ANALYSIS OF MULTI-MITIGATION SCENARIOS ON MARITIME DISRUPTIONS

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ABSTRACT

In the wheat supply chain, maritime operations have an essential role due to the critical linkages that connect the global transport of this large density and complex freight task (Craighead et al. 2007). Past research shows that an increase in maritime logistics risk is a major limiting factor in the efficient movement of grain from the producer (wheat farmers) to global wheat markets. Maritime logistical risks are wide-ranging and include the uncertainty in vessel arrivals, inventory levels of grain at the port, variety of wheat consignments that arrive, and the impact of a low rail car unloading rate. Other factors that can cause supply disruptions are uncertainty in demand, quality, and performance of maritime logistic services. These significant factors could subsequently create severe disruptive events in the supply chain process of wheat trading. This paper assesses four major mitigation strategies (inventory and sourcing mitigation, contingency rerouting, recovery planning, and business continuity planning) to determine their suitability for managing potential disruptions in the wheat supply chain. A Markovian-based methodology is the prime means used to evaluate the mitigation strategies which will be done in the context of wheat transport from Australia to Indonesia. As a result, the four-stage continuous time period of the Markov chain application enables the measurement and prediction of supply chain costs and time functions in relation to disruptive events to be determined. This may assist entities along the wheat supply chain to be better prepared both when attempting to manage maritime disruptions as well as when re-evaluating their supply chain operation planning in regards to mitigating future maritime disruptions.

Keywords: multi-mitigation scenarios, maritime disruptions, wheat supply chain

INTRODUCTION

Over the period when wheat supply chain design decisions are in effect, changes in supply chain performance may be identified beyond the assumptions predicted in the planning stage. These changes include factors such as a variety of transportation costs, demands, the origin of supply sources such as distances, and lead times, all which may fluctuate widely (as discussed in Abbas and El Deen Aly 2004; Bertrand 1996). However, supply chain optimization models have traditionally treated the wheat supply chain with certainty and frequently ignore some unpredicted events such as disruptions and disasters due to resource limitations (for example Julie *et al.* 1998; Titus and Dooley 1996; Young and Hobbs 2002).

In reality, however, operational parameter estimations may be inaccurate due to poor forecasts, measurement errors, changing demand patterns of the wheat commodity, inadequate sea transport infrastructure and managerial problems. Moreover, even if all the variables of the wheat supply chain are known with certainty, only some may be identified as causing disruptions, for example, in the case of wheat and its derivative products, these may be inclement weather, sea-terminal congestion, marketing systems and dry-bulk fleet shortage (Jayne and Myers 1994; Lian Qi 2007; Ljungberg 2006; Song *et al.* 2005; Sorenson 1973; Titus and Dooley 1996; Wilson and Dahl 1999; Young and Hobbs 2002). Therefore, significant attention to maritime disruptions in wheat supply chains is required, particularly because the wheat industry is more vertically integrated than in the past, and its supply chains are increasingly global (as stated in William *et al.* 2004; Young and Hobbs 2002). Consequently, the globalisation of wheat may lead to more complexity in the wheat supply chain including being more difficult to manage if an uncertainty event occurred, particularly when it occurs in maritime operations. An objective of this paper then is to provide a mitigation framework for both maritime service operators and users when responding to various maritime disruptive events along supply chains.

MARITIME DISRUPTIONS IN WHEAT SUPPLY CHAIN

Supply chain disruptions are generally discussed in the literature under three broad categories: (i) uncertainty, (ii) vulnerability and (iii) crisis management depending on how the disruptive events are explored. All of these categories, which are heavily impacted on by maritime-based disruptions, may occur during the process of the wheat supply chain. Therefore wheat supply entities and operators should fully consider the maritime leg of the supply chain as being a critical link for their domestic and international wheat shipment (Bushell 2007; Park and Koo 2001; Schlect 2001). In addition, the entities and operators need to also develop and assess their mitigation strategies as a means to avoid maritime disruptions and temporary closures of the wheat chain (Gaonkar and Viswanadham 2007; Garcia 2008; Phillips and Smyth 2007).

Figure 1 below shows the classification of different disruption elements in the case of the Australian-Indonesian wheat supply chain being conducted by the lead author of this paper. The maritime disruptions that occurred in the Australian-Indonesian wheat supply chain (as shown in Figure 2 below) may vary in frequency and severity. Some of them may be high probability and low consequence disruptions whereas others are low probability and high consequence disruptions. Specifically, the existence of the latter leads to difficulties in the disruption analysis process. Due to the rare occurrence of such disruptions, there is a lack of available data to determine the contribution of various situational attributes to disruption risks.

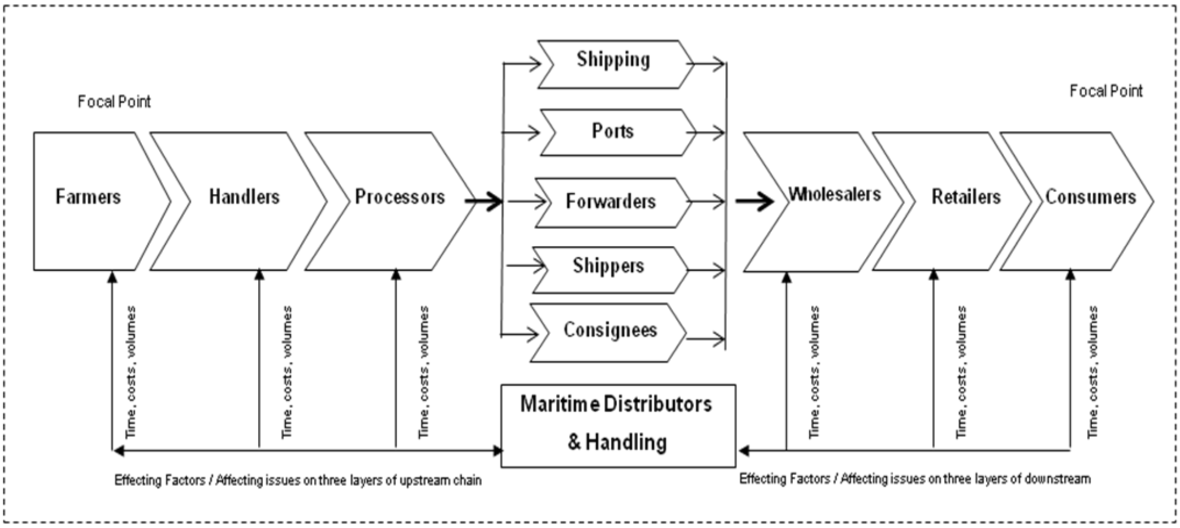

Figure 1 – Australian-Indonesian wheat supply chain and the maritime services (Gurning and Cahoon 2008)

