Mitigating the effects of climate change on maritime disruptions: An Indonesian perspective

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Abstract. This paper analyses the effect of severe weather conditions due to climate change and its impact on creating disruptions and the resulting unavailability of various maritime services transporting freight and passengers. The analysis is conducted within the context of case studies in Indonesia and focuses on the risk profiles that are emerging as a result of the weather factors contributing to disruptions in the maritime domain. This paper suggests that maritime service operators and users consider a hybrid approach to optimizing mitigation strategies that combines contingency rerouting, inventory strategy and business continue management The potential benefits of such an approach for managers include an effective approach to minimizing costs yet achieving an acceptable level of time delivery.

Keywords: Climate change, maritime disruptions, mitigation strategies, Indonesia

1 Introduction

One extreme weather event is not indicative of climate change; however, groups of events may be [1], particularly when they are associated with long term increases in oceanic and air temperature, which provide water vapour, or ‘hurricane fuel’ [2]. The Gulf Coast’s 2005 sequential hurricanes Katrina, Maria, Ophelia, Phillipe, Rita, Stan, Vince and Wilma are such an indicative group. These hurricanes were part of an anomalous season that included 28 tropical storms, of which Katrina, Rita and Wilma were three of the six strongest hurricanes ever recorded [3]. In the period of 2001-2008 hurricanes including tropical cyclone were reported as the major factors of disruption in maritime related operations. Alexander and Irwin [4], Brown [5], Coy *et al*. [6] , Frittelli [7], Shultz [8], Seba [9] have also analysed the impact of hurricane Katrina, Rita, and Dolly on ports, and shipping channels in US damaging buildings, cranes, and utility systems including delays in water, sewer, and power restoration. Port authorities also were reported [7] had to clearing waterways and debris removal as another difficulty. A report by Frittelli [7] reported that Katrina hurricane in 2005 had considerably increased port disruptions may include much higher shipping costs, as well as transport capacity shortages in terms of grain exports. In addition, Australian Transport Safety Bureau [10] reported the impact of major storms that caused considerable higher disruptive events at Newcastle Port in 2007 as well as in the period of 2004-2006. The severe weather conditions during that year generated a significant increase of ship queue numbers, interrupt the rail connection because of flooding and the closure of the port as a result of ship grounding in the port channel. Further, the wide effects of various disruptive events due to severe weather were the considerable increase of demurrage costs, decrease of the coal throughput of the port and consequently lower the coal chain capacity from that region to overseas market.

2 Indonesia Case Study

Studies on the impact of tropical cyclones in Indonesia have been started with the investigation of annual mean surface air temperature error by Neale and Slino [13] which may correlate the climate change with the existence of tropical cyclone in the area. This further may influence wave height level that have had a higher than normal rate of calm sea condition in the year 2007-2008. The regional tropical cyclones such as Helen, Melanie, and Durga were recognised as a primary generator of strong wind of more than 38 nautical miles per hour and higher wave level (more than four metres) which then became a main factor of maritime disruptions in Indonesia [Badan Meteorologi dan Geofisika 11, Badan Meteorologi dan Geofisika 12].

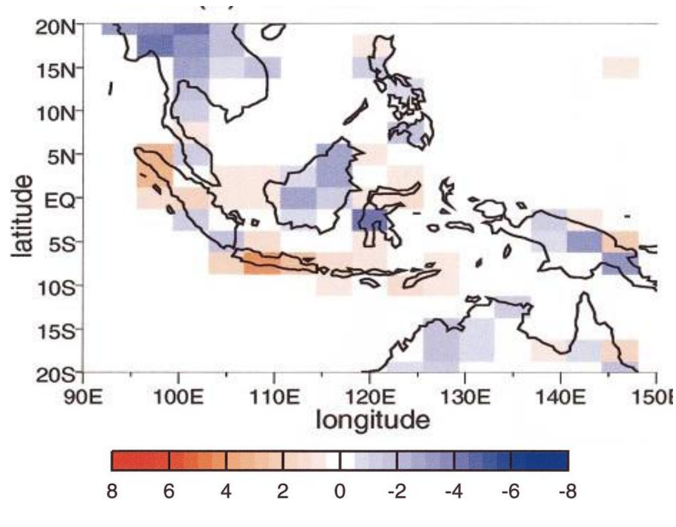

Figure 1. Annual mean surface air temperature error. Adapted from Neale and Slingo [13]

Reports between 2006 and 2007 further indicated that two other factors contributing interruptions for port and shipping operations in Indonesia are the increase of sea and tidal level compared to previous years [14-16].

