NEW RISK ANALYSIS METHOD to EVALUATE BCP of SUPPLY CHAIN DEPENDENT ENTERPRISE

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ABSTRACT :

Business continuity is now being regarded as an important factor in management of enterprises. Most of the enterprises are not stand-alone; they depend on Supply Chain (SC), for their operations. In order to draw BCP (Business Continuity Plan) for supply chain dependent enterprise, there is a need for a quantitative risk analysis method to evaluate such manufacturing system. The business interruption time is a crucial factor in terms of economic loss. A model enterprise with several factories connected through supply chain was applied in analyzing the risk. Several location types are considered. The supply chain connection, parallel, series and mixed are considered. The damage probability of factories and their business interruption time are calculated based on the seismic risk of different locations in Japan. The annual exceedance probability of business interruption time of these location and supply chain types are calculated and compared. Through combining these factors a realistic risk analysis method for evaluating business interruption is proposed and is proven to be functional. This method may be applied for strategic location planning of supply dependent enterprises who wish to minimize their risk.

KEYWORDS: business continuity, supply chain, seismic risk, business interruption, economic loss, risk curve

1. INTRODUCTION

Most of the modern enterprises are not stand-alone; they depend on SC, for their operations. In many of the competitive manufacturing industries, the management, for the sake of decreasing the cost of stockpiling and also to respond quickly to changing market demands, is shifting to the "Just in Time" procurement and manufacturing system. This system is based on the assumption that the SC to their factory functions without interruption. Therefore, once the SC is interrupted, they face the immediate risk of halt of operations. On the other hand, business continuity is now being regarded as an important factor in risk management of enterprises.

In the case of the Niigata-Chuetsu-Oki Earthquake on 16 July 2007 in Japan, an automobile engine piston ring manufacturer suffered serious damage. Since this manufacturer had a dominant share, most of the major automobile companies in Japan had to halt their assembly lines for one week, due to the fact that they did not have extra stock of piston rings in their hands. Since it was difficult to identify an alternate supplier for the sophisticated piston rings in a short period, the automobile companies sent their own engineers to this piston ring manufacturer to assist the quick restoration of the piston ring manufacturing lines. This is a typical example of a local disaster affecting production in other locations since they are SC connected. This incident demonstrated the need to consider the supply chain as an important factor in drawing BCP in such enterprises. Similar cases were seen in the October 2004 Niigata-Chuetsu Earthquake and in the 1995 Hanshin-Awaji Earthquake, where the direct damage to the factories hit by the earthquake spread to the enterprises located outside the affected area through the halt of the supply chain of parts and materials.

These cases call for the need to develop an earthquake risk evaluation method for business continuity planning of SC dependent enterprise. For such evaluation, multiple locations of the nodes of the SC system and the individual risks of the buildings on these locations need to be combined and considered. Not only the direct material damage by the earthquake to the nodes, but moreover the Business Interruption Time (BIT) of the enterprise is a crucial factor for the survival of the enterprise in the competitive market. The BIT is a crucial factor in terms of economic loss. If an enterprise halts its supply of products over a consumer acceptable timeframe, the consumer will be quickly taken over by rival enterprises and if the business resumption time exceeds a certain limit, the enterprise will no longer be able to return to the previous market. Therefore a method to quantify the BIT of the SC dependent system and to evaluate options to decrease the BIT is needed[1)].

This study, proposes a quantitative risk evaluation method of BIT of SC dependent enterprise, and applies to model enterprises with several factories connected through SC. Three location types are considered, factories concentrated in Tokyo, factories located in the Kanto plain and factories dispersed in Eastern Japan. The supply chain connection, parallel, series and mixed are considered. The damage probability of factories and their BIT are calculated based on the seismic risk of different locations. The annual exceedance probability (AEP) of BIT of these location and supply chain types are calculated and compared. Through combining these factors a realistic risk analysis method for evaluating business interruption is proposed and is proven to be functional. This method may be applied for strategic location planning of supply dependent enterprises who wish to minimize their risk. Also alternative options to decrease the BIT are proposed.

2. BUSINESS INTERRUPTION TIME AS THE CRITICAL FACTOR IN BCP

There are two main objectives for enterprises to draw BCP[2)] (Fig.2.1). First, to avoid the total halt of operations, even in case of disasters and maintain the minimal level of operations for business continuity. Second, to resume the operations to pre-disaster level within an acceptable timeframe from the viewpoint of corporate management in the competitive market.

