The Asian Journal of Shipping and Logistics • Volume 31 Number 3 September 2015 pp. 319-340 •

Cost Consequences of a Port-Related Supply Chain Disruption

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Contents

Abstract

Port functionality is a significant and important aspect of cargo transportation. Previous studies have identified a list of port-related supply chain disruption threats and developed a management model that seeks to address these threats. This paper adds value to these related studies by comparing four consequences of an example of these threats: (1) avoidance of disruption, (2) mitigation of disruption, (3) deviation of transportation plan and (4) delays and deviation of transportation plan. The impact of these consequences is simulated in a case study using data from a chemical manufacturer based in Singapore. This paper quantitatively measures the impact of a port-related threat on supply chains and thus highlights the importance of port-related supply chain disruption management.

Key Words : Port-related Supply Chain Disruption, Risk Management, Disruption Management, Port Resilience, Simulation

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I. Introduction

Many studies have reported the importance of the port's functionality depicted through the detrimental effects resulting from operational failures of ports as nodes in supply chains. The West Coast port lockout in the US in 2002 caused port management to incur a loss of approximately US$19.4 billion (Institute for Supply Management, 2002). Dock strikes at Kwai Tsing container terminal in Hong Kong in 2013 resulted in serious shipment delays and huge financial losses (TradeWinds, 2013). Defective or inadequate cargo handling equipment in Nigerian ports accounted for low productivity, inefficiency and damage or loss of cargo (Esq., 2001). These examples demonstrate the significant impact of man-made operational port threats on supply chains. This paper refers to this type of threat as port-related supply chain disruptions (PSCD) threats. A PSCD threat is an operational threat originating from the port and has a possible detrimental effect on supply chains. For instance, a PSCD threat can take the form of a port strike, congestion, power outage at port facilities, collisions, equipment breakdown and a shortage of facilities or equipment. Hence, natural disasters are not included in the discussion. The types of ports and supply chains affected by PSCD threats include those that transport containerized and non-containerized cargo. Previous studies have been conducted to develop a management model that addresses PSCD threats (Loh and Thai, 2014a, 2014b). This paper seeks to add to those works by providing a comparison of different scenarios of a PSCD threat's impact on supply chains using empirical data from a chemical manufacturer based in Singapore. This paper contributes to the existing literature by demonstrating the benefits of mitigating and avoiding a supply chain disruption caused by a PSCD threat. A more in-depth analysis of cost consequences would be meaningful, however, the purpose of this paper is to provide numerical evidence that the presence of effective management measures would help generate savings. The remainder of this paper is organized as follows. First, previous studies will be reviewed to establish the close relationship between ports and their communities in relation to the research background. Next, the supply chain network of the organization used in the case study and the descriptions of the case study methodology will be explained. The results will then be elaborated and the paper concludes with implications and future research directions.

II. Research Background

The convenience of modal transfer that comes with containerization, increasing customer demands for door-to-door transportation accompanied by flourishing trade, and the benefits from global sourcing have collectively fuelled the integration of ports into supply chains. The evolution of port functions has magnified the significance of ports in supply chain disruptions. The increased complexity in port operations has resulted in a port regionalization phase in port development (Notteboom and Rodrigue, 2005). From low value-adding to port-centric and agile logistical duties performed by ports, there is a higher level of integration of ports into supply chains (Beresford et al. 2011; Pettit and Beresford, 2009; Paixao and Marlow, 2003). This highlights the importance of addressing port-related disruptions from a supply chain perspective. Infusing supply chain management practices into building capabilities in ports produces beneficial effects (Song and Panayides, 2008).

From the supply chain perspective, the benefits of internal and external integration or collaboration are capable of producing feasible strategies that improve performance outcomes of the chains (Stank et al., 2001). The close relationship between diversity of port integration and port performance has been proven empirically, demonstrating that transport integration has become a crucial constituent of port performance (Ducruet and Van Der Horst, 2009). The trend towards increased integration arises from the realization of the need to have holistic container terminal operations due to outsourcing and globalized trade (Tan, 2006). In most cases, ports integrate into supply chains for the sake of gaining a competitive advantage and reaping diversification benefits (Beresford et al., 2011). The port selection process for shippers also sees degree of integration with supply chains as one of the determinants (Magala and Sammons, 2008).

More strategic alliances between liners and stevedores are anticipated (Midoro et al, 2005). Terminal operators are also expected to take on an active role in order to support the emergence of inland terminals in supply chains as the concept of inland terminals offers a possible solution to congested ports and un-optimized usage of storage time at deep sea terminals (Rodrigue and Notteboom, 2009). Suggestions for port operators also include introducing agility in horizontal and vertical integrations in logistics chains, as a manner to administer a dynamic port network (Paixao and Marlow, 2003). Furthermore, the degree of integration with other transportation providers involves both operational and commercial aspects before efficient delivery of value can be brought about (Ross, 2006).

