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Abstract: Systems Dynamic (SD) modelling is used to investigate the impacts of policy interventions on industry actors' preparedness to mitigate risks and to recover from disruptions along the maritime logistics network. The model suggests a bi-directional relation between regulation and maritime industry actors' behaviour towards Disaster Preparedness (DP) in maritime logistics networks. The model also showed that the level of DP is highly contingent on technology change, attitude to forecast accuracy, risk prevention, port activities, and port environment.

Scenario Analysis and Disaster Preparedness for Port and Maritime Logistics Risks

Highlights

- Ports and ship owners have become increasingly exposed (vulnerable) to logistics risks, disruptions, and uncertainties.
- System Dynamics modelling show effect on:
    - the impacts of policy interventions on shippers' preparedness to mitigate risks
    - ability to recover from disruptions along the maritime logistics network
- A bi-directional relationship between regulation and shippers' behaviour towards Disaster Preparedness in logistics networks is revealed
- The level of Disaster Preparedness is highly contingent on technology change, attitude to risk prevention, port activities, and port environment

Scenario Analysis and Disaster Preparedness for Port and Maritime Logistics Risk Management

Abstract

Systems Dynamic (SD) modelling is used to investigate the impacts of policy interventions on industry actors' preparedness to mitigate risks and to recover from disruptions along the maritime logistics and supply chain network. The model suggests a bi-directional relation between regulation and industry actors' behaviour towards Disaster Preparedness (DP) in maritime logistics networks. The model also showed that the level of DP is highly contingent on forecast accuracy, technology change, attitude to risk prevention, port activities, and port environment.

1 Introduction

The capacity to create feedback relationships between the causes and effects of policy change (interventions), and the need to understand and communicate real-time industry-wide evaluative reports has increased now than ever. Extant literature indicates an increase in disasters (Wagner and Neshat, 2009) and a corresponding increase in economic impact (Munich Re, 2006). For instance, Coleman (2006) has observed that man-made disasters have increased in number, which to a large extent can be attributed to increasing complexity of today's supply chain (Wagner and Neshat, 2009). Several seasoned researchers (Craighead et al., 2007; Tang, 2006; Wagner and Bode, 2006; Zsidisin et al., 2005) assert that supply chain managers have implemented initiatives to boost revenues, cut costs, and reduce assets. While risk managers at various ports seem to do their best to improve safety in a sustainable environment, investors and supply chain managers appear to continually reduce the amount of resources and time invested to promoting disaster preparedness. Such industry actors seem to encourage increase in port activities some of which may be increasingly risky and threatening to environmental sustainability (stability). Additionally, globalised production; increased reliance on sea transport for import and export; technological changes and increase in vessel size (e.g. 'Gigantism[1]'); port specialisation; and port decongestions (an attempt to hold inventory at sea); - are some of the current evolutions in the maritime logistics industry which may be traced to the consistent growth in world trade in the past decades and the

[1] Gigantism is a hub and spoke relationship between main ports that handle larger sized vessels and other ports in the neighbourhood.

increasing emphasis it places on maritime transport efficiency. Livey (2005) observes that good geographical location (which promotes best vessel transit/steaming time and port rotation), large consumer market, and available infrastructure that is also flexible, are some of the factors that tend to favour these talk-about evolutions in the maritime industry. These transformations also require that port authorities, ship-owners, ships operators, shippers, and transporters (herein referred to as maritime logistics industry actors) remain alert (or prepared) to tackle potential causes of disruptions in their supply chain.

From the above discourse, we argue that disruptions in the supply chain could have drastic effects on the entire global economy (Acciaro and Serra, 2013) (see example in Marshall, 2005). It appears that the evolutions discussed in the previous paragraph can potentially lead to increasing cost of operation, increasing influence of harsh environment on operations, increasing human errors leading to serious damage and loss, and many other risks. An attempt to counter these negative effects seem to have culminated to the maritime transport sector witnessing increase in regulations in recent years (Psaraftis, 2005) in order to mitigate the environmental impact and to improve industry security and safety. For instance, the industry has seen a change in port ownership and management (Brooks and Cullinane, 2006) from public to the private sector administration (Baird, 1995). Already, the relationship between port development, maritime traffic expansion, and the environment, has been questioned (see Finney and Young, 1995; Guhnemann and Rothengatter, 1999; and Vandermeulen, 1996). This became necessary especially at this era that ports are changing roles from just being simple link between terminals and the hinterlands, to becoming complex node in the logistics chain. The role changing can lead to change in structural and infrastructural layout (UNCTAD, 1993). As industrial hubs and nodes, the port/maritime industry can also become high population centres that can contribute significantly to global anthropogenic emissions (Tzannatos, 2010). Due to environment dynamics, ports are generally associated with other activities such as construction/extension, port maintenance, dredging and reclamation especially if they have been sited on rivers and estuaries. These activities can cause increases in water turbidity, lead to change in depth, and degradation of marine resources including beaches, wetlands, and land forms. At other instances, increasing such activities has the potential to increase the volume of discharged sewage, bilge waste, and oil into surface water which thereby create unfavourable condition (e.g. eutrophication) for the entire ecological sites (see Goulielmos and Pardali, 1998; Gupta et al., 2005; Trozzi et al., 1995).

These problems and environmental hazards might have orchestrated the promulgation of many international conventions (Goulielmos, 2000) by the IMO including the MARPOL 73/78 and the subsequent Convention Annexes (see Wright, 1999). There is greater need than ever to improve maritime logistics chain's efficiency and to sustain improvement in performance. Nonetheless, it seems that frequent changes in strategic policies can affect industry actor's preparedness for disaster and the capacity to recover from major disruptions.

Roberts and Bea (2001) proposed three policy levers that can help organisations to build a high-reliability safety, including: Managers aggressively seeking to know what they don't know; design reward and incentive systems to recognize the cost of failure and the benefits of reliability; and/or to communicate the big picture to everyone. Many managers and organisations may attain the first two levers but they are often unable to communicate the policies to those who implement them and those who may be affected by the policy change. Without understanding these, the likelihood of successful sustainable change is small (Sterman, 1992) due to internal resistance from policy effectors. We aim at employing a hybrid methodological approach to model the potential consequences of policy change on the structural behaviour of port industry actors' level of disaster preparedness so that they may gain insight into, communicate, and improve current level of understanding the potential causes of disruptions in the maritime logistics industry. Thus the SD models should help industry actors to identify, frame, understand, and discuss complex phenomena that can cause systemic disruptions such that real-time evaluation of alternative mitigation decisions can be made prior to policy implementation.

The scope of this research covers only water/ocean surface transport plus the shore-side infrastructure and personnel together which facilitate cargo handling (and passenger movement) that is essential to maintaining efficient (cost-effective, reliable, and seamless) operations. In particular, we focused on the industrial cluster of ports on the Humber River Estuary (HE) also known as the Humber Ports Complex (HPC). Section 2 examines the relevant literature and key research constructs while in Section 3, we focus on the research methodology. Section 4 analyses the research and draws conclusions based on those research findings plus research implications for both academia and management.

2 Reviewing disaster and preparedness

The increasing number of disaster declared cases (Drabek, 1995; Murphy and Bayley, 1989), the increasing economic value of losses, and the number of disaster declared victims (Blaikie et al., 2004) recorded in recent times calls for a review of the construct. The term ‘disaster’ has very broad definition and implications. However, we adopt definitions by the World Health Organisation (WHO) and that from McFarlane and Norris (2006).

> *“Disaster is a result of vast ecological breakdown in the relationship between man and his environment, a serious and sudden/slow onset disruption, on such a scale that the stricken entity* [individual, community, organisation, society] *needs extraordinary efforts to cope with it, often resulting in dependence on outside help or international aid”* (World Health Organisation – WHO).

> “*Disaster is potentially traumatic event that is collectively experienced, it has an acute onset, and is time delimited; disaster may be attributable to natural, technological, or human causes*” (McFarlane and Norris, 2006, p. 16).

The above definitions of ‘disaster’ covers acts of nature (e.g. flood, storms, earthquake, mass slides and avalanche); large industrial accidents (transportation and nuclear); and episodes of mass violence (e.g. terrorism, industrial unrest leading to vandalism); one will note that disruption is a consequence of disaster and the vice versa. Indeed, Horlick-Jones (1995) acknowledges that disasters can disrupt the general routine of an entity, destabilise social structures and long earned adaptations, as well as endanger worldviews of system meanings.

The divergent views (Table 1) about disasters suggest that one cannot tie the phenomenon to a fixed event, at any particular time and space (Quarantelli, 1995; Kreps, 1995; Kroll-Smith & Gunter, 1998).