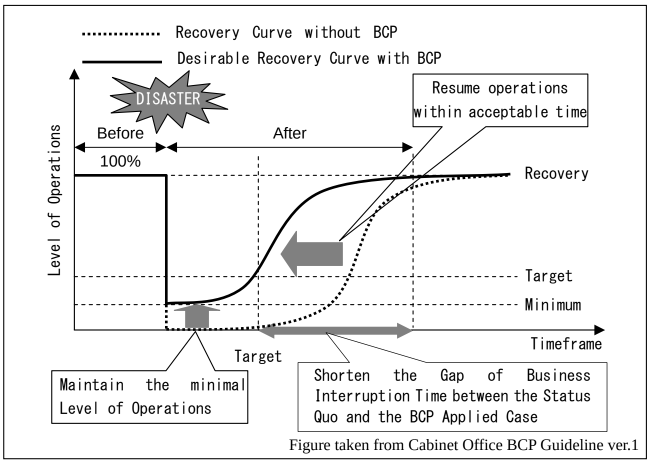


Fig.2.1 The Overall Concept of Business Continuity Planning

Let us suppose that a factory was hit by an earthquake. For the user of the product of the factory, his biggest interest would be when the factory would resume supply to him. If he sees that he cannot expect the supply within the period he can wait, he will search for an alternative product or manufacturer. If the user decides that he cannot wait anymore, the factory will lose the user. Even if the factory resumes production afterwards, since the previous user is already taken by other manufacturer, the enterprise who runs the factory will have to pay marketing efforts to regain the user or to find new customers, which will require additional marketing costs. The longer the BIT, the marketing cost necessary will augment. If the BIT of the factory is further prolonged, the enterprise may no longer be able to return to the market. Thus BIT is an important factor for business continuity of an enterprise.

2. STRUCTURE OF THE RISK EVALUATION METHOD OF BIT

There has been previous proposal and study on a method to evaluate earthquake damage risk of an enterprise who possesses a portfolio of multiple building assets in various locations[3)]. This method, by generating numerous possible scenario earthquakes (hereinafter earthquake events), estimates possible damage to the individual buildings and by summation of these damages calculates the damage risk of the portfolio. By expanding this methodology, 1) BIT of individual nodes of a SC is calculated according to each earthquake event and 2) by combining the results of BIT of individual nodes according to the SC patterns, thus generating event trees, the BIT of the SC dependent enterprise will be obtained.

2.1 Business Interruption Time of Individual Node

BIT of individual node *j* by earthquake event *i* shall be represented as $t_j(i)$ and is defined by Eqn.2.1 as follows.

$$t_j(i) = \sum_{k=0}^{4} [p_{j,k}(i) \cdot t_{j,k}(i)] \qquad (2.1)$$

k is the variable representing levels of damage as follows,
k=0: no damage, *k*=1: slight damage, *k*=2: moderate damage, *k*=3: severe damage, *k*=4: collapse.
$t_{j,k}(i)$ represents BIT of node *j* by event *i* according to level of damage *k*.
$p_{j,k}(i)$ represents conditional probability of $t_{j,k}(i)$.
$p_{j,k}(i)$ is drawn from the fragility curve of individual node *j*.

2.2 Business Interruption Time of Supply Chain

BIT of SC by earthquake event *i* shall be represented as $t_{SC}(i)$ and is defined by Eqn.2.2 as follows.

$$t_{SC}(i) = \sum_{l=1}^{N} f[\mathbf{p}_l(i)] \cdot g[\mathbf{t}_l(i)] \qquad (2.2)$$

l is the variable representing individual end-branches of event trees.
N is the total number of end-branches.
$\mathbf{t}_l(i)$ represents the vector composed from $t_{j,k}(i)$ for end-branch case *l*.
$\mathbf{p}_l(i)$ represents the vector of conditional probability corresponding to $\mathbf{t}_l(i)$.
$f[\cdot]$ represents the conditional probability of occurrence of end-branch case *l* and is defined by Eqn.2.3 as a function of $\mathbf{p}_l(i)$.

$$f[\mathbf{p}_l(i)] = p_{1,k1} \times p_{2,k2} \times \cdots \times p_{n,kn} \qquad (2.3)$$

n represent the number of nodes composing the SC.
$g[\cdot]$ represents the BIT of SC for each end-branch and is a function of $\mathbf{t}_l(i)$. This function is determined by the connection pattern of the nodes of the SC. For a series SC the maximum, for a parallel SC the minimum, is chosen.

