XIX International Conference on "MATERIAL HANDLING, CONSTRUCTIONS AND LOGISTICS"
©University of Belgrade, Faculty of Mechanical Engineering, Department of Material Handling and Design Engineering, October 15-16, 2009

A MARKOV CHAIN APPROACH TO MARITIME DISRUPTIONS IN THE WHEAT SUPPLY CHAIN

Saut Gurning[1], Stephen Cahoon[2]
[1]Australian Maritime College, Maritime and Logistics Management Department
Launceston, Tasmania, Australia, rgurning@utas.edu.au
[2] Australian Maritime College, Maritime and Logistics Management Department
Launceston, Tasmania, Australia, s.cahoon@amc.edu.au

Abstract: *Markov chain approach is used for the estimation of the risk probabilities that can result in delays, deviations and disruptions due to various maritime risks in a wheat supply chain. The objective of this paper is to analyse the overall risk of in the scale of supply chain given a risk structure of various maritime operations*.

Keywords: *Markov chain,maritime operation, disruptive events.*

1. INTRODUCTION

In this paper, a complex maritime disruptive event model is proposed that includes reliability states in a supply chain system. Discrete and continuous Markov process models are used to model the system in the operations of maritime services. Multi-state risks of the wheat transportation system are built on top of the Markov process for system continuity. One common approach to modelling a supply chain system and its disruptions is a Markovian-based methodology. This paper specifically focuses on the Markov chain analysis of maritime disruptions in the case of wheat transport from Australia to Indonesia.

2. LITERATURE REVIEW

The previous disruption analysis literature in maritime systems mainly focuses on risk analysis arguments and statistical data analysis rather than exploring disruption probabilistic including the modeling simulation in a complex network like a supply chain process.
The initial exploration maritime disruption probability may be found in Jason et al. [1] which applied a Bayesian probabilistic risk analysis approach for discrete shipping channel activities with uncertainty events of oil spill accidents as the study case. This approach then was expanded with a Semi-Markov probability analysis by [2] which became a recognized approach for various related transport operations especially on various risk selection with discrete methods as essentially discussed in [3-8]. Further, the use of Markov approach was coupled with performance analysis [9] of more stages beyond transportation. However, uncertainty in the context of shipping disruptions particularly on risk channel was dominantly considered as individual probabilities within a boundary region of a complex networking process specifically. Given this application, different types of disruptive events studies have started proposing new ideas in identifying the wide impact of transport operation along supply-chain. Conrad [10] for an example indicated long-term economic viability and risk assessment method of disruptive events such in port operations especially in queuing problems using the combination of Bayesian and Markov methods. Through this study, port security action plan was also proposed in the context of deviation and disruption stages assessed with various scenarios of long-term economic impact along supply-chain activities. Other study similar to Conrad [10] was undertaken by Pinto and Wayne [11] in combining risk-based assessment and risk-based return on investment used semi-Markov process to calculate the total loss in throughput of incident cycles of a port until port operations restored. On the basis of risk assessment analysis, Pachakis and Kiremidjan [12] further applied similar approach in measuring seismic hazard of port facilities and operation due to natural disasters (earthquake) in order to predict the revenue loss and downtime quantity of a disrupted port. Given these two applications, there has been very little attention paid to construct propagation effects of the disruptive events around maritime operations beyond the maritime boundary to the supply chain stages.
Further, studies on disruptions started to determine the impact of temporary closure of a port to the maritime users. Such as Garcia [13] with Markov decision process combined three consecutive synchronous events (inventory response, queuing problem and port closure) in modeling the average logistics lead-time and costs through a port. In addition, the random selection of incident probabilities in this study introduced a significant threat of internal validity as all process through the port is assumed synchronously as one process. Other studies using simple integer quadratic and Markov model was done by Gaonkar and Viswanadham [14] which considered the generalisation of disruption propagation process along supply-chain

operation. Through their study and also followed by Guerrero, Murray, & Flood [15], the linkage of a port and port users (especially manufacturers) were applied in order to identify the transition process and characteristic input–output relationships of disruptive events. Therefore, with the same direction of the exploration, this paper attempts to propose the application of Markov approach in analysing the disruption propagation including impacts of maritime operations in a supply chain using wheat transport between Australia and Indonesia as indicated in Figure 1 below.