Definitional perspective	Category of potential disaster incidents	author
Geographical perspective: disasters are “extremities”	i. geological events (e.g. faulting, earthquakes, volcanicity, mass slide); ii. meteorological events (e.g. floods, hurricane, storm surge, draughts, extreme temperatures); iii. ongoing social function disorder (e.g. strikes, war, and terrorism); iv. human-environment relationship (e.g. pollution, encroachment of designated sites, landfills and reclamations); v. historical structural process (e.g. land	Quarantelli, (1996)

	reclamation, coastal squeezing erosion isostatic rebound)	
Objectivity view based on their external complexity: disaster as a measure of the physical impacts of an incident on the entity	a) casualties (deaths and injuries) and measureable damage to property damage	Oliver-Smith (1999) Cutter (1996)
	b) social impact:	
	i. psychological impact	Bolin (1985); Flynn (2007); Houts, Cleary and Hu (1988); Perry and Lindell (1978)
	ii. demographic impact	Smith, Tayman and Swanson (2001)
	iii. economic impact	Charvériat (2000); Mileti (1999)
	iv. political impacts	Bates and Peacock, (1989); Bolin (1985); Bolin (1994)
Subjectivity view (internal complexity): disaster as a socially constructed perception		Oliver-Smith (1999)

Table 1: Summary of divergent views about disaster

These divergent views have broadened the definition and applicability of 'disaster' as well as allowed researchers to rope in social constructs and technological events which might cause or have the potential to cause social disruptions. Our research focuses on the material and infrastructural damage/failures or the physical impacts of disaster that have the potential to trigger off socio-psychological and psycho-cultural dimensions as mentioned in Oliver-Smith's (1999) article "*The angry Earth*".

Trends such as increasing dependence on technology, increasing urbanisation and social complexity suggest that disaster will continue to increase in frequency and magnitude (Quarantelli, 1991b). Smelser (1991) adds that the drive towards economic productivity, the pressure to improve technology, and internationalisation (or globalisation) of world economies are potential activities that can quicken the pace in the changing trend as per the prediction by Quarantelli. Arguably, technological advancement has propelled human development as well as enhanced extension of settlement to certain areas of the earth thus increasing our vulnerability to hazard (see Blaikie et al, 1994; Brammer, 1990; Hartmann and Standing, 1989; Kates and White, 1978). Richardson (1994) argues that the increases in environmental turbulence and crisis may be because the world today has more powerful technology that has the capacity to detect disaster as well as to generate disaster (e.g. computer failure, nuclear disaster, air plane crashes, collapse of oil rig platform on high seas, wreckage and piracy on the high seas plus terrorism attempts, environmental pollution [through emissions], trends of draughts and famine, as well as bad weather). One may refer to Burton (1993), White et al (2001) and Faulkner (2001) for general illustrations about how technology can expose humans to natural disasters. In the maritime logistics and supply chain industry, Wang (2006) recounts several technology related accidents in the recent past.

Knowing the precursors of disruption can lead to investigating why things/events happen, and the way they happened. It appears that with better understanding of the phenomena that can cause systemic disaster and consequently the disruptions it can cause, policy makers may be better informed. They would device and adapt sustainable alternative plans to confront future problems as well as plans to recover from disruptions associated with disasters.

In as much as disasters and disruptions are inevitable, industry actors need to understand port versus environment relationship and the impact of institutional policy changes on systemic disruption control. Human system’s failure to understand and to address the interactions between the set of interrelated systems can produce a collapsed cultural protection, which results in a set of effects called “disaster” (Dombrowsky, 1995). It seems Giddens’ (1979) ‘structuration theory’ acknowledges the relationship between human agency and social structure. Giddens notes that repetitive acts by agents in an environment can produce certain social structure (traditions, institutions, moral codes) and established ways of doing things. When the agents begin to ignore, replace, or reproduce them in a different way, changes can occur to the social structures. Furthermore, Heinrich (1958) asserts that accidents are caused by unsafe acts (i.e. person’s behaviour that deviates from normal) or unsafe conditions (i.e. hazard from mechanical failure and unstable environment). These and many other discourses can establish a dynamic relationship between behaviour and structure. Such sociological theories must account for unacknowledged conditions and unanticipated consequences (Giddens, 1979). From such theories that emerged the behaviour of the stock and flow structures of this research and the subsequent analysis of SD models.

On the other hand, disaster preparedness (DP) is a process of ensuring that an entity: has complied with preventive measures; is in a forecast state of readiness to contain the effects of a disastrous event in order to minimise loss of life, injury and damage to property; can provide rescue, relief, rehabilitation and other services in the aftermath of the disaster; and has the capability and resources to continue to sustain essential functions without being overwhelmed by demand placed on them (BusinessDictionary.com). All these must hold for one to be described as being disaster prepared. Booth (1993) observes that management of organisations recognise crisis situations too often too late. This can leave management and their organisations unprepared when disaster strikes. Disruption [disaster] in business can generate chaos (Faulkner and Russell, 1997; Peat, 1991; Gleick, 1987; Prigogine and Stengers, 1985). Good management tries to remove much of the risks and uncertainties in their business so that they can control their organisation's destiny (Fink, 1986). The uncertainty can be removed or at least be lowered through risk assessment and disaster preparedness. Hence many organisations and state nations have directed their attentions towards disaster preparedness and planning (Dynes and Drabek, 1994). For instance the UN, the World Bank, insurance companies, and many other agencies (e.g. Red Cross) are concern about building DP into development planning process. However, Huque (1998) challenges the claim to DP by most emergency service managers and other organisations. It seems that hierarchical structure (see Giddens's 1979 - stratification model) and bureaucratic policies can be hindrance to prompt response to emergency.

Some researchers (Christopolis, Mitchell and Liljelund, 2001) emphasise that efficiency, effectiveness, and impact of disaster response, are the central goal to preparedness. Others (McEntire, 2003; Twigg, 2002; UNDP, 2004) also believe that hazard mitigation[2] is core (critical) resource to DP. We note that in any case, an attempt to describe hazard mitigation involves describing aspects of disaster planning and preparation. McEntire (2003) went further to state that DP is a function of the local government and involves hazard and vulnerability [or risk] assessments. The ensuing discourse suggests that DP is all embracing and holistic, thus requiring entity's commitment in accurate assessment of hazard vulnerability and risk mitigation.

[2] Where Mitigation is defined as those collective actions taken by individual, or groups (public or private), to reduce the potential harm posed by an environment Bogard, W. C. (1988), "Bringing social theory to hazards research: conditions and consequences of the mitigation of environmental hazards." *Sociological Perspectives*, No.147-168.

3. Methodology

This research provides a conceptual understanding of the causes and effects of disruptions in port/maritime logistics industry. Based on insightful understanding of the consequences of policy change on industry DP, steps for risk mitigation leading to real-time recovery from disruptions may be designed, tested, and adapted prior to decision implementation.

The port/maritime logistics industry is very complex. Complex systems are extremely difficult to analyse, to understand how they function, to predict their behaviour, and also to determine their performance. There exist a variety of risk management models for decision-making in the port/maritime logistics industry. Most risk-based goal seeking regimes which researchers and safety engineers have relied on, to assess risk over the years can be described as being probabilistic and not always transparent to the user. With the increasing interest to improve safety in their industries, several large companies have depended on either quantitative risk assessment (QRA), or on qualitative safety analysis techniques (see Flin et al., 1996) to numerically (or otherwise) assess their safety levels. Sometime, the application of numerical risk assessment approach such as the IMO's Formal Safety Assessment (FSA) framework may not be appropriate due to input uncertainties and possible data insufficiency. One may accept such results with some scepticism perhaps due to lack of problem-owner involvement and difficulty to comprehend hard numerical results. On the other hand, Engineers may deem result from a purely qualitative research as unscientific. We bridge this methodological gap by applying a hybrid (SD) model as our analytic technique as we attempt to evaluate the consequences of policy decisions on DP prior to policy implementation. The SD technique is a modelling method that focuses on feedback structure and the resultant behaviour to understand complex systems in a holistic manner (Sterman, 2000). "[……] *continuous SDs models are mathematically equivalent to differential [or integral] equations, whereas discrete models are difference equations....typical SD models are descriptive, continuous, or discrete dynamic models that focus on policy problem involving feedback structures*" (Barlas, 2007).

Holling (1994) notes that globalisation processes have produced problems that are basically nonlinear in causation and are discontinuous in both time and space such that they become highly unpredictable. This characteristic nonlinearity makes it almost impossible to device a definite strategy for risk (or disaster) management. Hence the application of models (System Dynamics models) can help evaluate strategic decisions before they are implemented.

Apparently most dynamic problems are systemic. Therefore the use of SD model as our analytic method is to employ their feedback dynamics to assist industry actors to gain understanding into some problematic behaviour (or the causes of undesirable dynamics) in the port/maritime logistics system such that policies or strategies can be designed for improving the system's performance over time (Sterman, 2000; Richardson & Pugh, 1981). Management can thus engage the SD modelling techniques to formulate, explain, and effect long-term complex policy changes (Barlas, 2007) because of SD model's capacity to offer a platform for debates, idea sharing and learning. As a powerful approach (tool or technique) to dealing with dynamic complexities (Newsome, 2008; Wankhade and Dabade, 2006; Santo, Belton and Howick, 2002; Forrester, 1961), many researchers including Kopainsky and Luna-Reyes (2008) and Sterman (2000) have engaged it to structure the behaviour of complex dynamic systems through modelling, simulation, and feedback mechanisms within the field of systems thinking.

3.1 Data source

Major Ports on the Humber Estuary (HE) were studied and the results from personal in-depth, semi-structured interviews (Gillham, 2003; Barriball and While, 1994; Eisenhadt, 1989) granted by seven (7) port/maritime logistics industry executives concerning the effects of frequent changes (including: technology change; attitude to risk prevention; maritime activities; and port environment stability; and other influences as illustrated in Figure 2) on industry actors' level of DP were analysed and tested using the "extreme conditions test" . The selected individuals included six (6) Chief Risk Officers (CROs) and an academic expert in the field of coastal and estuarine studies. This category of industry experts were purposely selected for interview because we assumed that they hold key information about port/maritime industry security, emergency, and risk management since such related issues apparently form the core of their day-to-day experiences. Additionally, they can influence policy formulation and implementation concerning disaster planning, risk mitigation and management in their roles. They could therefore give a vivid naturalistic account of exactly what pertains in the maritime industry and how that can influence system-wide preparedness for disruptions. The personal in-depth semi-structured interview approach for data collection was adopted to enhance data validity and reliability.