Fig.2.2 shows the outline of evaluation of BIT for each earthquake event. Fig.2.3 shows the procedure of the proposed BIT risk evaluation method. In order to consider the uncertainties, a Monte-Carlo simulation with ground motion strength and building strength as stochastic variables is applied.

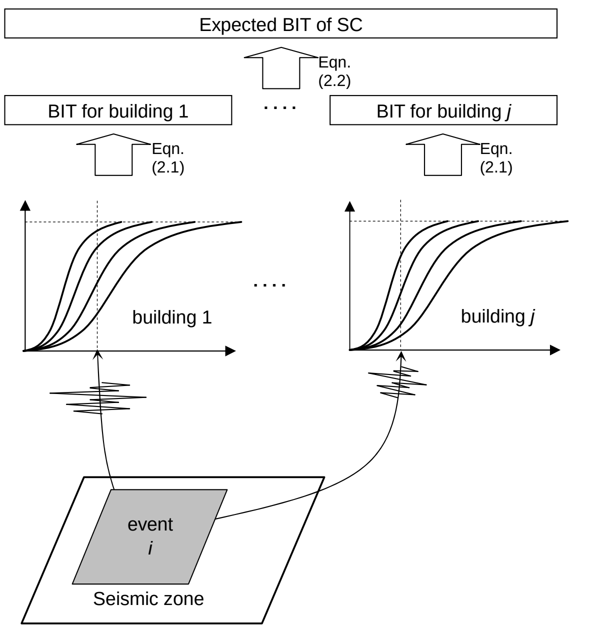


Fig.2.2 Outline of Evaluation Process of BIT of SC

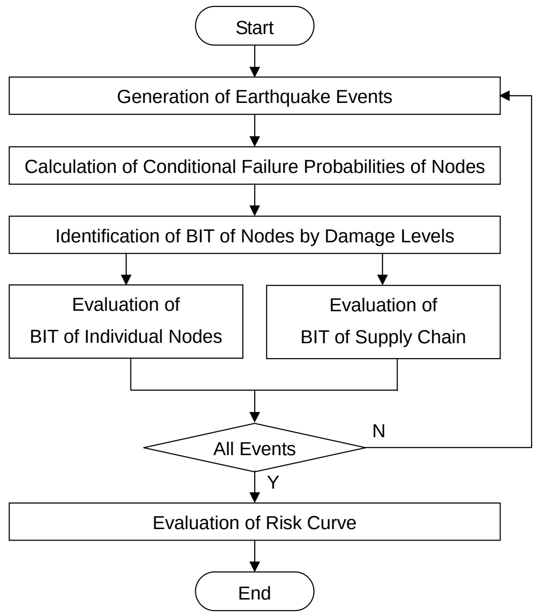


Fig.2.3 Flowchart of Risk Analysis of Supply Chain

3. APPLICATION TO MODEL SUPPLY CHAIN

3.1 Setting of Model Supply Chain

Five nodes(factories) located in three location types, A: factories concentrated in Tokyo (Fig.3.1), B: factories located in the Kanto plain (Fig3.2) and C: factories dispersed in eastern Japan (Fig.3.3) were set as examples. Based on the previous findings in Ref.4) and Ref.5), the seismic strength of each nodes and BIT by damage level were set as shown in Table 3.1. Fig.3.4 shows the three connection patterns of the five nodes, series, parallel and mixed, as model SCs.

3.2 Setting of Seismic Activity Model

Seismic activity zone model was set according to Ref.6). Fig.3.5 shows the location of seismic sources and the seismic parameters are shown in Table 3.2. With reference to Annaka & Yashiro [7)] attenuation relation of ground motion was calculated following the Annaka Model as shown in Eqn.3.1.

$$\begin{aligned} \log a &= 0.61M + 0.00501h - 2.203\log d + 1.377 \\ d &= \sqrt{\Delta^2 + 0.45h^2} + 0.22\exp(0.699M) \end{aligned} \qquad (3.1)$$

a stands for maximum ground acceleration, Δ for distance from the epicenter,
h for depth of seismic source, M for magnitude of the earthquake event.

Logarithmic standard deviation representing the variability of the range attenuation was set at natural logarithm 0.5.

