making activities. Existing modelling and analysis tools supporting top-down approach are extremely efficient for describing and simulating the aggregated system behaviour. However, they are not appropriate for precise understanding of complex and dynamic system that exhibits emergent behaviour and deals with large number of socio-technical [8] elements having adaptive, autonomous and dynamic behaviours.

In this paper, we demonstrate the effectiveness of bottom-up modelling approach to understand a complex and dynamic system (with emergent behaviour) using a case study that illustrates decision making of an industrial Research and Innovation (R&I) organisation. The goals of R&I organisation is to convert innovative ideas into business offerings, and make significant scholastic impacts to the research community (through publications and patents). In this context, the behaviour of the overall R&I organisation is not well-defined - rather it emerges from the activities of the individual researchers. Moreover, the progress of the organisation largely relies on the effective utilization of the researchers within the dynamic compositions structure where they operate (i.e., research project).

We adopt the concept of actor model of computation [6] to represent constituent elements, such as the *research projects* and *researchers*, of R&I organisation; formulate simulation setting by allowing these elements to interact with each other (as oppose to describing overall R&I organisation specification); and use actor based simulation technique to observe the emergent behaviour. The *what-if* scenario playing and exploration of decision alternatives to achieve organisational goals are accomplished through multiple simulation runs and comparing their results.

The rest of the paper organised as follows: the section 2 introduces R&I case study, section 3 illustrates the specification of the key elements of R&I organisation. The simulation runs to explore the decision alternatives of two key stakeholders of the R&I organisation namely *R&I head* and *research project head* are illustrated in section 4. The paper concludes in section 5 by

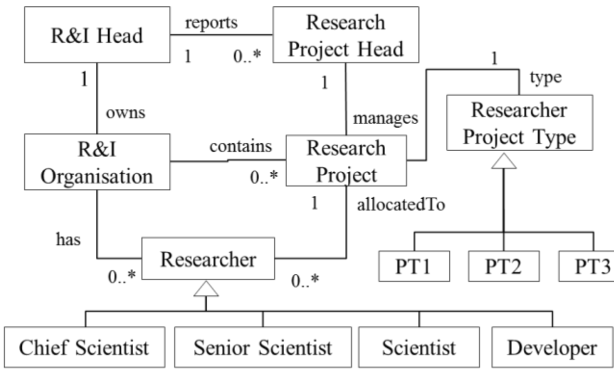


Figure 1: The structure of R&I organisation

highlighting our learnings from R&I case study and future explorations.

2 CASE STUDY DETAILS

We consider an industrial Research and Innovation (R&I) organisation of an IT firm that invites new ideas from its researchers and makes appropriate attempts to convert promising ideas into innovative business offerings. The R&I organisation adopts an organisation structure and relies on a research development process to realise its goals to transform ideas into business offerings and make significant scholastic impacts. The organisation structure and behaviour are described below:

Structure: The structural of R&I organisation is depicted in Fig. 1 using a class diagram. As shown in the figure, the R&I organisation contains multiple *research projects* and *researchers*. A research project is a unit that is formed with appropriate researchers to transform a research idea into business offering. A research project is associated with *Research Project Type* wherein a research project type represents specific characteristics of the research project. For example a research project that focuses an immediate industrial problem expects quick turn-around time (for converting an idea into business offering) whereas an idea that has potential to change the state-of-the-art and/or state-of-the-practice takes longer duration to reach expected maturity level. Similarly an idea that is not well-explored in research community expects rigorous research work, comprehensive validation strategy, and convincing evidences to establish the success. In this paper, we consider three research project types namely PT1, PT2 and PT3 for illustration purpose. PT1 type research project focuses on standard research requirements (with moderate research activity, moderate solutioning activity, takes moderate time to complete and has medium risk), PT2 type of research project focuses on well-explored research topic (i.e., less research work, more solutioning, relatively short-term and comparatively less risk), and PT3 type of research project deals with long term research on unexplored topic (i.e., more research work, more solutioning, long term and high risk).

