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AN ACTOR-MODEL BASED BOTTOM-UP SIMULATION - AN EXPERIMENT ON INDIAN DEMONETISATION INITIATIVE

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ABSTRACT

The dominance of cash-based transactions and relentless growth of a shadow economy triggered a fiscal intervention by the Indian government wherein 86% of the total cash in circulation was pulled out in a sudden announcement on November 8, 2016. This disruptive initiative resulted into prolonged cash shortages, financial inconvenience, and crisis situation to cross-section of population of the country. Overall, the initiative has faced a lot of criticism as being poorly thought through and inadequately planned. We claim that these emerging adverse conditions could have been anticipated well in advance with appropriate experimental setup. We further claim that the efficacy of possible courses of actions for managing critical situations, and probable consequences of the courses of action could have been estimated in a laboratory setting. This paper justifies our claims with an experimental setup relying on *what-if* analysis using an actor-based bottom up simulation approach.

1 INTRODUCTION

The cash in circulation in Indian economy has steadily been increasing over the years - the total cash in circulation was 2.1 trillion rupees in 2001 (Government of India 2016), and it reached 17.9 trillion rupees in early November 2016. Uncontrolled cash flow in the system and growing trend of cash-based transactions led to a shadow economy. As a course correction, the Indian government demonetised the currency notes of 500 rupees and 1000 rupees (Wikipedia 2016). Principally, 86% of the cash in circulation was pulled out from the system in an announcement on November 8, 2016.

The initiative was implemented with several precautionary measures to avoid a financial crisis. For example, ATM and Bank withdrawal limits were significantly reduced, and a limitation was imposed on the exchange of old notes wherein the citizens were allowed to exchange up to 4000 rupees with the remaining deposited to their bank account. In addition, the cash-less payment modes, such as mobile wallet and card payments, were incentivised. Despite all preventive measures, the demonetisation initiative resulted into prolonged cash shortages and several unforeseen situations. Government tried to ease the emerging situations through real-time monitoring and introduction of on-the-fly corrective measures. This reactive decision making approach wherein probably it was difficult to a-priori test working hypotheses has led to criticism as being poorly thought through and inadequately planned (Harvard Business Review 2017).

Sudden disruptive nature of the initiative, inadequate knowledge of possible consequences, and emergence of unforeseen conditions all contributed to the enhanced complexity of decision making. The traditional analysis techniques seemed ineffective in this dynamic and interlinked context. For example, AI-based predictive analysis techniques expect adequate (historical) data for reliable predictions but adequate and accurate data may not be available. Inability to a-priori know the overall system behaviour renders top-down techniques such as system dynamic model (Meadows et al. 2008) ineffective. Similarly, these techniques fall short of specifying and analyzing systems that exhibit emergent behaviour (O'Connor et al. 2002). Therefore, it can be said that for analyzing complex systems comprising of several interlinked systems behaviour of which can at best be known only locally, the use of bottom-up simulation-aided approach is a preferred line of attack. Moreover, bottom-up approaches can cater to emergent behaviour as well. The problem of understanding the impact of demonetization on various stakeholders of the society and evaluating the efficacy of multiple alternative courses of action available to these stakeholders are complex problems. Therefore, we choose a bottom-up simulation-aided approach as a possible line of attack. Our endeavour is to come up with a synthetic environment of reality (*i.e.,* a model) that is amenable to quantitative analysis in the form of *what-if* and *if-what* analyses. To do so for a situation characterized by inherent uncertainty and large number of significantly dissimilar stakeholders is a challenge.

Contributions of this paper are two-fold: (i) It presents a modelling approach to construct a bounded experimental model that closely characterizes the reality for analyzing impacts of demonetization on society, and (ii) it illustrates experimentation to validate the hypothesis that bottom up simulation approach is indeed suitable for performing this analysis.

Our modelling approach to construct a synthetic environment for demonetisation adopts a three-step process suggested by Robert Sargent (Sargent 2005) to construct a machine interpretable model in a systematic manner, refines the process step with introduction of bottom up modeling approach (Thomas et al. 1994) to include diversified population behaviour, and leverages a form of actor based modelling abstraction (Hewitt 2010) capable of specifying emergent behaviour. We augment the actor abstraction with the philosophy of *known* and *unknown* (Rumsfeld 2011) to cater to specification of uncertainty (Conrath 1967). Essentially, we model a notion of configurable society that can represent a city in India having constituent elements such as *citizens*, *banks* and *shops*; define the demonetisation initiative as an event that abruptly eliminates cash from constituent elements; and observe the emergent behaviour as the various societal elements respond to the chosen events taking place over a period of time.

Section 2 of the paper discusses existing design and analysis approaches, and establishes the suitability of bottom up simulation and actor model. Section 3 introduces the principal contribution of this paper, *i.e.,* how to construct an experimental model amenable for evaluating the available courses of action to understand the impact of a significantly disruptive event such as demonetisation. A formulation of demonetisation initiative in India that serves as an experimental validation of our hypothesis is presented in section 4. The experimental results correlating the reality are summarized in section 5. Paper concludes in section 6 highlighting future research necessary to establish a larger claim i.e. the proposed model construction method is generic enough to be applied to other complex dynamic decision making situations.