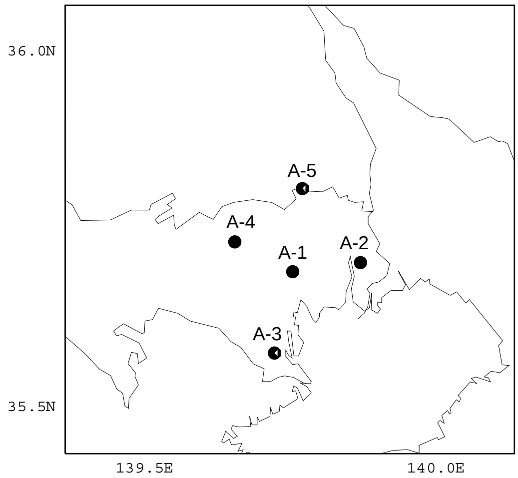


Fig.3.1 Location A: Tokyo Concentration

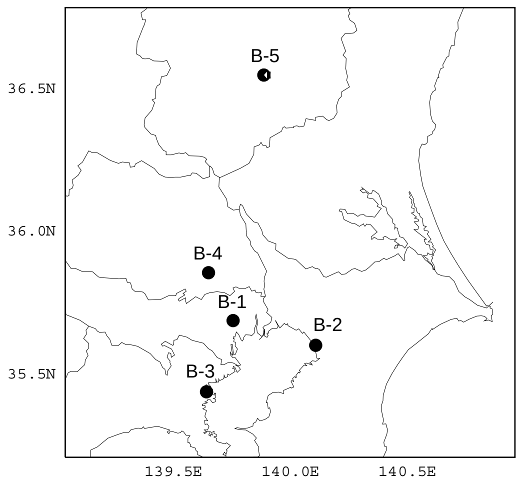


Fig.3.2 Location B: Kanto Plain

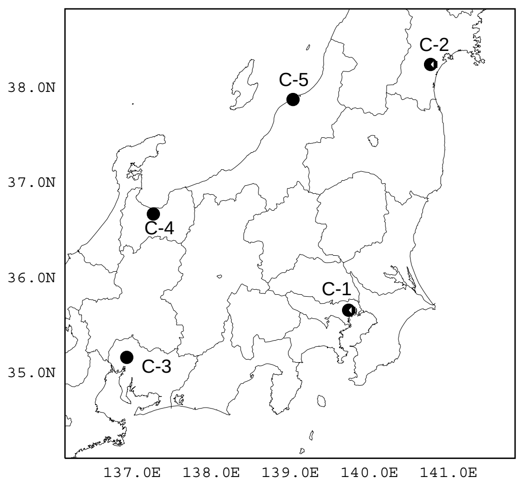


Fig.3.3 Location C: Eastern Japan

Table 3.1 Fragility Curve and BIT by Level of Destruction

Damage Level	Characteristic Values of Fragility		BIT (day)
	Median (cm/s/s)	Log-normal Std. Deviation	
Slight	200	0.4	3
Moderate	600	0.4	15
Severe	1000	0.4	60
Collapse	1400	0.4	180