A research project comprises multiple *researchers.* A researcher contributes research work to the research project based on their research experiences, skills and educational background. In this case study, the researchers are classified into 4 grades called *Chief Scientist*, *Senior Scientist*, *Scientist* and *Junior Researcher* (labelled as *Developer*). A range of work capability (i.e., quantum of work that a researcher is capable of contributing to a research project) and range of value weightage of the research work

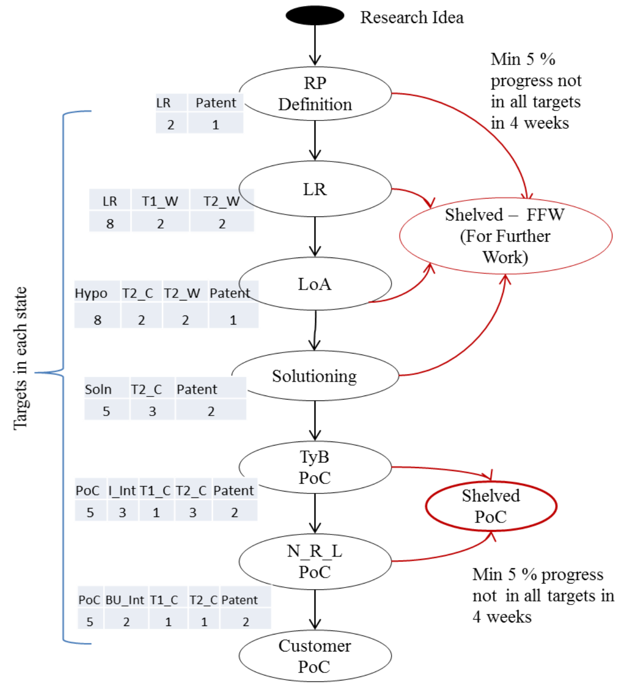


Figure 2: The behaviour of a Research project

(effectiveness factor of the contributed work) are associated with these research grades.

In this setting, two key stakeholders control the organisation and its units. The R&I organisation is owned by a unit owner, termed as *R&I Head*, and a research project is headed by designated researcher (known as *Research Project Head*). All research project heads reports to R&I head.

Behaviour: The process for transforming research idea into business offering starts with a new idea from individual researcher or a group of researchers. The initiator submits new idea as a research proposal to the research council (designated researchers) for evaluation. A research project is formed once the idea is accepted by the research council. Research project largely follows process steps as described using a state machine in Fig. 2. A research project progresses through 7 states namely *research problem formulation/definition* (RP Def), *literature review* (LR), *defining line of attack* (LoA), *defining solution* (Solutioning), internal technical validation through *toy-yet-believable proof-of-concept* (TYB PoC), solution validation through *near real-life proof-of-concept* (N_R_L PoC), and external validation through *customer proof-of-concept* (Customer PoC). An idea is transformed into business offering once the Customer PoC is completed successfully. The state of a research project advances based on the research work contributed by researchers, and research is acknowledge in research community through publications and patents. For example, a research project moves from LR state to LoA state when adequate research work is performed to address all research questions of a research project (through literature reviews), and the literature review outcomes are validated though appropriate publications. A research project may move from an internal state to *shelved for future work* (Shelved FFW) or *shelved for suitable opportunity in future* (Shelved PoC) state if the project is not progressed for a specific duration. For example, the research project in LR state may move to Shelved FFW state if the progress is not substantial for 4 weeks in a row. Essentially, each research

