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Investigation of the gasoline supply problem in the Great East Japan Earthquake and application to future earthquakes

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Abstract

The Great East Japan Earthquake exerted serious damage over an unprecedentedly wide range. The earthquake prevented the supply of materials indispensable to restoration and revival in its aftermath, including fuels such as gasoline. In this study, we apply a system dynamics solution to investigate the causes and bottlenecks of this problem in order to ameliorate similar problems in wide-ranging disasters that are expected to occur, such as the Huge Nankai Trough Quake.

According to data and information provided by the Agency of Natural Resources and Energy and interviews with workers at the JX Sendai oil refinery, we determined the following bottlenecks in gasoline supply in the damaged areas: (1) the number of tank lorries transporting gasoline from the oil refinery and oil terminal to the SSs was insufficient. (2) The standard number of tank lorry roundtrips per day was three, but damage to lorry racks at the oil refineries or oil terminals could decrease the number of tank lorry roundtrips.

Based on these points, we considered how the system dynamics model we formulated based on the case of the Great East Japan Earthquake could be applied to the future, expected Huge Nankai Trough Quake. We determined the influence of the Great East Japan Earthquake and the expected Huge Nankai Trough Quake according to damage to (a) supply sources and (b) supply routes.

In the case of the Huge Nankai Trough Quake, western Japan has more oil refineries and other advantages than did the Tohoku region during the Great East Japan Earthquake in view of (a) supply sources. However, in view of (b) supply routes, roads in western Japan have no redundancy and damaged roads may be a bottleneck in disasters; this is a matter of concern.

By considering these results, the method to estimate a supply delay of gasoline for a hypothetical earthquake was proposed. In this method, we developed vulnerability functions of oil refineries which took into account both ground shaking and tsunami force simultaneously.

To improve the system dynamics model, integrating the road restoration ratio with parameters such as the tank lorry roundtrips per day is necessary.

Keywords: Great East Japan Earthquake, gasoline supply, system dynamics

1. Introduction

The Great East Japan Earthquake, which occurred in March 2011, exerted tremendous damage in an unprecedentedly wide range. One serious problem that arose immediately after the earthquake that demands consideration was the delayed supply of materials indispensable to restoration and revival, such as gasoline. These delays were due not only to (a) damage to oil company supply tanks, but also to (b) the severing of roads and railways used for supply traffic; furthermore, in addition to damaged areas in the Tohoku region, the Tokyo metropolitan area also suffered from gasoline supply delays.

In this study, we used a system dynamics solution [1],[2] to model (a) and (b). The purpose of this study is to ameliorate similar problems in wide-ranging disasters that are expected to occur, such as the Huge Nankai Trough Quake.

This study comprises nine steps, as shown in Fig. 1. In the pilot study, we determined (a) damage to suppliers and (b) damage to supply routes. We then analyzed the results of interviews conducted on July 5, 2012 with workers at the Sendai oil refinery of the JX Nippon Oil and Energy Corporation (subsequently referred to as JX) to collect parameters for modeling and derive objectives. These parameters and necessary tasks were integrated into a system dynamics model. Based on the case of the Great East Japan Earthquake, we formulated measures to be implemented in the Huge Nankai Trough Quake to obtain particular objectives. The targets of this study are shown in Steps (1)–(4), (6) and part of Step (5) in Fig. 1.