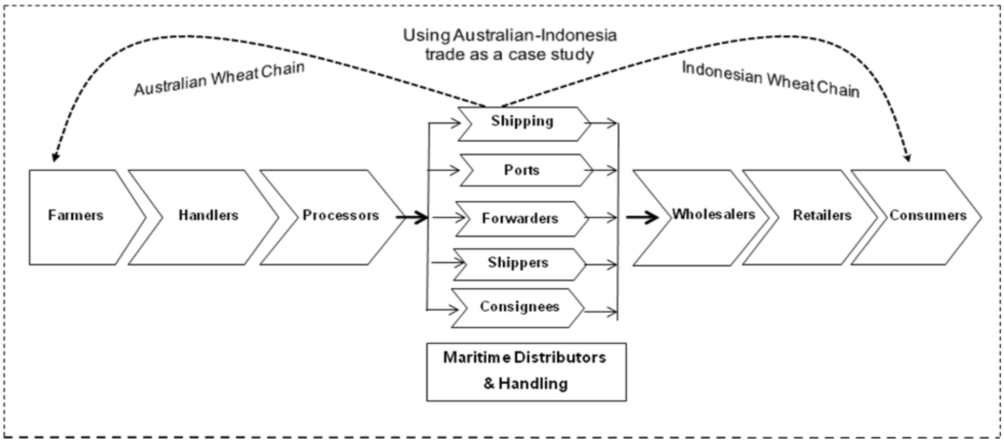
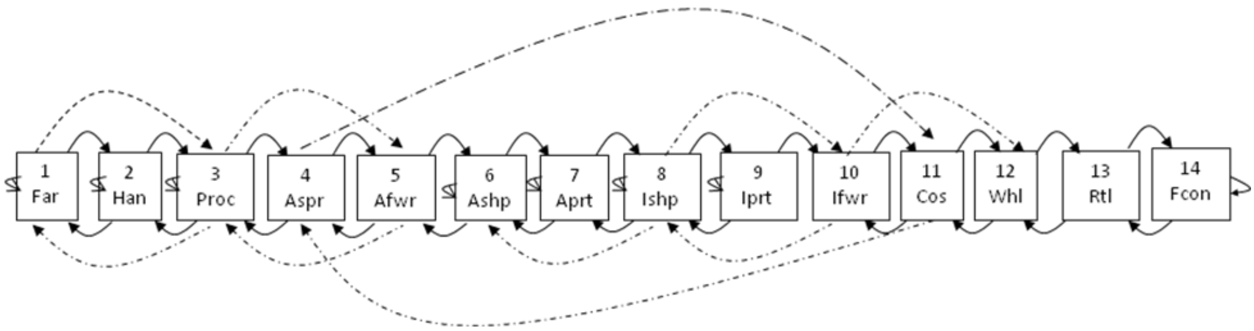


Figure 1. Australian-Indonesia wheat supply chain used as a case study

3. GENERAL STATE TRANSITION

As explained in Figure 1 above, wheat from farmers is brought to handlers and processors by trains or trucking fleet with self discharging wagons which are discharged to a hopper and then by means of conveyors are transported into storage tanks (silos) at ports or dedicated grain terminals. Transporting 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 under the control of shippers, freight-forwarders and consignees. In the buyers' locations, wheat is further distributed through wholesalers, retailers, and consumers. Therefore, the risk scenario and its risk relationships across the wheat supply chain are designed on a series system of subsystems S_1 to S_{14} as shown in Figure 2. Based on these stages, the transition matrix of the general risk structure can be presented below by utilising discrete Markov-chain approach.



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

Note:
Far : farmers;
Han: handlers
Proc: processor
Aspr: shippers
Afwr: Forwarders in Australia
Aprt: Ports in Australia
Ashp: Shipping operations in Australia
Ashp: Shipping operations in Australia Indonesia
Iprt : Ports in Indonesia
Ifwr : forwarders in Indonesia
Cos : Consignees
Whl : Wholesalers
Rtl : Retailers
Fcon : Final consumers

Figure 2. Transition matrix of wheat supply chain and maritime operations

4. Multi-State of Maritime Disruptions Model

With relation to maritime disruption models particularly for the states of S_6 (P_{66}), S_7 (P_{77}), S_8 (P_{88}), S_9 (P_{99}) as shown in Figure 3.

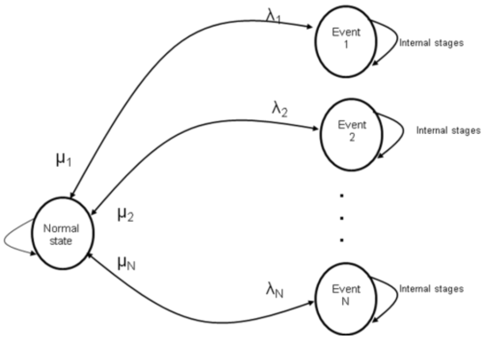


Figure 3. Multiple maritime disruptive events

Maritime stages such as port and shipping operations have more than one probable disruptive event (from 1 to N) which may occur from 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, long customs and quarantine procedures, earthquake, equipment breakdown, port congestion, and insufficient of empty containers may change the normal operation level of a port to a failure mode condition [16, 17].

