

A Case Study of Carbon Emissions from Logistic Activities During Supply Chain Disruptions

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ABSTRACT

Supply chain disruptions have significant negative effects on logistics operations, in which recovery actions could in turn affect the environment if certain green precautions are not undertaken. The objective of this research is to assess the effect of disruption on carbon emissions from logistics activities in the supply chain. A case study was carried out in this study to identify the factors of supply chain disruptions that affect logistics operations, and investigate the impact of the disruptions on the environment. Data collection using the Fuel Monitor application and real disruption data from a selected company were used to quantify the carbon emissions during disruption and non-disruption scenarios. Analysis of the study found that carbon emissions during disruption events increased to approximately 18 – 20 % as compared to normal operations. This is due to the increase in travelling distance in order to fulfill customer backorders during the disruption occurrence. The carbon emission amount was slightly higher when using fuel consumption as reference data in comparison to distance travelled, as fuel consumption takes into account the driving behaviour and efficiency of the truck engines. This study is useful for analyzing the impact of supply chain disruptions on the environment, particularly from the post-disruption recovery decisions.

Keywords: Disruption; supply chain; carbon emission; logistics

INTRODUCTION

The global warming phenomenon that exists today is largely due to the impact of greenhouse gases. Generally, greenhouse gases consisting of various carbon gases, such as carbon dioxide and carbon monoxide, are capable of trapping heat in the atmospheric layer and causing the earth to heat up. Carbon emissions from transportation, in particular, are attributable to rapid industrial activity (Xie & Liu 2017).

The main source of greenhouse gas emissions is from transportation as it accounts for 23% of the world's energy in relation to greenhouse gases (Kahn et al. 2007). Freight transportation is one of the back-bones of supply chain system to deliver commodities or raw materials to process a product or for final product delivery, locally or globally.

The supply chain is a system that involves the production, delivery, storage, distribution and sale of products to meet the demand of a product. Among the importance of managing supply chains is to reduce inventory costs, provide a medium for information sharing, increase customer satisfaction and service, and improve integration processes (Li et al. 2006).

The effectiveness of a supply chain depends on an efficient operation by ensuring that a product is at the right time and place to meet the consumer demand. Supplier

failures for service or goods distribution can lead to supply chain disruptions (Clemons & Slotnick 2016; Paul et al. 2016; Mustafa et al. 2018). Moreover, the sustainability aspect of supply chains nowadays accounts for the environmental performance of a supply chain, which increased researcher's interest in the area of sustainable supply chain management (SSCM) (Hammami et al. 2015; Jamian et al. 2015; Sarkar et al. 2016; Hariga et al. 2017; Lee et al. 2018). In an ideal SSCM, the flow of goods and management from the supplier to the retailer proceeds smoothly, but in reality, the presence of disruptions may result in the opposite to occur. Therefore, nowadays, researchers have focused on studying the integration of sustainable supply chain and disruption management in the development of more resilient systems (Fahimnia & Jabbarzadeh, 2016; Darom et al. 2018; Daryanto et al. 2019).

Carbon footprint is the amount of carbon emissions released directly or indirectly caused by activity or accumulation over a product's life span (Lin et al. 2015). Measurement of the carbon footprint is an important task to be undertaken by an organization that want to proactively manage their environmental improvement effort (Lee, 2012). In addition, there must be a coordinated effort across the entire supply chain to reduce the overall carbon emission (Benjaafar et al. 2012).

The accurate measurement of carbon emissions is important in order to monitor and manage the company's

targets. Montoya-Torres et al. (2015) who did a research on “Conceptual framework for measuring and analyzing carbon foot-print in the supply chain” used real data from an agricultural company. Data was then divided into several restrictions. Emissions from delivery was calculated using the transportation factor of the goods based on the specified methodology (Green House Gas Protocol) which combines the total distance and weight. Meanwhile Lee (2011) performed a case study on the integration of carbon footprint into the supply chain management of an automotive company.