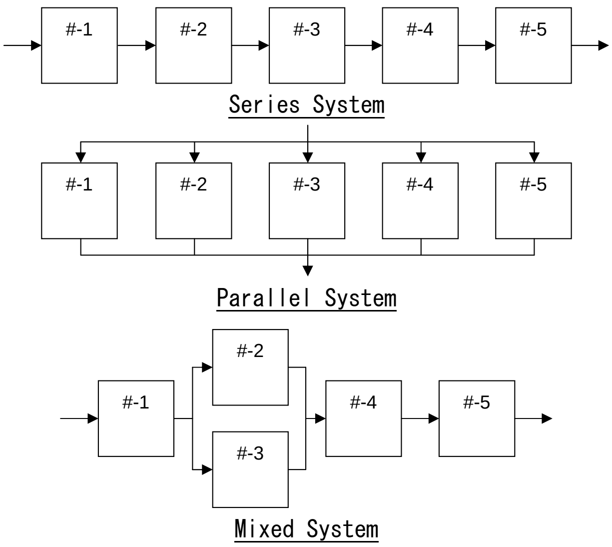


Fig.3.4 Supply Chain Pattern Models

Table 3.2 Parameters of Seismic Sources

Source Number	Range of M	Return Period (years)	Source Number	Range of M	Return Period (years)	Source Number	Range of M	Return Period (years)
th07	6.9-7.3	2 160	th11	6.8-7.2	3 380	th12	6.9-7.3	7 210
th13	7.0-7.5	2 040	th14	6.6-7.0	4 640	th15	6.8-7.2	5 930
th16	7.0-7.6	2 030	th17	6.9-7.3	1 710	-	-	-
kt01	7.0-7.5	2 030	kt02	7.0-7.6	1 180	kt03	6.9-7.3	5 210
kt04	7.0-7.4	79 300	kt05	6.8-7.2	5 930	kt06	7.1-7.5	2 840
kt07	7.0-7.4	2 640	kt08	6.8-7.2	5 680	kt09	7.1-7.5	8 710
kt10	6.6-7.0	1 370	kt11	6.9-7.3	7 240	kt12	7.5-7.9	1 630
cb01	7.1-7.5	9 120	cb02	7.2-7.6	10 800	cb03	7.0-7.4	2 630
cb04	7.0-7.4	2 400	cb05	7.1-7.5	9 500	cb07	6.8-7.2	5 960
cb09	7.1-7.5	2 850	cb10	8.1-8.5	1 070	cb11	7.4-7.8	1 090
cb12	7.0-7.4	2 400	cb13	7.2-7.6	1 070	cb14	7.6-8.0	1 820
cb15	7.0-7.7	1 160	cb16	7.3-7.7	3 700	cb17	7.3-7.7	3 620
cb18	7.5-7.9	5 020	cb19	7.6-8.0	1 820	cb20	7.7-8.1	2 210
cb21	7.0-7.7	1 090	cb22	7.1-7.5	9 640	cb23	7.1-7.5	8 940
cb24	7.3-7.7	12 000	cb25	7.7-8.1	7 060	cb26	7.1-7.5	9 400
cb27	7.7-8.1	1 940	cb28	6.9-7.3	6 890	cb29	6.9-7.3	6 770
cb30	7.1-7.5	2 830	cb31	7.1-7.5	8 650	cb32	7.1-7.5	880
cb33	6.8-7.2	1 920	cb34	7.1-7.5	8 490	cb35	6.4-6.8	32 700
kk01	6.8-7.2	6 350	kk02	7.1-7.5	8 770	kk03	7.0-7.4	7 750
kk04	7.1-7.5	8 680	kk05	7.0-7.6	1 170	kk06	7.1-7.5	9 030
e4	7.4-7.8	400	e5	7.3-7.7	400	-	-	-
j5	7.3-7.7	40	j6	7.4-7.8	400	j7	7.8-8.2	400
s1	7.8-8.2	200	s2	7.8-8.2	1 000	s3	7.3-7.7	630
n1	7.6-8.0	130	n2	7.9-8.3	130	-	-	-

Source Number	Range of M	A Value in G-R Equation	Source Number	Range of M	A Value in G-R Equation	Source Number	Range of M	A Value in G-R Equation
c08	5.0-7.0	2.34	c09	5.0-7.0	4.23	c10	5.0-7.5	4.32
c11	5.0-7.0	1.65	c12	5.0-7.0	2.34	c14	5.0-7.5	4.51
c15	5.0-7.0	3.69	c18	5.0-7.0	3.39			

注：b-Value in G-R equation for sources c08, c09, c10, c11, c12, c14, c15 and c18 is set at 0.9