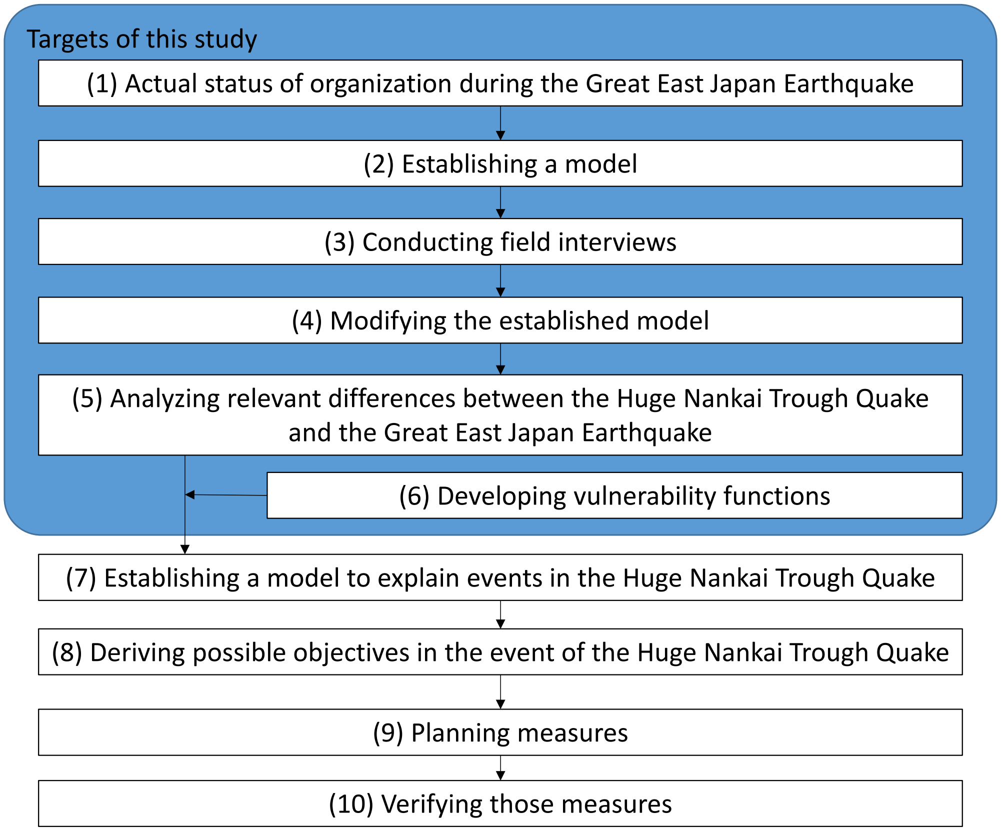

Fig. 1 – Overall steps and targets of this study

2. Outline of damage to gasoline suppliers and supply routes

2.1 Transport of gasoline and facilities' damage and recovery

The transport of gasoline starts at oil refineries, which produce petrochemical products from crude oil. Generally, gasoline from oil refineries is transported to gas stations (SSs) by tank lorries via oil terminals that store gasoline temporarily. As an example of the damage that oil suppliers can incur, 6 of the 27 oil refineries in our country halted operations immediately after the Great East Japan Earthquake[3]. Fig. 2 illustrates the damage to oil refineries caused by the Great East Japan Earthquake. Eight oil terminals in the vicinity of the Pacific Ocean stopped shipments or were shut down as of March 12, 2011. The Kamaishi, Kesennuma, Onahama, and Hitachi oil terminals remained unable to resume shipments as of March 21, 2011[4]. Many argued for the urgent restoration of the Shiogama oil terminal, essential to gasoline supply in the Tohoku region[5]. Accordingly, two oil terminals restarted operations on March 17 and 20, 2011. As of March 21, 2011, two additional oil terminals remained mired in preparations for resuming operations and could not accept large vessels[6].

2.2 Supplying gasoline to damaged areas

On March 17, 2011, the Agency of Natural Resources and Energy provided figures on gasoline that would be supplied from oil refineries in western Japan to the damaged areas[5].

First, the Agency stated that it would increase the operation rate of oil refineries in western Japan to 95% or higher (the operation rate of Japanese oil refineries in 2010 was 77.8%[7]) and constrain exports and demand; this additional production (approximately 20,000 kL/day) would be transferred to the Tohoku region. The Agency also stated that it would collect additional gasoline from two oil refineries in Hokkaido (Tomakomai and Muroran) in order to secure approximately 38,000 kL/day of gasoline in total, an amount that was equal to the demand per day in the Tohoku region prior to the earthquake.

As shown in Fig. 2, three oil refineries in the Kanto region that stopped operations during the earthquake had resumed operations by March 21, 2011 and supply shortages were nearly eliminated. Because of concerns several days prior to March 21 regarding the insufficient gasoline supply, oil companies were instructed to transfer and bring to market in the Kanto region, within approximately three days, 50,000 kL of oil inventory stored at refineries in western Japan. The oil companies made available oil stocks produced by their in-service oil refineries in the Kanto region (approximately 30,000 kL) and established an effective supply system through collaboration—for example, companies provided tank lorries to other companies.

Fig. 3 illustrates these efforts and Fig. 4 shows the locations of the 27 oil refineries in Japan and their crude oil processing capacity[6].

The Agency also sought to prepare additional tank lorries. Immediately after the earthquake, the number of tank lorries that supplied gasoline in the Tohoku region was around 1,100, of which 400 transported gasoline from the oil terminals to SSs. In the aftermath of the earthquake and tsunami, the largest regional supply bottleneck was a lack of tank lorries to transport gasoline from oil terminals to SSs. Additional tank lorries from the Kansai region and other areas (300 units) were requested to establish a supply system comprising 700 tank lorries.

Furthermore, the supply of gasoline to major SSs in the damaged areas was prioritized. SSs were specified as essential based on whether they were:

- critical for ensuring the functioning of fire and police emergency vehicles
- critical for maintaining the distribution of relief goods
- critical for supporting the lives of evacuees and inhabitants

On March 21, 2011, to ensure the supply of oil throughout the country, facilitate the provision of petroleum products, and encourage mutual accommodation between business operators and regions, civilian oil stocks were substantially reduced. Taking prior reductions into account, civilian oil stocks were reduced by 25 days' worth. Consequently, the number of days that civilian oil stocks were rationed was reduced from 70 to 45[8].

2.3 Damage and recovery of supply routes

Nearly all of the highways and open roads used for gasoline transport, as mentioned in (b) in Section 1, were traversable by March 21, 2011[9] with the exception of Route 45 along the Sanriku coast, which was shut down by the tsunami, and Route 6, which runs close to the Fukushima No. 1 Nuclear Power Plant. Furthermore, it was decided that a comb-like route from Route 4 to Route 45/Route 6 had to be prioritized as a relief route and cleared of road obstacles. This route became traversable between March 12 and March 15, 2011[10].

Kyokuto Petroleum Industries: Chiba oil refinery TonenGeneral Sekiyu: Kawasaki factory JX: Negishi oil refinery	Since the damage incurred was not serious, operations were resumed by March 21, 2011.
Kashima Oil: Kashima oil refinery	Its production facilities and facilities for reception and delivery were damaged by the earthquake and tsunami, and it halted production and shipment. It resumed production in early June 2011.
JX: Sendai oil refinery	Production was resumed in March 2012. Next chapter details the damage incurred.
Cosmo Oil: Chiba oil refinery	It is engaging in recovery operations, such as preparing preventive measures based on a report of the Accident Investigation Committee regarding fires at the time of the earthquake (no target date as of August 2011).

Note. Based on a response from the Agency of Natural Resources and Energy on August 24, 2011, information from oil refinery websites was added to this figure.