Port-related supply chain disruptions may affect on the total supply chain costs due to the increased integration of ports into supply chains. The implications of ports' integration into supply chains give rise to the discussion on port charges and supply chain costs Notteboom and Winkelmans 2001; Lirn et. al. 2004; Tongzon and Heng 2005; Chang et. al. 2008; Tongzon 2009). The severity of the consequences can also be reflected through the length of time required before equilibrium is restored. Following this principle, Gaonkar and Viswanadham (2004) quantified the different types of supply chain disruptions to determine the cost of each impact. Applying these disruptions to the various nodes of supply, transportation, demand, facilities and communications would render delays and failure of deliverability in them. Similarly, a subsequent study on maritime transportation system by Berle et al. (2011) examines disruptions in the form of loss of supplies, interruption of own internal operations, sudden drop in customer demands, communication failure with external parties, inability to deliver product, running out of cash and unavailability of own people. More specifically, Gurning (2009) and Gurning et. al (2011) used a Markovian-based methodology to measure and predict supply chain costs and time functions in relation to potential disruptive events in wheat supply chains. Chopra and Sodhi (2004) explained the different approaches that target supply chain risks and disruptions in terms of costs. Similarly, Kleindorfer and Saad (2005) explored supply chain costs that are outcomes of port operations disruptions. Other researchers such as Handfield et. al (2007), Pinto and Talley (2006), Gaonkar & Viswanadham (2007); Qiang et al. (2013); Snediker et al. (2008) have also examined effects consequences of risks and uncertainties.

Considering the close relationship between a port and its peripheral community, the role of ports in port-related supply chain disruptions needs to be examined for appropriate corrective and mitigative actions to be in place. The port users and customers constitute global supply chains, reiterating the possibility of a series of magnified disruptive effects triggered by PSCD threats. The absence of prior related studies to target these disruptions gives rise to the identification of PSCD threats (Loh and Thai, 2014a) and the development of a management model that address such disruptions (Loh and Thai, 2014b). This management model seeks to provide a comprehensive framework that offers a guide highlighting areas which port management should focus on to effectively manage disruptions that originate from the port operations. As an extension to these studies, this paper adds on to previous work by providing numerical evidence of the impact of PSCD threats on supply chains using realistic data from a manufacturer based in Singapore. This study compares the expected outcomes when the management model is effectively implemented and the different severities of disruptions due to absence of disruption management plans. In this manner, the significance of mitigating and avoiding a PSCD as well as the contribution of the management model proposed in the previous studies can be measured (Loh and Thai, 2014a, 2014b).

III. Numerical Example

1. Introduction

This section introduces the supply chain of Singapore Plastic Manufacturer (SPM), a major chemical manufacturer based in Singapore. The names of the company and their products have been modified to protect their identity. A comparison of costs using Excel was made with the usual non-disruption situation and when disruption strikes without the implementation of the port management model proposed in the previous studies (Loh and Thai, 2014a, 2014b). Interviews were conducted with an executive from the logistics department of SPM. This executive has 10 years of working experience with the company and is familiar with the financial flows and physical distribution of the cargo. The data used in the simulation are actual figures provided by the company for the year 2012. All information and data obtained and used in this simulation exercise were derived primarily from the interviews and also from the company website.

2. Background of SPM

SPM is a major manufacturer in the petrochemical industry since 1980s. It grew steadily over the next 20 years and has since become one of the region's largest producers, diversifying from its niche in manufacturing into the provision of a wide range of supply chain solutions. In 2013, SPM produced 50 different products, of which 80% were sold through cargo trading houses to almost 300 customers worldwide. The profit was approximately USD$9 million and asset value was about USD$35 million for the year 2012.

The core business of SPM supplies six main patented chemical products: PE, EA, PP1, PP2, PP3 and PP4. The full names of these products are omitted to ensure confidentiality guaranteed to the organization. These products are used in a wide array of applications such as thermal insulation material, household products, feeding bottles, food packaging, lamination films, bathroom equipment and automobile parts.

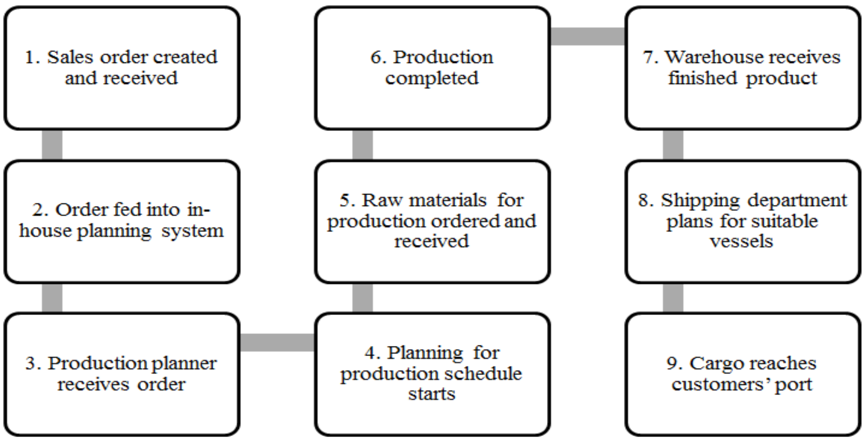
The production process is on-going, with the production plant operating 24-hours a day. The cost of producing every metric ton (MT)USD$1650 and the production cost is the same for each product. Production rates are largely determined by oil prices, forecasts in selling prices and seasonal peaks. Thus, fluctuations in production are not unusual especially when plastics are the considered commodity. There would be higher demand for the products during festive seasons. Hence, production is at peak from October to January with a rate of 2800MT/day and is at its lowest from June to September with a rate of 2200MT/day. From February to May, production is at its average rate of 2500MT/day. To cushion itself from the ill effects of uncertainties, the production process is such that 60% is pulled by customers' orders and 40% of production is stored as inventory. The finished products are stored in the warehouse for one to two months, depending on the period of demand.