In addition, the report also found 42 cases of maritime disruptive events including 20 physical and operational impacts occurred in ports, inter-island shipping (such as domestic oil transportation, coal transfer and food transport within the islands), short-sea shipping (mainly as ferry transport), inland road and coastal area (as described in detail in table 1 below). Flood around port areas is other events that frequently occur due to unusual higher sea-level combining with high raining intensity. Low land flooding in port area as well along the main accessible road to and from ports has been one major driver of congestion at ports and ferry terminals in Indonesia.

Table 1. Instigators and impacts on domestic maritime services in Indonesia in the period of 2007-2009

INSTIGATORS	IMPACTS	Port	Inter-island Shipping	Short-sea Shipping	Inland road	Coastal area
Increase wind speed	**Increased vulnerability of structures**	x	-	-	-	x
	Reduce the working hour of port equipment	x	-	-	-	-
	Reduced capacity of port service	x	x	x	x	-
	Increased wave agitation in port basin	x	-	-	-	-
	Exposure decks of wharf and jetties	x	-	-	-	-
Higher wave level	**Increased overtopping to decks and jetties**	x	-	-	-	-
	Reduced regularity of the port	x	-	-	-	-
	The closure of ferry terminal	x	x	x	-	-
	Increased port damages	x	-	-	-	-
	Vessel speed reduction	-	x	x	-	-
	Detour of shipping route	x	x	x	-	-
	Frequent shipping delay	-	x	x	-	-
	Unavailability of ferry service	x	x	x	-	-
Increase in sea-level	**Problems with bridge clearance**	-	x	x	-	-
	Low land flooding	x	-	-	x	x
	Congestion at port road accessibility	x	-	-	x	-
	Congestion around ferry terminal	x	-	x	x	-
Higher tidal level	**Problems in ship's manoeuvring**	x	x	x	-	-
	Increased damage to coastal channel	x	x	x	-	x
	Changed dredging requirements	x	-	-	-	-

With this, ports were unable to get their cargo quickly transported and handled. For instance, the flood in Priok, Jakarta 2007 and 2008 has critically blocked the port from trucker and cargo coming in and out from the port. Other ports, such as Tanjung Emas, Semarang also experienced service outages and reported limitations in cargo reception. The real economic impacts were the higher price of food commodities including grain and wheat-based products in the range of 200-250 percents, and longer lead-time (50 to 70 percent from the average level) due to unavailability of certain shipping services from 3 days to two weeks [17]. These, consequently generated seven navigational warnings in average (*Maklumat Pelayaran* in Indonesia) annually by ministry of transport of Indonesia during 2007-2008. Officials of eight port authorities in Tanjung Priok, Cilegon, Tanjung Perak, Padangbai-Lembar, Tanjung Emas, Cilacap, Belawan, and Makassar reported challenges related to awareness, communications, and coordination with port stakeholders as a result of these tropical cyclones. Port plans had no considerations and anticipations in addressing these types of vulnerabilities as natural disasters, despite pre-disaster preparedness documents that have been prepared by these ports.

Likewise, port users also did not anticipate the extent to which their freight and supply chain would be impacted especially for those who dealt with food, coal, oil and gas chains. High winds and wave from the regional cyclones rendered ferry terminal out of service due to navigational warning by which freight for short-sea and inter-island shipping were not allowed to be operated due to safety considerations.