Fig. 2 – Damage to oil refineries caused by the Great East Japan Earthquake

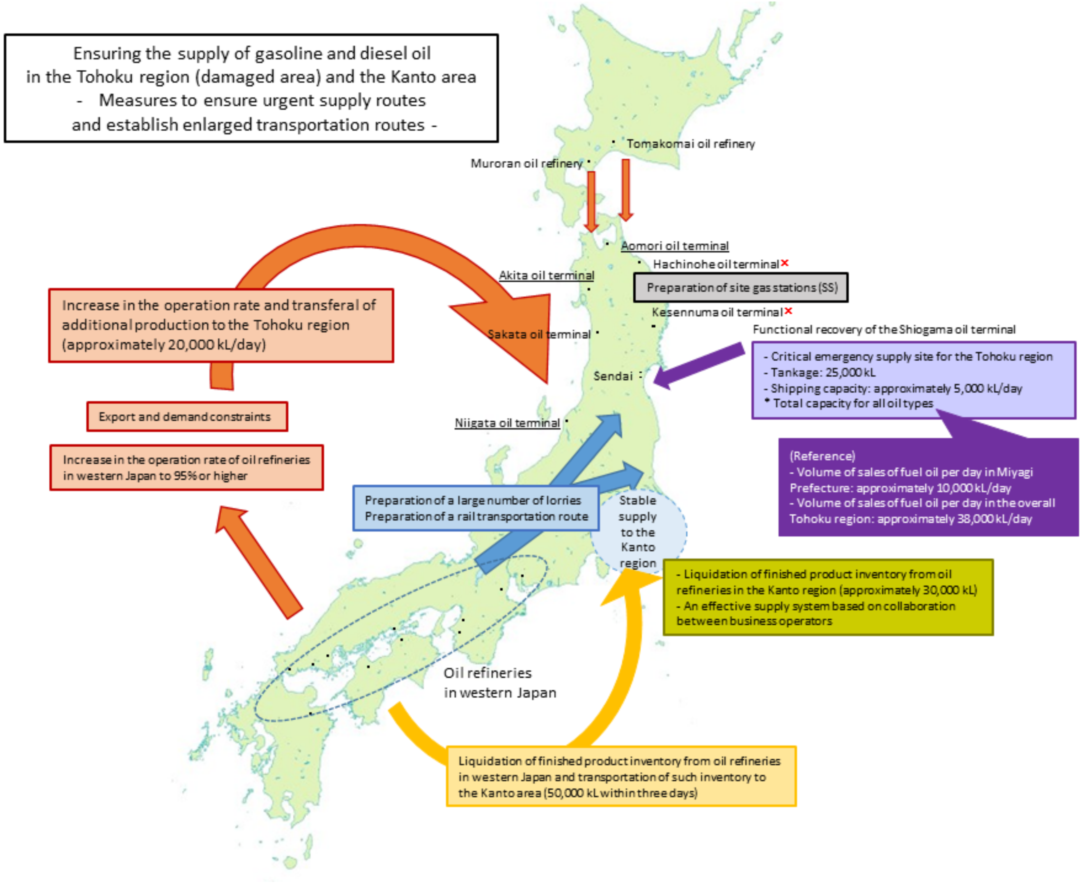

Fig. 3 – Gasoline supply routes[5]

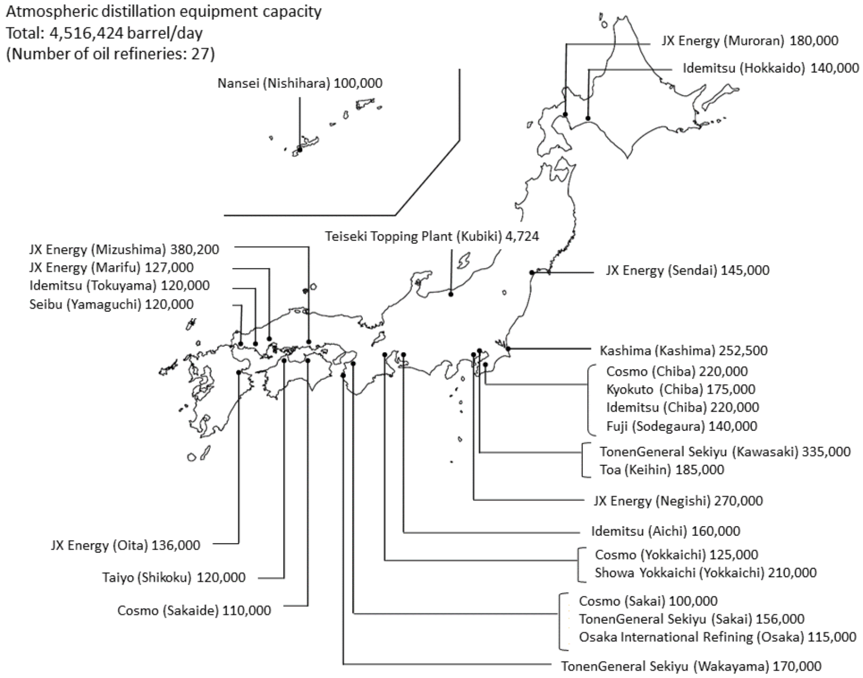

Fig. 4 – Location of the oil refinery and its crude oil processing capacity (as of January 2011)[6]

3. Integration of the case of the Great East Japan Earthquake with the system dynamics model

Taking the interview to the JX Sendai[11] results into consideration, we decided to employ a system dynamics model. Fig. 5 shows the model flow. In setting tentative conditions, detailed points regarding the gasoline supply were neglected; the conclusion provided in this chapter is only partial and based on estimated objectives.