2 DESIGN AND ANALYSIS RATIONALE

Specification and analysis of complex systems can be approached in two ways namely data-centric or model-centric. Data–centric approach makes use of sophisticated AI algorithms over past data to predict future consequences of a course of action. The model-centric approaches come in two categories namely top-down or bottom-up (Thomas et al. 1994). Top-down approach considers a reductionist view (Beckermann et al. 1992) wherein global state and overall system behaviour contribute to conceptualise a system. A top-down approach, typically, relies on simulation of aggregated macro-behaviour to understand the system, and uses operations research techniques and system dynamics theory (SD) (Meadows et al. 2008) to bring mathematical rigour. For instance, SD model uses the concepts of stocks, flows and information to represent system state, and differential equations for system level behaviour that

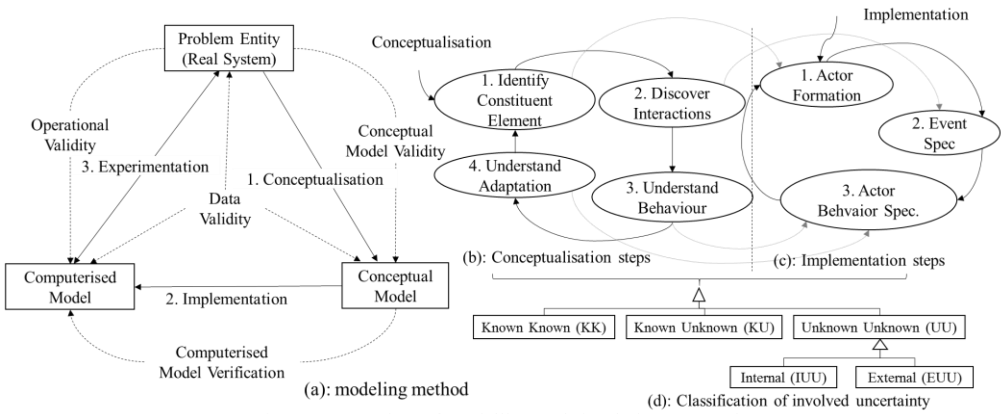


Figure 1: Overview of modelling and simulation approach

include nonlinearity, feedback, and the time delays. A bottom-up approach, in contrast, considers emergentism (O'Connor et al 2002) as advocated in actor model of computation (Hewitt 2010), and agent-based systems (Macal et al. 2010). Essentially, the method starts with specifying micro-behaviour of constituent elements (in contrast to the global behaviour) wherein the individual element may exhibit socio-technical characteristics (McDermott et al. 2013) such as adaptive, autonomous and dynamic behaviour. The global behavior of such system is considered to have emerged out of interactions among constituent elements.

We argue that the key difference among these approaches is primarily manifested in available information – data-centric approaches are effective when available (historical) data is rich and reliable, the top-down simulation approaches are useful in a context when system level macro-behaviour is precisely known and specifiable, and the bottom up simulation is suitable when the behaviour of individual elements, their interactions, and adaptation logics are known.

Demonetisation is a disruptive initiative that can lead to several emergent situations as associated stakeholders are autonomous and may adapt themselves differently. For example, bank may introduce adaptations such as changing banking transaction limits to serve larger population; the suppliers and shops may start offering alternative payment options to stay viable in cash-crunch situation; and citizens may change buying behaviour as well as buying means or may resort to hoarding in order to avoid undesired consequences. The frequent changes to banking transaction limits, uncertainty in cash availability in banks and ATMs, and randomness of cash hoarding behaviour of individuals lead to emergentism in the system.

Therefore, we consider the context to be a large, complex, and dynamic enterprise comprising of large number of interacting socio-technical elements such as banks, shops and citizens. Each of these elements has own goals, and exhibits stochasticity, adaptability, temporality in its behaviour to achieve their goals. The behaviour of the entire enterprise is not known (and hence it cannot be specified) but emerges through the interactions of constituent elements. These inherent characteristics motivated us to use actor model (Hewitt 2010) as modeling abstraction, the bottom up approach as a design method (Thomas et al. 1994), and actor based simulation as analysis technique. Next section proposes a modelling approach to systematically construct an experimental model (*i.e.,* a synthetic environment) to study demonetisation.