3.2 Model formulation and development

We derived the below textual data from the semi-structured interviews:

"[….] *increasing attitude to risk prevention can lead to increases in maritime activities*".

"The Humber estuarine and it surroundings can be considered as one of the most stable in UK. It is this feature that is attracting many businesses including energy companies to relocate to the enclave leading to the increase in port activities".

"[…..] in my business, we are adequately prepared (i.e. have spare for each essential parts of our equipment) and cannot afford to lose billions of pound if we reduce our activities".

"We have very good IT infrastructure that allows everything we do to be replicated and saved off site. Other sophisticated IT systems help us in forecasting, inspection, and any activity you can think of….thus reducing the time that vessels spend at our ports. In our own way, we are well prepared for any incidents".

The filtered data were text-coded such as the following:

"*…. improved risk preventive attitude"* can lead to *"increase maritime activities*"

"….a more stable environment" can lead to *"increased port activities"*

"*....more preparedness""* can lead to "*more port/maritime logistics activities"*

"*….improved technology"* can change levels of "*disaster preparedness*"; ….etc.

Causal structures (Kim and Anderson, 2012) in the form of word-and-arrow diagrams (Eden et al., 1992; Axelfrod, 1976) that represent respondents' mental models emerged. Each set of text-codes was linked to one or more other concepts in a cause and effect conceptual frame (Figure 1) with a specified relationship arrow.

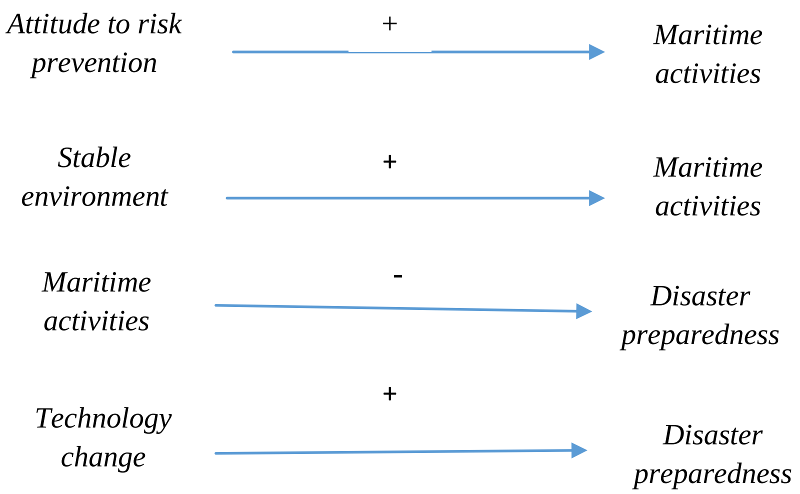


Figure 1: Basic causal relationship between key variables

We note that the use of rich data source (qualitative data) in SD model building and subsequently for simulation purposes has been recognised in Kim and Anderson (2012), Ackermann et al (2010), Luna-Reyes and Anderson (2006), Ford and Sterman (1998), Forrester (1992), and many others. Thus through these steps of coding process as in the Grounded Theory (Straus and Corbin, 1990, 1998; Corbin and Strauss, 2008), we were enabled to attach labels to segments of data to depict what each segment is about (Charmaz, 2006) and to form the feedback loop diagram (Figure 2) which became our structural theories.

We engaged Vensim software to build a feedback loop structure (Figure 2) from the basic causal links (Figure 1). The feedback loop suggests that to increase our level of DP, we need to improve technology [+]. However increasing technology can reduce environment stability [-]. A stable environment may encourage more maritime activities [+], which subsequently reduces the level of DP [-].The overall polarity of the loop (Figure 2) suggests a reinforcing or self-perpetuating feedback loop [+] which indicates that an action can produce results which influences more of same action (growth or decline) in the future unless a solution is found to stop the recurrence. From the above relationship, we argue that levels of DP and environment stability interdepend on each other directly or indirectly. Two or more of such feedback loops (Figure 2) were joined to form the causal loop mapping (CLM) as represented in Figure 3.

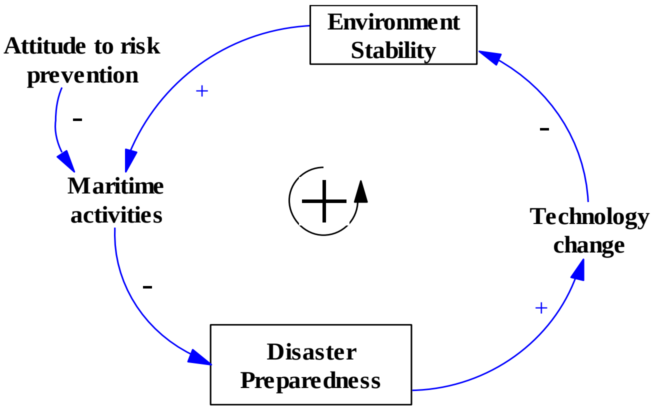


Figure 2: The feedback loop diagram for disaster preparedness

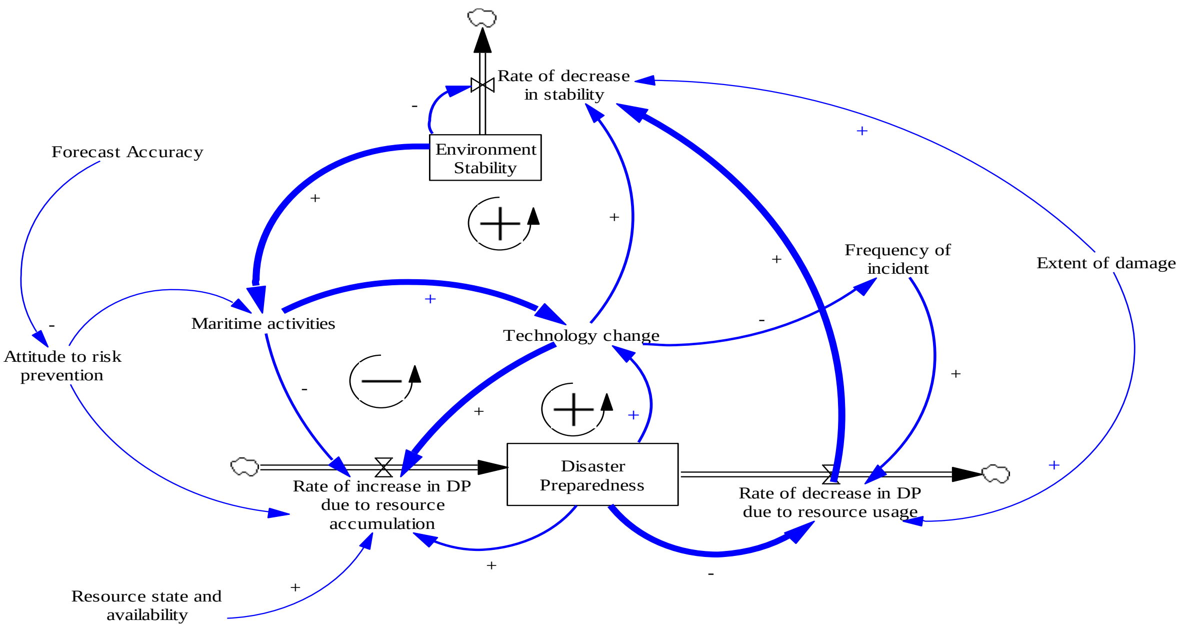


Figure 3: The general integrated CLM indicating interdependencies in research variables extracted field data

We note from Howick et al. (2008) that in SD modelling, it is usual and acceptable that the modeller determines which variables in the influence diagram to model as stock, which to model as flow variables and which variables not to include in the model at all. We have selected "Disaster Preparedness" and "Environment Stability" as the stocks [box], the double arrow lines represent the rates of change (or flows) of the stocks, and any other variables as our endogenous variables.

4. Analysis

4.1 Model analysis

Stocks as applied in this research may represent mental images, perceptions, or physical stock such as infrastructure and emergency response equipment, which may be used to enhance the logistics chain's operations in times of emergency. We measure DP on the basis of how resourceful and agile a port system is able to respond to crisis so that it can quickly contribute to speed up recovery time (t) employing the below dynamic functions:

$$Stock(t) = \int_{t0}^{t} [Inflow(s) - Outflow(s)]ds + Stock(t0) \ldots\ldots eqn\ (1)$$

Or

Stock $_{(t)}$ = INTEGRL (Inflow – Outflow, stock$_{t0}$) ……eqn (2)

The differential equations describe the behaviour of the state variables and their rates of change. Equations (1) and (2) represent the value of stocks (i.e. DP, or Environment Stability) at instantaneous time **S** between the initial time $\mathbf{t_0}$ and final time (**t**). Both equations can be interpreted as meaning that stock accumulates at the rate of the inflow variable less (or minus) the rate of outflow variable, beginning with an initial value of stock$_{t0}$. It may also represent the perceived safety/stability levels of a port network against operational disruptions.