To determine the number of tank lorries, based on the information released by the Agency of Natural Resources and Energy[5], we added 300 units to the number of tank lorries available at the time the earthquake occurred (400 units) and conducted estimation based on a system with 700 units in total.

The responses of the JX Sendai oil refinery and the Petroleum Association of Japan to our inquires indicated that the Sendai oil refinery, Shiogama oil terminal, Morioka oil terminal, and Koriyama oil terminal adjusted warehousing to prevent the build-up of gasoline stocks. In consideration of this information, we checked and adjusted transportation data pertaining to tankers and railways separately. The Tohoku region requires 38,000 kL of gasoline per day; we estimated that the amount of gasoline transported from the Tokyo metropolitan area and western Japan directly after the earthquake would be 50% of that value and would be able to increase up to 100% over 10 days.

Based on the conditions above, we calculated the total cumulative amount of gasoline transported from the Tokyo metropolitan area and western Japan; the amount of gasoline stored in the Sendai oil refinery, the Shiogama oil terminal, the Morioka oil terminal, and the Koriyama oil terminal; and the total cumulative amount of gasoline transported from the Sendai oil refinery, Shiogama oil terminal, Morioka oil terminal, and Koriyama oil terminal to the SSs.

Fig. 6 illustrates gasoline transportation given two tank lorry roundtrips per day, and Fig. 7 illustrates gasoline transportation given three tank lorry roundtrips per day.

Given two tank lorry roundtrips per day, as shown in Fig. 6, the transportation capacity of the tank lorries to the SSs is insufficient and the Sendai oil refinery, Shiogama oil terminal, Morioka oil terminal, and Koriyama oil terminal must engage in adjust warehousing to prevent the amount of gasoline received from exceeding tank capacity, thus limiting the amount of gasoline that can be transported from the Tokyo metropolitan area and western Japan to less than the required amount. By contrast, at three roundtrips per day, as shown in Fig. 8, the transportation capacity of the tank lorries to the SSs is sufficient. Therefore, the Sendai oil refinery, Shiogama oil terminal, Morioka oil terminal, and Koriyama oil terminal require no warehousing adjustments, and it is expected that the amount of gasoline transported from the Tokyo metropolitan area and western Japan can almost equal the required amount.

As interviews at the JX Sendai oil refinery indicated, under normal conditions, three roundtrips per day are standard. This number was consistent with the simulation results (Fig. 7), which indicated that three roundtrips per day enabled the successful transportation of gasoline to the SSs without necessitating warehousing adjustment. However, damage to lorry racks at the oil refineries or oil terminals could decrease the number of possible tank lorry roundtrips per day. The JX Sendai oil refinery completely restored lorry rack capacity in May 2011; before this, the actual number of possible roundtrips per day was less than three, and transportation capacity to the SSs was reduced.