Let $p_i\ (t)$ be the state probability of $X(t)$ at time t. So $p_i(t) = P[X(t)=i]$ *where* $i \in X$. (1)

The following system of differential equations for finding the state probabilities $p_i(t)$ for the Markov process can be written as:

$$\frac{dp_i(t)}{dt} = \sum_{j=i}^{v} p_j(t)\lambda_{ji}(t) - p_i(t)\sum_{j=i}^{v}\lambda_{ij}(t) \qquad (2)$$

While for the probabilities of internal stages for each risk event (in Figure 3) are further approached with four different maritime disruption stages which are indicated with stage 3,2,1,0 [5, 9, 18, 19]. The definition of the stages are:

i). Stage 3 – ensuring the normal level of the maritime service availability as planned.
ii). Stage 2 – the occurrence of delays along maritime services which creates less efficient level of service performance.
iii) Stage 1 – the events of deviations as the results of further divergences of maritime services.
iv). Stage 0 – the conditions which disruptions occur due to variable factor that create various maritime services unavailable.

These four stages as Markov process, can be defined also as the transitions of maritime disruptions which the value will depend on the combinations of these four stages [18, 20, 21] as explained in Figure 3 where;

λ_{32}: the transition rate from stage 3 to state 2;
λ_{31}: the transition rate from stage 3 to state 1;
λ_{30}: the transition rate from stage 3 to state 0;
λ_{21}: the transition rate from stage 2 to state 1;
λ_{20}: the transition rate from stage 2 to state 0;
λ_{10}: the transition rate from stage 1 to state 0;
μ : the transition rate from stage 0 to state 3.

Assume that the probability functions for the maritime disruptive stages 3, 2, 1 and 0 are $F_3(t)$, $F_2(t)$, $F_1(t)$, $F_0(t)$ respectively, where $F_3(t) + F_2(t) + F_1(t) + F_0(t) = 1$ (3) for any operational period t which is continuously changing with t. Therefore, to find the probability function for each stage, a system of differential equations is applied under the assumption that the transition rates are relatively constant and can be estimated from the historical record [7, 18, 22]. Referring to these scenarios each stage may be formulated in the following equations:

$$\frac{dF_3(t)}{dt} = -(\lambda_{32} + \lambda_{31} + \lambda_{30}) * F_3(t) + \mu * F_0(t) \qquad (4)$$

$$\frac{dF_2(t)}{dt} = -(\lambda_{21} + \lambda_{20}) * F_2(t) + \lambda_{32} * F3(t) \qquad (5)$$

$$\frac{dF_1(t)}{dt} = -\lambda_{10} * F_1(t) + \lambda_{21} * F_2(t) + \lambda_{31} * F_3(t) \qquad (6)$$

$$\frac{dF_0(t)}{dt} = -\mu * F_0(t) + \lambda_{30} * F_3(t) + \lambda_{20} * F_2(t) + \lambda_{10} * F_1(t) \qquad (7)$$

Therefore, M(t) or the states probabilities of these four stages equals to $F_3(t) + F_2(t) + F_1(t)$. (8)
And if this considers equation (1), consequently the value of $F_0(t)$ = 1- M(t) (9)

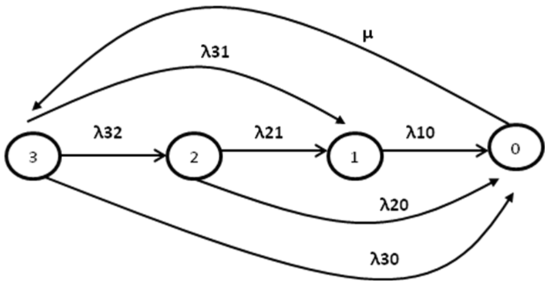


Figure 4. Maritime disruption stages and scenarios

…

5. Results

Modelling maritime disruptions in a complex system is a major aim of this paper. The discussions focus on the risk analysis structure of a general maritime service in the Australian-Indonesia wheat supply chain. First, a discrete Markov process is used to model the general state transition for the entire wheat supply chain. Then, the multi-state maritime disruption model is built to assess the probability of main maritime states in the wheat supply chain. Multiple maritime risk events are arranged in other to calculate the contribution of each events creating failure mode the any particular maritime states. Further, the internal stages of each risk events are structured into four probability functions based on the stages of delays, deviations, and disruptive events. The real calculation process is not presented in this paper as the survey risk probability survey is being undertaken at this period. However, the idea of incorporating the potential risk events into maritime disruption model is a useful example in the simple evaluation of the wheat supply chain, especially during the planning stage.