By the dynamic systems theory (van Geert and Steenbeek, 2005; Fisher and Rose, 2001; Thelen and Smith, 1994), we assume the rate of stock depletion (i.e. resource usage for the purposes of emergency response) is proportionally dependent on already accumulated resources. Furthermore, we assume that there is no obsolescence and waste such that there is high level efficiency in the logistics chain within the period under investigation.

Therefore the causality diagrams [Figure 4a and 4b] below describe the various influence relationships that exist between DP and other endogenous variables. In Figure 4a (causal tree), the level of DP is directly influenced by its rates of increase/decrease, each of which are also caused by other endogenous factors. The use of the tree diagram (Figure 4b) on the other hand tells the story of what factors are directly influenced by DP and which ones are influenced indirectly.

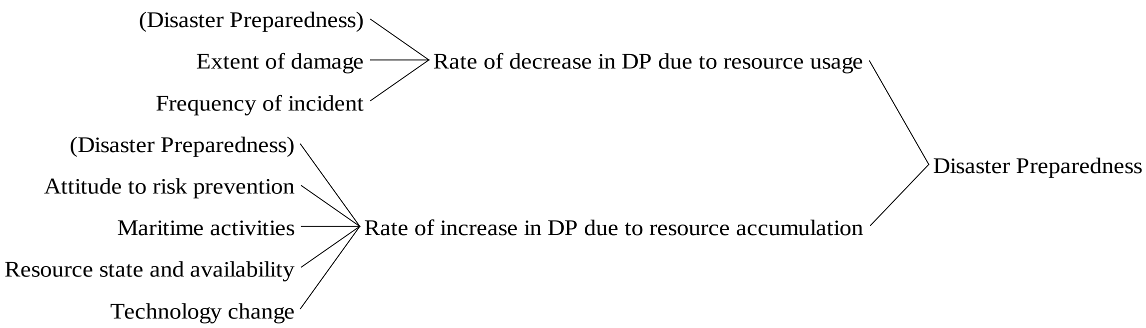


Figure 4a: The causal tree diagram representing different variables that can influence DP

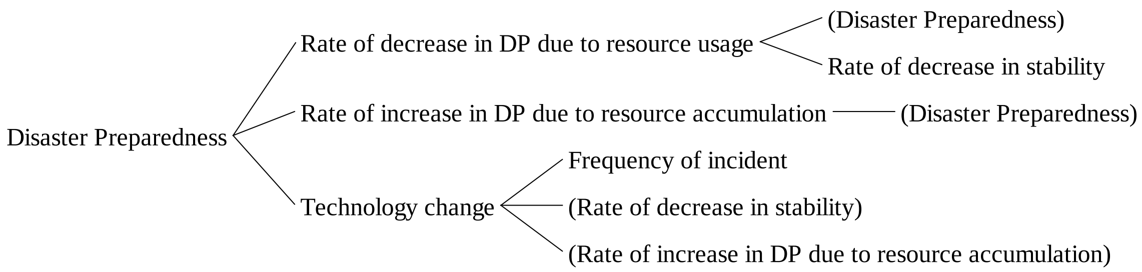


Figure 4b: The use tree diagram representing different variables that can be influenced by DP

Consequently, it appears that the level of DP at time (t) can increase (or improve), or decrease (level reduce) dependent on the following endogenous variables: port activity; policy on risk preventive compliance measures; technology change; forecast accuracy; resource flexibility and so on. For example, increased awareness of location effects (in terms of port size and physics) and the accompanying change in port activities can lead to increased preparedness (risk awareness/alertness) and improvement in real-time response due to advance planning. It is expected that when any of the above listed endogenous variables experienced favourable change, management team would be enabled (through the disaster management plan), to strategize how to avoid, or how to mitigate the impacts of disruptions in all the key phases (pre-disaster, disaster, and post-disaster phases). Together, those auxiliary variables feed into the inflow (rate of increase in preparedness due to resource accumulation) of Figure 5 and potentially resulting in increase in the stock (DP) levels. We considered natural environmental dynamics and policy formulation processes as exogenous variables since they appear to be out of control by port/maritime logistics industry actors. The structural illustrations of the above arguments gives rise to Figure 5 below.

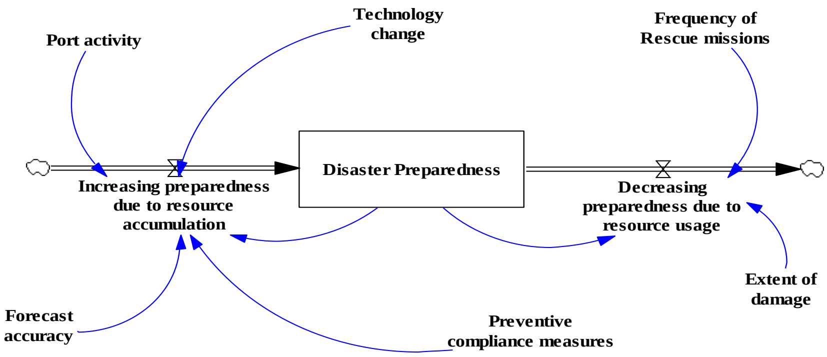


Figure 5: The dynamic conceptual model of DP

Furthermore, Figure 5 assumes that the only way by which the level of DP can reduce is by the rate of decrease in preparedness as a result of resource usage (or large scale resource depletion) for the purposes of disruption management in the logistics chain. Such change may rather increase the rate of outflow, or constrain the inflow; a phenomenon which tends to reduce the amount of already accumulated stock and subsequently makes the system more vulnerable to risks; slow to respond to disruptions; or even become non-responsive to future incidents of disruptions (especially if the needed resources are scarce, or if the resources are non-replaceable in the short-run). As a miniature representation of Figure 3, the inclusion of the few necessary auxiliary variables to Figure 5 makes our concept clearer to the audience.

We also conceive DP as a state of readiness (or alertness) leading to port actors acting promptly and decisively accurate at a particular time in order to save a crisis situation. The concept is perceptual (hypothesized): the actual state of preparedness cannot be valued or ascertained with any certainty prior to the occurrence of event, neither can it be quantified. Therefore the port industry actors can only assume a state of readiness at a particular time, just as the below excerpt represents the view of a large majority of our interview respondents:

> 'By our work efforts and also by our standards we are probably fairly prepared, we are fairly well protected in our own sense theoretically but we have not tested our readiness in a real life scenario'.

In other words, industry actors appear to trust their current state of DP; a perception which seem to be normal in the way people perceive risks/hazard in their environment. This seems to support Lichtenstein et al (1978) observation that people tend to overestimate their ability to control or prevent accidents, leading to an under-estimation of risks [hazards] in a system. Since entities have the tendency to over-estimate safety conditions around them when they get used to a situation, it appears that the actors' beliefs and perceptions will remain the same until the system is tested by real life scenario. However, experimenting with real-world scenario can be highly catastrophic in terms of costs (i.e. financial, and casualty). Therefore models of this research have been set out to mimic the real-world scenarios that can help to stress test the level of disaster preparedness by port industry actors in the case study area.

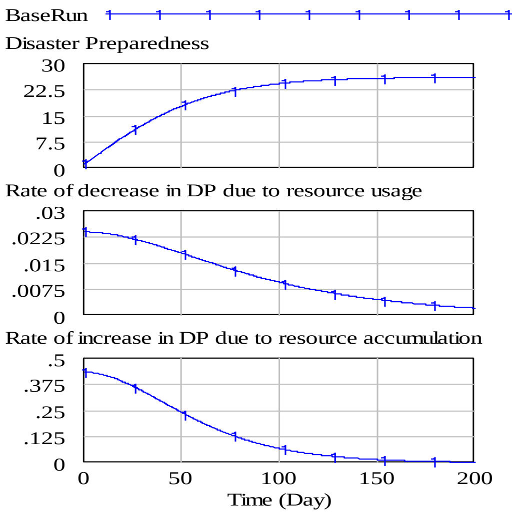
4.2 Model testing

The time horizon for the simulation models is 200 days (i.e. approximately 6 months). We selected this time horizon on the basis of the responses we received from the respondents concerning the expected duration of some disruption incidents they illustrated. Responses suggest that time is generally event dependent. However by the nature of their activities, the port logistics industry actors cannot endure any major disruptions in their network for longer than a day. Besides, modelling gurus (e.g. Meadow et al., 1974; Backus, 1996; Bunn and Larsen, 1997; Sterman and Richardson, 1985; Sterman, Richardson and Davidsen, 1990) have advised that the duration be set several times as long as the longest time delays in a system being investigated (Sterman, 2000) or should extend far back into history enough to show how a problem emerged, and to adequately describe the symptoms of the effects of any strategic policy interventions. Thus it seems 200 days is long enough for the system we are modelling to be able to learn whether the planned mitigation activity (policy intervention) will fail or otherwise (see Sterman, 2000, pp.90-94).