SPM's customers are manufacturers or traders predominantly located in China, Japan and other South-East Asian countries. Each customer usually orders enough to fill between 1 TEU to 20 TEUs and the usual mode of transportation to customers is by sea.

3. The SPM Supply Chain

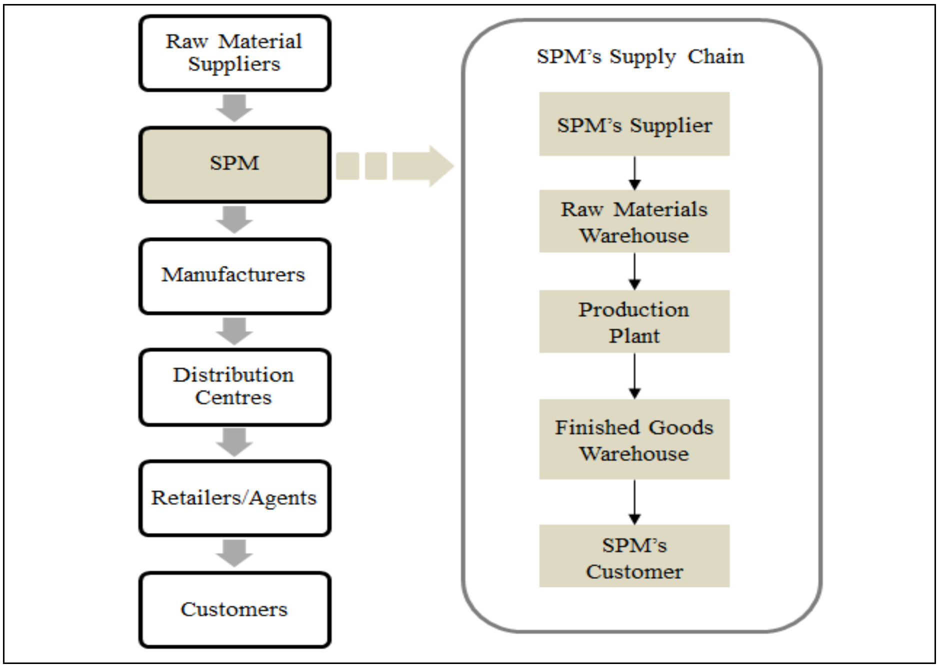
The general process from point of sales inquiry to product delivery is shown in Figure 1. The process starts with a sales order. As soon as it is officially created, the company's in-house planning systems transmit the information to its production planner who will then start planning for production schedule for that batch of order. Before production begins for the order, raw materials will be ordered from Japanese suppliers. The supplies of raw materials will be shipped from Japan. After which the production process will be activated and the finished products will be stored in the warehouse. Finished products are stored in the warehouse for one month during off-peak seasons (June – September), two months during peak period (October – January) and one and a half months during the remaining months (February – May). The re-stuffing process at the warehouse is automated and the stuffing rate is 2.5TEU/hr. The un-stuffing process is manual and the rate is slower, at 1TEU/hr. As SPM sells products on CIF terms, the shipping department then arranges for delivery of product by sea freight to the customers' port.

<Figure 1> Order fulfilment process at SPM



The network of suppliers, production plants, warehousing sites and customers for PE, EA, PP1, PP2, PP3 and PP4 comprises the SPM supply chain and is depicted in Figure 2. As can be seen from this figure, SPM is positioned before the manufacturers of consumer products. There are several other entities in its downstream supply chain and uncertainties occurring earlier at the chain tend to have its ill effects being felt down the chain. In this case, manufacturers, distribution centres, retailers and end consumers would feel the impact.

<Figure 2> SPM supply chain



Raw materials are transported from Japanese suppliers and stored in the SPM warehouse in Singapore until it is needed for production. At the production plant, raw materials are converted into finished products which are then kept at an in-transit storage area near the production site. They are then transported to the finished products warehouse until it is ready to be packed by the in-house contractors and transported to the export port for shipment to the customers' port. However, in the case of an occurrence of PSCD threat, alternatives might be undertaken. This will likely result in modifications to material flow in terms of time spent at each stage and routes taken to reach the next stage. Therefore, the costs involved at each stage will be different in such situations, depending on the actions taken. A simulation exercise in the following section illustrates the impact of the disruption from the SPM's perspective.

IV. Case Study Methodology

During the occurrence of PSCD threat, there are four main categories of outcomes. Scenarios 1 and 2 depict two expected outcomes when the management model is implemented - disruptions are avoided or mitigated. This section demonstrates the difference between the four scenarios in terms of costs involved. The costs reflect time spent as well since time is reflected by storage cost, manpower charges, warehouse cost, inventory holding cost and transportation cost. However, the outcomes are hypothetical and thus do not indicate the presence of a supply chain disruption management plan at SPM. This exercise seeks to illustrate the impact of different outcomes to ascertain the importance of port disruption potential by using realistic data. More specifically, the four scenarios are as follows:

- Scenario 1: Containers were stored at the finished goods warehouse for 15 days, then trucked to a terminal of the Port of Singapore Authority (PSA) and used the first shipping line (SL1) for sea transportation to Guangzhou port. No disruptions were experienced or negligible disruptive effects were felt.
- Scenario 2: Containers were stored at the finished goods warehouse for 15 days and stayed for an additional six hours before being trucked to PSA and used SL1 for sea transportation to Guangzhou port. Twelve hours delays were experienced.
- Scenario 3: Containers were stored at the finished goods warehouse for 15 days then trucked to PSA. However, PSA experienced a major accident in its waterway and an investigation is undergoing, PSA is temporary closed. SPM decides to transport the containers through the nearby Jurong Port instead. As SL1 does not call at Jurong Port, containers are then re-trucked from PSA to SPM's warehouse for re-stuffing and then transported by SL2 to Guangzhou port. A second shipping lines (SL2) offers transportation to Guangzhou at a higher charge; a difference of US$210 per TEU.
- Scenario 4: Containers were stored at the finished goods warehouse for 15 days then trucked to PSA. PSA is closed due to port strike, and SPM decides to wait, hence containers are re-trucked from PSA to SPM's warehouse. However, the crisis escalated and the issues remain unresolved after 10 days. SPM decides to transport the containers

through Jurong Port instead. As SL1 does not call at Jurong Port, containers are then re-trucked from PSA to SPM's warehouse for un-stuffing and re-stuffing, then transported by SL2 to Guangzhou port. SL2 offers transportation to Guangzhou at a higher charge; a difference of US$210 per TEU.

The expression of total costs comprises three components – production cost, warehousing cost and transportation cost incurred. Table 1 shows a breakdown of each type of costs and the costs components involved. Figure 3 shows the cargo flow as each cost component is incurred. Costs for the four scenarios were calculated and a comparison was made to examine the amount of savings generated should the proposed port management model[1),2)] be implemented. The assumptions of the supply chain system are as follows:

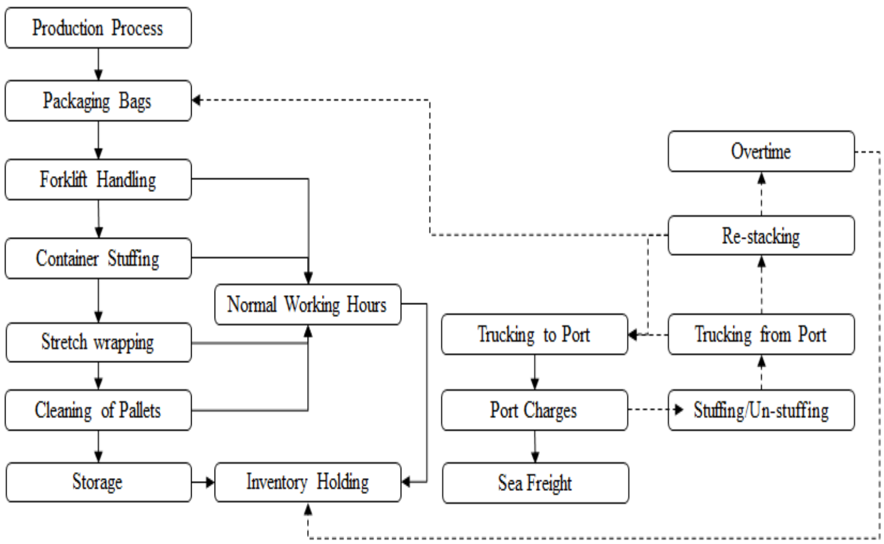
1. Disruptions at the port are the only disruptive event encountered from the time finished product enters warehouse till it reaches customer's choice of port.
2. Information is shared truthfully among all involved parties.
3. Lead time and customers' orders are independent.
4. Finished products are left in warehouse for an additional 10 days, after which alternative plans will be activated by SPM.
5. Alternative plans are executed without disruptions.
6. All involved ports and transportation service entities are willing to accept cargo.
7. Cargo handling rates are the same at all involved ports.
8. No berthing and cargo handling constraints at all involved ports.
9. Tariffs and port charges of all involved ports are the same.
10. Sea freight and inland transportation costs do not fluctuate due to the crisis/disruption.
11. Transportation on alternative routes does not encounter further disruptions.
12. Customers are infinitely patient and will not switch to other suppliers.
13. All months have 30 days.

1) Loh and Thai (2014a)
2) Loh and Thai (2014b)

<Table 1> Costs involved in simulation

1.Production Cost	**2. Warehousing Cost**	**3.Transportation Cost**
Production	Storage - Packaging bags - Forklift handling	Trucking to port
	Container stuffing	Port charges
	Manpower - Normal working hours - Over time charges	Sea freight
	Miscellaneous services - Restacking of palletized cargoes (when applicable) - Supply of labors & material for stretch wrapped - Cleaning of empty pallet	Stuffing/un-stuffing at port (when applicable)
	Inventory holding	

<Figure 3> Processes that incur costs



In addition, the following symbols and notations of parameters were used in the simulation exercise:

1. *PC* = Production cost
2. *WC* = Warehouse Cost

3. W_s = Warehouse storage cost
4. $W_{s.PB}$ = Cost of packaging bags
5. $W_{s.FH}$ = Forklift handling cost
6. W_{CS} = Container stuffing in warehouse
7. W_{MP} = Manpower charges
8. W_N = Normal working hours
9. W_{OC} = Overtime charges
10. W_{MS} = Miscellaneous warehouse charges
11. $W_{MS.R}$ = Restacking of palletized cargo
12. $W_{MS.SW}$ = Supply of labor and materials for stretch wrapped
13. $W_{MS.C}$ = Cleaning of empty pallet
14. W_{IH} = Inventory holding cost
15. T = Transportation costs
16. T_T = Trucking
17. T_{pc} = Port charges
18. T_{SF} = Sea freight
19. $T_{S/US}$ = Stuffing/Un-stuffing
20. X = Customer order (TEU)
21. X_{MT} = Customer order (MT)
22. N = Number of pallets in each 20' container
23. w = Number of days product spent at warehouse
24. t = Number of days from production completion to delivery to destination