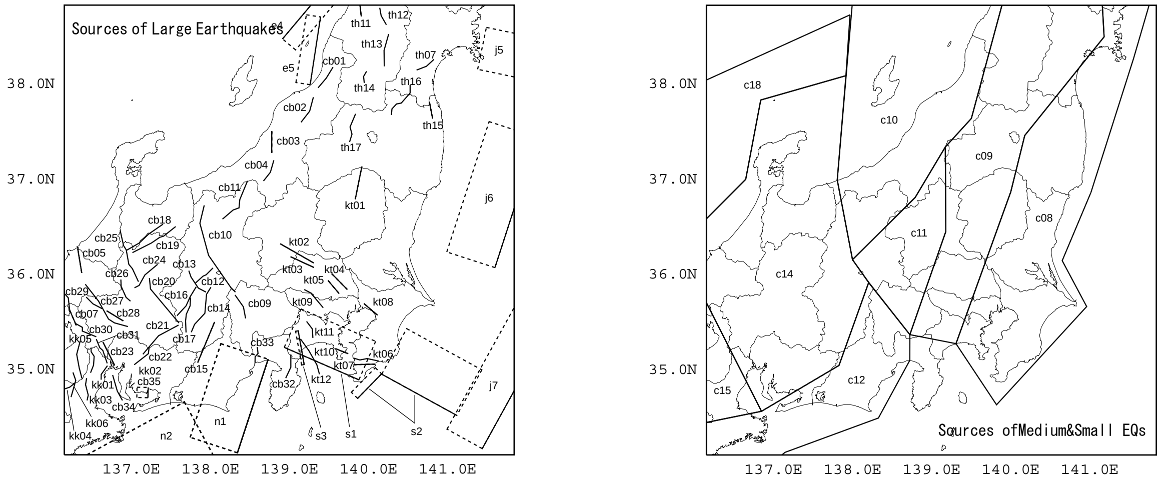


Fig. 3.5 Location of Seismic Sources

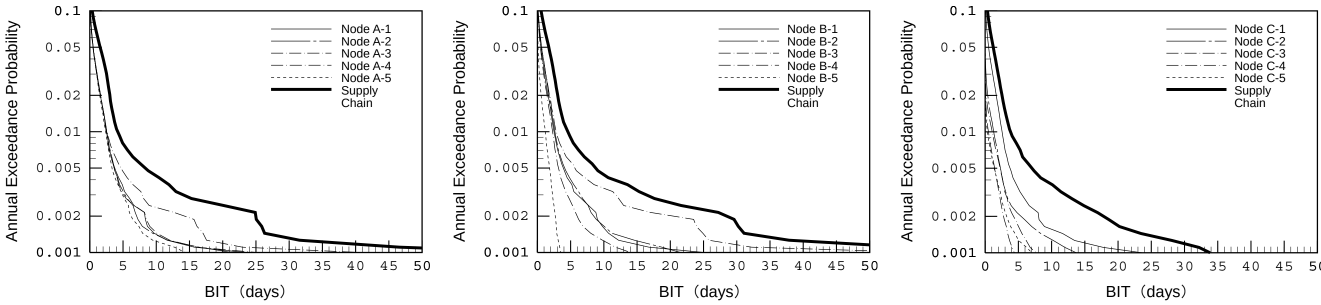
4. BIT RISK CURVE OF MODEL SUPPLY CHAIN

Risk Curve of BIT for the Series Model SC is shown in Fig.4.1. Risk Curve of BIT for the Parallel Model SC is shown in Fig.4.2. Risk Curve of BIT for the Mixed Model SC is shown in Fig.4.3. In these figures, the horizontal axis shows the 90 percentile exceedance of BIT(days), the vertical axis shows the AEP. The bold line shows the risk curve of the SC, the thin lines show the risk curve of the different nodes.

In Series SC, if one or more of the five nodes suffers damage, the SC halts. Therefore, as shown in Fig.4.1, the risk curve of the SC is larger than any of the individual risk curve of the different nodes in all locations A, B and C. When we compare the risk curves of the three location patterns, C<A<B. Risk curve of location in Kanto plain B is larger than concentration in Tokyo A, since the possibility of one of the nodes in Kanto plain being hit by an earthquake is relatively high, due to the fact that Kanto plain has many seismic sources distributed. Risk curve of distribution in eastern Japan C is smaller than others since 4 out of the 5 nodes are located outside the Kanto plain.

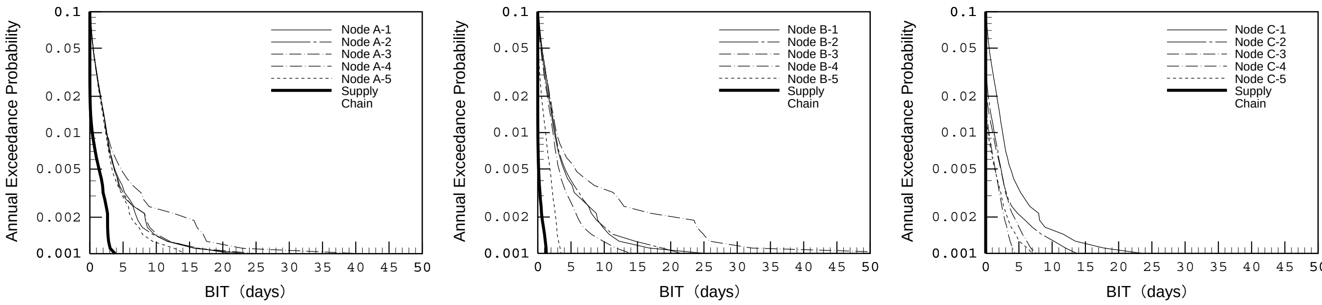
In Parallel SC, the SC halts only when all five nodes suffer damage at the same earthquake event. Therefore, as shown in Fig.4.2, the risk curve of the SC is smaller than any of the individual risk curve of the different nodes in all locations A, B and C. When we compare the risk curves of the three location patterns, C<B<A. The more the nodes are geographically dispersed, the parallel SC has greater redundancy and the halt risk of SC becomes smaller. In location pattern C the expected BIT of SC is zero, since the possibility of all five nodes dispersed in eastern Japan being hit by a same earthquake event is zero.