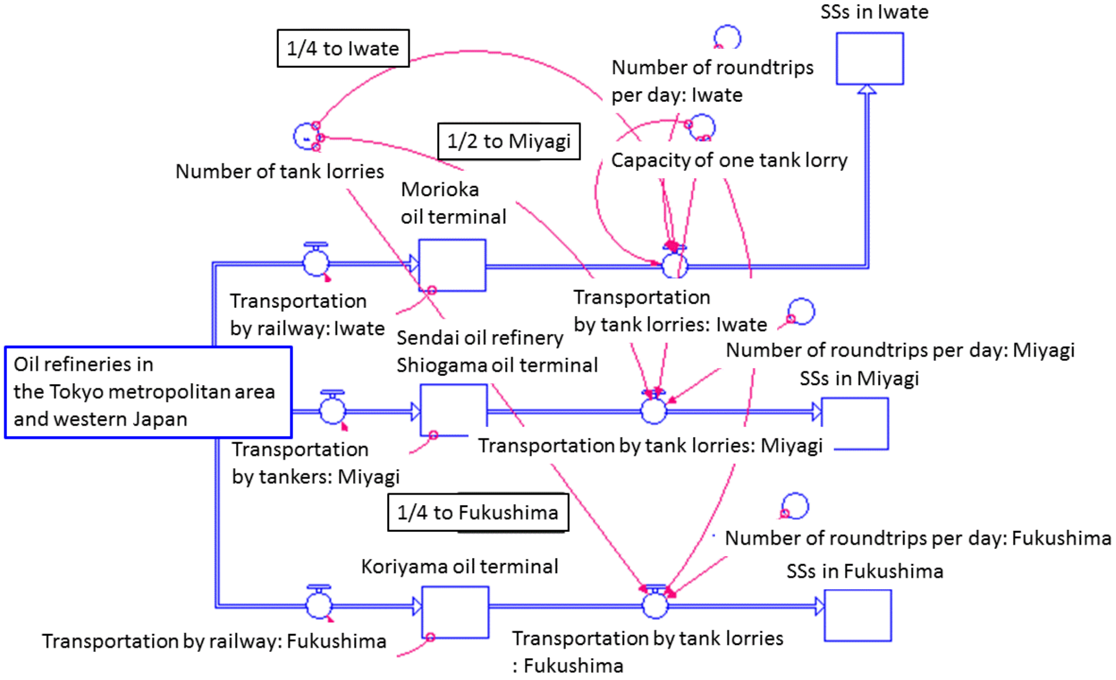

Fig. 5 – Flow of the system dynamics model

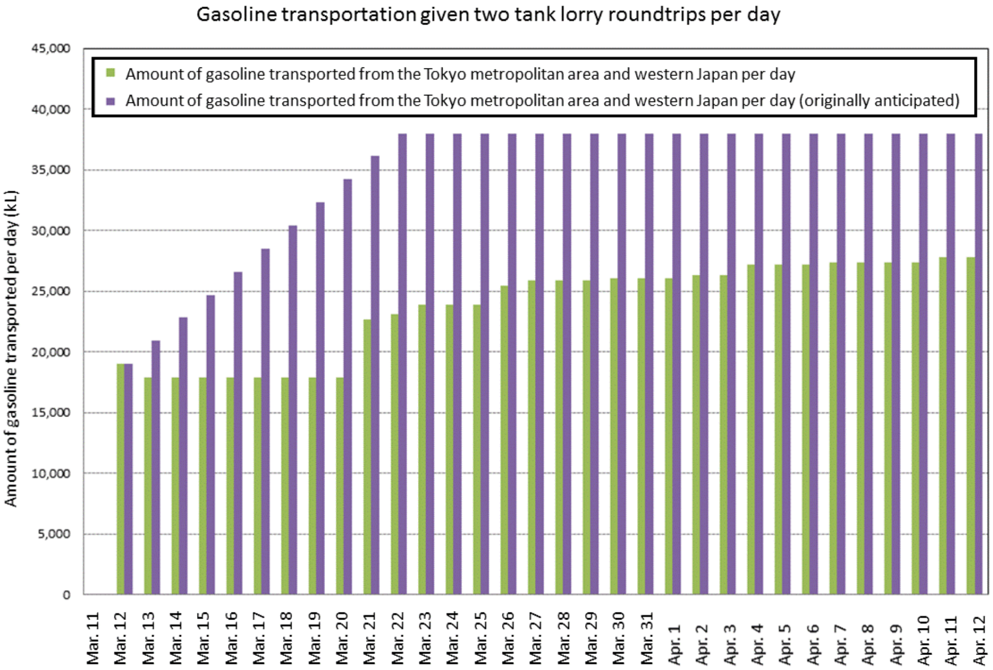

Fig. 6 – Amount of transported gasoline (given two tank lorry roundtrips per day)

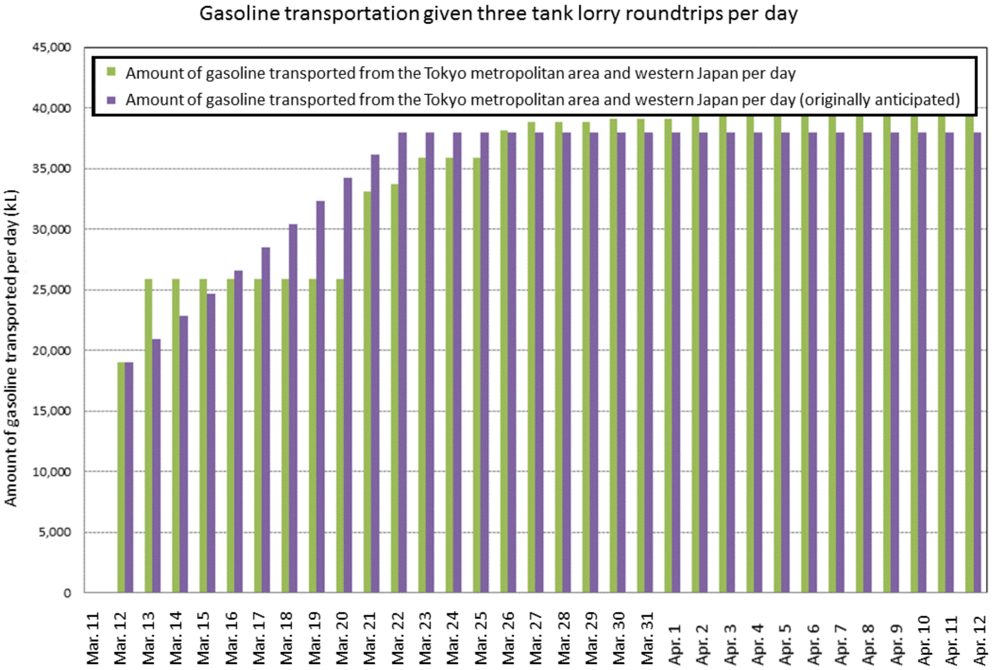

Fig. 7 – Amount of transported gasoline (given three tank lorry roundtrips per day)

4. Objectives for the future Huge Nankai Trough Quake

According to data and information provided by the Agency of Natural Resources and Energy[5] and interviews with workers at the JX Sendai oil refinery, we determined the following bottlenecks in gasoline supply in the damaged areas: (1) the number of tank lorries transporting gasoline from the oil refinery and oil terminal to the SSs was insufficient. (2) The standard number of tank lorry roundtrips per day was three, but damage to lorry racks at the oil refineries or oil terminals could decrease the number of tank lorry roundtrips.

Based on these points, we considered how the system dynamics model we formulated based on the case of the Great East Japan Earthquake could be applied to the future, expected Huge Nankai Trough Quake. We determined the influence of the Great East Japan Earthquake and the expected Huge Nankai Trough Quake according to damage to (a) supply sources and (b) supply routes, as shown in Table 3.

Table 2 shows that in the case of the Huge Nankai Trough Quake, western Japan has more oil refineries and other advantages than did the Tohoku region during the Great East Japan Earthquake in view of (a) supply sources. However, in view of (b) supply routes, roads in western Japan have no redundancy and damaged roads may be a bottleneck in disasters; this is a matter of concern.

To improve the system dynamics model, integrating the road restoration ratio with parameters such as the tank lorry roundtrips per day is necessary.

Furthermore, to increase the accuracy of the model, incorporating the influence of the increased demand of gasoline after disasters is necessary. However, because such figures are currently difficult to determine, we considered this a future objective.