…

REFERENCES

[1] Jason, R.W.M., J.R.v. Dorp, M. Thomas, R.H. John (2002), The Prince William Sound risk assessment, *Interfaces*, 32 (6),25.

[2] Tomlin, B., (2006), On the Value of Mitigation and Contingency Strategies for Managing Supply Chain Disruption Risks, *Management Science*, 52 (5),639-657.

[3] Lee, Y.-D. and T.-E. Lee, (2005), Stochastic cyclic flow lines with blocking, *OR Spectrum*, 27 (4),551-568.

[4] Lewis, B., A. Erera, and C. White, (2006), Impact of Temporary Seaport Closures on Freight Supply Chain Costs, *Transportation Research Record: Journal of the Transportation Research Board*, (1),64-70.

[5] McCormack, K., ed. *Measuring and Managing Risk*. Supply Chain Risk Management: Minimizing Disruptions in Global Sourcing, ed. R. B.Handfield and K. McCormack. 2008, Auerbach Publications: New York. 65-91.

[6] Uluscu, O., B. Ozbas, T. Atiok, and I. Or, (2008), *Risk analysis of transit vessel traffic in the strait of Istanbul*. Industrial Engineering Department, Bogazici University: Istanbul, Turkey.

[7] Xiao, H., Y. Li, M. Xie, and K. Ming-Ng, (2009), A model for reliability analysis of repairable transportation system, The 2009 Industrial Engineering Research Conference.Miami, USA, 30 May - 3 June, 2319-2324.

[8] Kolowrocki, K. and J. Soszynska, (2009), Safety and risk evaluation of Stena Baltica ferry in variable operation conditions, The 2009 Industrial Engineering Research Conference.Miami, USA, 30 May - 3 June, 2146-2151.

[9] Qiang, Q., A. Nagurney, and J. Dong. *Modeling of Supply Chain Under Disruptions with Performance Measurement and Robustness Analysis*. 2008 [cited 2008 20 July 2008]; Available from: http://supernet.som.umass.edu/articles/QiangNagurneyDongSupplyChainRobustnessRandomDemands.pdf.

[10] Conrad, S., W. Beyeler, R. Thomas, T. Corbet, T. Brown, G. Hirsch, and C. Hatzi, (2004), *How do we increase port security without imperiling maritime commerce? Using Flight Simulators and Workshops to Begin the Discussion*, NISAC, 2004, NISAC.

[11] Pinto, C.A. and K.T. Wayne, (2006), The Security Incident Cycle of Ports, *Maritime Economics & Logistics*, 8 (3), 267.

[12] Pachakis, D. and A.S. Kiremidjian, (2005), *Estimation of downtime related revenue losses in maritime ports due to earthquakes*. 2005, Department of Civil and Environmental Engineering, Standford University: Standford, USA.

[13] Garcia, B. *Port Disruption and Recovery Model (PDRM)*. 2008 [cited 2009 8th February 2009]; Available from: http://www.ccdott.org/transfer/projresults/2006/impact08/impact08_p.pdf.

[14] Gaonkar, R.S. and N. Viswanadham, (2007), Analytical Framework for the Management of Risk in Supply Chains, *IEEE Transactions on Automation Science & Engineering*, 4 (2),265-273.

[15] Guerrero, H., D. Murray, and R. Flood, (2008), A model for supply chain and vessel traffic restoration in the event of a catastrophic port closure, *Journal of Transport Security*, 1 (2),71-80.

[16] Bearing-Point and Hewlett-Packard, (2005), *Impacts of Major Disruptions On The Maritime Industry*. 2005.

[17] Gurning, S. and S. Cahoon, (2009), Analysis of random disruptive events in shipping and port operations, International Forum on Shipping, Ports, and Airports (IFSPA).Hongkong, 24-27 May,

[18] Kumamoto, H. and E.J. Henley, eds. *Probabilistic risk assessment and management for engineers and scientist*. 2nd ed. 1996, IEEE Press: New York, USA.

[19] Macdonald, J.R., (2008), *Supply Chain Disruption Management: A Conceptual Framework and Theoritical Model*, in *FAculty of the Graduate School*. 2008, University of Maryland, College Park: Maryland, USA.

[20] Jianyong, L. and Z.Xiaobo, (2004), On average reward semi-markov decision process with a general multichain structure, *Mathematic Of Operations Research*, 29 (2),339-352.

[21] Yu, G. and X. Qi, (2004), *Disruption Management*, World Scientific Publishing Co. Pte. Ltd,

[22] Hermanns, H., J.-P. Katoen, J. Meyer-Kayser, and M. Siegle, (2003), A tool for model-checking Markov chains, *International Journal Software Tools Technology Transfer*, 4 (2),153-172.