The exact rate for each cost component is not shown as the company has requested not to release the figures. According to the data provided by SPM, the parameters follow the formulae below:

$N = 16,$
$PC = 1650X_{MT},$
$X_{MT} = 16X,$

$$\text{Total Costs} = \sum_{i=1}^{X} (\text{PC}_i + \text{WC}_i + \text{TC}_i)$$

$$= \sum_{i=1}^{X} \left(\begin{array}{l} [1650(\text{X}_{\text{MT}})_i + (\text{W}_{\text{s.PB}})_i + (\text{W}_{\text{s.FH}})_i + (\text{W}_{\text{CS}})_i + (\text{W}_{\text{N}})_i + (\text{W}_{\text{OC}})_i + \\ (\text{W}_{\text{MS.R}})_i + (\text{W}_{\text{MS.SW}})_i + (\text{W}_{\text{MS.C}})_i + (\text{W}_{\text{IH}})_i + (\text{T}_{\text{T}})_i + (\text{T}_{\text{pc}})_i + \\ (\text{T}_{\text{SF}})_i + (\text{T}_{\text{S/US}})_i\,] \end{array} \right)$$

As there are three main cost components, the spreadsheet was given three sections: production cost, warehousing cost and transportation cost. The units for each of these components and their sub-components are per order and the different costs for orders that fill from 1 TEU to 20 TEUs are generated, by adding 1 TEU to the previous consequence until the 20^{th} TEU. As the same product is compared between the four scenarios, there is no differences between production costs when different scenarios are compared. The sub-components that fall under warehousing cost and transportation costs are those displayed in Table 1. At the end of simulation, the total costs incurred for orders that fill from 1 TEU to 20 TEUs are computed as well.

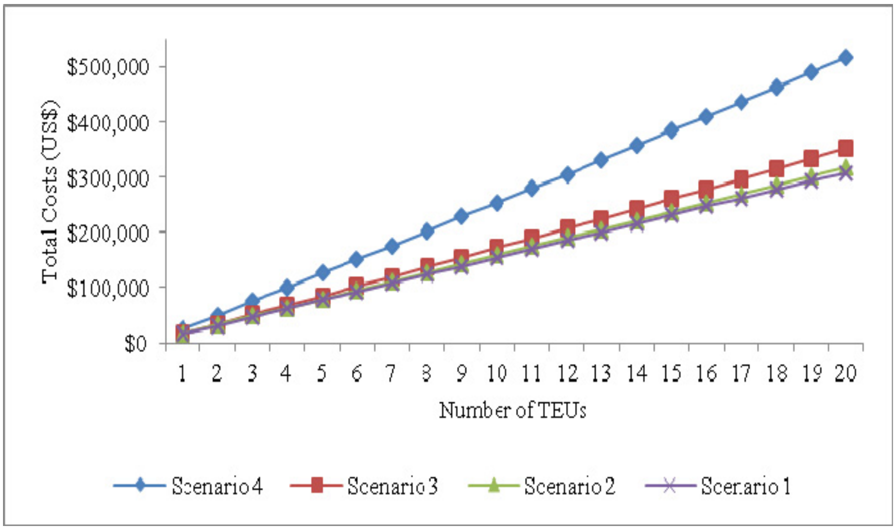
V. Results

The graphical comparison of total costs, warehousing costs and transportation costs incurred for the four scenarios is depicted respectively in Figures 4, 5 and 6, while Table 2 shows the costs in exact figures. As can be observed from Figure 4, the gaps between total costs of each scenario become larger when the order increases in size and Scenario 4 experiences the highest total costs. The large difference between scenarios 3 and 4 is mainly due to the additional 10-day inventory holding costs experienced in Scenario 4. The graphs of Scenario 1 and Scenario 2 lie very close to each other because of the similarities in circumstances shared by both. The only difference between the two scenarios is that there is a 12-hour delay in scenario 2 and this gives rise to higher inventory holding costs and higher warehouse storage costs as shown by the figures in Table 2. The graphs for total costs are broken down into graphs for warehousing costs and transportation costs for a closer look to account for the observations in Figure 4. The graphs for warehousing costs are shown in Figure 5. The graph of Scenario 4 shows that the highest warehousing costs are incurred mainly due to the additional 10-day storage at warehouse while the lowest occurs in Scenario 1. The differences among Scenarios 1, 2 and 3 are due to whether un-stuffing and re-stuffing processes are required and these in turn involve manpower which constitutes additional charges as the order size increases. While it is not apparent in Figure 5, the figures in Table 2 show that warehousing costs of Scenario 2 are higher than that of Scenario