The events that may trigger maritime disruptions as causal factors are defined here as *stimulators*. Various stimulators, as shown in Figure 2, may include security threats, political riots or wars, lack of facilities and management at ports, long customs and quarantine processes, severe weather conditions and earthquakes, electrical outages, lack of maintenance, shortage of ships, insufficient of empty containers, uncertainty of bunkering costs, communication failure, and the lack of inland accessibility. The *first layer disruptions* occurring as a result of the stimulators include congestion, ship accidents at ports, shortage of port and shipping services, and the disputes between port operators and shipping companies. The *second layer disruptions* that may occur following the first layer disruptions include delays, deviations, and unavailability of maritime services such as port stoppages and no shipping services for particular routes. The potential consequences of maritime disruptions then, may include cargo rerouting, poor business reputation, higher logistics costs, loss of profit, and higher the price of commodities handled. These represent the consequences of both the first and second layer of disruptions (Gurning and Cahoon 2009). The first step of a maritime disruption analysis process is the identification of the series of events leading to a disruption and its consequences. It should also be noted that a disruption is not a single event, but the result of a series of events (Blackhurst *et al.* 2005).

This paper applies a maritime disruption model constructed for use in the Australian-Indonesian wheat supply chain study, which incorporates a wheat supply chain simulation, available data, and judgments from practitioners and senior managers in order to quantify a disruption level of the contribution of situational attributes to maritime disruptions. While wheat consignments flow through the wheat supply chain, there is a possibility of various uncertainties occurring including disturbances during the supply chain process. For example, a deviation process in wheat transport may be necessary if the unloading port is having problems due to a port strike or equipment down-time situation. These events may trigger a disruption that could be *stimulator*.

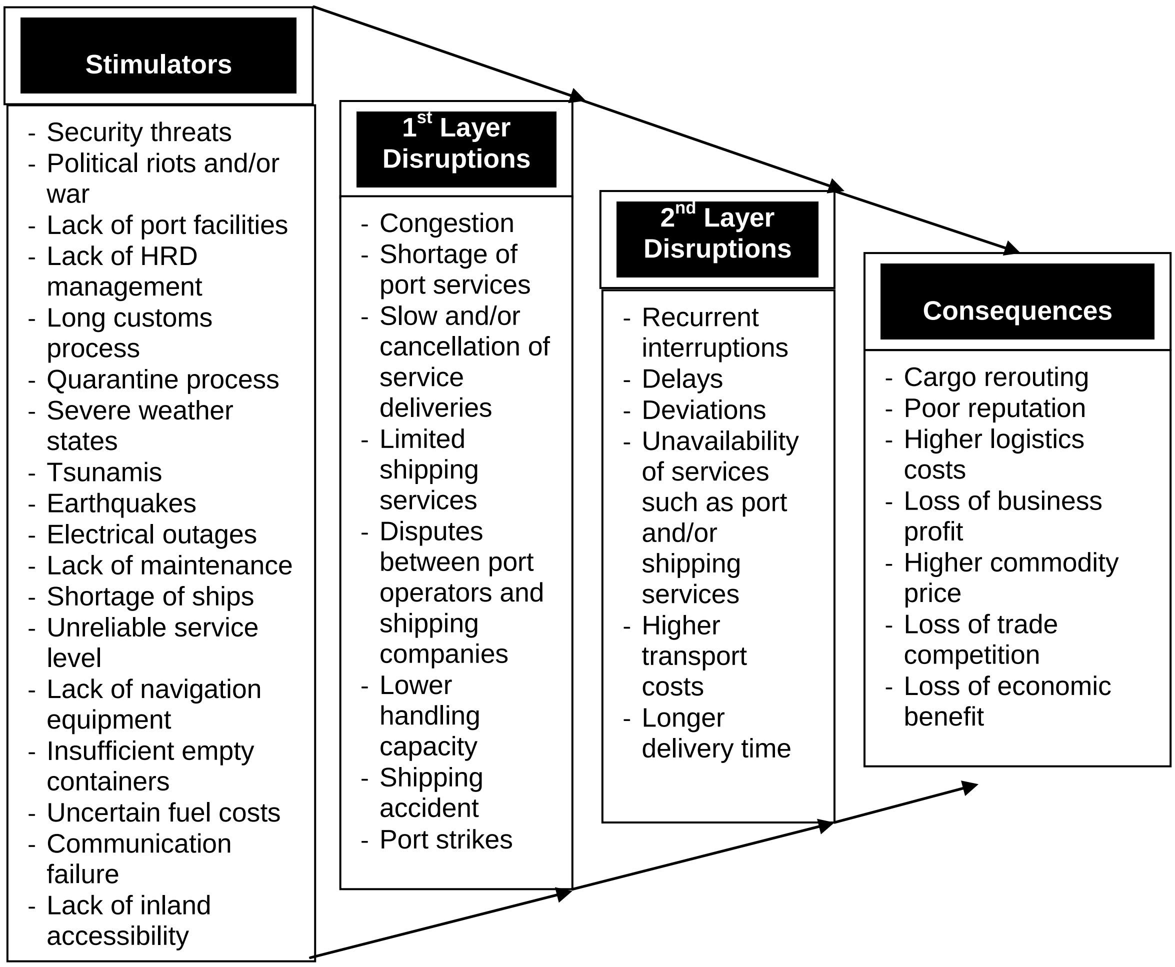

Figure 2 – The structure of maritime disruption event (Gurning *et al.* 2009)

The occurrence of a stimulator depends on the *circumstances* which relates to a vector of situational attributes. Obviously, some system states are more “likely in risk” than others. For instance, a port operating with a variety of multimodal transport modes for its inland access is at a lower “risk” than a port operating with a poor transport capacity due to road accessibility issues. A stimulator may lead to one disruptive event, for example, when a wheat unloader in a grain terminal is unavailable due to a breakdown that may cause congestion or longer ship waiting times at that terminal. Here, the probability of congestion after the equipment down depends on the situational attributes.