3 MODELLING AND SIMULATION APPROACH

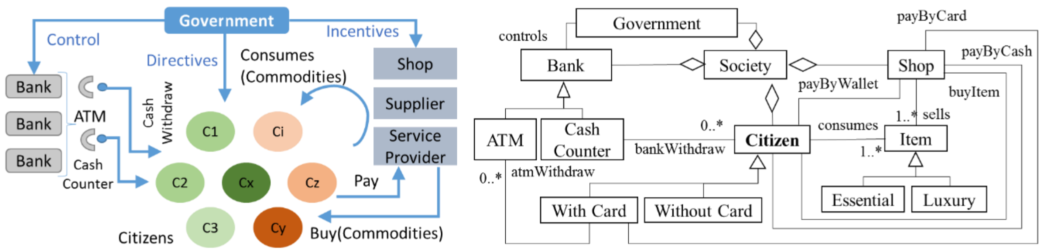
We adopt a modelling method recommended by Robert Sargent in (Sargent 2005) to conceptualise and implement an experimental model. Method presented by Robert Sargent proposes three distinct representations namely *problem entity*, *conceptual model* and *computerized model*, to systematically transform a real-life problem into reliable bounded analyzable model. The overview of proposed method is shown in Fig 1 (a). The problem entity is the real environment, conceptual model is a purpose specific logical model that sufficiently represents a problem entity with bounded number of concepts, and computerised model is experimental model, *i.e.*, machine interpretable specification of the conceptual model. The proposed method helps to convert a problem entity into purpose specific computerised model in two steps namely *conceptualisation* and *implementation*. The conceptualisation step constructs a conceptual model from real context, and the implementation step transforms the conceptual model into computerised model so that experiments can be conducted. It advocates three possible means to validate the relevance of a computerised model namely *transformational*, *operational* and *data* validation.

We refine this modelling process along two dimensions: (i) we visualise the three steps of conceptualisation, implementation and experimentation as an iterative cycle as, in general, it is observed that a convergent iterate-till-saturate process has greater probability of leading to a more convincing and reliable fixed point, and (ii) we specialize each of these steps to construct an experimental model.

The conceptualisation step uses a bottom-up formulation to arrive at a conceptual model iterating over the principal steps as depicted in Fig. 1 (b). The steps are: (i) identify key constituent elements from problem entity, (ii) identify interactions between identified elements, (iii) identify prominent state variables and behaviours of identified elements, and (iv) understand possible adaptation strategies (*i.e.*, *what* kind of adaptation, and *when* to adapt). Steps (iii) and (iv) of Fig 1 (b) try to recognize three kinds of behaviour and adaptation, namely *known knowns* (KK), *known unknowns* (KU) and *unknown unknowns* (UU), as classified by Donald Rumsfeld in (Rumsfeld 2011). The KKs are facts, rules, behaviours, and adaptations that are known with certainty, KUs are the gaps in the knowledge but existence of the gaps are known (*i.e.*, essentially the nature of behaviours are known but existing knowledge is not adequate to quantify them), and UU is phenomena whose existence is unknown. We use probabilistic distribution to specify KU kinds of uncertainty. We classify UU uncertainty into two kinds, namely *internal unknown unknown* (IUU) and *external unknown unknown* (EUU), as recommended in (Okashah et al 1994). IUUs are internal phenomena that emerge from system behaviour, and EUUs are external phenomena that occur in the environment without any prior indication. We believe, multiple experiments (simulations) can help in identifying IUUs, and observation of sufficiently large set of experimental results can help in transforming an IUU typically into KU and rarely into KK. The EUU kind of phenomena, in contrast, cannot be identified through experiments and ought to be considered as inputs to the models as recommended in (Okashah et al 1994). We use class diagram and an extended form of state machine to depict the structural and behavioural aspects of conceptual models. We extend state machine notation on the following lines: a dotted transition line represents adaptation, a transition label with single underline indicates KUs, and a transition label with double underlines indicates EUUs. An illustration can be seen in Fig. 3.

We use actor model to represent a computerised model that can be seen as a machine interpretable form of conceptual model. The implementation step (see Fig. 1 a.) is refined with a three steps process as shown in Fig. 1 (c). The process steps convert all elements of conceptual model (*i.e.*, elements defined in class diagrams) into actor specification, interactions among elements into event specifications, and the behavioural descriptions that also includes adaptation behaviour into behavioural specifications of actors. A high-level mapping schema between conceptual model and computerised model is shown using arrows between Fig 1 (b) and (c). We consider standard language constructs such as assignment, evaluation expression, loop, recursion, message passing, etc., to express KK kind of behaviour. The KU kind of behaviour expects constructs to express probabilistic behaviour; and the EUU behaviour requires a notion of event specification as we consider EUUs are inputs to the model. We don't consider IUU kind of behaviour in computerised model as either they are unknown or identified as KU in our formulation.

We use actor based simulation as an aid to conduct experimentations. An experimentation can be conducted for two purposes: (i) to validate conceptual and computerised models, and (ii) conduct *what-if* analysis leading to decision making. An experiment to validate models involves iterations of conceptualization-implementation-experimentation process steps followed by a comparative analysis of



(a) Problem entity Description (b) A conceptual model

Figure 2: Overview of Demonetisation Problem Statement

experimental results under supervision of a human expert. Essentially we establish *operational validity* (Sargent 2005) of models by having a human expert certify the observed experimental results. The simulation machinery generates a *trace i.e.*, complete information about system states and state transitions for a simulation run. The visualization machinery provides the desired graphical views, *operational graphics* (Sargent 2005), of trace. Early experience has shown that human experts find these views quite helpful. The proposed approach relies on prior domain knowledge to come up with probability distributions of KU behaviour and to set up the simulator initially. This helps in ensuring data validity to an extent. For large complex problem like demonetization, we rely on establishing correctness through operational validity as a pragmatic solution. The other alternative of ensuring correctness through transformation validity – of conceptual model, computerized model, and conceptual model to computerized model transformation – seems rather difficult and arguably impractical. An iterative approach involving two kinds of cycles, *i.e.*, – i) a localised cycle within conceptualization step and implementation step as shown in Fig. 1 (b) and (c), and ii) a global cycle involving conceptualization-implementation-experimentation as shown in Fig 1 (a) is proposed to ensure operational validity.