We randomly (arbitrarily) generated some initial values for the parameters (constants) to allow manipulation and estimation for the next values as permitted in Euler's numerical approximation. For example we assumed a high value of 80% and 85% (0.8 and 0.85) for forecast accuracy and resource availability respectively and a reasonably low value of 0.03 (3%) extent of damage in all port/maritime logistics operations. Furthermore, the numbers 0, 1, 10, 100 and their multiples seem to be the most common basic units that Euler's numerical method[3] as well as the Vensim® software uses as initial values for modelling; though the

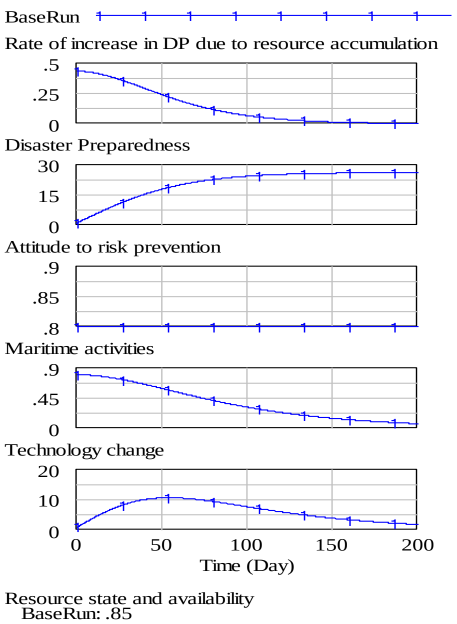
[3] Euler's numerical methods is a basic explicit mathematical or computational procedure for solving by approximation, the ordinary differential equations (ODEs) given some initial value and is the simplest Runge-Kutta method

modeller may choose other values to suit the problem of the day (Sterman, 2000, pp. 90-94). With these parameters defined, we subjected the CLM model (Figure 3) to “extreme condition test” (or sensitivity analysis) using the dynamic model in equations 1 or 2 to arrive at the graphs below (Figures 6 to 19). A similar approach has been applied in Shin et al (2014) to analyse safety attitudes and behaviours among some construction workers in the USA, while Georgiadis et al (2005) adopted a similar technique to model strategic management of food supply chain in Greece.



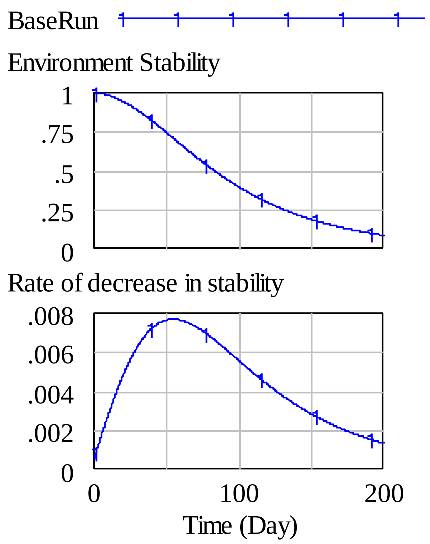
All curves in Figure 6 appear to be non-linear. The trajectories of the curves show that DP rises gently, reaches a peak (at approximately 100 days) and remains constant. Within the same period, both the inflow curve (Rate of increase in DP due to resource accumulation) and the outflow curve (Rate of decrease in DP due to resource usage) decline gradually to approach zero.

Figure 6: The dynamics of Disaster Preparedness and its flows over 200 days



Following from Figure 6, Figure 7 suggests that the trajectory for “Technology change” also rise, reaches its peak, and then declines gradually to approach zero whiles “Port/Maritime supply chain activities” decline contemporaneously with the fall in technology change. The trajectories for all graphs in Figure 7 also appear to be non-linear except the graph for “Attitude to risk prevention” which remains constant at 0.80 (or 80%).

Figure 7: The dynamics of Rate of increase in DP due to resource usage and cohorts over 200 days



The graphs in Figure 8 describe the dynamics of "Environment Stability" and its rate of decrease. The environment may become vulnerable and thus increasing the level of hazard as soon as operations starts and thus environment stability begins to decline right from the start. This can cause the rate of decrease in "environment stability" to increase very fast to reach its peak just at the time when "Technology change" also seems to reach its peak approximately in 50 days from start. The rate of decrease in stability declines thereafter to approach zero.

Figure 8: The dynamics of Environmental Stability and its rate of decrease over 200 days

Figures 9 – 19 present different scenarios as we test for sensitivity of key variables under the 'extreme test condition'.

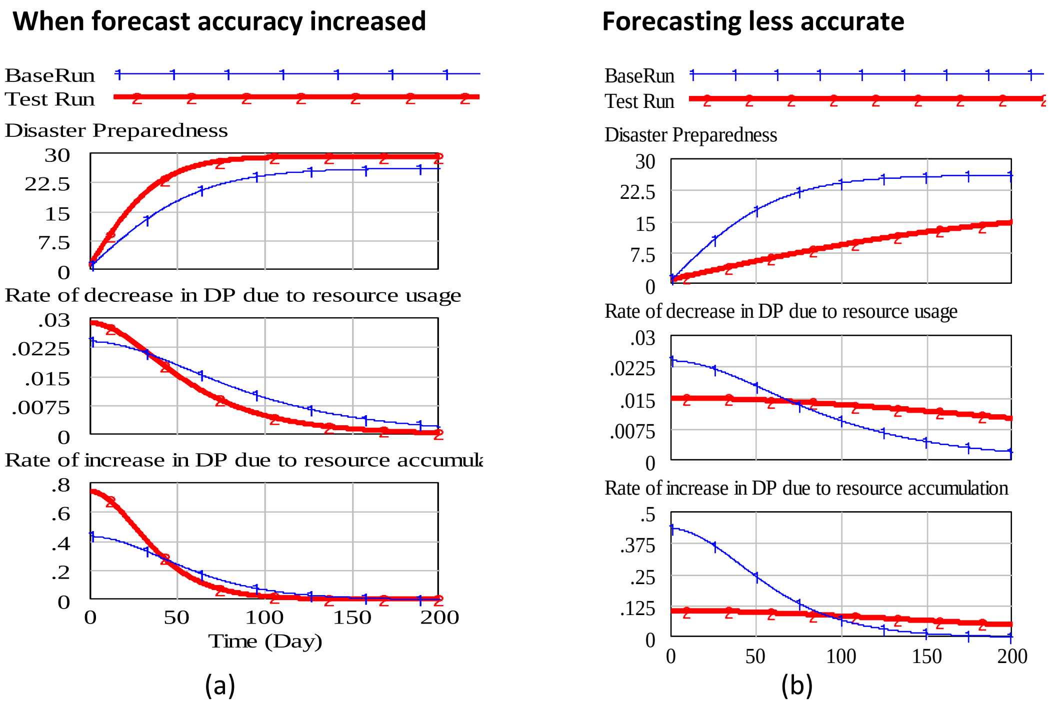


Figure 9: The real-time change in DP and its flows over 200 days over response to change in forecast accuracy

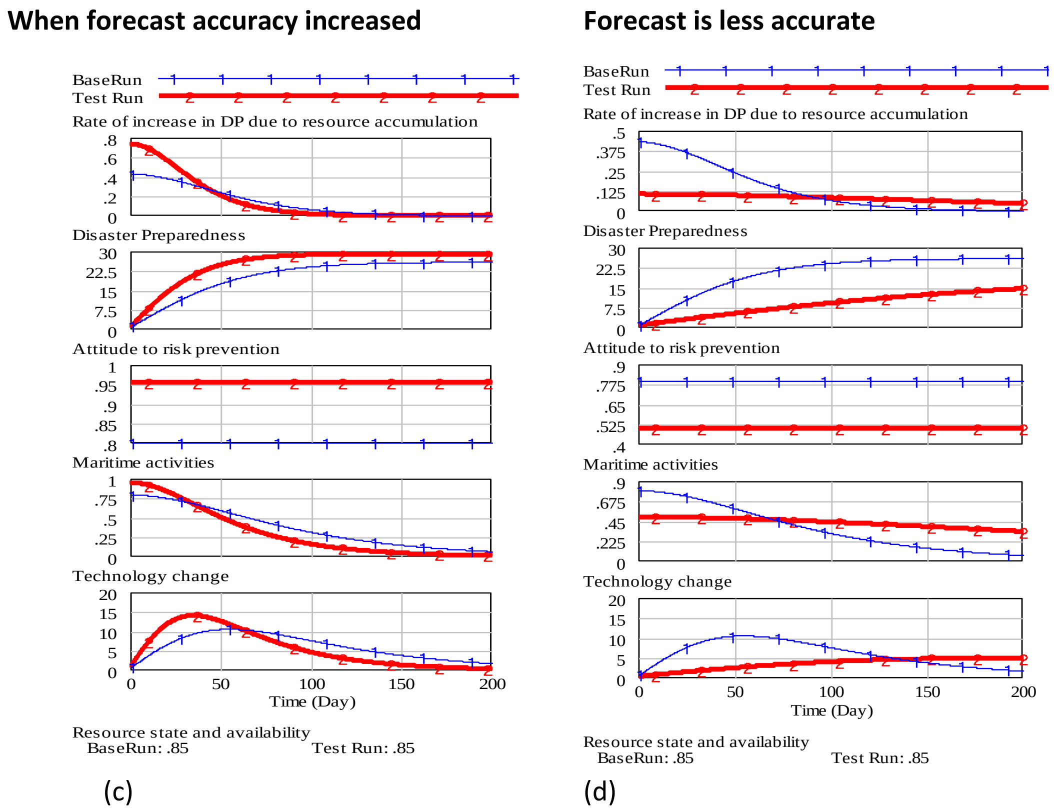


Figure 10: The real-time Rate of change in DP due to resource accumulation and cohorts over 200 day in response to change in forecast accuracy