MITIGATION APPROACH OF DISRUPTIONS IN WHEAT-CHAIN PROCESSES

The goal of mitigating maritime disruption in the wheat supply chain is to alleviate the consequences of disruptions and risks or, simply put, to increase the *robustness* of a wheat supply chain through the maritime leg. However, there are very few qualitative concepts related to mitigating maritime disruptions concerned about the perspective of time-based manners (pre disruption, on disruption, and post disruption stage) when responding to maritime disruptions. The majority of supply-disruption papers (as shown in Table 1 below) focus on the combination of contingency rerouting and inventory/sourcing mitigation strategies in response to maritime disruptions. From the literature, it may be identified that the dominant reactions of maritime users in wheat supply chain management tend to be to adjust to a new route on the maritime leg, provide strategic stock (when no alternative source available), provide back-up systems, and to implement business continuity actions. These are critical initial steps in disruption risk management and contingency planning for responding to worst case scenarios of maritime disruptions.

The following section focuses on the transportation mitigations of the wheat supply chain from loading terminals to a destination market. In particular, this involves examining the logistical costs and maritime disruptive risks associated with the wheat and grain-marketing system.

Table 1– Mitigation strategies for the wheat supply chain

Mitigation	Strategies	Literatures
Inventory and Sourcing	Inventory polling at ports	Young 1999; Vachal & Reichart 2000; Park & Koo 2001; Sheffi 2001
	Utilising agency service	RIRDC 2005; Tomlin 2006; Rick & Van Horn 2008
	Apply other chain links	Janzen & Rice 2001; Kleindorfer & Saad 2005; Tang 2006
	Optimum ordering policy	Wilson & Preszler 1993; Depak 2003; Tomlin 2006
	Postponement delays	Sheffi 2001; Tang 2006; Tomlin 2006;
	Supply flexibility	Schlect 2001; Buschel & Mac Aulay 2005; McCormack 2008
Contingency Rerouting	Reserves routes	Duval Biere 1998; Handfield and McCormack 2008
	Critical nodes mapping	Binkley 1983; Handfield *et al*. 2008; Blackhurst *et al.* 2005
	Applies other chain links	Schlect, Wilson & Dahl 2004; Tang 2006
	Formal assessment	Faruquee *et al.* 1997; Zsidisin *et al.* 2004; Philip & Smyth 2007
Business Continuity Planning	Changes to working practices	Beatty (2001); Gibb (2006); Skelton (2007);
	Maximum allowable interruption	William (2002); Haque & Burton (2004); Tomlin (2006)
	Develop warning system	Craighead *et al.* 2007
	Implication monitoring	Howick and Eden (2001); Rosamond *et al.* 2007; Elkins *et al.* (2008)
Recovery Planning	Develop warning system	Craighead *et al*. 2007
	Apply discovery responses	Blackhurst et al 2005; Craighead *et al.* 2007; Garcia (2008)
	Apply recovery actions	Pinto & Wayne (2006); Craighead *et al.* 2007;
	Network & procedures redesign	Handfield *et al.* 2008

Inventory and sourcing

Vachal and Reichart (2000), Sheffi (2001) and Kleindorfer and Saad (2005) consider the mix of inventory/sourcing mitigation concepts when managing maritime disruptions. These strategies are recommended for a firm (as maritime user) that faces unstable supply and sources from two identical-cost and infinite-capacity suppliers when maritime disruptions occur along the wheat supply chain. The mitigation strategies here include inventory polling at ports, utilising agency services, applying other chain links, optimising ordering policy postponement delays and using supply flexibility. The studies focus on demurrage costs and not incurring high government cost or distorting price signals. In light of these points, Schlecht (2001) and Schlecht, Wilson and Dahl (2004) expand the supply chain risk as a result of the different grade of commodities to the importing market. This is broadly developed by Janzen and Rice (2001) who focus on two main joint risk measures namely the wheat market and wheat shipments in a wheat chain. Further, Park and Koo (2001) undertook an empirical study to assess whether a port buying strategy succeeds in removing maritime risks for wheat shipments at domestic points. The study found that active and flexible responses by port operators in providing facilities and services were evident in relation to acceptable optimum costs and the price of wheat for various maritime risks depending on the sizes and capacities of available ships and the freight rate. From an Australian perspective, the research of the Rural Industries Research and Development Corporation (2005) further explores the structure of logistics costs and prices calculated from the Australian farm gate to port.

Contingency Rerouting

Biere (1983), Handfield and MacCormack (2008) examine the concept of an international reserved route in grain trade and its impact mechanism particularly on costs and benefits of alternative supply chains under dynamic conditions of transportation operations including the shipping freight rate. Further, Binkley (1983), Blackhurst (1993) and Handfield *et.al* (2008) identify a general method by identifying critical nodes with uncertainty coefficients and risk probability index of suppliers on the import demand of wheat. Their research also includes transportation and trade expenses to various importing countries. The main goal of their research in identifying critical points is to determine the uncertainty of supply level and potential costs. Similarly, the mitigation strategy of applying other alternative chains is recommended by Schlect, Wilson and Dahl (2004) and Tang (2006) as being one applicable response when any interruptive events occur in the targeted wheat market. Regarding this, Duval and Biere (1998) develop framework parameters for a wheat model in a vulnerable supply chain system examining logistical risks associated with marketing homogenous corn between an inland and export terminal. Uncertainties included in the study are related to annual supplies of commodities, deliveries into the transport system such as railcar and barge placements, vessel arrivals, and problems of transportation transit times.

Business Continuity

Other mitigation strategies that can be implemented when maritime disruptions occur are business continuity planning. In relation to supply chain disruptions, Beatty (2000) and Gibb (2006) emphasise the importance of changes to working practices of companies when maritime disruptions occur in order to achieve the optimum efficiency under interruptive operations of maritime services. This may be achieved through transferring risk or risksharing decision methods such as insurance plans and outsourcing strategies. Given that application, the implication of monitoring the supply chain flow through a certain maritime leg, as well as the damage control plans were discussed by Elkins *et al.* (2008) and Howick and Eden (2001) in order to find real continuity actions when disruptive events occur. Similalry, Rosamond *et al.* (2007) proposes a broad business continuity grain chain mitigation model that examines three main risk factors such as bio-fuel, food security and the environment.