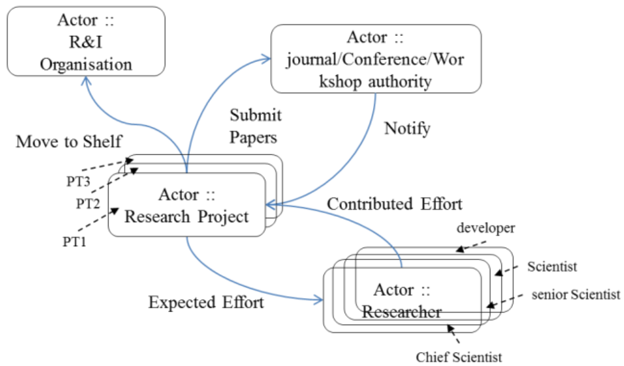


Figure 3: Specification of R&I organisation using Actor abstraction

project defines the entry-criteria and exist-criteria for all states in terms of two factors – the progress on the core activities associated with a state (e.g., literature review activity for LR state) and validation of the research work through publications. This case study uses three publication categories namely journal, conference and workshops and two sub-categories (for each category) termed as tier 1 and tier 2 for defining such criteria. In addition to these succession criteria, the R&I unit defines the rules for moving a research project into shelved states as shown in Fig. 2.

The progress of a research project largely relies on the research work contributed by individual researchers. A researcher contributes work for core activities (such as literature review, arriving at solution, and validating though PoC) and validation effort (publication and patent related work) based on the instructions provided by the research project head. The effective work contribution of an individual researcher for a research project is primarily a function over effort spent on specific activity and the value weightage associated with the grade (and the quality) of a researcher. Further there is a non-linearity associated with the contribution from individual researcher towards the project progress. An individual contribution can be accounted to research project contribution if the contribution is above some threshold value. For example, a researcher with a value weightage 0.5 spend 30 minutes in a day for literature review related work (which is equivalent of 15 minutes effective work) cannot be a contribution from an individual to a research project. One can say that the minimum one hour of effective work from an individual in a day should be considered as effective work to a research project.

The external factors, such as paper acceptance, also influence the research project progression. For example, state transition of a research project is a function over number of papers accepted for a specific category. The acceptance of a paper in a journal/conference/workshop largely depends on internal factors (such as the quantum of core work done, effort spent for preparing a paper, the rank of the researchers who contributed to the paper and the experience of the involved researchers), and external factors such as the rank of the conference and inherent randomness associated with the review process, etc.

In this paper, we models individual elements of R&I organisation, i.e., different kinds of researchers, research projects and journal/conference/workshop authority, and their interactions to define R&I organisation. The specification of R&I organisation is illustrated in section 3.

3 SPECIFICATION

We model R&I organisation using an actor based language, named as ESL [9], that we have developed by extending the concept of actor model of computation [6] (as described in [10]) for our overarching research initiative[1]. ESL is capable of representing an organisation using a set of modular, autonomous and reactive actors wherein an actor may define probabilistic behaviour and interacts with other actors to support emergentism. In particular, an actor encapsulates the values that represent actor characteristics, state information, historical data, and the internal elements; actor exhibits autonomous, stochastic and temporal behaviour, and supports an interaction protocols to interact with others.

The R&I organisation specification contains two types of internal actors namely *research project* actor and *researcher* actor. It also contains an actor to represent conference/workshop/journal authority as shown in Fig. 3.

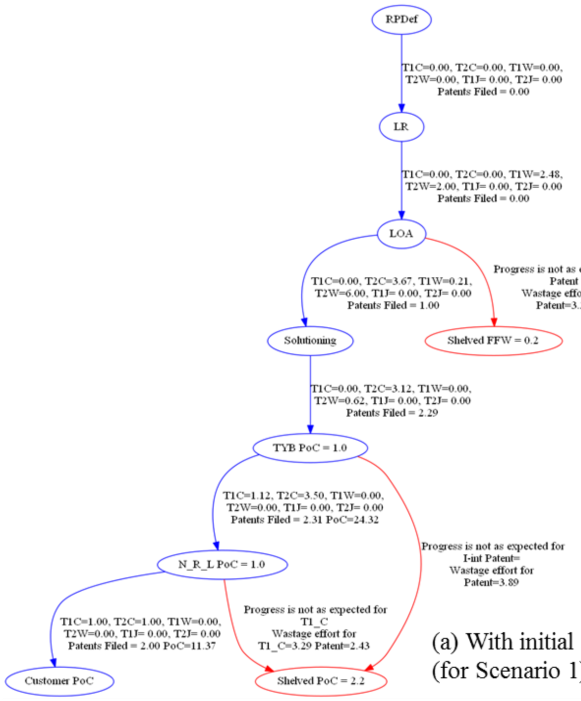
A research project actor contains:

a. Characteristic variables: to capture the parameters associated with state transition rules, such as the quantum of core work expected for each state (as shown in Fig. 2) and expected publication counts for all publication categories in a state (as shown in Fig. 2); and the other factors such as the minimum quantum of effective work expected from an individual researchers to consider the work as an effective contribution to a research project.
b. State variables: to represent research project state (i.e., one of the 7 states presented in Fig. 2), work progress (i.e., how much work is completed for core activity, publication and patent related work) in a state, and output produced in a state (i.e., number of papers accepted for different publication categories).
c. History: traces of the research project, and
d. Internal elements: the number of researchers (having their own grade and behaviour) allocated to a research project.

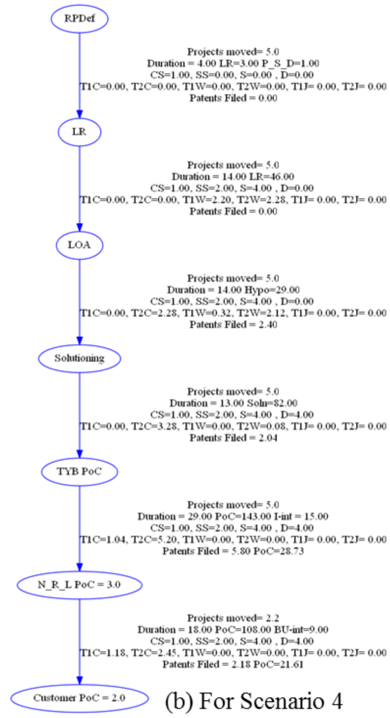
The behaviour of a research project actor specifies the state transition rules using the events that occur within research project actor (e.g., an event indicating an actor has completed targeted core work for a state or achieved specific publication targets) and/or the outside of research project actor (e.g., a paper is accepted in a journal/conference/workshop). The behaviour of a research project largely follows the behaviour described by the state-machine depicted in Fig. 2 and realizes the interaction protocol depicted in Fig. 3. The type specific variations of the research project to represent project types PT1, PT2 and PT3 are realised by parameterising the characteristic variables.

A research actor encapsulates the characteristics variables that capture the grade, experiences, areas of interest, efficiency factors (*value weightage*), and the work capabilities (a list tuples describing the research activities and corresponding work limit) of a researcher. It also captures the work distribution instruction, i.e., the list of research work that a researcher should do in week (a researcher gets this instruction at the time of allocation to a research project as *Expected Work* event). The state variable of a researcher actor captures work done in week and publication counts for various publication categories; the history captures the experiences that include the kinds of work done in the past, their quantum, and achievements such as publication and patent histories. The behavioural specification captures inherent dynamism and uncertainty. The dynamism in work contribution from a researcher

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



(a) With initial setting (for Scenario 1)



(b) For Scenario 4

Figure 4: Simulation results describing progress of R&I organisation

to a research project is implemented by factoring evolving value weightage of the researchers (value weightage changes as the researcher gain experiences) and considering an uncertainty in working hours for an activity (typically it is point value from range). The nonlinearity in effective contribution to a research project is implemented by considering effective work (computed from the quantum of work spent in a week and value weightage of a researcher, where former value is uncertain and later one is dynamic) to a research project if the effective work is significant (i.e., effective work is more than a threshold value). The difference in characteristics of Chief Scientist, Senior Scientist, Scientist and Developer are realised by parameterising the characteristic variables of researcher actor.

The external entity of this case study, i.e., journal editors, conference organisers and workshop organisers are visualised as actor with probabilistic behaviour. The research project actor that sends a paper to this actor gets an acceptance or rejection notification after a time delay. The acceptance rate and time delay are pre-defined in this implementation but one may realise a complex conference system by implementing the dynamics associated with the paper acceptance behaviour.