There exists a gap in the study, in which the emissions calculations are influenced by limited data and uncertainty surrounding variable values. Furthermore, the data was analyzed from the logistics activities in the supply chain during non-disruption scenarios. In addition, there is no specific study of disruption analysis in supply chains involving the relation of environmental impacts. Therefore, this study aims to involve environmental impacts in the supply chain analysis during disruption. The data collection methods needed to analyze the amount of carbon emissions will also be presented.

The objective of this study is to analyze the relationship of disruptions and its effect on carbon emissions from logistics activities in the supply chain. The contribution is to propose managerial insights in terms of green logistics practices to industrial practitioners, particularly in the face of disruption risks.

The remainder of this paper is organized as follows. Section 2 will propose the experimental procedures conducted in this study. In Section 3, the results of the study along with discussion will be presented, followed by the conclusion in Section 4.

METHODOLOGY

A case study was conducted at an automotive manufacturing company located in Negeri Sembilan. The case study aims at identifying scenarios and factors in the supply chain that cause disruption in logistical activities. After collecting disruption data, the changes in logistics activities due to disruption were captured and carbon emissions were calculated to quantify the effect of disruptions to the environment. A comparison analysis was done on carbon emissions during disruption and non-disruption scenarios.

Among the company data collected were production and Overall Equipment Effectiveness (OEE) data throughout January to March 2018. Truck schedule and criterion data were also recorded and fuel consumption data were taken using the “Fuel Monitor” application. Descriptive analysis was done using Microsoft Excel based on two different formulas, namely (i) activity-based approach and (ii) energy-based approach to show the accuracy in data obtained between the two methods.

RESULTS AND DISCUSSION

PERFORMANCE DELIVERY DATA

Table 1 shows the logistics performance data of the company when a disruption began in January until March 2018 for Product A to be sent to one of their customers. The table shows six disruption events throughout the three months of production. The highest (actual) total delivery of the scheduled shipment was dated March 7th with a total of 3600 parts. Meanwhile, the total difference between the total actual and the total planned shipment was dated February 2nd by 1680 parts. This was due to production failure that occurred during the disruption event. Therefore, the company had to post-pone delivery to the next session. Consequently, the truck capacity also changed according to the increased amount of product shipment at the respective scheduled time.

In general, disruptions that occur during the production process will have a direct effect on logistics. Due to the failure to deliver the goods according to plan, the company will rearrange the original plan so that it does not affect the customer’s demand. In the event of a delivery failure, the company may be penalized. This would cause the company to incur big losses.

CARBON EMISSION QUANTITATIVE ANALYSIS

In this section, the methods used to calculate the carbon emissions will be presented. Each method will calculate carbon emissions for two scenarios, (i) disruption and (ii) non-disruption, where a comparison will be made between the two scenarios and methods.

COMPUTATION USING ACTIVITY BASED APPROACH

The first method used to quantify carbon emission focusses on truck weight and truck journey distance without considering drivers styles of driving, transportation engine efficiency, etc. With the availability of travel distance data from logistics activities, the carbon emissions could be quantified.

According to the Guidelines for Measuring and Managing CO₂ Emission from Freight Transport Operations (ECTA, 2011), the formula for carbon emission for distance is shown in (1) as follows:

$$\text{Carbon emissions} = \frac{\text{Truck journey distance (km)} \times \text{Truck weight (ton)} \times \text{Release factor (grams CO}_2 \text{ per ton km)}}{1,000,000} \quad (1)$$

The assumption for truck release factor is 62 (grams CO₂ per ton km / 1,000,000).

Table 2 and 3 show the results of carbon emission for disruption and non-disruption scenarios, respectively. This data summarizes the original performance data in Table 1

TABLE 1. Performance data

No.	Date	Total Deliveries (Plan)	Total Deliveries (Actual)	Truck tonnage (Plan)	Truck tonnage (Actual)	No. of trip (Plan)	No. of Trip (Actual)
1.	29 Jan	960	1680	1	1	1	2
2.	2 Feb	960	2640	1	3	1	1
3.	7 Mar	3360	3600	3	3, 1	2	2, 1
4.	9 Mar	2520	3120	3	3	1	2
5.	10 Mar	840	1920	1	1	1	2
6	26 Mar	2880	3480	3	3	1	2