Recovery Planning

Studies of recovery planning on wheat chains was initiated by Clark and Miller (1967) who developed an impact analysis study on export related costs of Canadian wheat due to the uncertainty of wheat shipment availability. The study provides a cost analysis and comparison of various changes of transportation and shipment arrangements to international markets. The typical research approach now can be found in the work of Garcia (2008) that enlarges the inter-correlation impact of port operators, agents of shipping companies, shippers, and agricultural consignees. A study undertaken by Craighead *et al*. (2008) differs somewhat in that it builds a comprehensive assessment technique not only to identify threats in the grain industry but also includes the warning system of various threats. In another study, Pinto (2003) focuses more on the security-risk incurred when a port facing disruptive events. The research developed incident cycles including a comparison of ships versus container movements.

MARITIME DISRUPTION ANALYSES USING MARKOV CHAIN PROCESSES

The Markov chain methodology has been found to be a general tool for modelling network and dynamic maritime disruption systems due to its ability to predict precedence, and concurrent and asynchronous events on a mathematical basis and capability to present a system graphically (Cheng 1989; Jason *et al.* 2002; Loury 1983; Parlar and Perry 1996; Tomlin 2006). The four-stage continuous time period of the Markov chain application allows measurement and prediction of supply chain costs and time functions in relation to disruptive events affecting the transportation and distribution processes of millers, wholesalers, and retailers.

An initial exploration of maritime disruption probability can be found in Jason *et al.* (2002) who applied a Bayesian probabilistic risk analysis approach for discrete shipping channel activities with oil spill accidents as the uncertainty events. Another study four years later (Tomlin 2006) expanded this approach by using a semi-Markov probability analysis. This became a recognized approach for various transport-related operations using various risk selections with discrete methods (Kolowrocki and Soszynska 2009; Lee and Lee 2005; Lewis *et al.* 2006; Mccormack 2008; Uluscu *et al.* 2008; Xiao *et al.* 2009). Further, the use of the Markov approach has been coupled with performance analysis (Bushell 2007; McMullen *et* *al.* 1989; Pachakis and Kiremidjian 2005; Pinto and Wayne 2006; Qiang *et al.* 2008; Wang 2000) of more stages in agricultural supply chain including the wheat supply chain. However, uncertainty in the context of shipping disruptions, particularly in risk channels, was predominantly considered as being individual probabilities within a boundary region of a complex networking process and was not considered as an impact on one particular supply chain.

Markov chain principles in wheat supply chain

A Markov chain has a set of *states*, $S = (s1; s2; : : : ; sr)$. The process starts in one of these states and moves successively from one state to another. Each move is called a *step.* If the chain is currently in state *si*, then it moves to state *sj* at the next step with a probability denoted by *pij* , and this probability does not depend upon which states the chain was in before the current state. The probabilities *pij* are called *transition probabilities.* The process can remain in the state it is in, and this occurs with probability *pii*. An initial probability distribution, defined on *S*, specifies the starting state. Therefore a Markov model M main contain S, A, T, R consisting a set of environment states **S**, a set of actions **A**, a transition function T: $\mathbf{S} \times \mathbf{A} \times \mathbf{S} \rightarrow [0,1]$, $T(s,a,s') = Pr(s' | s,a)$, a reward function R: $\mathbf{S} \times \mathbf{A} \rightarrow \mathbf{R}$. In addition, a policy is a function π: $S \rightarrow A$, and its expectation as expected cumulative reward -- value function V^{π}: $S \rightarrow R$.

As indicated in Figure 1 earlier in this paper, the interactions of entities in the wheat supply chain are structured as states in the Markov chain process as shown in Figure 3.

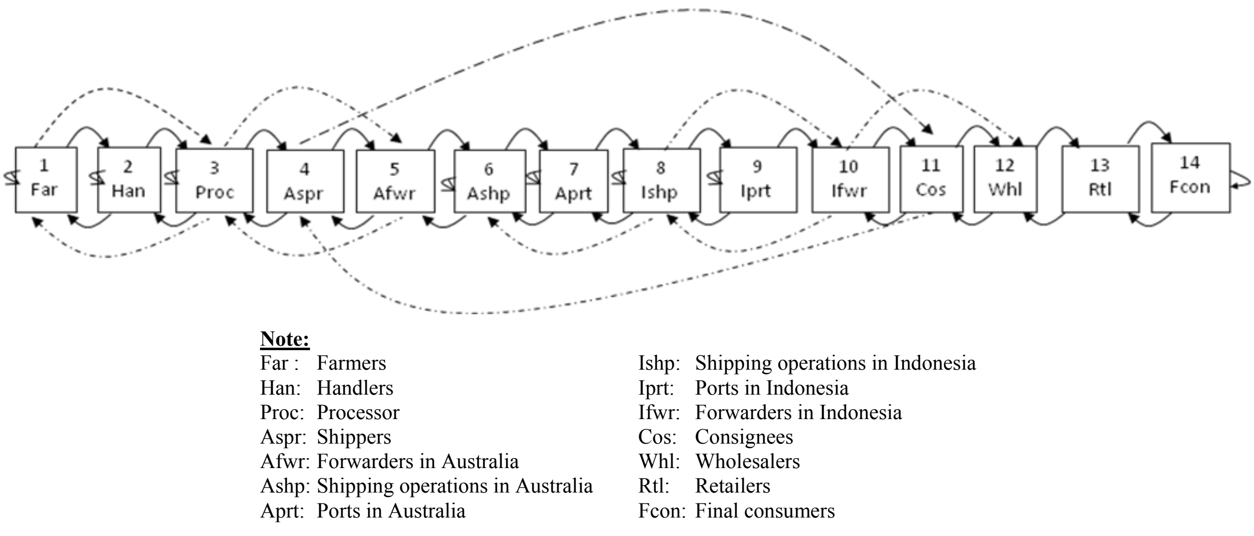

Figure 3 - States in the wheat supply chain and Markov structure (Gurning and Cahoon 2009a)

The transportation of wheat from loading ports to unloading ports uses international shipping operations consisting of bulk and containerised shipments which allows the transfer of wheat cargo through ports (labelled as maritime distributors and handling) under the control of shippers, freight-forwarders and consignees. In the buyers' locations in Indonesia, wheat is further distributed through wholesalers, retailers, and consumers, the Markov transition matrix is shown in Figure 4.