4 SIMULATION

A simulation of R&I organisation specification is essentially execution of multiple research projects that start with *RP Def* state with specific number of Chief Scientists, Senior Scientists, Scientists and Developers. The simulation progresses with time event that represents a 'week' time. Researchers contribute efforts on various activities (as decided by the research project heads and the research capability of research actor) using *contributed work* event (as shown in Fig. 3) every week tick. Research project consumes *contributed work* event and computes effective contribution. Contributed effort gets wasted if effective work is below expected quantity. The research project triggers *submit paper* event to the journal/conference/workshop authority (the events are shown in Fig. 3) when expected core work and the minimum paper submission criteria are satisfied for a type of publication. The authority *notifies* the acceptance/rejection after specified time delay. An accepted paper event updates research project state and researcher state (and history) appropriately.

An internal state change event of a research project is triggered once state exit criteria is satisfied. The exit criteria of PT1 research project are shown on every transition edge in Fig 2. For example, the transition from LR state to LoA state transition is possible only when 8 PW (Person Week) efforts is spent on LR activity and 2 Tier1workshop papers and 2 Tier2 workshop papers are accepted.

4.1 Decision making using simulation

We illustrate relevant what-if scenarios for two stakeholders of R&I organisation namely the *Research Project Head* and *R&I Head*. The goals of the research project heads are to reach business offering state within desired time and make significant scholastic contributions in terms of papers and patents. The research project heads explore the decision alternatives associated with researchers profiles (the capability of the researchers), team distribution (research profile), the work distribution in terms of core work and publication related work, etc. In contrast, the R&I Head, who manages multiple research projects (with different research project type), explores suitable strategy to maintain a steady flow of innovative business offerings and improve research portfolio with high impact publications and patents. In the interest of space, we discuss limited what-if scenarios in this paper.

4.1.1 Research Project Head

In this sub-section, we first demonstrate a case (scenario 1) of an R&I organisation with five PT1 research projects each having one

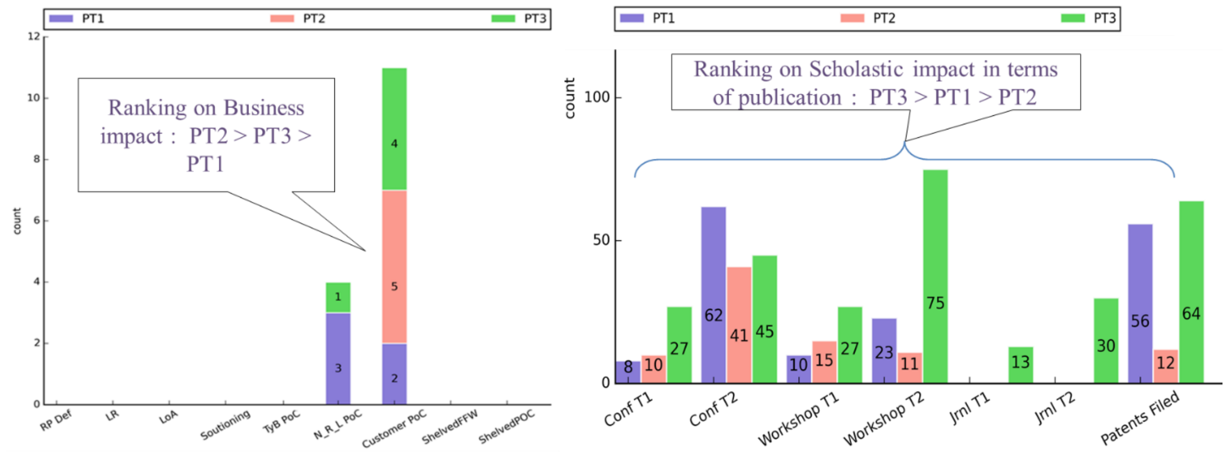


Figure 5: Simulation results describing progress of the R&I organisation

Chief Scientist, two Senior Scientists, four Scientists and four Developers , and then we explore improvement alternatives.