TABLE 2. Disruption data

Date	Truck Tonnage	No. of Trips	Distance (km)	Emission Factor (g CO ₂ /tonne km)	Carbon emission (kg CO ₂)
29 Jan	1	2	236	62	14.632
2 Feb	3	1	118	62	21.948
7 Mar	3	2	236	62	43.896
	1	1	118	62	7.316
9 Mar	3	2	236	62	43.896
10 Mar	1	2	236	62	14.632
26 Mar	3	2	236	62	43.896
Total		12	1416		190
Average		3	202		27

TABLE 3. Non-disruption data

Date	Truck Tonnage	No. of Trips	Distance (km)	Emission Factor (g CO ₂ /tonne km)	Carbon emission (kg CO ₂)
29 Jan	1	1	118	62	7.316
2 Feb	1	1	118	62	7.316
7 Mar	3	2	236	62	43.896
9 Mar	3	1	118	62	21.948
10 Mar	1	1	118	62	7.316
26 Mar	3	1	236	62	43.896
Total		7	944		132
Average		1.7	157		22

which is a summary of the data following the interruption that occurred during the 3 months. Additionally, the total emissions of carbon dioxide for each disruption instance is presented. The results show that the carbon emissions increased significantly following a big disruption magnitude. For example, on 29th January, the number of trips doubled as a result of production failure, which in turn doubled the carbon emissions to 14.632 kg CO₂, where the original schedule could have merely produced 7.316 kg CO₂. Furthermore, on the 2nd of February, the disruption event caused an emission of 21.948 kg CO₂ as opposed to 7.316 kg CO₂ due to increased shipment quantity that forced the company to use a larger tonnage truck, (Daihatsu), instead of the usual truck used (Isuzu). This caused the carbon emission to triple from the original plan.

For the disruption instance on 9th, 10th and 26th March, the total number of trips doubled, which in turn resulted in the amount of emissions to double as well compared to the non-disruption schedule.

Figure 1 shows the histogram comparison of the number of trips between disruption and non-disruption cases. The total number of trips during the interruption was higher by 5 times the number of trips than when the disturbance did not occur. The disruption in the supply chain caused the company to fail to reach the delivery target. Therefore, the company was forced to postpone delivery on the following day. This has led to increased product delivery capacity and the number of trips for the delivery process to meet customer demand.

Figure 2 shows a histogram of the ratio of the total distance between the disruption and non-disruption occurrence. The total distance during disruption was 472 km higher than the ideal condition. This is due to the increased number of travels due to failure during production.

Figure 3 shows the pie chart of the difference in carbon emissions between disruption and non-disruption periods. The percentage of carbon emissions during disruption was higher than when the non-disruption case by 18%. This is due