$$
\begin{pmatrix}
P_{11} & P_{12} & P_{13} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
P_{21} & P_{21} & P_{23} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
P_{31} & P_{32} & P_{33} & P_{34} & P_{35} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & P_{43} & 0 & P_{45} & 0 & 0 & 0 & 0 & P_{411} & 0 & 0 & 0 \\
0 & 0 & P_{53} & P_{54} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & P_{65} & P_{67} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & P_{77} & P_{78} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & P_{87} & P_{88} & P_{89} & P_{810} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & P_{98} & P_{99} & P_{910} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & P_{108} & 0 & 0 & P_{1011} & P_{1012} & 0 & 0 \\
0 & 0 & 0 & P_{114} & 0 & 0 & 0 & 0 & P_{1110} & 0 & P_{1112} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & P_{1211} & 0 & P_{1213} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & P_{1312} & 0 & P_{1314} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & P_{1413} & P_{1414}
\end{pmatrix}
$$

Figure 4 - Markov transition matrix in the wheat supply chain (Gurning and Cahoon 2009a)

Maritime stages such as port and shipping operations have more than one probable disruptive event (from 1 to N) which may occur from a normal state to failure mode (λ) and may be recovered again due to responses or proper mitigation strategies (μ). For example, in terminal or port areas, events such as terrorism acts, port strikes, lack of port infrastructure, lengthy customs and quarantine procedures, earthquakes, equipment breakdown, port congestion, and insufficient of empty containers may change the normal operation level of a port to a sub-optimal or failure mode condition (Bearing-Point and Hewlett-Packard 2005; Gurning and Cahoon 2009b).

Mitigation assessment analysis

The four mitigation approaches can be implemented within one particular wheat supply chain when facing a maritime disruptive event both to reduce the likelihood of occurrence of primary disruptive event, and to lower maritime risk after being in normal (initial) state, μ_0. To depict the different approaches of mitigation measures and its processes, mitigation tree formalism is used in the mitigation assessment and is shown in Figure 5. The Figure shows the sequence of mitigation events from normal (initial) state to their possible consequences. Mitigation measures denoted by (λ) that reduce the probability of entering a disruptive state are referred to as single or multi-mitigations. The event sequence begins with the initial risk state to a disruptive state that may come from one or more potential disruptive events. Maritime stages such as port and shipping operations have more than one probable disruptive event (from 1 to N) which may occur from a normal state to failure mode (λ) and may be recovered again due to responses or proper mitigation strategies (μ). For example, in terminal or port areas, events such as terrorism acts, port strikes, lack of port infrastructure, lengthy customs and quarantine procedures, earthquakes, equipment breakdown, port congestion, and insufficient of empty containers may change the normal operation level of a port to a sub-optimal or failure mode condition. The third stage is to obtain the initial probability vector, which represents the occurrence possibility of each disruption-state when one particular mitigating plan is implemented. In order to obtain the initial probability, the most recent disruption-occurrence data are used, which can be divided by the time period such as three, six, and nine months and one year.

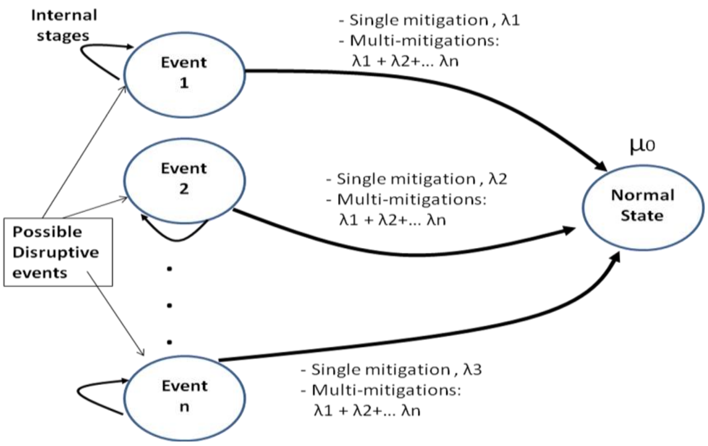

Figure 5 - Markov mitigation process from disruptive events to normal state

Mathematical model

By analysing the most recent data, the initial probability vector is calculated using Formula (1) satisfied by the condition in Formula (2). For this analysis, the mitigation functions are combined to simplify evaluation of mitigation measures that typically couple detection and recovery functions. Each decision node has a set of conditional probabilities that describe the probability of occurrence of each branch conditional upon the previous states. The overall likelihood of each outcome is determined by multiplying conditional probabilities through the branch, and the risk level is aggregated along potential consequences in different branches as shown in the Formula (1) where: $V_{j,i}$ = mitigation value index for the *j* type of disruptive events related to the *i* scenario; P_i =*i*-scenario probability of occurrence; $D_{M,j,i}$ = *j*-type Mitigated consequences related to the i-scenario.

$$V_{j,i} = P_i . D_{M,j,I} \quad (1)$$

The lists of i-scenarios and j-types of damage are shown in Table 2A and Table 2C. The matrix combining scenarios with types of consequences shows all indexes $V_{j,i}$ that it is possible to represent the impacts based on 2009 maritime disruption research survey (Table 2B). The mitigated consequence is evaluated from the potential consequence that is 'mitigated' by the susceptibility and coping capacity of the strategy (as mentioned in Table 1). The *j*-type mitigated consequences relative to the *i*-scenario ($DM_{j,i}$), which is calculated through the Formula (2) as the sum of all consequences referred to the intensity threshold value m. $V_{j,i,m}$ is the vulnerability related to intensity m of the *j* type of consequence and related to the *i*-scenario, $DP_{j,i,m}$: is the *j*-type potential consequence related to *i*-scenario, to *j*-damage and to *m*-intensity.

$$D_{Mj,i} = \Sigma_m (D_{Pj,i,m} . V_{j,i,m}) \quad (2)$$

The potential consequence of selected mitigation $D_{Pj,i,m}$, is determined by comparing the impact areas *i*-th to supply chain links. This operation is expressed by the following relation:

$$D_{Pj,i,m} = \pi_{i,m} \times E_{j,i,m} \quad (3)$$

Where α, β, γ, and δ represent the number of disruption occurrence for each state S_1, S_2, S_k, and S_n respectively.