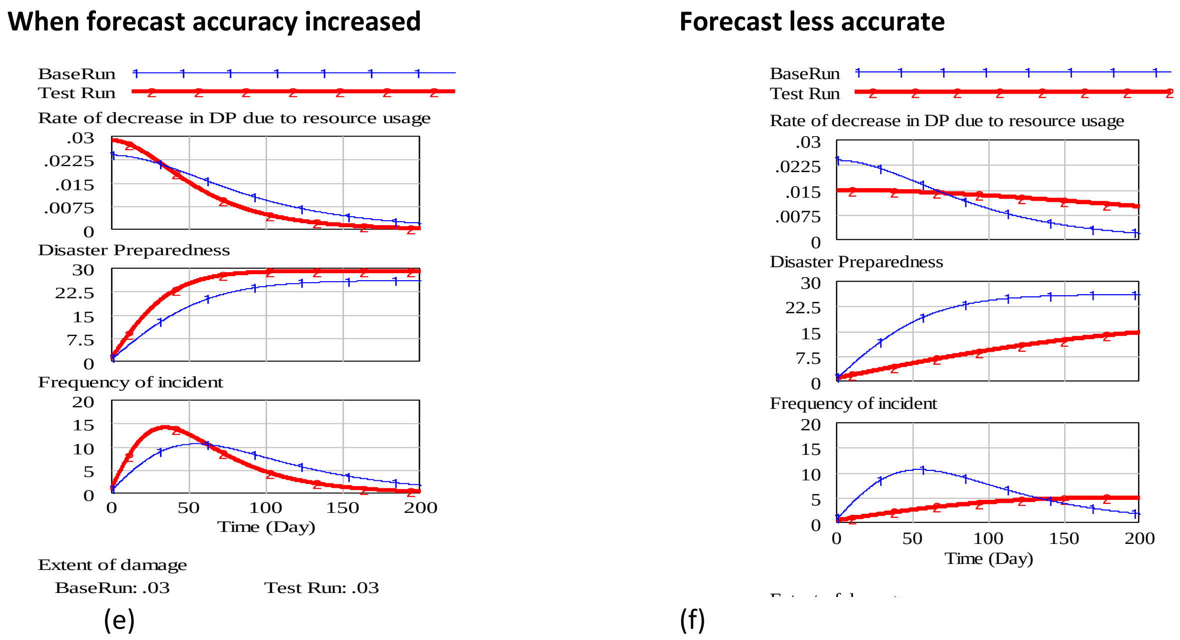
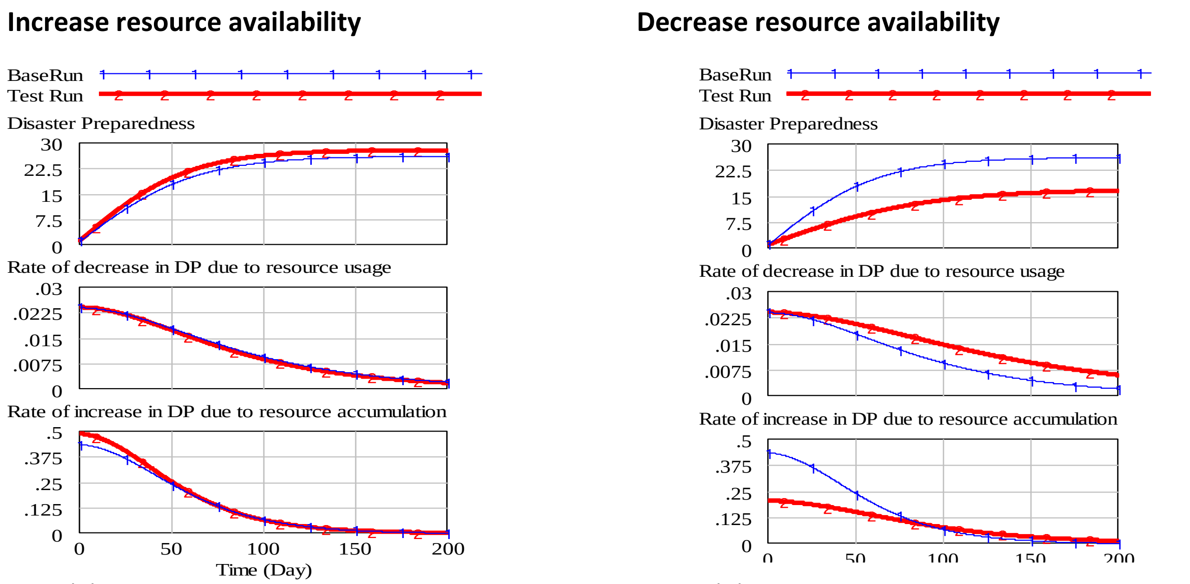
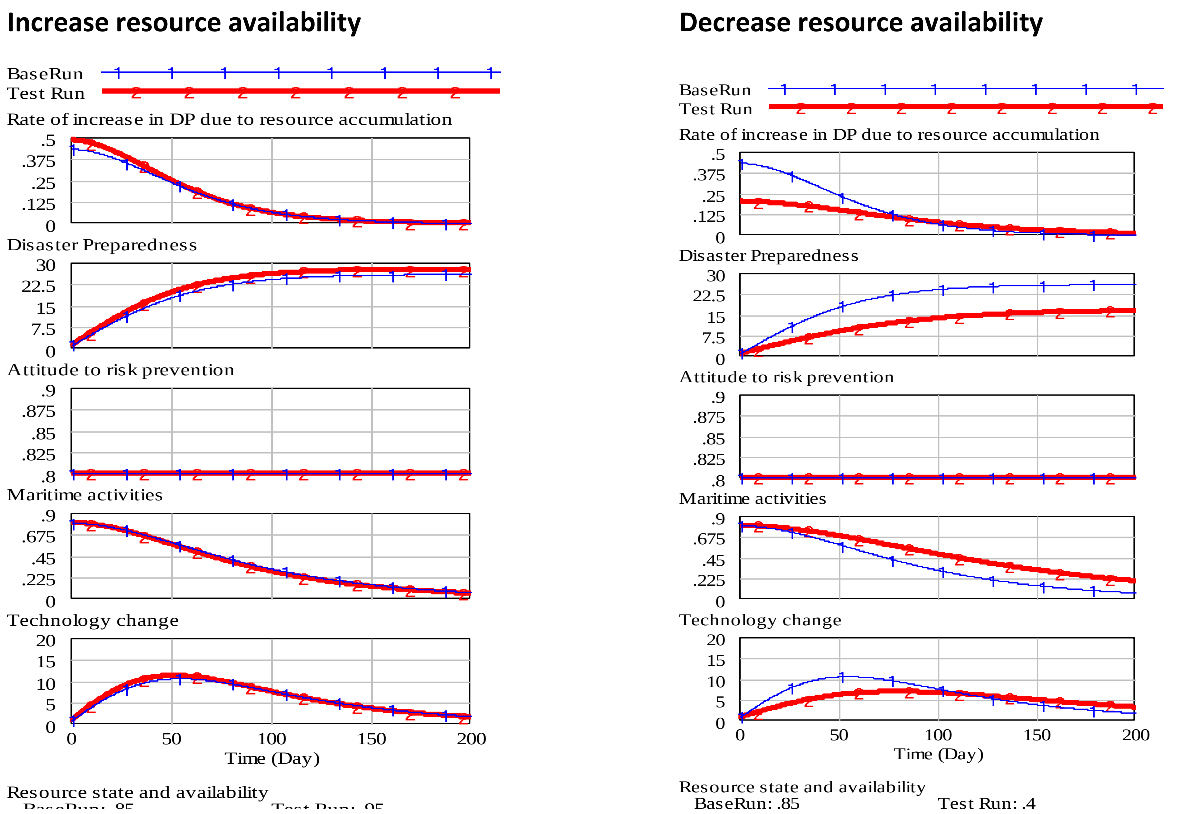


Figure 11: The real-time Rate of change in DP due to resource usage and cohorts over 200 day in response to change in forecast accuracy



(g) (h)

Figure 12: The real-time change in DP and its flows over 200 days in response to change in resource availability

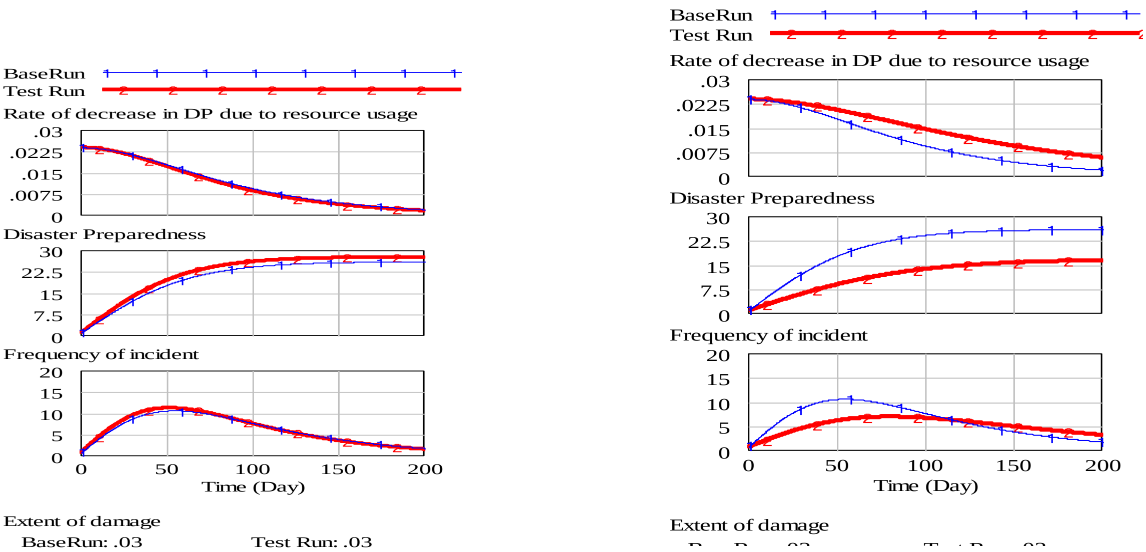


(i) (j)