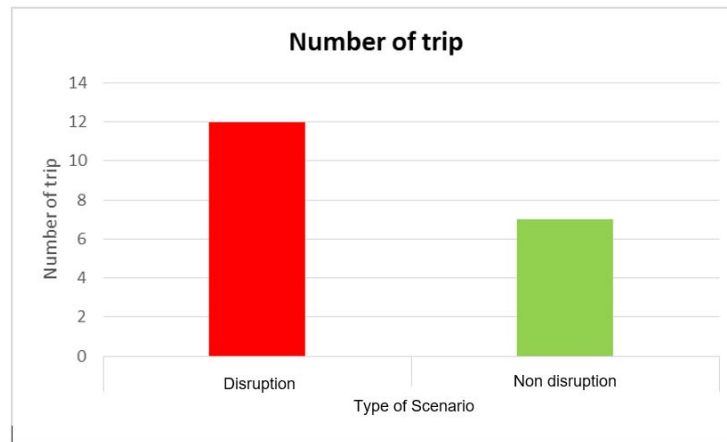


FIGURE 1. Number of trips during disruption and non-disruption

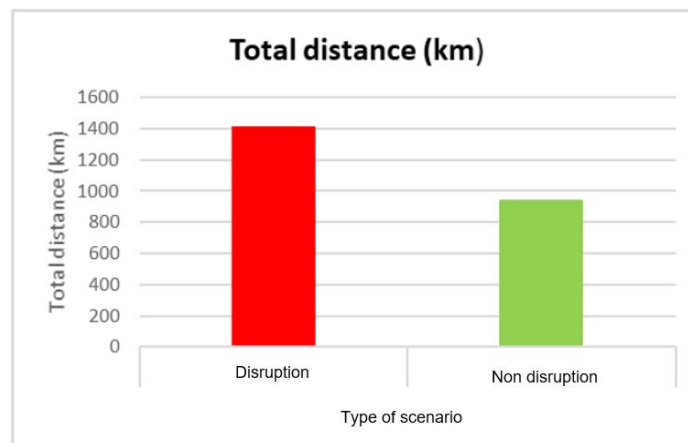


FIGURE 2. Total distance travelled during disruption and non-disruption

to the fact that carbon emissions are directly proportional to the weight of the truck, as well as the total distance traveled. In other words, the higher the travel distance and the weight of the truck, the higher the carbon emissions. Since the weight of the truck and the total distance of the ride during disruption were higher when there was no disruption, the carbon production during disruption resulted in higher values.

COMPUTATION USING ENERGY BASED APPROACH

The second method used to calculate carbon emission was using the average fuel consumption, where the driver styles of driving, transportation and engine efficiency were considered. The fuel consumption data was gathered using the Fuel Monitor application, as shown in Figure 4. The carbon emission amount was then calculated using the appropriate equation.

With reference to ECTA (2011) the formula used is shown as in (2) below:

$$\text{Carbon emissions} = \text{Average fuel consumption (litre)} \times \text{Diesel coefficient (kilograms CO}_2 \text{ per litre)} \quad (2)$$

$$\text{Diesel coefficient} = 2.9 \text{ kg CO}_2 / \text{litre}$$

Similar to the previous method, Table 4 and 5 show the results of carbon emission for disruption and non-disruption scenarios, respectively, with reference to fuel consumption data.

Figure 5 shows a comparison histogram of fuel consumption between the disruption and non-disruption scenarios. The amount of fuel consumption when the disruption occurred was higher by 50 liters than when disruption did not occur. This is because the amount of fuel consumption depends on the amount of distance used. The higher the distance, the higher the fuel consumption. The use of fuel during interference is higher than no interruptions due to the total distance at which disruption is higher than non-disruption. Figure 6 shows a pie chart of the percentage of carbon emission difference between disruption and non-disruption events. The percentage of carbon emissions during disruption was found to be much higher than non-disruption by 20%. This is due to the use of fuel during disruption that is higher than non-disruption periods.

RELATIONSHIP BETWEEN DISRUPTION AND ITS IMPACT ON THE ENVIRONMENT

The failure of raw material supply and machine failure are among the common disruptions that occur within the supply chain. These disruptions can affect the entire supply chain

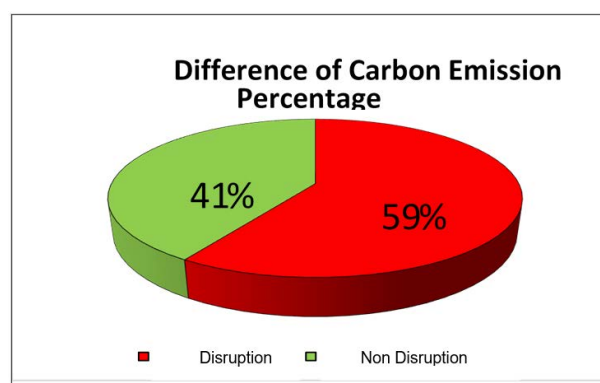


FIGURE 3. Difference of carbon emission percentage during disruption and non-disruption using distance data



FIGURE 4. The Fuel Monitor Application

TABLE 4. Disruption data

Date	Truck Tonnage	No. of Trips	Fuel Consumption (L)	Diesel Coefficient (kg CO ₂ /L)	Carbon emission (kg CO ₂)
29 Jan	1	2	25.22	2.9	73.138
2 Feb	3	1	12.61	2.9	36.569
7 Mar	3	2	25.22	2.9	73.138
	1	1	12.61	2.9	36.569
9 Mar	3	2	25.22	2.9	73.138
10 Mar	1	2	25.22	2.9	73.138
26 Mar	3	2	25.22	2.9	73.138
Total		12	1416		439
Average		3	202		63