$$P(S_1 \ S_2 \ \dots S_k \ \dots. S_n) = P\left(\frac{\alpha}{F}\dots\frac{\beta}{F}\dots\frac{\gamma}{F}\dots\frac{\delta}{F}\right) \quad (4)$$

$$F = \sum_{i=1}^{n} fi = \alpha + \beta + \dots + \gamma + \dots + \delta \quad (5)$$

Moreover, the initial (mitigating plan) probability $P(S_i)$ of each state S_i satisfies the formula (6) as the total value of the initial probability must be one in total.

$$\sum_{i=1}^{n} P(S_i) = 1 \quad (6)$$

Table 2 – Model scenarios; The *i*-scenarios of (A) mitigation and (B) *j*-consequences indicators proposed by authors. The combination of scenarios–mitigation indicators determines consequences indexes Vj,i (C). Adopted from Carpignano *et al*. (2009)

(2A)

Scenario i	Type of mitigation scenarios
i = 1	Inventory polling ports
i = 2	Utilising agency service
i = 3	Apply other chain links
i = 4	Optimum ordering policy
i = 5	Postponement delays
i = 6	Supply Flexibility
i = 7	Reserves routes
i = 8	Critical nodes maping
i = 9	Formal assessment
i = 10	Changes to working practices
i = 11	Maximum allowable interruption
i = 12	Develop warning system
i = 13	Implication monitoring
i = 14	Apply discovery responses
i = 15	Apply recovery actions
i = 16	Network & procedure redesign

(2B)

i/j	1	2	3	4
i = 1	V11	V21	V31	V41
i = 2	V12	V22	V32	V42
i = 3	V13	V23	V33	V43
i = 4	V14	V24	V34	V44
i = 5	V15	V25	V35	V45
i = 6	V16	V26	V36	V46
i = 7	V17	V27	V37	V47
i = 8	V18	V28	V38	V48
i = 9	V19	V29	V39	V49
i = 10	V110	V210	V310	V410
i = 11	V111	V211	V311	V411
i = 12	V112	V212	V312	V412
i = 13	V113	V213	V313	V413
i = 14	V114	V214	V314	V414
i = 15	V115	V215	V315	V415
i = 16	V116	V216	V316	V416

(2C)

Potential j	Type of consequences
j = 1	Delay of Port (Chain) Services
j = 2	Reduce/Deviate Port (Chain) Services
j = 3	Port (chain) stoppages
j = 4	Loss of port (chain) service platform

Case study and initial result

A case study of the Australia-Indonesia wheat supply chain is explored to investigate the effectiveness of mitigation strategies by entities along the chain. All the necessary information to characterize the risk, exposed elements and vulnerability in supply chain operations is identified from previous research (Gurning and Grewal 2007). The wheat-chain between Australia and Indonesia in the period of 2006-2008 experienced various uncertainty factors mainly due to natural reason and particularly generated by maritime disruptive events which caused significant higher price of wheat in raw and flour market, especially to Indonesia's consumers. In 2005-2008 due to the effect of drought, the harvest quantity of Australian wheat was approximately at 11 million tons (at the end of 2006) compared to 24 million tons in 2005.

For this reason, in January 2006, the price of hard wheat (APH1 and APH 13) was about US$ 170 per ton FOB to Indonesia (as in Drewry 2007; Gunawan 2007). Further, in October 2006, the price rose more rapidly to US$ 227 per ton FOB. If the trading term based on CIF in 2007 is compared to the January 2007 price, the wheat level achieved US$ 326 per ton CNF in contrast to US$ 212 per ton CNF in January 2006 (Drewry 2007; Fearnsearch 2007; Gunawan 2007). Further, in 2007 the natural based wheat disruption of the drought caused an increased price of wheat in the range of 50 to 60 per cent in 2006-2007. More significantly, in fact the shipping sector, especially ocean carriers contributed considerably to the increase of wheat price in the period of February 2007 – February 2008. The increase of wheat price due to maritime related operations was nearly 230 per cent (if CNF wheat price is considered). The main reason of this impact is due to the imbalance of the dry-bulk shipping market which started in the middle of 2006 which subsequently created a significant increase in the charter rate for the dry bulk fleet especially for Panamax and Handymax (Badan Urusan Logistik 2007; Clarkson 2007; Wheat Exports Australia 2008). Between January and September 2007, the cost continued rising from US$54 to US$ 95 per ton which an increase of approximately 76 per cent (Clarkson 2007).

Millers and wheat traders in Indonesia were not able to respond to the increasing trend directly by increasing the selling price of the flour because of the relatively low purchasing ability of Indonesia consumers (Peter 2007; Siagian 2007). During 2006-2007, Bogasari Ltd, as the biggest wheat-miller in Indonesia, increased the selling price of their flour product to the market by only 12 per cent, which was far short of the 76 per cent increase. In responding to those disruptive factors of maritime operations, the wheat industry, especially between Australia and Indonesia, had been using containerised wheat transport in contrast to dry bulk that had created a substantial problem in wheat trade. Gurning and Grewal (2007) found that using containers for consignment of wheat from Australia to Indonesia was much cheaper compared to dry bulk shipments. Temporarily, bulk shipping and dry bulk terminal operations were presumably no longer able to rely solely on the benefits of exploiting bulk commodities and trades to sustain growth and competitive success compared to containerised shipping due to its loss of economic scale (Department of Foreign Affairs and Trade 2007; Ray 2007).

The result of maritime disruption survey over telephone in 2009 is used to provide inputs collected from 34 executives of entities along the Australian-Indonesian wheat supply chain. The descriptive statistics of the survey (as shown in Figure 6) provide a starting point for the interpretation of probabilities of 20 maritime disruptive events that exist in the case study. The three highest risk probabilities of maritime disruptive events are port congestion with a 34 per cent probability value followed by equipment breakdowns (22 per cent), the checking process of wheat cleanliness at port (15 per cent) and insufficient empty containers (14 per cent). However, the standard deviation values of the first and last events are relatively dispersed (22 per cent for equipment break-down and 20 per cent for port congestion). The lowest risk probability was for a tsunami with a risk value of 4per cent, along with communication failures, earthquakes and political events. According to the respondents, 83per cent of them experienced port congestion every month, both in Australia and Indonesia. Therefore generally, respondents confirm that port congestion is the biggest event with an average probability of 34 per cent. The second most probable disruptive event is an equipment breakdown, which is given a 22 per cent chance by the respondents of occurring in the future.