The experimentations can be carried out by changing data for initial simulation setting (to reflect data of to-be environment), probability distributions (to experiment with uncertainty) and/or (conceptual and computerized) models (to experiment with to-be system).

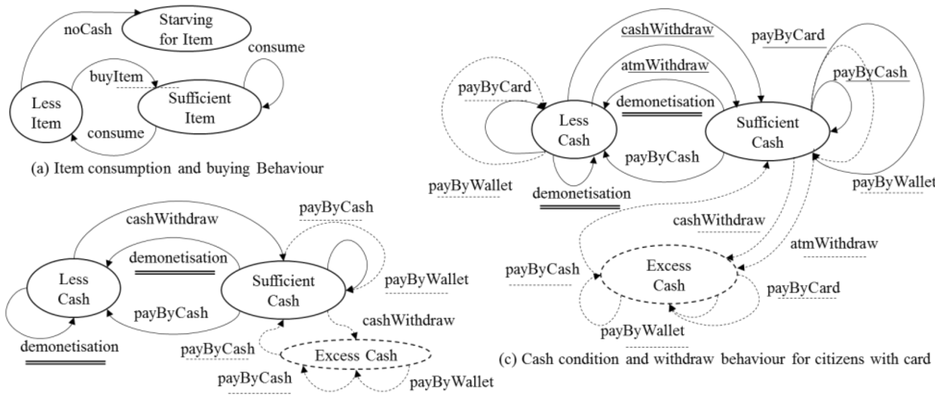
4 DEMONETISATION

This section describes demonetisation initiative, defines the scope for experimentation, and illustrates construction of a synthetic environment to conduct experiments with a degree of certainty. The construction of synthetic environment to conduct experiments uses approach described in section 3.

4.1 Problem Entity

Our experiment considers a small but well-formed subset of demonetisation as a problem entity. We limit our focus to common Indian citizens, who are largely confined to a bounded set of activities, as shown in the Fig. 2 (a). Essentially, citizens consume essential and/or luxury commodities (*e.g.*, food, medicines, perfumes *etc.*), and avail various services (*e.g.*, medical assistance, hospitality services, fitness related services *etc.*). They buy commodities from shops/suppliers, avail services from service provides, and pay for their purchases and services. Citizens withdraw cash when cash-in-hand dips below a threshold value. A class of citizens may hold credit and/or debit cards - a citizen who holds card may choose to pay by cash or by card for a purchase, and may withdraw cash from ATM machine and/or bank counter. In contrast, a citizen without a card always pays by cash and withdraws cash from bank counters. We assume all citizens are able to satisfy their daily needs *i.e.*, we exclude poverty related societal conditions from our experiments.

Pre-demonetization stage is characterized by sufficient cash in ATMs and Banks to service their customers (*i.e.*, citizens), sufficient stock in shops, and no notable denial of service from banks and ATM machines (*i.e.*, citizens are able to withdraw cash when in need). We consider this condition as normal



(a) Item consumption and buying Behaviour

(b) Cash condition and withdraw behaviour for citizens without card

(c) Cash condition and withdraw behaviour for citizens with card

Figure 3: Behavioural representation citizens – a conceptual model

situation. Demonetisation event disrupts this normalcy with abrupt elimination of 86% cash from the economy with a plan to slowly restore cash levels back to 70% of pre-demonetisation level.

Banks adapted several restrictions on cash withdrawals right after the demonetisation event to manage fair distribution of new currency notes being introduced at a fixed rate – a mint-centric constraint. Notable restrictions observed were: ATM withdrawal limit was reduced to rupees 2000 in a day for a citizen, bank withdrawal limit was reduced to rupees 10,000 in a day for a citizen, and weekly withdrawal limit was imposed to rupees 20000 per citizen. Shops adapted to accept alternate payment options such as mobile wallet and card payment whenever they observed a drop in sales record. A citizen, as an individual, also adopted appropriate strategies to avoid undesired circumstances. The adaptation strategies that were observed during post-demonetisation phase can be visualised along two dimensions:

Payment Pattern: Citizens started using mobile wallet and/or card as a payment option to save the trouble of standing in long queues to withdraw cash. However, not everyone used alternate option, an individual's decision were based on several factors such as availability and familiarity with payment technology, and whether the citizen was an early or late adopter to the new technology.