TABLE 5. Non-disruption data

Date	Truck Tonnage	No. of Trips	Fuel Consumption (L)	Diesel Coefficient (kg CO ₂ /L)	Carbon emission (kg CO ₂)
29 Jan	1	1	12.61	2.9	36.569
2 Feb	1	1	12.61	2.9	36.569
7 Mar	3	2	25.22	2.9	73.138
9 Mar	3	1	12.61	2.9	36.569
10 Mar	1	1	12.61	2.9	36.569
26 Mar	3	1	12.61	2.9	36.569
Total		7	101		293
Average		1.7	16.8		49

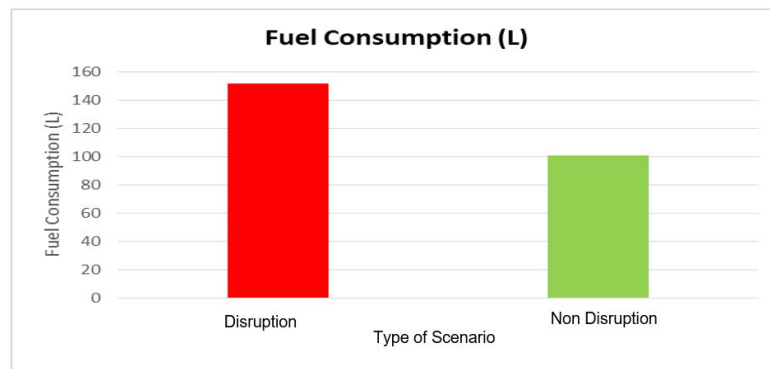


FIGURE 5. Average fuel consumption during disruption and non-disruption

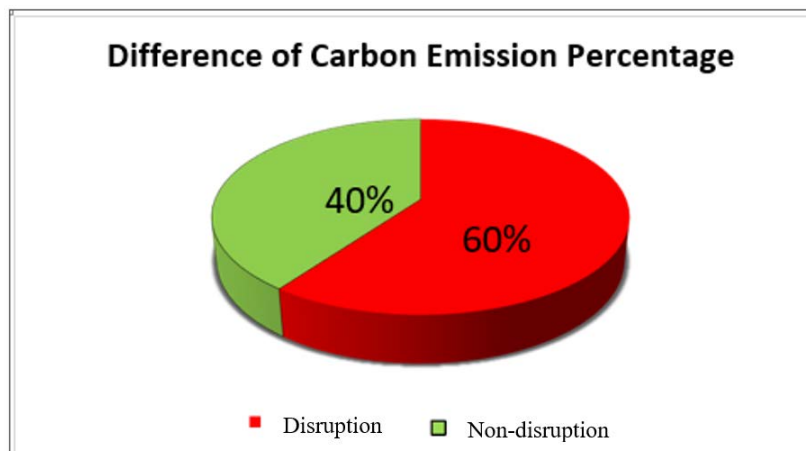


FIGURE 6. Difference of carbon emission percentage during disruption and non-disruption scenarios using fuel data

and thus impact goods delivery to customers. Based on the company data collected, frequent disruptions interfere with the production process of goods and logistics operations. When disruptions occur during or before the production process, the targeted delivery of goods to customers becomes interrupted. When shipment cannot be executed as planned, the company will adjust the delivery planning so as not to disrupt the customer's supply chain. Normally, the company will postpone delivery to the next day in the event of an unexpected disruption. Additionally, the truck capacity that is used will increase. Referring to the company's practice, the truck types used for shipment are 1 ton truck (Isuzu) and 3 ton (Daihatsu). The company will determine the weight of the appropriate trucks according to one shipment. If the weight of the goods exceeds the weight of the trucks, the company will usually increase the number of trips to the customer. The maximum number of delivery trips for the company is three deliveries per day. The increasing number of shipment trips will make the total distance during delivery to increase as well. According to ECTA (2011), for the activity-based approach, carbon emissions are directly proportional to the weight of the trucks and the distance of one shipment. The higher the weight of the truck, or the increasing number of shipping distance, the higher the carbon emissions in the air. Likewise, for energy-based approaches, carbon emissions are directly proportional to the average use of fuel. As the number of trips increase, the

average fuel used increases, thus, increasing the amount of carbon dioxide in the air. In the absence of any disruption in the supply chain, the amount of carbon production can be reduced.