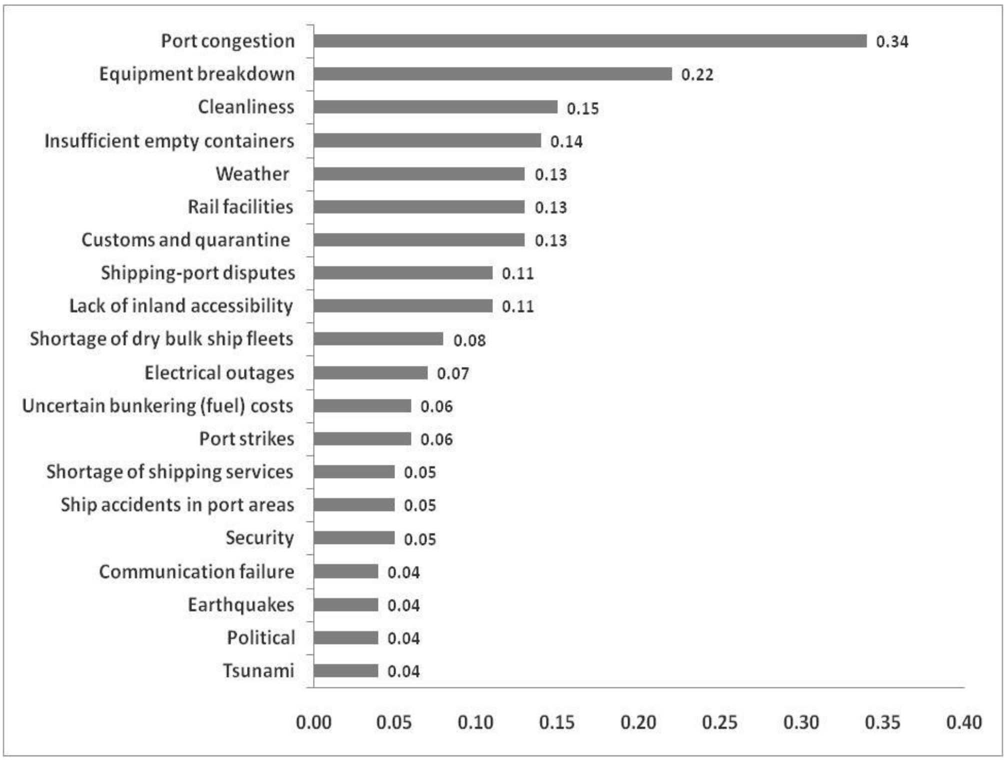

Figure 6 – The general rank of 20 maritime disruptive events

On the basis of mitigation strategy described previously, the business continuity concept was implemented by the wheat chain players of Australia-Indonesia. The players in that period applied changes to working practices that implemented containerised wheat transport in wheat transport between the two countries instead of using bulk shipping operation. Figure 7 shows the generic wheat supply chain model using *Powersim 8* and causal loops diagram with scenario of changes to working practices with the consequences of reduce wheat supply chain (V102 which *i* = 10; *j* = 2 as shown in Table 2A, 2B, and 2C) using five Indonesian ports in Tanjung Priok, Tanjung Perak, Belawan, Tanjung Emas, and Makassar with all wheat sources in West Australia.