Table 2 – Influence of the Great East Japan Earthquake and the expected Huge Nankai Trough Quake on the gasoline supply

	Tohoku region in the Great East Japan Earthquake	Western Japan in the Huge Nankai Trough Quake
Supply source considerations based on bottlenecks and the formulated model	Due to the earthquake and tsunami, the number of the tank lorries was insufficient. The Tohoku region has only one oil refinery, JX Sendai, at which lorry racks were damaged. Thus, only long-distance transportation from other regions could be used to supply gasoline.	Western Japan has a number of oil refineries, mainly located around the Seto Inland Sea (see Figures 3 and 4). Regarding the expected damage of the Huge Nankai Trough Quake, the Cabinet Office[12] estimated that tsunami height in the Seto Inland Sea would be lower relative to that on the Pacific coast. Therefore, if one area is damaged, other areas will be able to provide support. Preparing a sufficient number of tank lorries and ensuring that lorry racks at oil refineries and oil terminals incur no damage is desirable.
Supply route considerations	Even though Route 45 and Route 6 along the coast were damaged, the Tohoku Expressway and Route 4, an inland route, were usable. A comb-teeth-like route along these roads was employed for transporting the gasoline supply.	In contrast to the Tohoku region, roads have no redundancy. There are no expressways in the upper portion of the Kii Peninsula or in southeast and southwest Shikoku; thus, transportation is a serious potential problem.

5. Proposal of vulnerability functions taking into account both ground shaking and tsunami force

It is the picture of a study to make the restoration with chronological gasoline provision in the disaster area of the hypothetical Nankai-trough earthquake an output and estimate a supply delay of gasoline as Fig.1. In this section, we develop vulnerability functions of oil refineries taking into account both ground shaking and tsunami force simultaneously.

5.1 Basic concept of developing vulnerability functions

The vulnerability function is built only targeted for hazard of one of an earthquake or a tsunami in the case of the conventional way, therefore we have to evaluate for respective hazards. On the other hand, paying attention to force, ground shaking force or tsunami force, it is the feature of this study that we could estimate in unifying way by an identical index for example it might be suitable for the damage value around the boundary of a tsunami flooding area in oil refinery site.

When the damage function which expressed ground shaking force and tsunami force in an identical index was built, a basic concept was considered as Fig.8. First we suppose the static force and find ground shaking force and tsunami force respectively. For ground shaking force, if the peak ground acceleration α_j in the site is known, it is possible to cross acceleration α_j and building mass and find ground shaking force. For tsunami force, we can find it from width and height of the building in addition to flooding shin of tsunami. As the merit of this way when comparing only flooding shin with vulnerability function made a parameter, it is possible to calculate tsunami force according to shape of each building. Acceleration α_t caused by tsunami is purchased to remove this tsunami force by building mass. Conversion acceleration α_{jt} which combined α_j and α_t, vulnerability function is built in a parameter.

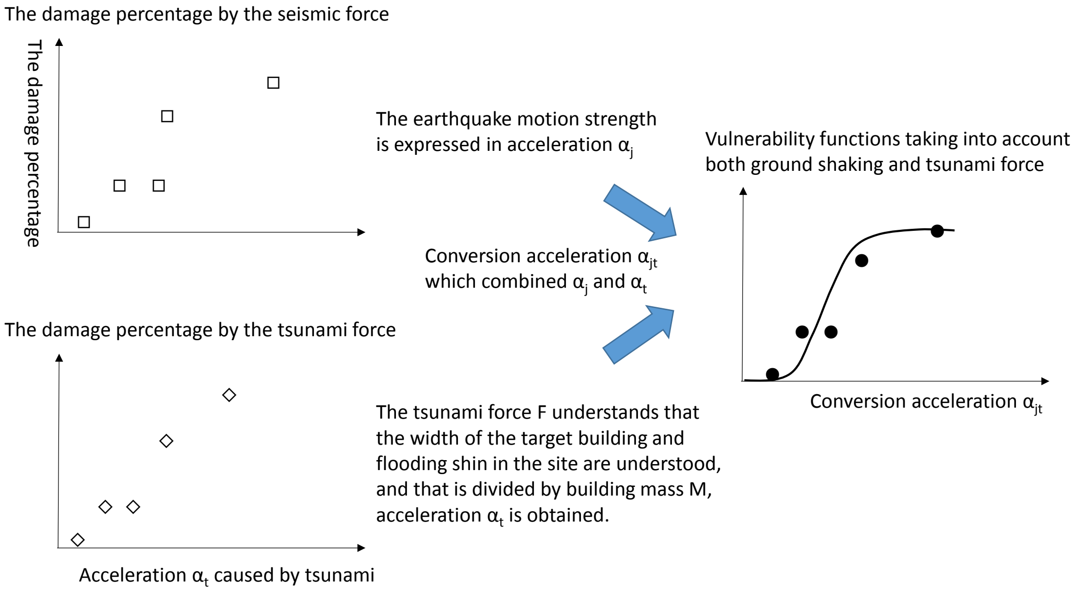

Fig. 8 – Basic concept of developing vulnerability functions

5.2 Used data

In this study, when the vulnerability function was built, building damage data was needed first, therefore a data base of Monma et.al[13] was employed as information on the building damaged by the Great East Japan Earthquake. The Ministry of Land, Infrastructure and Transport city bureau "Reconstruction aid investigation archive" data[14] was employed as data of tsunami flooding shin.