Figure 13: The real-time Rate of change in DP due to resource accumulation and cohorts over 200 day in response to change in forecast accuracy

Increase resource availability

Decrease resource availability

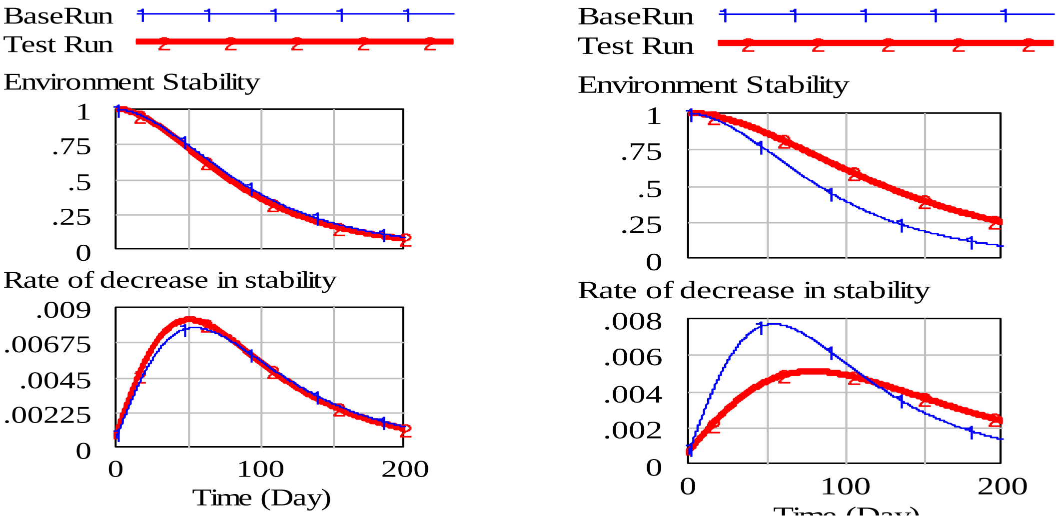


(k) (l)

Figure 14: The real-time Rate of change in DP due to resource usage and cohorts over 200 day in response to change in forecast accuracy

Increase resource availability

Decrease resource availability

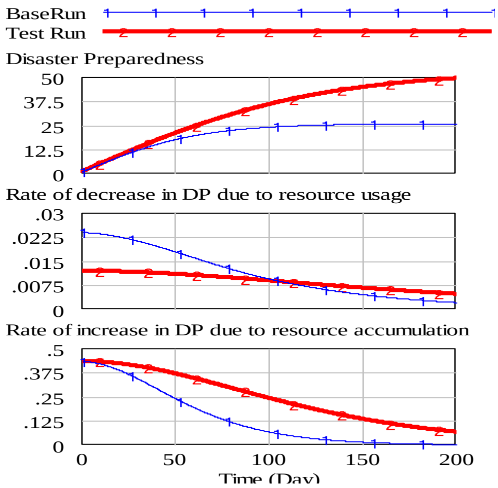


(m) (n)

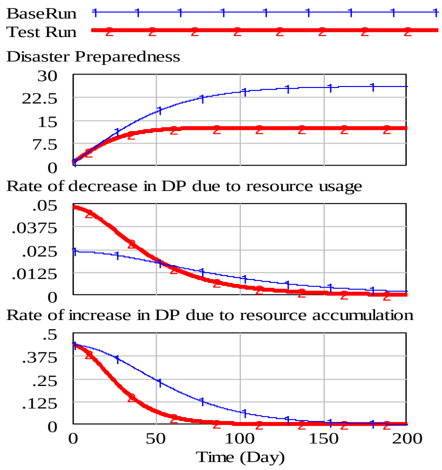
Figure 15: The real-time change in Environment Stability and its flows over 200 day response to change in resource availability

Increase damage

Damage decrease



(o)

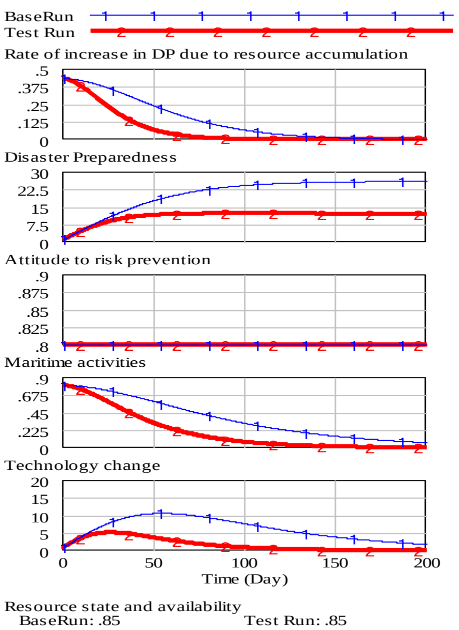


(P)

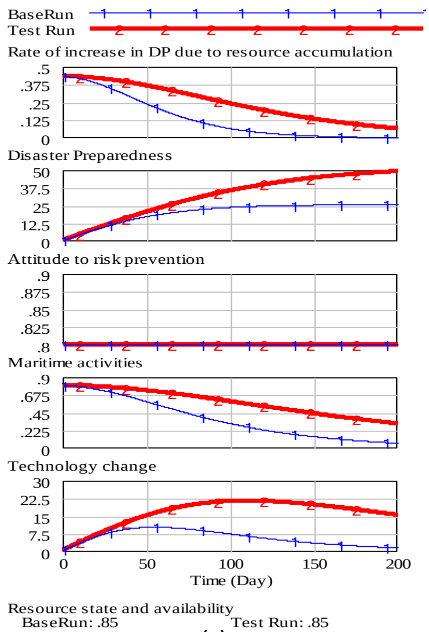
Figure 16: The real-time change in DP and its flows over 200 days in response to change in the extent of damage

Increase damage

Damage decrease



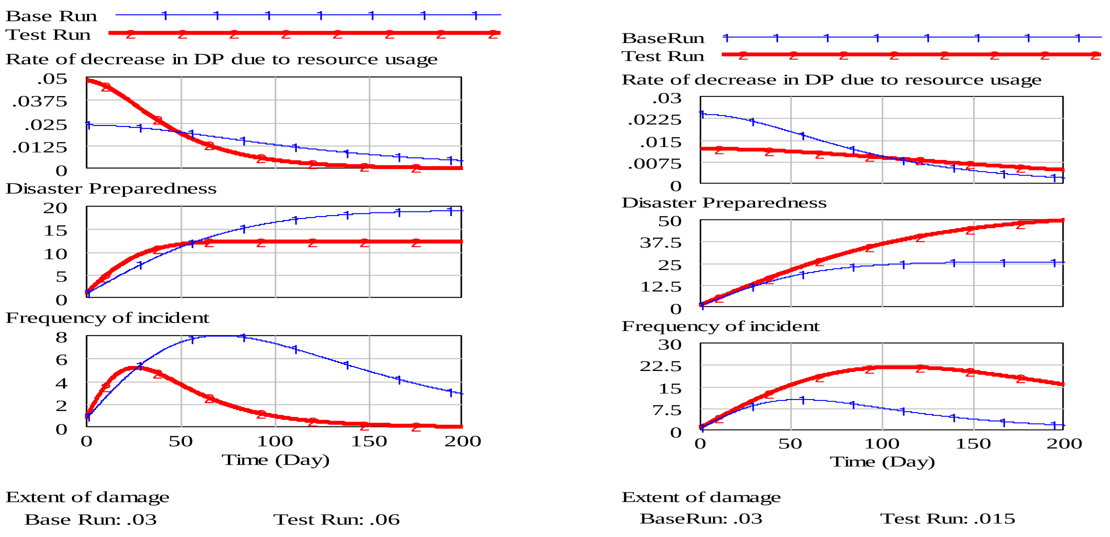
(q)



(r)

Figure 17: The real-time Rate of change in DP due to resource accumulation and cohorts over 200 days in response to change in the extent of damage

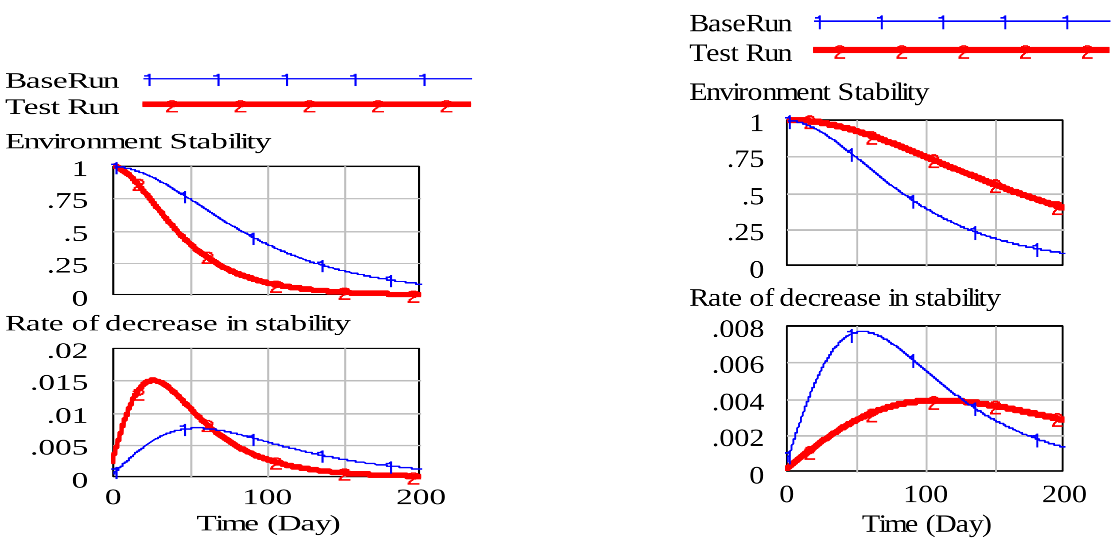
Increase damage **Damage decrease**



(s) (t)