In Mixed SC, if one of the nodes out of #1, #4 and #5 suffer damage, the SC halts. If both nodes #2 and #3 suffer damage at the same earthquake event, the SC halts. When we compare the risk curves of the three location patterns, C<B<A. Since nodes #2 and #3 are alternates, the more the two are geographically dispersed; the halt risk of SC becomes smaller. When we compare location A and B, the possibility of nodes B-2 and B-3 suffering damage at the same earthquake event is smaller than the possibility of nodes A-2 and A-3 suffering damage at the same earthquake event. Therefore, although location B has nodes in Kanto plain where many seismic sources are distributed, the risk curve of SC is smaller than that of location A. This is different from the Series SC and this indicates that provision of alternate node contributes to decreasing the risk of a series SC. When we compare the risk curve of the Series SC and Mixed SC for location B, in Series SC the risk curve of SC is greater than the risk curve of node B-3, by providing node B-2 as alternative and making Mixed SC, the risk curve of Mixed SC is much smaller than the risk curve of node B-3. Node B-3 is Yokohama which has the highest possibility, among all the nodes in this example, of being hit by earthquakes and may become the bottleneck in the Series SC. This indicates that in order to decrease the risk of a series SC, providing alternative node to the most vulnerable node and locating it away from the original node would be a good solution.



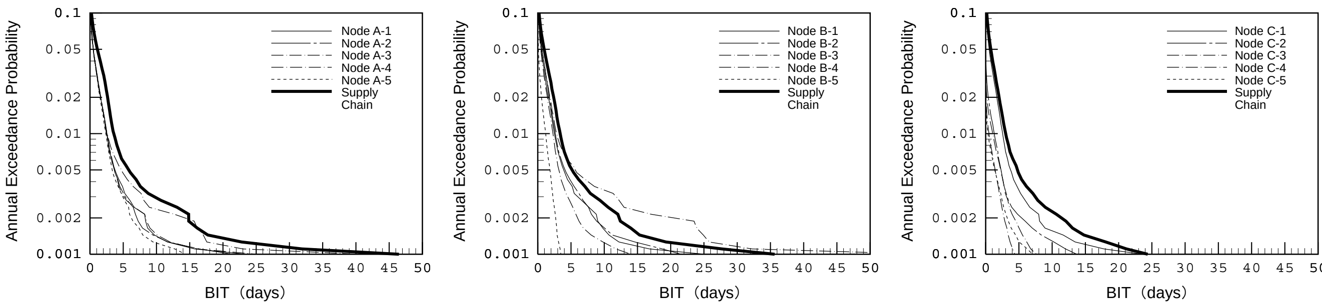
Location A : Tokyo Concentration | Location B : Kanto Plain | Location C: Eastern Japan

Fig. 4.1 BIT Risk Curve of Series SC



Location A : Tokyo Concentration | Location B : Kanto Plain | Location C: Eastern Japan

Fig. 4.2 BIT Risk Curve of Series SC



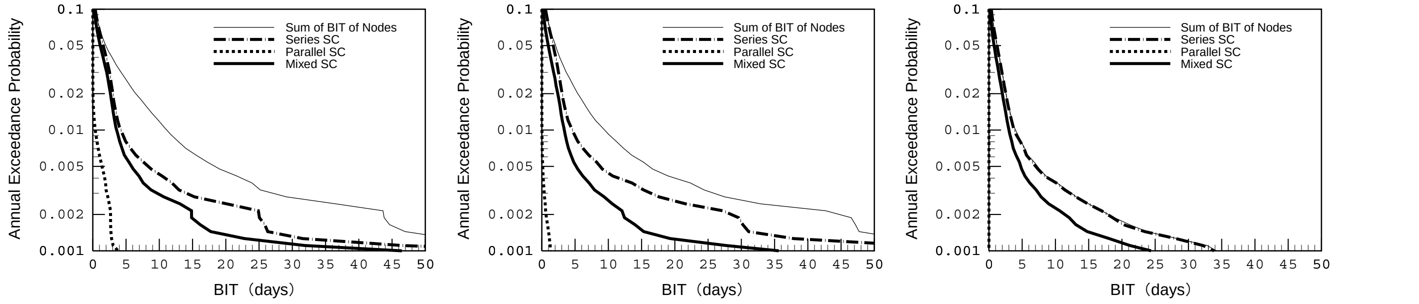
Location A : Tokyo Concentration | Location B : Kanto Plain | Location C: Eastern Japan