5.3 Calculation of ground shaking and tsunami force

In this section, we calculated the ground shaking force and the tsunami force about 10 buildings of Minami-

Sanriku town and 10 buildings of Natori city. For ground shaking force, the acceleration is calculated form grid information on the instrumental seismic intensity recorded in Monma et al.[13] by using Dong and Yamasaki[15] and cross it and the average weight of buiding, then we can find the ground shaking force. For tsunami force, It was purchased by inputting data of the width of the building read from Monma et al.[13] data base to the equation of tsunami force indicated by the tsunami evacuation building guideline[16] by the Cabinet Office disaster prevention charge (Eq. (1) referring). The damage, a parameter and the calculated value are indicated about total of 20 buildings in Table.3. Italic letters are the value derived by calculation. In this paper, for finding the damage function of the oil refinery, large-scale buildings are chosen relatively, its structure and number of stories are 2 story of a Non-wooden (height 8m), the sum of prudence and the movable load per and 1 square meter was assumed 3,200kg. The weight of water per unit volume was made 1.030 (t/m^3) as seawater.

$$\mathrm{Qz} = \frac{1}{2}\rho g B\{(6\hbar z_2 - z_2^2) - (6\hbar z_1 - z_1^2)\} \quad (1)$$

Where, Qz: The tsunami force of the direction of movement for structure designs (kN)

ρ: Weight per unit volume of water

g: The gravity (m/s^2)

B: The width of the part concerned (the way which crosses at right angles to flow) (m)

h: Flooding shin for designs

z_1: Most slight elevation of the pressed face ($0 \leqq z_1 \leqq z_2$) (m)

z_2: Most thick elevation of the pressed face ($z_1 \leqq z_2 \leqq 3h$) (m)

Table 3 – The damage, parameter and calculated value of 20 buildings

City, Town name	Building ID	The damage	JMA Seismic intensity	Flooding shin h （m）	The width of the building B （m）	The depth of the building （m）	*Seismic force (kN)*	α j *(gal)*	*Tsunami force Qz (kN)*	α t *(gal)*
Minami-Sanriku Town	M01	T.L.	5.85	8.1	50	87	*84,471*	*607*	*81,963*	*589*
	M02	T.L.	5.84	15.6	34	17	*11,088*	*599*	*117,510*	*6,353*
	M03	L.H.L	5.52	3.4	11	16	*2,286*	*406*	*5,507*	*978*
	M04	H.L.	5.52	0	9	16	*1,871*	*406*	*0*	*0*
	M05	P.L.	5.52	0	28	12	*4,365*	*406*	*0*	*0*
	M06	T.L.	5.60	3.7	11	23	*3,623*	*448*	*6,307*	*779*
	M07	H.L.	5.60	0	18	11	*2,835*	*448*	*0*	*0*
	M08	P.L.	5.60	1.5	16	10	*2,291*	*448*	*1,635*	*319*
	M09	T.L.	5.59	7.3	8	14	*1,584*	*442*	*11,564*	*3,226*
	M10	T.L.	5.81	7.4	18	7	*2,330*	*578*	*26,454*	*6,561*
Natori City	N01	T.L.	5.81	3.8	44	100	*81,378*	*578*	*26,293*	*187*
	N02	L.H.L.	5.90	2.8	11	40	*9,081*	*645*	*3,908*	*278*
	N03	H.L.	5.88	0.8	46	60	*55,591*	*629*	*1,337*	*15*
	N04	P.L.	5.88	0.2	91	189	*346,414*	*629*	*165*	*0*
	N05	P.L.	5.88	0	60	62	*74,926*	*629*	*0*	*0*
	N06	T.L.	5.91	3.3	45	16	*15,042*	*653*	*21,440*	*931*
	N07	L.H.L.	5.91	1.8	10	15	*3,134*	*653*	*1,472*	*307*
	N08	L.H.L.	5.91	2.8	13	6	*1,630*	*653*	*4,619*	*1,851*
	N09	T.L.	5.91	1.6	37	11	*8,503*	*653*	*4,302*	*330*
	N10	H.L.	5.91	1.6	16	15	*5,014*	*653*	*1,861*	*242*

T.L.:Total loss, L.H.L.:Large-scale half loss, H.L.:Half loss, P.L.:Partial loss

5.4 Calculation of conversion acceleration α_{jt}

Conversion acceleration α_{jt} combines and purchases acceleration α_j by ground shaking force and acceleration α_t by tsunami force. As the first way, there is a way to add α_j and α_t each other (It is called a way (I)). In this way, because a tsunami comes following an earthquake motion, we think the acceleration by those is added and influences damage. Next, as the second way, there is a way to get a big way of α_j and α_t (It is called a way (II)). This way is based on the idea that either of an earthquake motion and a tsunami decides about damage.

5.5 Development of vulnerability functions

For 20 buildings above-mentioned, points are plotted to horizontal axis as conversion acceleration α_{jt} and vertical axis as the damage percentage in 1 building, we found a regression curved line to cumulative probability distribution function of a lognormal distribution with a transverse was chosen as a method of least squares (Eq. (2) referring). The result by a way (I) is indicated in Fig.9 and the result by a way (II) is indicated in Fig.10. When expressing it in the damage percentage of the dwelling house from the damage authorization unification standard of the Cabinet Office[17] when damage division was converted into the damage percentage, more than 50 % for total loss, less than 50 % more than 40 % for large-scale half loss, less than 50 % more than 20 % for half loss, on the other hand, partial loss in earthquake insurance is less than 20 % more than 3 %[18]. Therefore large-scale half loss, half loss and partial loss considered an average in the range and converted it into 45%, 35% and 11.5% respectively. For total loss, economical value also disappeared by the case by which structure building flame is left at the building hit by a tsunami, the damage percentage was set to 100%.

$$F(x;\lambda,\zeta)=\Phi\left(\frac{\ln x-\lambda}{\zeta}\right) \qquad (2)$$

Φ is cumulative probability distribution function of standard normal distribution.