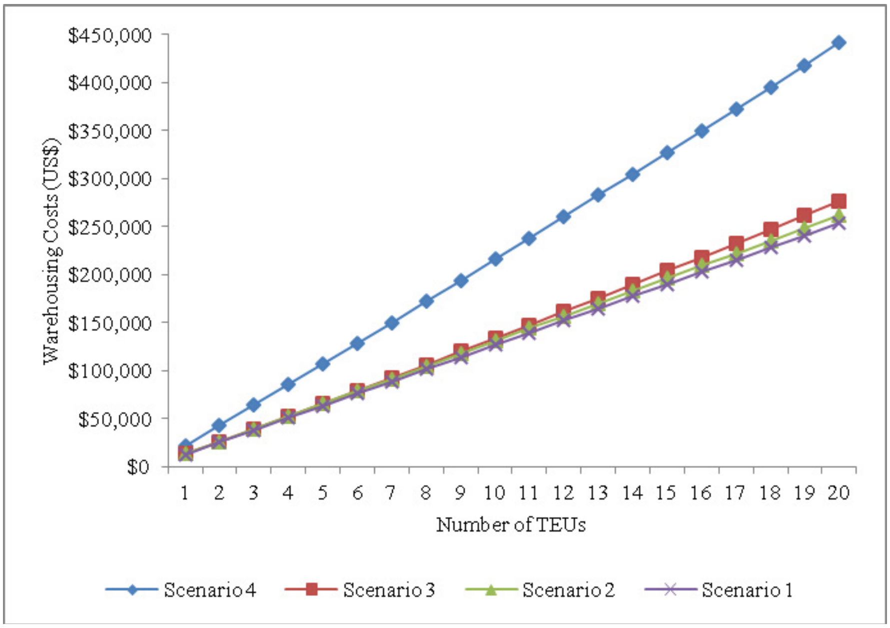
3 for the first two TEUs. For orders with three TEUs or more, the warehousing costs of Scenario 2 become lower than that of Scenario 3. This trend is attributed by the un-stuffing and re-stuffing rates experienced in Scenario 3 and the duration of delays in Scenario 2. Therefore, the warehousing costs for different duration of delays were investigated in Table 3, with those that are higher than that of Scenario 3 highlighted. This sets the boundary at which warehousing costs of Scenario 2 exceeds that of Scenario 3.

On the other hand, the graphs for transportation costs as displayed in Figure 6 show that there are only two lines which account for all four scenarios. Scenarios 1 and 2 share the same line as the transportation means and plans for these two scenarios are the same. Due to the deviation in transportation routes and shipping lines from the initial plan, the graphs of Scenarios 3 and 4 lie on each other. The higher transportation costs of Scenarios 3 and 4 as compared to Scenarios 1 and 2 can be explained by the extra un-stuffing and re-stuffing of products at the port as well as two additional trucking legs (from PSA to warehouse and from warehouse to Jurong Port).