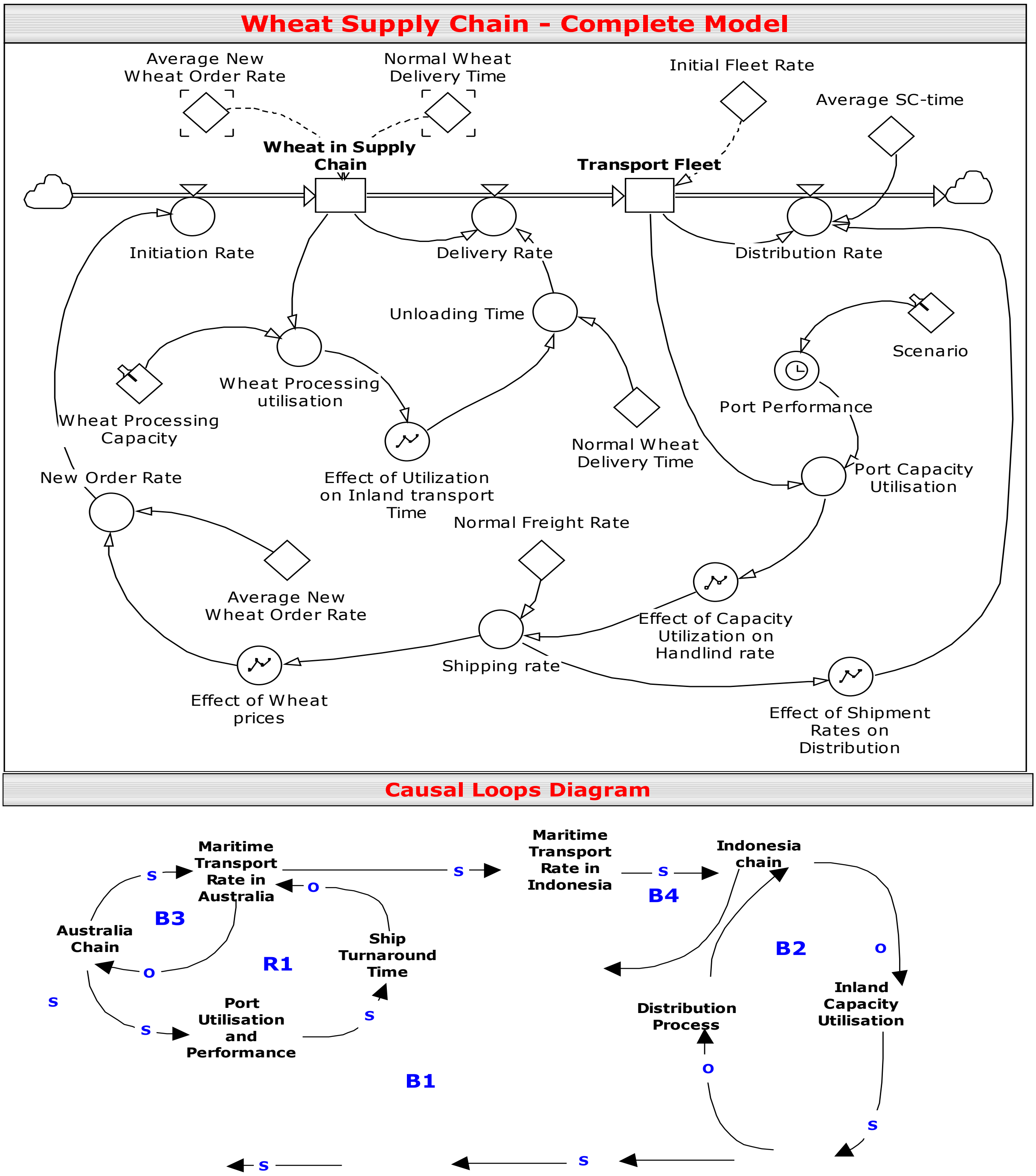

Figure 7 - The completed model and causal loop diagram of Powersim 8 in the case

From Figure 8 below, five operational factors such as total volume of wheat in supply, new order rate, transport fleet, level of shipping rate and distribution rate can be evaluated. The selected V102 mitigation scenario of changes to working practices such as altering the shipment process from dry bulk to container mode has resulted in a positive effect compared to the current practices of using dry bulk shipping. By implementing this change, the volume of supply and continuous order of wheat may increase including the transport capacity on maritime leg. This also consequently may reduce shipping costs both for international and domestic routes of the case. Further, the strategy may increase the annual volume accumulation of wheat along the chain compared to the previous initiation and delivery rate.

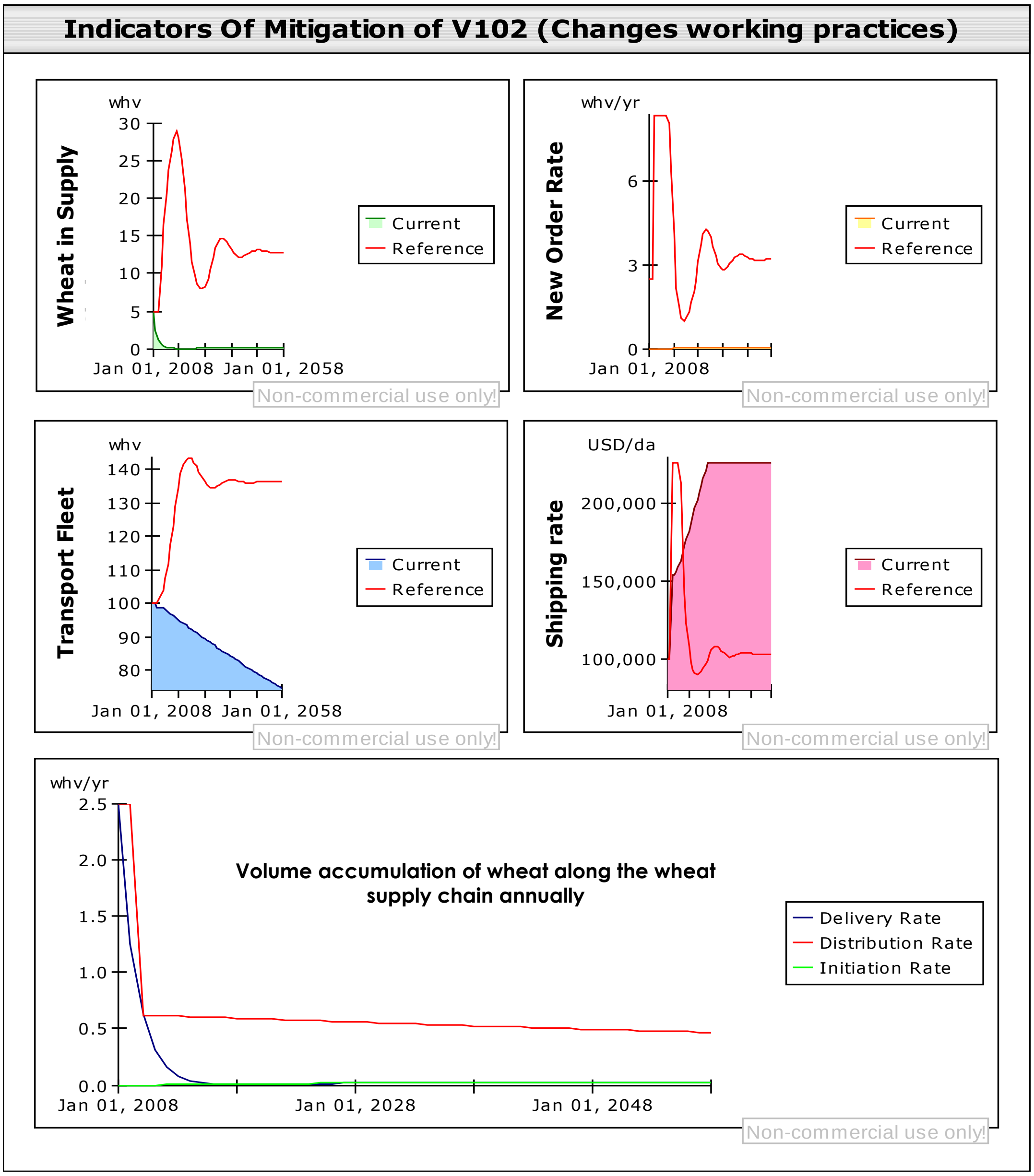

Figure 8- The initial result of mitigation V102 in Powersim 8

CONCLUSION

This Markovian-based methodology allows the issues to be addressed in relation to multi-mitigation analysis. The evaluation of multiple mitigation strategies were considered as a characteristic of maritime disruptive events investigated in this study. The integration and the comparison of each scenario were obtained by considering the effects of each single scenario on different sensitive targets. This is performed by defining a mitigation model and related indicators for assessing the impacts. With respect to existing methodologies and approaches, the study focuses on the definition of mitigation strategies. The definition of accurate mitigation parameters and the related weights reflects the relevant issues for stakeholders of the Australian-Indonesian wheat supply chain as an empirical case. If the set of indicators could be applied to another territorial context, the expression of their relevance would need to be discussed with stakeholders of this new region. The choice allows highlighting of the most critical aspects of a wheat supply chain in agreement with mitigation strategies carried out by supply chain entities. At the same time, it is possible to verify how changes in operational criteria can modify the results.

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