The way (I) started to be Fig.9 as a result of the regression, 6.70, 0.730 respectively for coefficient λ, ζ, and the coefficient of correlation were 0.685. On the other hand, a way (II) started to be Fig.10, 6.48, 0.751 respectively for coefficient λ, ζ, and the coefficient of correlation were 0.558.

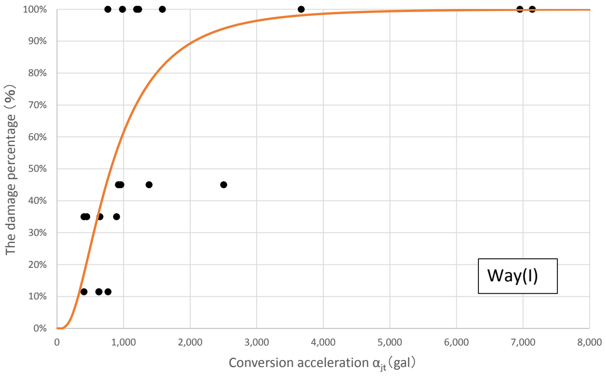

Fig. 9 – Relation between the conversion acceleration and the damage percentage, and the vulnerability function which regressed (way (I))

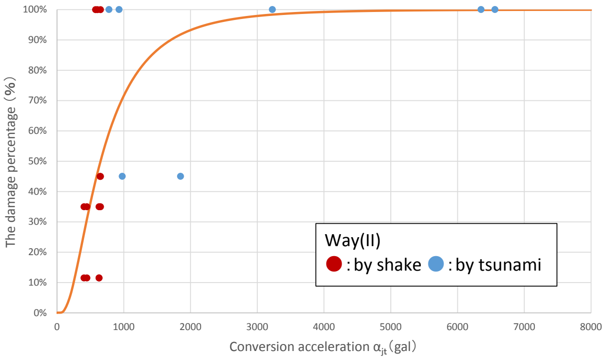

Fig. 10 – Relation between the conversion acceleration and the damage percentage, and the vulnerability function which regressed (way (II))

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References

[1] Tsuchigane, T. (2005): "Introduction of system dynamics by simulation." Tokyo Denki University Shuppankyoku.

[2] Nojima, N., Ueno, S. and Sugito, M. (2006): "Support for creation of a Business Continuity Plan (BCP) using a supply chain system dynamics model." Report from the Tono Research Institute of Earthquake Science, Seq. No. 19, pp. 73-88.

[3] Agency of Natural Resources and Energy (2011a): Data released on March 16, 2011. Retrieved from http://www.enecho.meti.go.jp/sekiyu/110316oil.pdf.

[4] The Petroleum Association of Japan (2012): "Current oil industry 2012."

[5] Agency of Natural Resources and Energy (2011b): Data released on March 17, 2011. http://www.enecho.meti.go.jp/sekiyu/oil110317.pdf.

[6] The Petroleum Association of Japan (2011): Refinery capacity list (201101up.xls). Retrieved from http://www.paj.gr.jp/statis/statis/data/08/paj-8

[7] Kakimi (2012): Retrieved from http://www.kakimi.co.jp/2012-11.htm.

[8] Agency of Natural Resources and Energy (2011c): Data released on March 21, 2011. Retrieved from http://www.enecho.meti.go.jp/sekiyu/oil110321.pdf.

[9] Emergency Mapping Team (EMT) (2011): Data released on March 21, 2011. Retrieved from http://www.drs.dpri.kyoto-u.ac.jp/emt/maps/

[10] Nikkei Construction (2011): "Overall picture of infrastructure damage," in "Civil Engineering" in Lessons of the Great East Japan Earthquake. pp. 164-167.

[11] Saeki, T. and Kiyono, J. (2005): INVESTIGATION OF THE GASOLINE SUPPLY PROBLEM IN THE GREAT EAST JAPAN EARTHQUAKE BY USING SYSTEM DYNAMICS APPROACH, Journal of Japan Association for Earthquake Engineering, Vol.15, No.3, pp.49-60 .

[12] Cabinet Office (2013): Web page for disaster prevention information. "Anticipated damage of the Huge Nankai Trough Quake (secondary report)," "Tsunami height and distribution of seismic intensity of the Huge Nankai Trough Quake." Retrieved from http://www.bousai.go.jp/jishin/nankai/nankaitrough_info.html

[13] Monma N., Fujiwara, H., Nakamura, H., Shimomura, H., Okabe, T. and Fujisawa, S. (2014): Building damage information database of Tohoku-district Pacific offing earthquake, The 14th Japan Earthquake Engineering Symposium, pp.931-937.

[14] The Ministry of Land, Infrastructure and Transport city bureau: "Reconstruction aid investigation archive" data, http://fukkou.csis.u-tokyo.ac.jp

[15] Tong, H. and Yamazaki, F. (1996): Relationship between Ground Motion Indices and New JMA Seismic Intensity, Seisan Kenkyu, Vol.48 No.11, pp.547-550.

[16] The Cabinet Office disaster prevention charge: the tsunami evacuation building guideline, http://www.2x4assoc.or.jp/builder/news/pdf/jisinchosa_08.pdf

[17] The Cabinet Office: the damage authorization unification standard, p.1, http://www.bousai.go.jp/taisaku/pdf/shishinall.pdf

[18] General Insurance Rating Organization of Japan: Earthquake Insurance in Japan, pp.64-65, http://www.giroj.or.jp/disclosure/q_ofjapan/nihonjishin_3.pdf