Fig. 4.3 BIT Risk Curve of Mixed SC

5. ANALYSIS OF THE RELATION BETWEEN THE LOCATION OF NODES AND BIT RISK CURVE

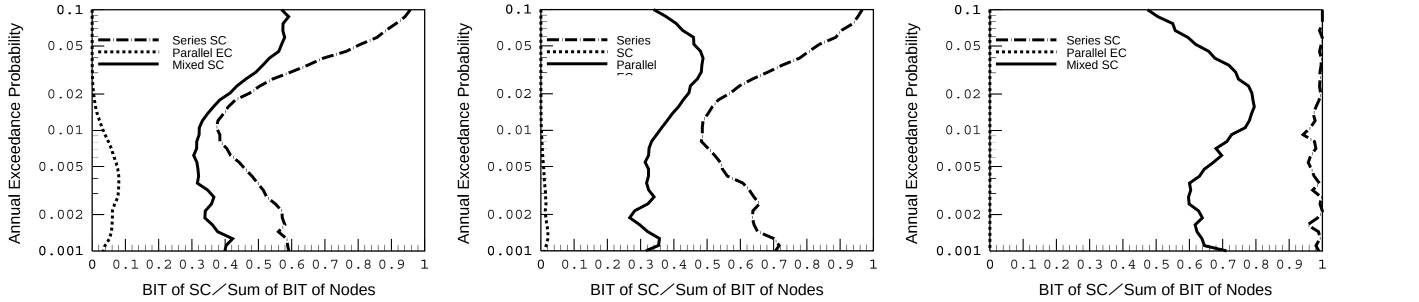
In addition to the location of the nodes (including the possibility of multiple nodes hit by the same earthquake) and the supply chain patterns, the earthquake environment of the location of the individual nodes is another factor of the BIT risk curve. In order to exclude the third factor and examine the influence of the former two factors to the BIT risk curve, comparison of the sum of the BIT of individual nodes and the BIT of SC is shown in Fig.5.1.

In Series SC, as the nodes are geographically dispersed, the BIT of SC becomes closer to the sum, and in Location C the two curves overlap. In Location C, the nodes in SC are influenced by individual earthquakes, and the SC halts if one of the nodes stops. In Location A, since there are cases which an earthquake affects multiple nodes, the BIT of SC is smaller than the sum. In Parallel SC, in all three location types, BIT of SC is far smaller than the sum, and as the nodes are geographically dispersed, BIT of SC nears to zero. The Mixed SC risk curve, in the domain where the AEP is larger than 0.01, nearly overlaps the Series SC, whereas, in the domain where AEP is smaller than 0.01, shows intermediary nature of the Series SC and Parallel SC. Fig.5.2 shows the ratio of BIT of SC against the sum of the BIT of individual nodes.



Location A : Tokyo Concentration | Location B : Kanto Plain | Location C: Eastern Japan

Fig. 5.1 Comparison of BIT of SC and the Sum of BIT of Individual Nodes



Location A : Tokyo Concentration | Location B : Kanto Plain | Location C: Eastern Japan

Fig.5.2 The Ratio of BIT of SC against the Sum of the BIT of Individual Nodes

6. CONCLUSION

The proposed method enables the BIT risk curve analysis of SCs composed of multiple nodes in different geographical locations. BIT of different types of SCs, Series, Parallel and Mixed, can be quantitatively analyzed and be compared according to the various locations of the nodes. Therefore the enterprises dependant on SCs for their operations can quantitatively compare the earthquakes risks from one location pattern to another. They can also identify the most critical node in the Series SC, and evaluate the reduction of the risk by providing additional alternative node to that node, and furthermore evaluate the risk reduction according to the location of this alternative node. Three location patterns were applied; however this method may be applied to other locations provided that the seismic source data is available. Also the SC patterns can be expanded to various combinations.

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