Initially, we observe the progress of R&I organisation with a setting defined for scenario 1 by simulating R&I organisation specification for two years (considering 'week' as primitive simulation tick). The overall observation is depicted in Fig. 4.a (the graph is generated by averaging 20 simulation runs to show statistically significant result) and key data points are recorded in Table 1 (for readability purpose). As shown in the figure and table, one research project (out of 5) has reached to the final state (i.e., Customer PoC is completed) whereas one research project has reached to N_R_L PoC state and one has reached to TYB PoC state respectively. Two research projects have ended up in Shelved PoC state. The key reason for slow progression is for not achieving the publication target as shown in the diagram (in Fig. 4.a). In particular, the research project has gone to Shelve PoC state for not contributing sufficient progress on Tier 1 conference paper for more than 4 weeks. It is also observed that the effort spent on patent related activity is exceeded to an extent for some research projects.

Next we demonstrate a scenario (scenario 2) that explores the impact on allocating more researchers to the earlier simulation settings. In this scenario, 1 Chief Scientist, 4 Senior Scientists, 8 Scientists (instead of 4 in earlier setting) and 8 Developers (instead of 4 in earlier setting) are allocated to PT1 research project and the progress is observed for five PT1 research projects. The progression, recorded in Table 1, is not satisfactory. The issue with tier 1 conference paper is continued in this scenario and significant wastage on tier 1 conference related work is additionally observed. The simulation result provides a hint that the resources allocated to the research project are not capable for tier 1 conference publication i.e., researchers are putting their effort in tier 1 conference paper but the effective contribution from individual researchers are not adequate to reach individual threshold value.

We further demonstrate two scenarios – scenario 3 and scenario 4. In scenario 3, 1 Chief Scientist, 2 Senior Scientists, 4 Scientists and 4 Developers are allocated as scenario 1. However, this scenario considers different work distribution to reduce excessive work on patent and focus more on Tier 1 conference paper (mainly by Chief Scientist and Senior Scientist). In this scenario, 2 research projects have reached to customer PoC, 2 research projects have reached to N_R_L PoC and 1 research project has reached to TyB PoC. For further improvement, the allocation of researchers with better experience is considered (scenario 4). With this setting, 2 research projects have reached to Customer PoC, 3 research projects have reached to N_R_L PoC. This scenario playing capability shows how formation of simulation setting and simulation results lead to a decision making. In next section, we illustrate the scenario playing capability of R&I head.

Table 1: Simulation results for research project head

	Completed	In Progress	Reached to Shelved States
Scenario 1	1	TYB PoC= 1, N_R_L PoC= 1	Shelved PoC =2
Scenario 2	1	N_R_L PoC= 1	Shelved FFW= 1 Shelved PoC =2
Scenario 3	2	TYB PoC= 1 N_R_L PoC= 2	0
Scenario 4	2	N_R_L PoC= 3	0

4.1.2 R&I Head

As discussed earlier, R&I head tries to improve the flow of business offerings (i.e., the ideas that reaches to Customer PoC state) and maximize the publication portfolio in terms of publications and patents. We configure an R&I organisation with five PT1 type research projects, five PT2 type research projects and five PT3 type research projects. The simulation results describing research project progresses and publication counts of these three types of research projects are shown in Fig. 5. As shown in the figure, the PT2 type research projects are producing more business offerings than PT3 type research projects and PT3 type research projects are producing more business offering than PT1 type research projects. In contrast, PT3 types research project are producing more publications than PT1 types research projects and PT1 type research projects are performing better than PT2 for publication. Thus PT2 type research project is better for churning out business offerings but not so effective for scholastic impacts whereas PT3 type research projects are better for scholastic impacts but not affective for producing business offerings.