Cash Withdrawal Pattern: Some citizens restored to temporary hoarding of cash *i.e.,* withdrawing cash way in excess of their needs.

Given the above scope problem entity description, our experimental objectives are two-fold: (i) to understand if the normal condition is likely to be disturbed as a result of the disruptive change of demonetization, and to what extent, and (ii) to identify the courses of action to restore normalcy.

4.2 Conceptual Model

We consider four primitive identities namely *Bank*, *Shop*, *Government*, and *Citizen*, a composite identity, termed as *Society*, and an entity, termed as *Item* to capture the problem entity described in Fig. 1 (a). The formulation is depicted using a class diagram in Fig. 2 (b). Item is a representative entity for all kinds of essential and luxury merchandise/services; Bank represents a financial institution that stocks cash and allows citizens to withdraw cash through cash counters and ATM machines; Shop is a location where Items can be purchased and services can be acquired; Government is an identity that observes situations and tries to control other identities; and Citizen represents common individual having a prototypical behaviour of which there could be many variants. Two kinds of citizens are formed from problem entity - a class of citizens hold card for financial transactions, and other class of citizens are not having a card. A Society as a composite identity comprises of government, citizens, banks and shops. It's a dynamic identity wherein associations with citizens, banks, and shops can change over a period of time.

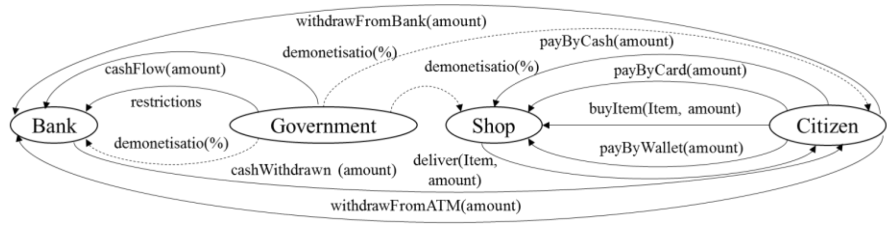


Figure 4: Actor Implementation– a computerised model

All primitive identities, such as banks, shops, government and citizens react to the events of interest in a manner to help accomplish stated goals as per a-priori known set of strategies. Thus, primitive identities exhibit a bounded set of behaviours, which therefore can be specified. Behaviour of society, on the other hand, emerges from the behaviour of primitive identities and interactions there between.

The item consumption, buying behaviours, and cash withdrawal behaviour of citizens with card and without cards are illustrated using extended state machines notation in Fig 3 wherein the transitions with firm line represent standard behaviour, firm line with single underlined label represent KU behaviour, firm line with double underlined label represent the impact of EUU, dotted line represent adaptation, and dotted line with single underlined label represent KU behaviour after adaptation respectively.

Figure 3 (a) describes item consumption and buying behaviour of an individual citizen. Essentially, it describes a citizen can be in one of the three states namely *Less Item* (item quantity dips below a threshold value), *Sufficient Item,* and *Starving for an Item* state. A citizen consumes item to cater to daily needs; a consumption may change the state of a citizen; citizen attempts to buy Item when citizen reaches to *Less Item* state; and a citizen moves to *Starving for an Item* state from *Less Item* state if citizen cannot buy an item (due to *Less Cash* condition of other state machine such as Fig. 3(b) and 3(c)). A citizen can consume multiple Items as part of their daily life, thus a citizen may contain multiple state machines with varying states information for items being consumed.

Figure 3 (b) and (c) describe the cash condition and withdrawal behaviour of citizens without card and with card respectively. A citizen with card may choose to pay by cash or by card for a purchase (KU behaviour), and may withdraw cash from ATM machine or bank counter (KU behaviour). In contrast, a citizen without a card always pays by cash and withdraws cash from bank counters. The adaptation strategies of citizens (that are described in problem entity) are depicted using dotted lines in Fig. 3 (b) and (c). A citizen, as an individual, may adopt an appropriate strategy (with multiple options selected based on personal intuition and experience – KU behaviours) to avoid entering an undesired state.

The bank, ATM machines and shops also exhibit behaviour and adaptations. The banks and ATM machines, typically, have three states *NoCash*, *LowCash*, and *WithCash*; they try to replenish the cash when they are in *LowCash* state, and they refuse withdrawal requests when they are in *NoCash* state. The state machines representing behaviour and adaptations of banks and shops are not shown due to space limitation.

4.3 Computerised Model

A computerised model is essentially a model of a society that contains government, citizens, shops, and banks. We (manually) translate class diagram and multiple state machines defined as part of conceptual model into actor specifications. We believe existing actor languages and frameworks, such as SALSA (Varela et al. 2001), Kilim (Srinivasan et al. 2008), Scala Actors (Haller et al 2009), and Akka (Allen 2013), are the possible candidate languages to specify computerised model as they support the notion of *actor*, and are capable of expressing *autonomy*, *adaptability* and *emergent* behaviour. In this experiment, we consider an actor-based language named as *Enterprise Simulation Language* (ESL) (Clark et al. 2016) to specify the computerised model. The explicit support for specifying *actor* types, uncertainty (using 'probably(p) x y' construct that evaluates x in p% of cases otherwise y), *Time* construct to recognise primitive 'time' unit make ESL suitable to specify demonetisation scenario. Moreover, the support for animation, traces, and operational graphics in ESL simulator helps in ensuring operational validity of our experiments.

