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A Reliability Model of Truck Transportation Using FMEA and FTA

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Abstract **–**Nowadays the reliability of the logistics in Supply Chain (SC) is realized as an important factor in order to provide high quality of service to customers. The trend of globalization and the development of the communicational technique led to the needs of the high quality of logistics service and the complexity of supply chain. In fact, the better service that customers require, the more important is the reliability of the logistics. Therefore, measuring the reliability of the specific supply chain that differs from industries or products is needed. This paper describes the transportation model. For measuring the transportation reliability, the Fault Tree Analysis (FTA) and Failure Mode and Effect analysis (FMEA) are applied. By identifying the failure events and assessing the evaluation factor, the quantitative reliability of a link is obtained. The classification of the failure is catastrophe and event which could happen in the transportation situation. And each of the failure event is calculated and aggregated based on the severity, occurrence possibility and detection possibility.

Keywords**:** Transportation reliability, Transportation modelling, FMEA, FTA, Assessment reliability

1. Introduction

Today's market environment has become global and complex. In addition to the development of communicational technical, the customers' needs for the product and freight transportation are specified and diverse. The importance of the logistics reliability is increasing through these trends of the development.

There are some studies about logistics reliability called as resilience, flexibility and robustness. In the literature, there are variety of strategies and estimation methods of the SC model with qualitative approach available to reinforce the reliability of SC. Beyond the limitation that these researches have, this paper proposes the engineering methodology to define, identify and assess about the transportation reliability.

This paper is focused on the road transportation model particularly the mode of truck. There is no literature that is only focused on the reliability of the truck transportation. This paper shows transportation network and each of the link is measured by the FTA and FMEA. The FTA and FMEA are identified the failure event of transportation. FTA shows the highest level of failure and the basic events in detail. FMEA informs the failure basic events and each of the event includes the effect. There are severity, possibility of occurrence, possibility of detection.

This paper is organized as follows: Section 2 describes the methodology used in this paper. Section 3 presents an analysis of the transportation reliability. Finally, section 4 describes the conclusion and limitation of this paper.

2. Methodology

In this section, the methodologies used to analyse the quantitative reliability are described. Firstly, the transportation network model is illustrated in Fig. 1. Then, engineering formulae are described. To identify the parameters, FTA and FMEA are used.

2. 1. Transportation Modelling

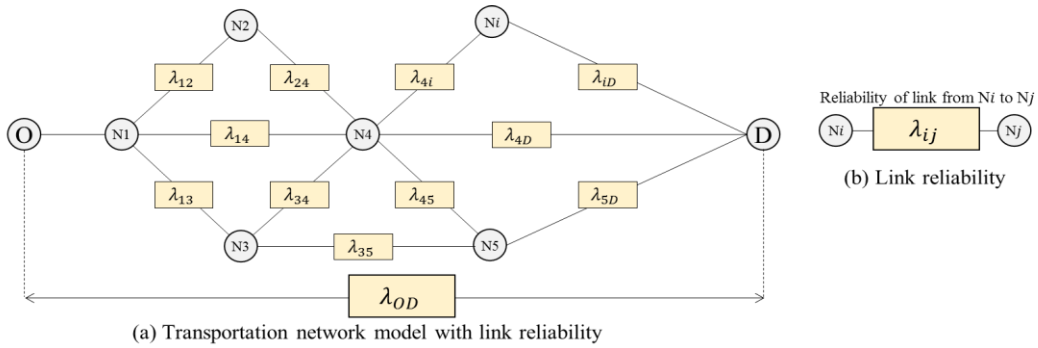

Fig. 1. The reliability of the transportation model

The network is composed of number of nodes, modes and links where node is defined as a connection point and mode is defined as a way to move freights by such as rail, road, ship, flight and so on. In this network, the mode is used only trucks. Link is the line that shows the connection with another node. L_{ij} explain the link from node i to node j. In this paper, there are 6 nodes and 12 links from origin (O) to destination (D) in road way (truck) are considered as shown in Fig. 1. These links are combined to constitute the O-D transportation network.

2. 2. Reliability of the Transportation Model

Like constitution of the network, the total reliability of the network is organized with links' reliability. In other words, by aggregating each of link's reliability value, total network reliability is obtained. The λ_{ij} represents reliability of L_{ij}. It is comprised in Fig. 1 (b).