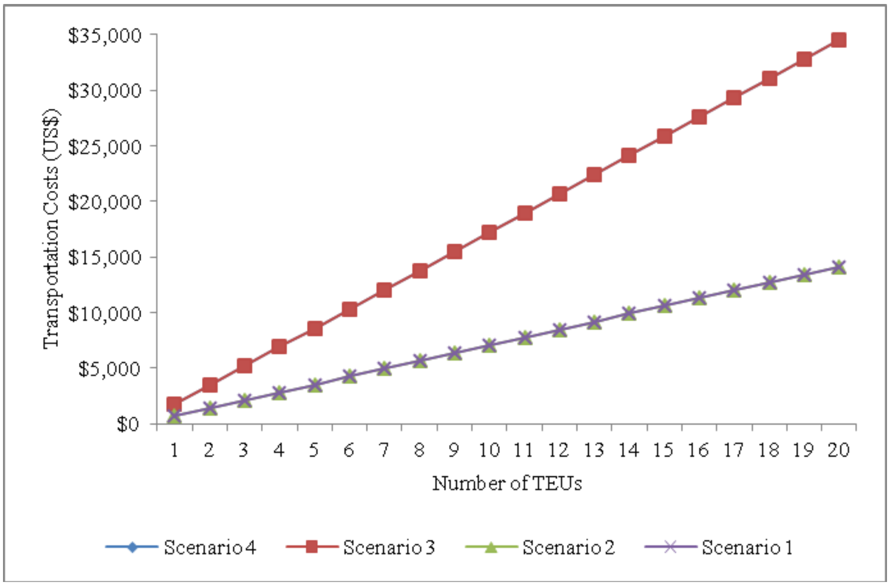
<Figure 4> Total cost of each scenario



<Figure 5> Warehousing costs of each scenario



<Figure 6> Transportation costs of each scenario



<Table 2> Overview of different costs (US$) incurred

TEUs	Warehousing Costs				Transportation Costs				Total Costs			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	$12,661.83	$13,074.09	$12,908.06	$21,153.14	$706.88	$706.88	$1,723.75	$1,723.75	$15,431.21	$15,843.46	$16,694.31	$24,939.39
2	$25,323.67	$26,148.18	$25,912.30	$42,402.48	$1,413.75	$1,413.75	$3,447.50	$3,447.50	$30,862.42	$31,686.93	$33,484.80	$49,974.98
3	$37,985.50	$39,222.26	$39,012.74	$63,748.01	$2,120.63	$2,120.63	$5,171.25	$5,171.25	$46,293.63	$47,530.39	$50,371.49	$75,106.76
4	$50,647.34	$52,296.35	$52,209.38	$85,189.73	$2,827.50	$2,827.50	$6,895.00	$6,895.00	$61,724.84	$63,373.85	$67,354.38	$100,334.73
5	$63,309.17	$65,370.44	$65,502.20	$106,727.65	$3,534.38	$3,534.38	$8,618.75	$8,618.75	$77,156.04	$79,217.32	$84,433.45	$125,658.90
6	$75,971.00	$78,444.53	$78,891.22	$128,361.76	$4,241.25	$4,241.25	$10,342.50	$10,342.50	$92,587.25	$95,060.78	$101,608.72	$151,079.26
7	$88,632.84	$91,518.62	$92,376.43	$150,092.06	$4,948.13	$4,948.13	$12,066.25	$12,066.25	$108,018.46	$110,904.24	$118,880.18	$176,595.81
8	$101,294.67	$104,592.71	$105,957.84	$171,918.55	$5,655.00	$5,655.00	$13,790.00	$13,790.00	$123,449.67	$126,747.71	$136,247.84	$202,208.55
9	$113,956.50	$117,666.79	$119,635.43	$193,841.24	$6,361.88	$6,361.88	$15,513.75	$15,513.75	$138,880.88	$142,591.17	$153,711.68	$227,917.49
10	$126,618.34	$130,740.88	$133,409.22	$215,860.12	$7,068.75	$7,068.75	$17,237.50	$17,237.50	$154,312.09	$158,434.63	$171,271.72	$253,722.62
11	$139,280.17	$143,814.97	$147,279.21	$237,975.19	$7,775.63	$7,775.63	$18,961.25	$18,961.25	$169,743.30	$174,278.10	$188,927.96	$279,623.94
12	$151,942.01	$156,889.06	$161,245.38	$260,186.45	$8,482.50	$8,482.50	$20,685.00	$20,685.00	$185,174.51	$190,121.56	$206,680.38	$305,621.45
13	$164,603.84	$169,963.15	$175,307.75	$282,493.91	$9,189.38	$9,189.38	$22,408.75	$22,408.75	$200,605.71	$205,965.02	$224,529.00	$331,715.16
14	$177,265.67	$183,037.24	$189,466.31	$304,897.56	$9,896.25	$9,896.25	$24,132.50	$24,132.50	$216,036.92	$221,808.49	$242,473.81	$357,905.06
15	$189,927.51	$196,111.32	$203,721.06	$327,397.40	$10,603.13	$10,603.13	$25,856.25	$25,856.25	$231,468.13	$237,651.95	$260,514.81	$384,191.15
16	$202,589.34	$209,185.41	$218,072.01	$349,993.44	$11,310.00	$11,310.00	$27,580.00	$27,580.00	$246,899.34	$253,495.41	$278,652.01	$410,573.44
17	$215,251.18	$222,259.50	$232,519.15	$372,685.66	$12,016.88	$12,016.88	$29,303.75	$29,303.75	$262,330.55	$269,338.88	$296,885.40	$437,051.91
18	$227,913.01	$235,333.59	$247,062.48	$395,474.08	$12,723.75	$12,723.75	$31,027.50	$31,027.50	$277,761.76	$285,182.34	$315,214.98	$463,626.58
19	$240,574.84	$248,407.68	$261,702.00	$418,358.70	$13,430.63	$13,430.63	$32,751.25	$32,751.25	$293,192.97	$301,025.80	$333,640.75	$490,297.45
20	$253,236.68	$261,481.77	$276,437.72	$441,339.50	$14,137.50	$14,137.50	$34,475.00	$34,475.00	$308,624.18	$316,869.27	$352,162.72	$517,064.50