A schema of translated actor specification is depicted in Fig. 4. As shown in the figure, the entity Item is translated as an entity (with parameterised price information); the primitive identities of Fig. 2 (b) (*i.e.*, government, shops, banks and citizens) are translated into four actor types namely *Government*, *Shop*, *Bank* and *Citizen*; the interactions are translated as events; and the behaviours and adaptations (*i.e.*, multiple state machines) are translated into actor behaviour wherein KUs are specified using *'probably(p) x y'* construct, adaptations are specified using (temporal) expression over state variable(s), and demonetisation is specified as event of government actor. We use initialisation parameters (*i.e.*, input parameter in (actor) 'new' operator) to specify initial state of an actor. This helps configure individualistic behaviour and/or adaptation strategies. We make *consumption rates* of required essential and luxury items of a citizen, personal preference of using card, cash and wallet for different kinds of purchases, cash withdrawal preferences of a citizen under various conditions as input parameters to citizen type of actor. Similarly, the preference of accepted payment mode is an input parameter to shop type of actor.

Configurable specification enables a society to be configured along two dimensions: (i) formation of society with different number of bank, shop, and citizen actors by instantiating actor types Bank, Shop, Citizen respectively, and (ii) configuration of individual elements of society through parameterisation.

4.4 Simulation

Simulation of a society progresses with primitive *Time* events that represents a 'day'. Each day, citizen actors consume items, buy items from shops if any item is below a certain threshold, pay for the purchases, and make an attempt to withdraw cash if needed. Similarly, bank actors try to stock up cash to fulfil ATM and Bank withdrawal requests, and shop actors stock up the items for their customers (*i.e.*, citizens). The government actor triggers 'demonetisation' event at specific day (an input parameter) of a simulation run. Overall, the citizens exhibit significant individualistic, uncertain, and adaptive behaviour with shops showing moderate dynamism whereas banks and ATMs exhibiting largely deterministic behaviour.

We visualize a simulation run into three phases: *setup*, *pre-demonetisation*, and *post-demonetisation*. Setup phase is an initial) time span of a simulation run that quantifies input parameters that are dependent on the definition of a society. Pre-demonetisation phase is the time-span between setup phase and occurrence of demonetisation event. Post-demonetisation phase is the time span after demonetisation event till the end of simulation. We quantify composition of society and pre-demonetisation cash-flow rates of banks and ATMs during setup phase. We rely on simulation to arrive at initial values for these parameters. Pre-demonetisation is an observation phase that validates normalcy of a society that includes: (i) Banks and ATMs have enough cash to service their customers; (ii) Shops have sufficient stock to cater to the needs of their customers; and c) Citizens face no problems in buying items as well as withdrawing cash. The post-demonetisation phase is observation phase to understand the impacts of demonetization event.

ESL simulator provides the required simulation environment. Simulator is configured to display relevant state variables and traces, as the simulation progresses, in the form of animation and operational graphics as shown in Fig. 5. We have chosen nine operational graphic panels to help understand condition of the society at a specific time. The 'Citizen Type' table describes the citizens and their card/wallet usage capabilities. The 'Payment Distribution' pie chart shows distribution of Card (green), Wallet (blue) and Cash(red) payments. The 'Payment Transaction Volume' chart describes the history of overall payment transactions where card transactions are displayed in green, wallet transactions in blue, and cash transactions in red. The 'Cash Availability in Bank and ATM' graph shows the history of cash availability at Banks and ATMs using red and blue colours respectively. The 'Transaction Declined Rate' graph describes the denial of service at Banks and ATMs using red and blue colours respectively. In addition, the 'Citizen with no Cash' and 'Citizen with excess Cash' charts describe the financial condition

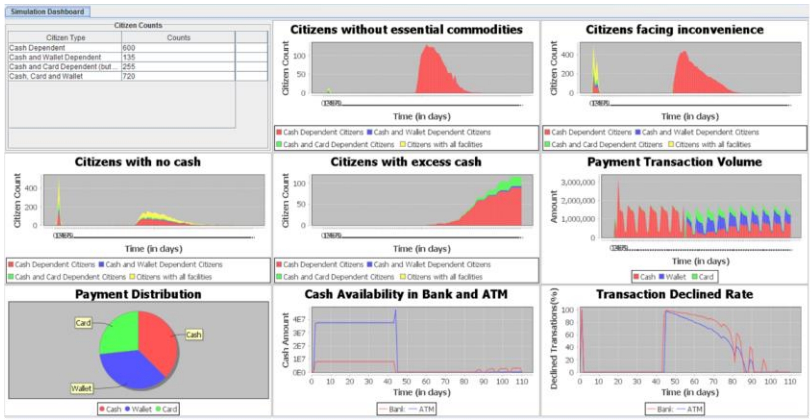


Figure 5: Simulation Dashboard – Operational Graphics

of the citizens: the former chart describes the number of citizens having considerably less cash, and the latter represents the number of citizens hoarding cash. The cash dependent citizens are displayed in red, cash and wallet dependent citizens in blue, cash and card dependent citizens in green, and citizen with all facilities in yellow. The 'Citizens without essential commodities' and 'Citizen facing inconvenience' charts represent the number of citizens starving for essential items and luxury items respectively.