Further, port users also identified coordination challenges with local, national, and international partners while planning for and recovering from maritime disruptions. At the local level, one common response they made was to reroute cargo to other ports which very close to consignee premises. The users also decided to poll their inventory into one particular port in order to ensure the effectiveness of their freight flow of their cargo if they may find some disruptions in one particular port of loading

3 Literatures on mitigation strategies

The goal of managing maritime disruption is to alleviate the consequences of disruptions and risks or, simply put, to increase the *robustness* of a supply chain through maritime leg. However, there are very few qualitative concepts of managing maritime disruptions that concern about the perspective of time-based manners (pre disruption, on disruption, and post disruption stage) in responding maritime disruptions. The majorities of supply-disruption papers focuses on the combination of contingency rerouting and inventory/sourcing mitigation strategies in response to various uncertainties in maritime operations [18, 19]. Derived from these literatures, it may be identified that, the dominant reactions of maritime users in the supply-chain management by adjusting new route of maritime leg and providing strategic stock (no alternative source available) including providing back-up systems are critical initial-steps in disruption risk management and contingency plans for responding to worst case scenarios of maritime disruptions (see figure 2). [20] is one of the supply-chain disruption papers that consider the mixture of inventory/sourcing mitigation and business continuity concept in managing maritime disruptions. These strategies are recommended for a firm (as maritime user) that faces constant demand and sources from two identical-cost and infinite-capacity suppliers (similar described in figure 2). Further, Blackhurst *et al.* [21] emphasised the importance of maritime operators to minimise the ultimate loss from maritime disruptions by considering the trade-off between robustness of the supply chain to maritime disruptions and the overall efficiency under normal operations of maritime services. This may be achieved through risk-sharing decision through insurance plans, redesign of supply-chain flow through a certain maritime leg, and damage control [22].

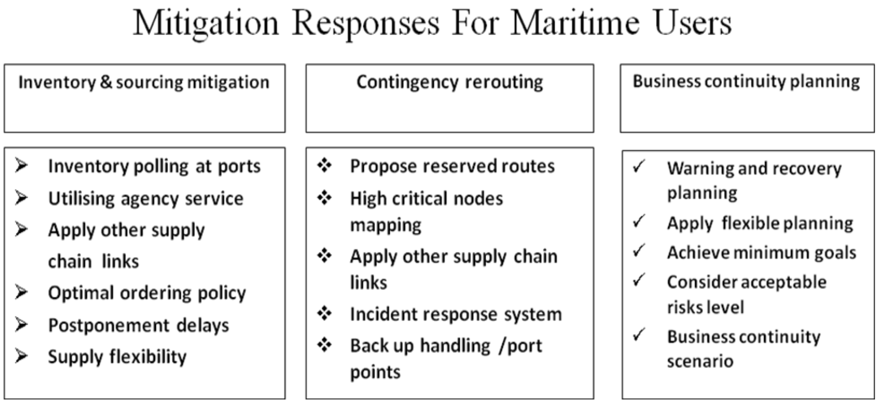

Figure 2. Mitigation responses from the perspectives of maritime users

Moreover, even though most maritime entities anticipated and had plans in place to mitigate infrastructure destruction from delay to natural disasters, dominant maritime authorities, operators and users as reported that the delay, deviation, disruption and disasters created infrastructure challenges [23-26]. Some port authorities were able to provide specific dollar amounts for repair damage and resolve its performance and various deviation of plan through buildings, cranes, or other equipment (as described in figure 3 below). Ports were still faced with these repair costs even though a majority of the port plans we reviewed included facility damage mitigation [19]. As a way to work around the damaged structures, ports also utilized temporary trailers for administrative and operational functions. For example, this occurred at the Port Arthur, where the strategy of reserving backup equipment with appropriate vendors was included in that port's Hurricane Readiness Plan [7, 19, 27-29]. Besides the repair costs involved, another indication of the significance of changes to infrastructure was the effect on port and shipping operations. In several cases of ports [7, 19, 27-29], tenants left the port and moved elsewhere.