The equations to assess the total reliability of the network are shown below. There are combination rules among the network reliability. The network is aggregated as follows: λ_{ij} represents reliability of L_{ij}

For Serial rule:

$$\mathrm{R} = \lambda_{i(i+1)}(t) \cdot \lambda_{(i+1)(i+2)}(t) \cdot \cdots \cdot \lambda_{(i+n-1)(i+n)}(t) = \prod_{i=1}^{n-1} \lambda_{i(i+1)}(t) \tag{1}$$

For Parallel rule:

$$\mathrm{R} = 1 - \{1 - \lambda_{ik}(t)\}\{1 - \lambda_{(i+1)k}(t)\} \cdot \cdots \cdot \{1 - \lambda_{(i+n)k}(t)\} = 1 - \prod_{i=1}^{n} [1 - \lambda_{nk}(t)] \tag{2}$$

The serial rule is used for series connection of the nodes. Fig. 2 (a) shows serial link. The parallel rule is used for parallel connection of the nodes. Fig. 2 (b) shows parallel link. Fig. 3 shows multi-link. Multi-link's reliability is calculated with the combination of the Eqs. (1) and (2).

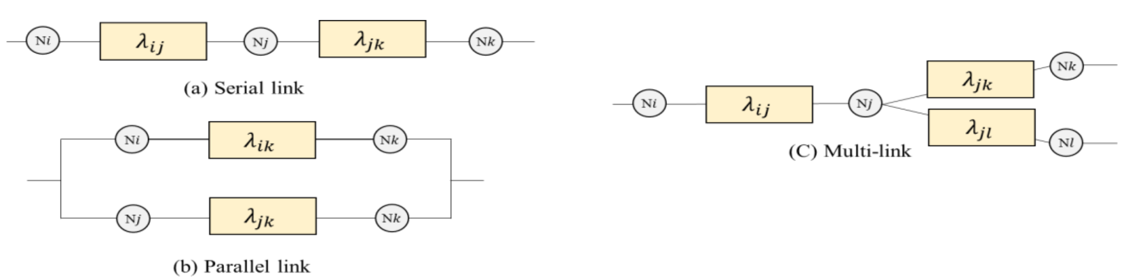

Fig. 2. Serial and Parallel types of network

Before aggregating the reliability of the links, it is needed to estimate each link's reliability λ_{ij}. As shown in Eq. (3). Suppose i is the evaluation factor such as a likelihood of the failure, a possibility of the failure prevention and a failure impact scope. C_i is the coefficient of the evaluation factor that is estimated with technical criteria. Through Eq. (3), a reliability of the link can be calculated.

$$\lambda_{ij} = (C_1 \cdot C_2 \cdot C_3 \cdots C_n)^{\frac{1}{n}} \qquad (0 \le C_i \le 1) \tag{3}$$

Depending on the transportation situation and evaluation factor, the value of λ_{ij} is different.

3. Analysis

In this section, the evaluation factors which are appropriate in transportation situation are analysed with FTA and each of the factors measured with FMEA. With the coefficients that are resulted in FMEA, the link's reliability λ_{ij} is calculated. The transportation reliability is resulted with these steps: Basic event reliability→ Event reliability → Link's reliability → Network total reliability

3. 1. Transportation Model FTA and FMEA

There are 2 kinds of reliability analysing methods as FTA and FMEA. The FTA is a method of analysing causes from top to down. There is the highest failure event which is organized by many reasons of basic events. In this study, it is 'Transportation delay'. The FMEA is a method mostly used for failure identification and analysis. It is applied to transform qualitative value into quantitative value.

Fig. 3 shows failure events about transportation model. In identifying the failure events, there are some presumptions of the transportation node. At first, the loading and unloading process would not impact on the transportation node. Loading and unloading time is not considered. Second, only truck is used to move the product or freight. Third, every basic event is independent of each other. Finally, truck drivers have driven the trucks with the standardized skill and abundant experiences except the case of basic event 'Driver's carelessness'.