5 EXPERIMENTATIONS AND VALIDATION

For conducting experiments, we simulated a society with one government, one bank, 15 shops and 1710 citizen actors for 150 days, where the first 15 days are considered for setup phase, next 30 days are the pre-demonetisation phase, and 105 days are the post-demonetisation phase. A snapshot of simulation dashboard with operational graphics at the day of 115 days (*i.e.*, after 70 days of demonetisation) is depicted in Fig. 5.

We observe that the graphs are unstable for first 15 days of simulation run as simulator is trying to set the values based on actor behaviours and their interactions. The simulation outcome for pre-demonetisation phase is stable and normal: no bank withdrawal request is denied, no citizen is facing any financial crisis, and citizens are not experiencing any deficiency for essential or luxury items. The demonetisation event is triggered at day 45 causing a sudden reduction of 86% cash from the bank and ATM machines. Subsequently, the withdrawals from bank and ATM decline whilst wallet payment and card payment increase significantly: the citizens have started facing a financial crisis and the citizens who are solely dependent on cash have started starving for essential and/or luxury items. The adverse effects continue for almost 50 days and then the situation returns to normal.

In graph with title 'Citizen with excess cash' in Fig. 5, we observe 115 citizens are hoarding cash when the situation is on the verge of returning back to normal. We also observe that cash dependent citizens are more prone to cash hoarding behaviour. The 'Payment Transaction Volume' chart describing the history of overall payment transactions shows an interesting trend – the card (green) and wallet (blue) usage have increased in first 30-40 days of post-demonetisation phase, and then it slowly started reducing. We correlated these simulation observations with the information found in authentic press-releases and newspapers. The trends on cash conditions of different citizens (shown in 'Citizen with no Cash' and 'Citizen with excess Cash' charts in Fig. 5), the inconvenience due to deficiency of essential items (shown in chart 'Citizens without essential commodities' in Fig. 5) and luxury items (shown in cart 'Citizen facing inconvenience' in Fig. 5) for cash dependent citizens, and service of denial at Bank and ATM withdrawal are in tune with the reality. In reality, the cash conditions in ATMs and Banks at the end of January 2017 (after 3 and half months of demonetisation) were just sufficient to serve their customers - this observation relate with the graph shown in 'Cash Availability in Bank and ATM' graph of Fig. 5. Alternative payment volume trend 'Payment Transaction Volume' chart also matches with the Bloomberg report (BloombergQuint 2017). These observations and close correlations with reality ensure operation validity of our experimental model and simulation. After ensuring the operation validity, we experimented with five *what-if* scenarios either by modifying composition of society in terms of its constituent elements and/or modifying the characteristics of the constituent elements individually. The scenarios and observed behaviours are summarized in Table 1. The row 1 is the standard configuration of a society that we described above. Other five rows are the possible means that we explore as part of our experiment. The scenario are: (i) a society *without cash-hoarder* citizen (row 2 of Table 1), (ii) a society *with more e-wallet users* - a case where citizens are convinced to use alternate payment options (row 3), (iii) *reduced cash withdrawal limits* where cash withdrawal limits from banks and ATMs were respectively reduced to rupees 1000 and rupees 5000 per day per citizen (row 4), (iv) *faster cash replenishment* where cash replenishment is 5 times faster than standard configuration; this is a hypothetical case that we considered to know the situation if the government was well-equipped with newly minted cash (row 5), and (vi) *combination of the scenarios discussed in rows 2, 3, and 4* of Table1.

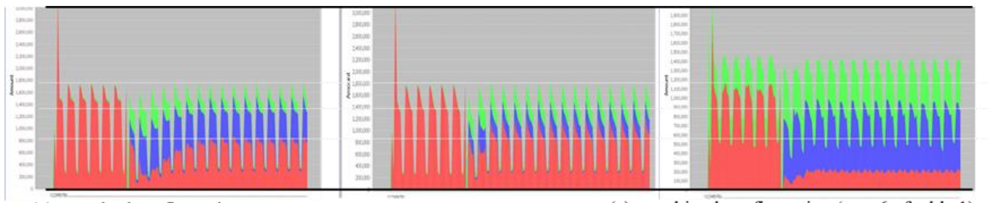
Detailed simulation results (Barat et al. 2017) with operational graphics are not included in this paper due to space limitation. We, instead, summarized observed simulation results in Table 1. The column 'No Denial of service at Bank and ATM' represents the *day* when denial of ATM and Bank withdrawal services are dipped below 5% in 'Transaction Declined Rate' graph (see Fig. 5 as reference); column 'Citizen with No Cash' represents a tuple describing the peak value (*i.e.*, maximum number) of cashless citizens during post-demonetisation phase and time-span of 'Citizen with no Cash' graph (see Fig. 5); and column 'Cash hoarder After 105 days' describes the number of citizens who are converted to cash hoarder at the end of simulation (captured from 'Citizen with excess Cash' graph). Similarly the columns 'Citizens without essential item' represents a tuple describing maximum number of citizens who were lack of essential items (from 'Citizens without essential commodities' chart) and time-span of such kind of inconvenience; and 'Citizens without luxury items' represents tuple describing maximum number of citizens who were lack of luxury items (from 'Citizen facing inconvenience') and time-span.