COMPARISON OF METHODS BETWEEN ACTIVITY BASED APPROACH AND ENERGY BASED APPROACH

Based on Figures 3 and 6, the difference in percentage of carbon production for energy-based approach is higher than activity-based by 1% in disruption scenarios. According to Tanskanen & Hameri (1999), vehicle weight is one of the factors that causes average fuel consumption to increase. In addition, engine performance also affects fuel consumption. Low engine performance causes reduced fuel efficiency. Consequently, more fuel consumption is needed. In addition, irregular vehicle maintenance factors result in poor use of the vehicle engine, leading to reduced fuel efficiency. Finally, the driving force factor also affects the amount of fuel consumption. Most of the trucks used by the company are of manual transmission type. The inclination of drivers to drive vehicles using the wrong gear may also occur. Gear conversion depends on a certain speed. For example, on certain drives, drivers are required to use gear 3, but drivers drive the truck at 80km / hr. This leads to more energy needed to drive the truck and indirectly increases fuel consumption. Aggressive driving can also increase fuel

consumption. This is because the speed of the vehicle makes the engine revolution rise, bringing in the use of high fuel consumption

PROPOSED LOGISTICS PRACTICE

In this section, proposed logistics practices to reduce carbon emissions during disruptions will be proposed. The amount of carbon production depends on the weight of the truck used and also the total distance travelled. There are several suggestions to reduce the amount of carbon emissions in the air from disrupted logistics activities. The first suggestion is to use a smaller capacity truck for short distances if the truck capacity is sufficient for the delivery. By reducing truck capacity, reduction in the amount of carbon production can be achieved. While trucks with large weight cause high carbon footprint, it is recommended to use this type for long distances and large shipments.

Secondly is by specifying the best shipping route for delivery. The best delivery route can be identified by knowing the intricacies of traveling from the company to customers. With this strategy, the total travel distance can be reduced during delivery, thus reducing the amount of carbon emissions in the air (Karagul et al. 2018). The third recommendation is to perform regular truck maintenance to improve fuel efficiency. With a scheduled regular maintenance plan, fuel consumption can be reduced, thus, reducing the amount of carbon emissions to the environment.

The fourth suggestion is to make use of third party logistics provider. The function of the third party logistics is to deliver finished goods if the company fails to ship to the customers. This will ultimately reduce the negative effects of disruption such as high backorder costs or loss in sales. Lastly, by adopting pro-active measures to deal with disruptions in the supply chain such as having backup inventory or safety stock. This ensures that all customer demand is met and mitigates the losses incurred due to backorders or lost sales. However, the optimal level of safety stock should be identified so that extra inventory holding costs can be avoided. Additionally, by implementing predictive shipments where the product is delivered on an expected request. This way, the company can respond flexibly to changing demand and suppliers. Planning is a continuous process that can respond dynamically to changing needs or constraints.

CONCLUSION

This quantitative study has been conducted to achieve the first objective set out for this study, which is to identify the disruption factors that cause logistical activities to be disrupted and their impact on the environment. Quantitative analysis shows that carbon emissions increased following disruption occurrence in the supply chain. Two approaches were adopted, namely (i) based on activity and (ii) based on energy. As a result of the calculations of both approaches, it

has been identified that carbon emissions using an energy-based approach was 2% higher than activity-based. Based on the results of this study, it can be concluded that disruptions in the supply chain have a direct impact on carbon emissions to the environment. Therefore, it is highly recommended that managers seek greener alternatives during post-disruption, particularly in decision making pertaining to logistics activities to ensure that the sustainability of the supply chain is conserved. This study can be considered as a pilot study and can be used as a reference for future studies.

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DECLARATION OF COMPETING INTEREST

None.

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