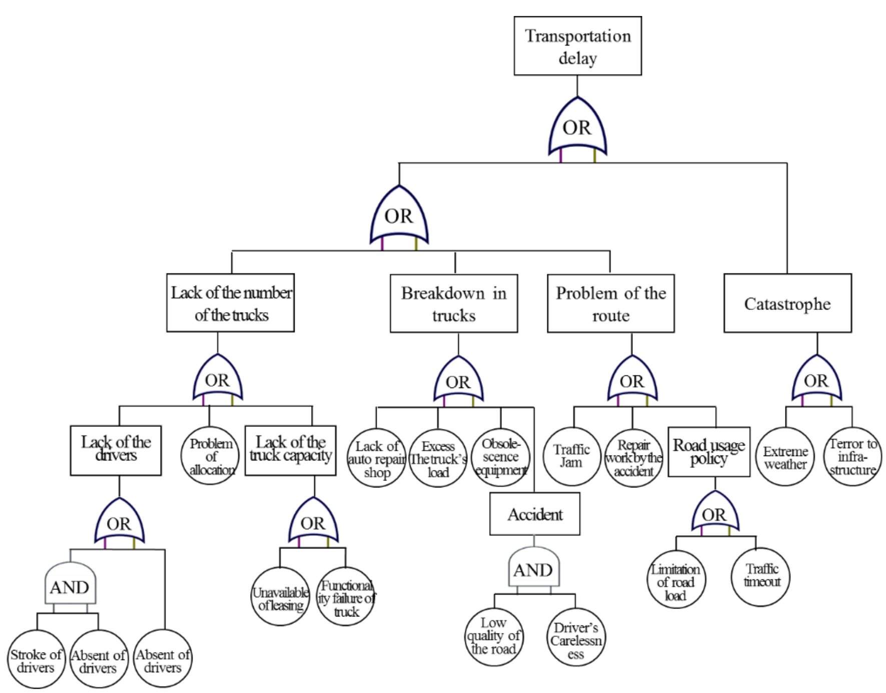

Fig. 3. The Supply Chain (SC) network

All of the basic failure events derived from FTA are measured and their evaluation factors are shown in Table. 1. The factors are composed of 3 elements as severity, possibility of occurrence, and possibility of detection. Even though there are papers that are applied the same classifications such as Curkovic S., (2013), Chaudhuri A. et al., (2013), Bradley J. R., (2014), these papers are not attempt to divide the severity as cost, time and company's reputation to reduce scale differences which are occurred by respondents' priority.

In order to measure the quantitative failure coefficient, the aggregated equations are used. In the Eq. (4), C_S represents severity coefficient, C_O represents occurrence possibility, C_D represents detection possibility. Likewise Eq. (4), C_S is divided into 3 elements as follows where S_c represents cost severity, S_t represents time severity, S_{rep} represents reputation severity.

$$C_S = (C_S \cdot C_o \cdot C_D)^{\frac{1}{3}}(0 \leq C_S, C_o, C_D \leq 1) \tag{4}$$

$$C_S = \frac{1}{3}(S_c + S_t + S_{rep}) \qquad (0 \leq S_i \leq 1) \tag{5}$$

Each value of the failure event is aggregated with Eqs. (1) and (2) considering the FTA structure.

3. 2. Reliability of the Link

Each value of the failure event is calculated as shown in the last column of Table 1. A link's reliability results in 0.79 considering the FTA structure of the Fig. 3.

Table. 1. Failure mode and effect analysis (FMEA) of transportation

Mode	Number	Failure event	Severity			Possibility of Occurrence	Possibility of Detection	Value of the failure event
			C	T	R			
Event	1	Stroke of drivers	0.5	0.3	0.3	0.3	0.3	0.34
	2	Absent of drivers	0.8	0.8	0.7	0.8	0.7	0.75
	3	Problem of allocation	0.8	0.8	0.8	0.8	0.8	0.80
	4	Unavailable of leasing	0.6	0.8	0.8	0.7	0.7	0.71
	5	Functionality failure of truck	0.6	0.8	0.7	0.8	0.8	0.81
	6	Lack of auto-repair shop	0.7	0.6	0.9	0.7	0.7	0.67
	7	Excess of truck's load	0.5	0.8	0.7	0.6	0.5	0.56
	8	Obsolescence equipment	0.5	0.4	0.4	0.5	0.6	0.56
	9	Low quality the road	0.8	0.8	0.7	0.8	0.7	0.75
	10	Driver's carelessness	0.9	0.9	0.7	0.9	0.8	0.85
	11	Traffic jam	0.9	0.9	0.8	0.9	1.0	0.95
	12	Repair work by the accident	0.9	0.9	1	0.9	0.9	0.90
	13	Limitation of the road load	0.6	0.6	0.9	0.8	0.8	0.78
	14	Traffic timeout	0.6	0.6	1	0.8	0.8	0.78
Catastrophe	15	Extreme weather	0.2	0.3	1	0.5		0.47
	16	Terror to public infra-structure	0.8	0.3	0.8	0.6		0.60

4. Conclusion

This study proposed a methodology for assessing the reliability of transportation model. By analysing and measuring transportation failure event applied FTA and FMEA, it resulted in numerical values of reliability in the link. In addition, it could be resulted in the total network reliability value. Considering literature related with the reliability, this study contributed to describing the quantitative reliability of practical transportation model.

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