A comparative analysis of rows 1-4 of Table 1 shows that the hoarding behaviour is one of the contributing factor for prolonged cash shortage – note row 2 is addressing the cash shortage issue better than other options. However, ATM and Bank withdrawal limits, as shown in row 4, are found as most critical to mitigate cash-less condition and deficiency of essential and luxury items - significant contributors to citizen inconvenience. This observation is in tune with the reality – government had realized the importance of cash-limits after a week of demonetisation, and tried to arrive at optimum value through multiple alterations (Wikipedia 2016).

It was felt that faster introduction of new currency to banks and ATMs can lead to reduced inconvenience to the citizens. A simulation run with faster cash-replenishment(5 times more than standard configuration as shown in row 5 of Table 1) resulted into less cash shortage and less inconvenience to the citizens as compared to other options. However, we found this option is not helping in moving toward a less-cash society. As cash was readily available in the desired quantity, citizens resorted to old habits *i.e.,* falling back on payments in cash at the exclusion of electronic payment options such as credit/debit cards and wallet payments as shown in Fig. 6 (a) and (b) (where (a) is standard configuration and (b) is faster cash replenishment option respectively).

Table 1: Summary of simulation results

	Scenario	No Denial of service at Bank and ATM	'Citizen with No Cash'	Cash hoarder After 105 days	Citizens without essential item	Citizens without luxury items
1	Standard	After 52 days	140, 45	160	120, 41	450, 42
2	Without hoarder	After 40 days	120, 39	0	105, 38	440, 40
3	With more e-wallet users	After 45 days	120, 31	160	100,34	440, 35
4	With reduced cash withdrawal limits	After 48 days	100, 46	160	80, 40	400, 39
5	Faster cash replenishment	After 18 days	110, 17	0	54,16	375, 15
6	Combination of 2, 3, 4	After 37 days	115, 35	0	70, 26	360, 29



(a): standard configuration (b): with faster cash replenishment (c): combined configuration (row 6 of table 1)

Figure 6: Payment Transaction Volume

As part of exploring possible options that have potential to reduce negative impacts of demonetisation while moving towards the less-cash society, we experimented an option that combines the options described in rows 2, 3 and 4 of Table 1. The observed simulation results are recorded in row 6 of Table 1 and Fig 6 (c). The result indicates significant improvement towards less-cash society as the alternate payment modes, *i.e.,* card and wallet transactions, in Fig. 6 (c) are high as compare to Fig. 6 (a) and 6 (b). The citizens without essential commodities and citizens without luxury items are also less as compare to the options depicted in rows 2, 3 and 4. Thus, we believe, coordinated and judicious usage of multiple options could have reduced the negative impacts to an extent and helped to achieve the goals better than the current demonetisation implementation.

6 CONCLUSION

In this paper, we began by arguing the need of bottom up simulation approaches to understand impact of a disruptive event on a complex system. We extended a well-known modelling method (Sargent 2005) with the concept of a bottom up approach for developing a conceptual model (Thomas et al. 1994). We built further on the notion of actor model for organisations (Hewitt 2010) to come up with an executable/simulatable model. We use actor-based simulation as experimentation technique for *what-if* scenario playing. We adopted operational validation techniques presented in (Sargent 2005) to ascertain correctness of the proposed simulation based approach for helping decision-making in complex, dynamic and uncertain environment.

Next, we illustrated the proposed approach using a non-trivial example – a subset of demonetization initiative undertaken by Indian Government in November 16. We discussed how the proposed approach can help identifying most satisficing courses of action without compromising the overall objectives. In particular, we presented citizens viewpoint of demonetisation initiative, conducted *what-if* scenario playing to understand the impact of this disruptive event on a synthetic environment, and correlated results of simulation with real-life data. Our experimental results closely relate to the real-life data reported in newspapers thus validating our hypothesis of using actor-based bottom-up simulation approach to understand complex transformational endeavours such as demonetisation. Though issues such as robustness, efficiency and usability remain to be addressed, this non-trivial experimentation, we think, can be seen as an encouraging sign that proposed modelling approach can be adopted to other complex dynamic decision making situations that deal with uncertainty and emergent behaviour. We are in the process of applying our approach in socio-economic systems where the quantitative economics based techniques are the only potential aids available for the decision makers.

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