Mitigation Responses For Maritime Operators

Area of Anticipation	Mitigation Responses (Measures)
➢ Maritime facility planning and operation	❖ Redevelopment of wharf fendering ❖ Provide supporting construction of sea wall structures ❖ Increase the damage limit of the construction ❖ Revision of ship navigation areas ❖ Increase maintenance and replacement costs
➢ Vessel design and operation	❖ Provide larger ship's dimensions ❖ Provide larger areas for anchoring of vessel ❖ Design stronger ship construction ❖ Allocate real-time marine climate information ❖ Reduce greenhouse gas emision from ships

Figure 3. Mitigation responses from general maritime operators in Indonesia

4 Modeling on mitigation strategies

The model framework, Maritime Mitigation Strategies (Mar-MS) provides a preliminary reference of potential mitigation strategies that meet the objectives and requirements in company mitigation responses; however, in this model, it is possible to select the lowest costs that may occur to each strategy and combination of three mitigation strategies taken. To do so the model utilise the concept of complementary anti-cover in risk situations [30] and also the concept of back up facilities [31, 32]. The model formulation to address the minimum consequences (costs) is given here:

$$\text{Minimise} \quad \sum_{j \epsilon J}^{\infty} f_j \, X_j Y_j Z_j \quad :$$

$$\sum_{j \epsilon \{J-\{k\}\}}^{\infty} c_{jk} X_j \geq 1 \quad \forall_k \in K \tag{1}$$

$$\sum_{j \epsilon \{J-\{k\}\}}^{\infty} a_{jk} X_j \leq 0 \quad \forall_k \in K \tag{2}$$

$$M(X_i - 1) + \sum_{j \epsilon \{J-\{i\}\}}^{\infty} b_{ij} X_j \leq 0 \quad \forall_i \in J \tag{3}$$

Where:

J = the set of potential sites for backup facilities, $i,j \in J$;
K = the set of current supply chain facility locations, $k \in K$;
Xj = 1, if a rerouting mitigation plan is applied at site *j (as re-routing)*, 0 otherwise;
Yj = 1, if ISM (inventory sourcing mitigation) plan is applied at site *j*, 0 otherwise;
Zj = 1, if a business continuity plan is applied at site *j*, 0 otherwise;
ajk = 1, if $djk \leq A$, 0 otherwise; bij = 1, if $dij \leq B$, 0 otherwise;
cjk = 1, if $djk \leq C$, 0 otherwise–cjk is said to be in the cover set *C* for facility k;

The accumulated cost of selecting facility *j* (*fj*) would be incurred in the objective function only if a backup facility is chosen to be “opened” (operating) at *j* in the optimal solution (Xj = 1, and $fj * Xj = fj$). The sum of these costs would yield the accumulated cost of opening backup facilities (re-routing). To properly assess costs, the set of potential re-routing port (*J*) has to be augmented by the set of existing facilities *K* (note *i*, *j*, and *k* are now elements of *J*). The objective function, and constraints in (1) and (2), are similar to the Hale and Moberg [32] model.

The objective function minimizes the costs of applying mitigation plan should be sited. The first set of constraints (1) assures that there is at least one plan destination locating within distance of the primary facilities (existing supply chain facilities including ports). The second set of constraints (2) assures that the backup facilities are not within distance of any primary facility. The constraints represented in (3), assure that none of the backup facilities or re-routing that are chosen to be sited in the model solution will be within distance of each other.

Figure 4 provides a comprehensive simulation and optimization process. The mitigation strategies are represented as input risk parameters in the model.. All mitigation input parameters are in the form of the probability of interaction between maritime operators and maritime users. Sensitivity analysis using risk factors for maritime mitigation is also conducted in the model. In supporting the process, Powersim 8 may present the level of cargo transported both before and in the period of disruption after optimizing 300 scenarios of generic disruptive events due to climate change factors in Indonesia.

Additional information of disruption costs, accumulated costs, and cost level on each mitigation strategy considered in the system would thereby have the effect of narrowing the potential number of alternate optimal solutions, while perhaps better meeting the decision-makers’ preferences and needs. In this way, supply chain and logistics managers can anticipate both the effects of different threats to the supply chain and the possible ways to utilize backup facilities to attenuate maritime disruptions due various climate those threats.