Figure 18: The real-time Rate of change in DP due to resource usage and cohorts over 200 day in response to change in the extent of damage

Increase damage **Damage decrease**



(u) (v)

Figure 19: The real-time change in Environment Stability and its flows over 200 day response to change in the extent of damage

All curves [Figure 9 – 19] exhibit nonlinearity. The trajectories of all curves indicate exponential increase/decrease except the graph for 'attitude to risk prevention'. In Figure 9 – 19, the line marked 1 shows the current situation while line 2 represents the experimental situation. Where one line is displaced above the other, it suggests a higher sensitivity in one than the other. For example, Figure 9a suggests that industry actors will become more prepared when they trust the forecast data than when forecasting is less accurate and that transients throughout to induce the behaviour of the other variables. When shown to several of the original interviewed experts as a follow up, they were able to confirm the direction and logic of the causal loops. They were also able to confirm that the model seemed to accurately show the return to stability over time, although there was discussion on the length of time needed to return to stable operations depending upon the exact event that occurred.

The results suggest that Forecast Accuracy is key to industry actor's behaviour. We find a high increase in level of DP, Attitude to risk prevention, Environment stability, and Technology capacity. However, the same factor increases Maritime activities and Frequency of incidents in the logistics system. The reverse occurs when Forecasting becomes less accurate. It also appears that all variables of this research are highly responsive to 'Extent on damage' suffered during an incident. Increase in Extent of damage reduces level of DP, Technology capacity, Environment stability, as well as Maritime activities in the short run. However, industry actors' "Attitude to risk prevention" is not influenced by change (increase/decrease) in 'Extent of damage'. We also found that an increase in 'Resource available' does not significantly affect the factors that we modelled within the time frame. Industry actors' DP, Technology capacity, and Environment stability are rather sensitive to decrease in 'Resource availability'. Note that "Attitude to risk prevention" did change in response to change in Resource availability within the time specified in this research. The apparent constant shape (parallel to time axis) in 'Attitude to risk prevention' might have originated because there is usually some delay in human response to changing environment, a constraint which we did not place on the model.

Simulation models are well suited for "what-if" dynamic scenario decision evaluations. Borshchev and Filippov (2004) state that 'simulation model is a dynamic set of rules (i.e. dependent on equations, flow charts, states, and cellular automata[4]), which defines how a system under investigation will change in the future, given its present state'. The grand objective of the modeller is to mimic an observed performance in order to aid in explaining phenomena from a 'puzzling dynamic world' (Morecroft and Robinson, 2005). The simulation models thus provided us better answers for the complex problems considering that

[4] Cellular Automata are discrete, abstract computation systems that have proven useful both as general models of complexity and as more specific representation of non-linear dynamics in a variety of scientific fields.

time dynamics is very important (Borshchev and Filippov, (2004) in the selecting alternative decisions.

However, one challenge we encountered in this research was our inability to do exhaustive iterative data work as required by the Grounded Theory (Glaser and Strauss, 1967) philosophy and also by SD modelling approach. Both techniques require the modeller to work hand-in-hand with problem owners, to build the model in stages so that there can be full participation by problem owners. However time constraint force us to truncate the process prematurely. Nevertheless we do not believe that this has affected the SD simulation models (graphs) significantly, based on the follow up interviews conducted with the industry experts.

Today's logistics networks appear to be more vulnerable to risks of disruption, thus requiring systemic systematic analysis of levels of vulnerability, security and resilience (Blackhurst, et al, 2005; Lynn, 2005; Sheffi, 2005; Juttner et al, 2003; Rice and Caniato, 2003). One way of attaining disaster preparedness can be by creating necessary redundancy (Sheffi, 2005). However some scholars have argued that 'slacks' or 'redundancy' is expensive. Snyder et al (2006) contend that policy makers should consider various kinds of risks or uncertainties when planning their strategies for operation.

Bogard (1988) argues that unacknowledged condition in hazard mitigation may consist of two parts: the mythological part and the uncertainty part. The mythological part talks about how entities tend to behave during crisis time including: panic reactions, frustrations, and egoistical behaviour among others (see Wenger, 1985; Wenger and Friedman, 1986). The uncertainty part relates to the constraints posed to mitigation due to lack of information (e.g. forecast data, resource state and availability, or extent of damage). This may be due to the fact that disasters can be highly unpredictable, and generally endemic in the life of any entity. On the other hand, humans tend to overestimate safety conditions around them (Lichtenstein et al., 1978) especially when the environment seems to be highly stable. We agree with extant theorists that unacknowledged conditions and unanticipated consequences (Giddens, 1979) feed back into decisions and thus change the bounded knowledge which the decision maker has about the environment. It appears that policy changes can affect how industry actors' respond to hazardous conditions in real-time as portrayed in the models above. The seemingly stable environment that prevails in the case study area should equally trigger a concern about the future thus making it obligatory to prepare more towards effects of policy changes.

5 Conclusion and research significance

A hazard is 'a physical situation which has the potential to cause injury, damage to property, damage to the environment or some combination' (Marine Safety Agency, 1993). An accident is the status of an entity, at the stage where it becomes a reportable incident which has the potential to progress to loss of life, major environmental damage, or loss of infrastructure (MSA, 1993). Common accidents in the shipping industry include: contact/collision, explosion, external hazards, fire, flooding, grounding/stranding, hazardous substance related failure, loss of hull integrity, machinery failure and handling equipment failure (Wang, 2006)

Disaster preparedness is a fluid, dynamic concept that keeps changing over time, dependent on a particular event and the specific hazards encountered. Each event and each entity affected by disaster may be unique, thus requiring a unique approach to reach a solution. Designing response structures for such events can be difficult particularly due to resource scarcity. Moreover, the event dependence and the uniqueness makes it almost impossible to match preparedness with best practice, since the latter often lags behind the former. Hence, a hybrid modelling technique (the SD model) was engaged in framing, understanding, and discussing this complex problem in the maritime logistics industry. The models were built to enhance understanding of system forces that have created a systemic problem and continue to sustain it (Albin, 1997). Several scholars including Sterman (2000) say that the SD approach can be employed to understand the behaviour of complex systems over time. It deals with internal feedback loops and time delays that can impact the behaviour of an entire system leading to theory building. The models presented suggest that DP is behaviour driven. Policies designed to improve levels of DP can produce reinforcing (virtuous or vicious) feedback processes. Industry actors' level of "DP", "Attitude to risk prevention", "Technology change" and "Maritime activities" are significantly sensitive to 'Forecast accuracy' and 'Extent of damage', but not very dependent on increases in 'Resource availability'. Within the research time frame, 'Attitude to risk prevention' appears not to be responsive to 'Extent of damage or 'Resource availability' perhaps due to the fact we did not place a delay constraint on attitudinal change. However, the variable is significantly responsive to 'Forecast accuracy'. We also point out that changes or fluctuations in disaster preparedness and risk status of entities (as observed in the hypothesized reference mode and test models) may depend on the type of disaster; where it occurred; when it occurred; how it occurred; resource availability; and potentially other factors specific to a particular disaster.

Lichtenstein et al (1978) observed that people tend to overestimate their ability to control or prevent accidents, leading to an under-estimation of risks [hazards] in a system. Since entities have the tendency to over-estimate safety conditions around them when they get used to it, it seems that their beliefs and perceptions will remain the same until the system is tested by a real life scenario. On the other hand, experimenting in the real-world can be highly catastrophic in terms of costs (i.e. financial, and casualty). Our models have been set out to mimic the real-world scenarios that industry actors can face leading to failure to respond to, or recover quickly from systemic disruptions. Our paper thus provides industry actors with a series of alternative assumptions and test scenarios in an interactive session for which they can evaluate strategic decisions prior to their implementation. Risk managers can use this model to examine, test, and evaluate the systemic preparedness to disruptions in real-time leading to policy change management. The models can serve as the 'learning laboratory' (Forrester, 1961) to enhance communicating the outcomes of strategic risk management decisions prior to implementation. They can serve as one of the dynamic risk assessment models in the maritime logistics industry for actors to use for self-evaluation. At academic levels, this research can become the preliminary stage for additional theory building in the field of safety science leading to accident prevention, disaster management, and risk mitigation in the maritime logistics industry.

It is suggested that future research employs advanced statistical tests to determine the correlations between the variables of this research, using appropriate econometric analytic tools (models) such as the [General] Autoregressive Conditional Heteroskedasticity ([G]ARCH), or the Logistics Function, to support/falsify the results either in the maritime industry or elsewhere in other complex organisation set up.

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