<Table 3> Warehousing costs (US$) for Scenario 2

TEUs	Delays (Hours)											
	2	4	6	8	10	12	14	16	18	20	22	24
1	$12,730.54	$12,799.25	$12,867.96	$12,936.67	$13,005.38	$13,074.09	$13,142.80	$13,211.51	$13,280.22	$13,348.92	$13,417.63	$13,486.34
2	$25,461.09	$25,598.50	$25,735.92	$25,873.34	$26,010.76	$26,148.18	$26,285.59	$26,423.01	$26,560.43	$26,697.85	$26,835.27	$26,972.69
3	$38,191.63	$38,397.76	$38,603.88	$38,810.01	$39,016.14	$39,222.26	$39,428.39	$39,634.52	$39,840.65	$40,046.77	$40,252.90	$40,459.03
4	$50,922.17	$51,197.01	$51,471.84	$51,746.68	$52,021.52	$52,296.35	$52,571.19	$52,846.03	$53,120.86	$53,395.70	$53,670.53	$53,945.37
5	$63,652.71	$63,996.26	$64,339.81	$64,683.35	$65,026.90	$65,370.44	$65,713.99	$66,057.53	$66,401.08	$66,744.62	$67,088.17	$67,431.71
6	$76,383.26	$76,795.51	$77,207.77	$77,620.02	$78,032.28	$78,444.53	$78,856.78	$79,269.04	$79,681.29	$80,093.55	$80,505.80	$80,918.06
7	$89,113.80	$89,594.76	$90,075.73	$90,556.69	$91,037.65	$91,518.62	$91,999.58	$92,480.55	$92,961.51	$93,442.47	$93,923.44	$94,404.40
8	$101,844.34	$102,394.02	$102,943.69	$103,493.36	$104,043.03	$104,592.71	$105,142.38	$105,692.05	$106,241.72	$106,791.40	$107,341.07	$107,890.74
9	$114,574.89	$115,193.27	$115,811.65	$116,430.03	$117,048.41	$117,666.79	$118,285.18	$118,903.56	$119,521.94	$120,140.32	$120,758.70	$121,377.08
10	$127,305.43	$127,992.52	$128,679.61	$129,366.70	$130,053.79	$130,740.88	$131,427.97	$132,115.06	$132,802.16	$133,489.25	$134,176.34	$134,863.43
11	$140,035.97	$140,791.77	$141,547.57	$142,303.37	$143,059.17	$143,814.97	$144,570.77	$145,326.57	$146,082.37	$146,838.17	$147,593.97	$148,349.77
12	$152,766.51	$153,591.02	$154,415.53	$155,240.04	$156,064.55	$156,889.06	$157,713.57	$158,538.08	$159,362.59	$160,187.10	$161,011.60	$161,836.11
13	$165,497.06	$166,390.28	$167,283.49	$168,176.71	$169,069.93	$169,963.15	$170,856.37	$171,749.58	$172,642.80	$173,536.02	$174,429.24	$175,322.46
14	$178,227.60	$179,189.53	$180,151.45	$181,113.38	$182,075.31	$183,037.24	$183,999.16	$184,961.09	$185,923.02	$186,884.94	$187,846.87	$188,808.80
15	$190,958.14	$191,988.78	$193,019.42	$194,050.05	$195,080.69	$196,111.32	$197,141.96	$198,172.60	$199,203.23	$200,233.87	$201,264.51	$202,295.14
16	$203,688.69	$204,788.03	$205,887.38	$206,986.72	$208,086.07	$209,185.41	$210,284.76	$211,384.10	$212,483.45	$213,582.79	$214,682.14	$215,781.48
17	$216,419.23	$217,587.28	$218,755.34	$219,923.39	$221,091.45	$222,259.50	$223,427.56	$224,595.61	$225,763.66	$226,931.72	$228,099.77	$229,267.83
18	$229,149.77	$230,386.54	$231,623.30	$232,860.06	$234,096.83	$235,333.59	$236,570.35	$237,807.12	$239,043.88	$240,280.64	$241,517.41	$242,754.17
19	$241,880.32	$243,185.79	$244,491.26	$245,796.73	$247,102.21	$248,407.68	$249,713.15	$251,018.62	$252,324.09	$253,629.57	$254,935.04	$256,240.51
20	$254,610.86	$255,985.04	$257,359.22	$258,733.40	$260,107.58	$261,481.77	$262,855.95	$264,230.13	$265,604.31	$266,978.49	$268,352.67	$269,726.86

VI. Implications

The results of this simulation reiterate the significance of port resilience in supply chain continuity. The marginal cost differences as depicted by the graphical representations show that the increase in costs in an undesirable event is mainly attributed by higher warehousing storage costs, inventory storage costs, manpower costs as well as transportation costs. The duration of delays encountered will likely affect the management decision to stay put or deploy alternatives as the costs incurred involves the amount of additional work and rework to be carried out and the charges of alternative plans. In summary, assuming no other types of disruptions encountered in the supply chain, a port user will experience additional costs when a PSCD threat occurs resulting in undesirable consequences ranging from a slight delay to loss of port service.

The implications of this study are of two folds. Academically, the results of this study strengthens the long-argued proposition that ports play an important role and are inseparable players of global supply chains. In this connection, this study also contributes to the theoretical foundation that port-related disruptive events would potentially lead to disruptions of the whole supply chain. On the other hand, results from the numerical examples in this study may provide supply chain managers with insights on the importance of risk management involving nodes such as ports. Meanwhile, port managers would be able to appreciate the quantifiable benefits of port-related supply chain disruption management and therefore help to design and implement an effective work coordination mechanism with their supply chain partners.

VII. Conclusion

Recognizing the significance of ports in supply chain disruptions, this paper seeks to provide a comparison, in terms of cost, between four possible consequences of a PSCD threat to highlight the importance of port-related supply chain disruption management. Simulation was carried out using actual data from a port user based in Singapore.

Evidence from this paper encourages better dissemination of information from ports to their stakeholders as well as closer collaborative working relationships between ports and their users. Such actions would allow port users to adopt cost saving practices in time. In addition, contingency measures become more efficacious with better understanding of the circumstances experienced by ports.

Although this simulation was carried out only on a particular port user with the imposed production limitation of 20 TEUs, the capacity of a port is much higher than that and, therefore, the impact of PSCD threats on all industries involved and users alike is expected to be comparatively higher. A limitation of this paper is that effects on only one type of cargo were studied. Hence, future research related to the impact of PSCD threats on perishable cargo and an examination of existing collaborative contingency measures between ports and their users or other possibilities of simulated scenarios will likely generate different magnitudes of results and implications for port managers. A more scientific approach examining the factors or variables that affect the extent of cost consequences can be conducted. The extent of cost savings would be affected by the assumptions in this study; hence, it would be helpful if the assumptions can be identified as variables in cost consequences from the supply chain entity's perspective in future research. Another limitation of this simulation exercise is that the outcome of the model in numerical simulation exercise is predetermined and hypothetical and hence no sensitivity tests were carried out. Future research can be conducted to carry out simulation to validate the model by using realistic inputs and output to determine whether the desired outcome is achieved, such that the cost impact of port users and port operators can be more realistically portrayed. *

* Date of Contribution ; August 18, 2014
Date of Acceptance ; August 1, 2015

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