R&I head can explore the suitable combination of PT1, PT2 and PT3 in R&I organisation to optimise the business impact and

Table 2: Simulation results representing business impacts

Scenario	Definition	RP_Def	LR	LoA	Solutioning	TyB PoC	N_R_L PoC	Customer PoC
1	PT1=5, PT2=5, PT3=5	0	0	0	0	0	4	11
2	PT1=2, PT2=8, PT3=5	0	0	0	0	0	3	12
3	PT1=4, PT2=2, PT3=9	0	0	0	0	0	4	11

Table 3: Simulation results representing scholastic impacts

Scenario	Definition	Journal Tier 1	Journal Tier 2	Conference Tier 1	Conference Tier 2	Workshop Tier 1	Workshop Tier 2	Patents
1	PT1=5, PT2=5, PT3=5	19	30	47	139	54	112	140
2	PT1=2,PT2=8, PT3=5	15	28	47	123	52	104	118
3	PT1=4, PT2=2, PT3=9	26	55	60	130	64	163	170

scholastic impact through simulation runs. For example, the R&I head can explore what will be the situation if PT2 types of research projects are encouraged within R&I organisation. We evaluate this scenario by reducing PT1 type of research project to 2 (from 5), increasing PT2 type of research to 8 (from 5), and keeping PT3 type research project count unchanged. We observed marginal improvement in business offering as shown in Table 2 but significant reduction in publications and patents counts as shown in Table 3. For an illustration of scenario playing capability, we simulated another scenario with 4 PT1 type research projects, 2 PT2 type research projects and 9 PT1 type research project. The simulation result is recorded in Table 2 and Table 3 respectively. As shown in the tables, the significant improvement is observed in publication (shown in Table 3) without any trade off on business offering (as shown in Table 2).

5 DISCUSSION AND FUTURE WORK

In this paper, we adopted bottom up approach as a design methodology and exploited actor model [6] as design abstraction to specify R&I organisation. Further, we applied simulation technique to explore decision alternatives of two key stakeholders of R&I organisation. In particular, we visualised R&I organisation using its constituent elements; the constituent elements are specified using the concept of actor; and finally emergent behaviour is observed through simulation run (i.e., the output produced by ESL simulation engine). We also demonstrated how probabilistic behaviour (e.g. paper acceptance), randomness (e.g. effort spent in day), non-linearity (e.g., effective research work), and dynamism (e.g. resources experience) of individual elements (that are represented as actors) influence the overall system behaviour (e.g. progress of research project and R&I organisation as a whole) over multiple simulation runs.

From methodology perspective our focus (while specifying R&I organisation) was to find constituent elements of R&I organisation, understand their micro-behaviours and interactions (rather than understanding the overall system behaviour of R&I organisation). Moreover, the what-if scenario playing are also driven by individual elements (for example, what will be the situation if a research project head recruits more eligible researchers in a research project, or research head instructs team member to work differently) and emergentism rather the following the principles of top-down approaches [11] where the primary exploration objective is to change high-level system parameters and observe system performance.

We found the use of bottom up approach is favorable for two key activities: a) specification: the specification does not expect additional expertise (other than knowing specification language) for abstracting out the system behaviour in terms of equations or any other aggregated form (one should specify elements as one see them in reality), and b) exploration of decision alternative: the change specification to explore decision alternatives are localized within actor (no need to find out a system parameter that represents the changes). The complete case study (not elaborated in this paper due to space limitation) makes us believe that the bottom up approach, actor model and simulation are suitable for understanding the intricacy of socio technical systems.

However, we acknowledge that the case study is not sufficiently large to validate our claim. More experiments and real life business critical case studies are needed. At present, we are working on a case study with more complexities. For example, we considered the research projects as fairly independent element and they do not compete with other research projects for resources (i.e., researchers) and research outputs. Moreover, we experimented our options without any constraints such as financial constraint and resource limitation. The psychological aspect of the researchers while working in a research project are also not considered in this case study. Introducing them in our case study and exploring trade-off, competition and optimization (under constraints) are our next focus.

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