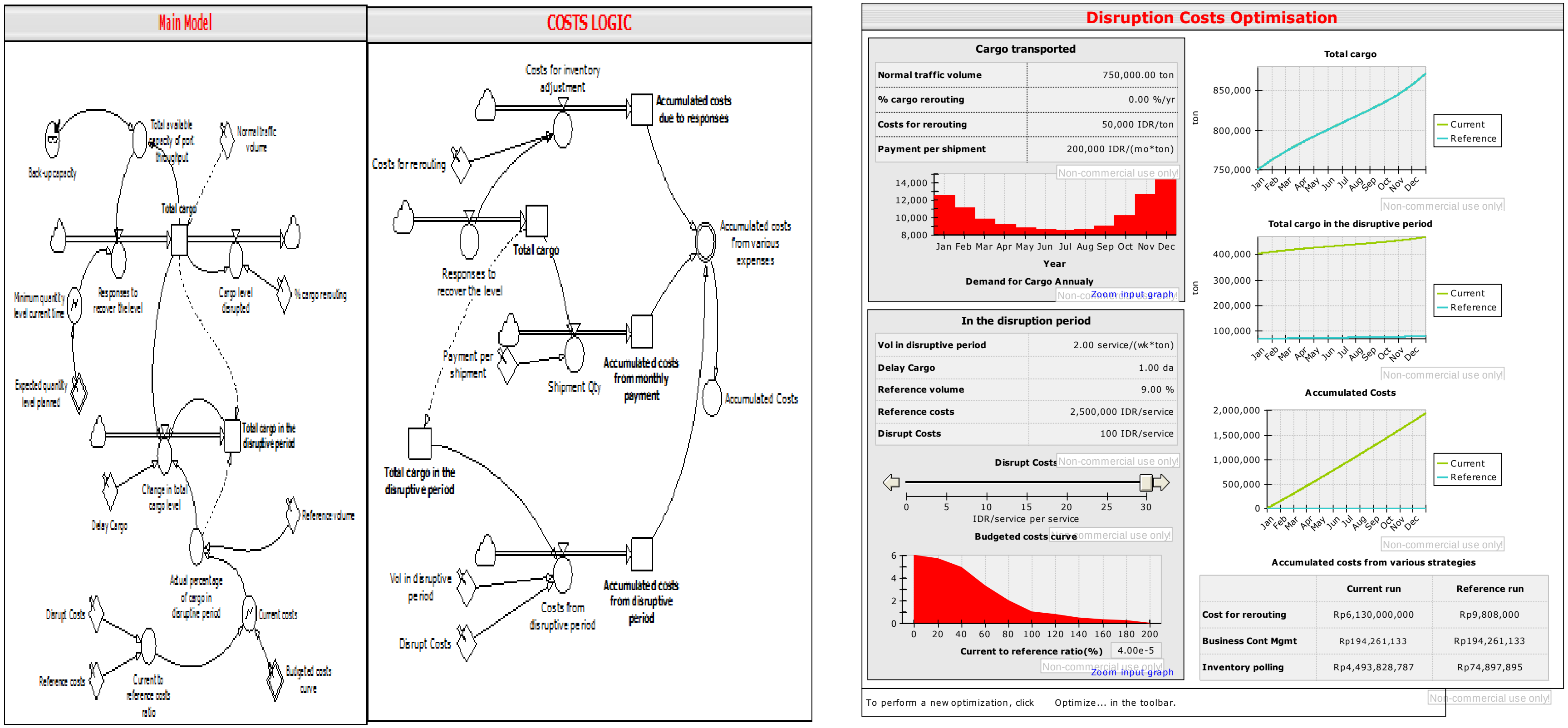

Figure 4. The modeling concept of main model and costs arrangement using Powersim 8.

5 Conclusion

As a result of the lessons learned from recent natural disruptions, both maritime users and operators' in Indonesia recognise the impact of marine climate change that taking many steps to mitigate these vulnerabilities. One mitigation tactic reported by many port authorities is to prepare their facilities from the planning to operation stages including to develop redundant systems to help during any recovery efforts. Similar to this, port users have to consider the most optimum decision to be made whether they may apply inventory and sourcing mitigation, contingency rerouting, and business continuity management.

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