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A RESOURCE ALLOCATION PROBLEM FOR THE BUSINESS CONTINUITY PLAN IN THE SUPPLY CHAIN NETWORK

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Abstract. *In Business Continuity Management (BCM), each organization assesses risk caused by natural disasters and prepares its critical processes to continue its operation at the acceptable level. Recently many natural disasters caused large scale disruptions to the global supply chain networks and more companies are now trying to establish its disaster readiness by adopting BCM strategy. In this paper, we develop a resource allocation model that minimizes the loss of business resilience during BCM recovery plan. The proposed model is a variant of the multi-commodity network flow model in the time-level expanded network. Some computational results are shown to validate the proposed model.*
Keywords: Business Continuity Management, Business impact analysis, Loss of resilience, Resource allocation

1. **Introduction.** Recently we observed several incidences where the natural disasters include hurricane, earthquake, and fire disrupt manufacturing and supply chain networks in global scale. In 2005, Hurricane Katrina stopped oil refineries, and caused coffee and lumber shortages and rerouting of fresh produce delivery. In 2001, fire in Phillips semiconductor plant almost stopped the Ericsson and earthquakes in Taiwan in 2009 and 2010 disrupted semiconductor and electronic parts industry. In 2011 Great Tohoku Earthquake and Tsunami, automotive electronics part suppliers in the area were greatly impacted and the disruption causes the stopping of production of Japanese automakers inside Japan as well as oversea plants in USA and UK [1]. In these natural disasters, the companies that have well prepared contingency planning recover their operation quicker than other companies: Home Depot reopens their stores in the hurricane impact zone in one day and Wal-Mart prepared with the prepositioned inventory in non-affected area. Supply chain disruption is an event that disrupts the flow of goods or services in a supply chain and the consequences are financial, market, and operational performance of the organizations [2].

To operate with the disruption risk, supply chain network must have a capability of quick recovery by preparing the disruption readiness through efficient and effective response. A resilient organization has a capability of returning to the normal state after a disruption event. Most of supply chain firms recognize the need for resilient supply chain to mitigate the negative impact of supply chain disruptions. Specifically, supply chain resilience corresponds to the capability of i) anticipating the occurrence of disruptions to monitor supply chain components, ii) overcoming disturbances to normal operation while maintaining an acceptable performance, and iii) returning to normal operation, restoring desired operation [3].

Business Continuity Management (BCM) is a type of risk management that deals with business interruptions caused by natural disasters. Precursor of the BCM is the information technology disaster recovery (ITDR). BCM tries to minimize operational interruption caused by external disasters. Nowadays the organization's preparedness is audited and assessed how the organization prepared for business disruptions to minimize the impact and protect the key stakeholder's interests. Business continuity methods standards BS25999 and ISO22301 are published by British Standards Institution (BSI) and International Standard Organization, respectively. ISO22301 sets the requirements for implementing, operating and improving the BCM systems and provides guidelines to processes and principles of BCM [4]. In this paper, we describe Business Impact Analysis (BIA) and recover planning in BIA and develop an integer programming model that finds best recovery plan minimizing the loss of resilience and show some computational results.

This paper is organized as follows. In Section 2, concepts and components of BCM are introduced and the loss of resilience is explained. In Section 3, we formulate a mathematical model for resource allocation to minimize the loss of business resilience during BCM recovery plan. In Section 4, we illustrate the recovery plan obtained from the proposed model applied to a scenario with multiples CPs with different recovery objectives and Section 5 concludes the paper.

2. **Business Continuity Management and Resilience.** BCM lifecycle includes five steps: classification of risk, causes of disruption, and risk assessment; business impact analysis (BIA), establishing BCM strategy; implementing BCM Plan; finally test and assessment. These are illustrated in Figure 1.

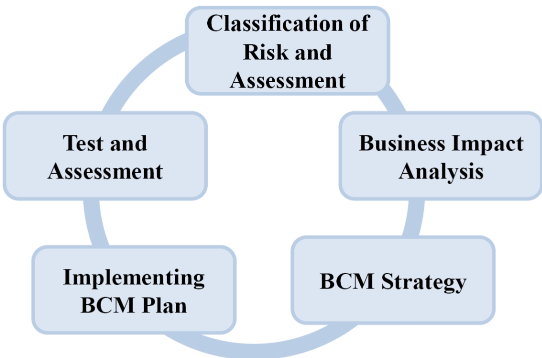


FIGURE 1. BCM lifecycle

The identification of resources and recover plan for supply chain recovery is mostly described in BIA. In BIA, core products or services of the organization are identified and ranked according to the organization's strategic goals. Next, critical processes (CP) for each core product are determined/ranked, and essential resources for each CP are identified. Identification and ranking of the core (products, processes, resources) can be aided by various methods including multi-criteria decision analysis tools such as analytic hierarchy process (AHP), work breakdown structure (WBS) method, operation process charts, information from the material requirements planning (MRP) systems. For each critical processes, BIA determines recovery time objective (RTO), recovery point objective (RPO), maximum tolerable period of disruption (MTPD), and minimum business continuity objective (MBCO). RTO is the length of the tolerable period during which the firm can continue to operate its core activities when the disruption happens. RPO is the operating level during RTO period. At the end of RTO, recovery starts and the firm's operating level tries to increase to its normal level. MTPD reflects the revenue loss effect

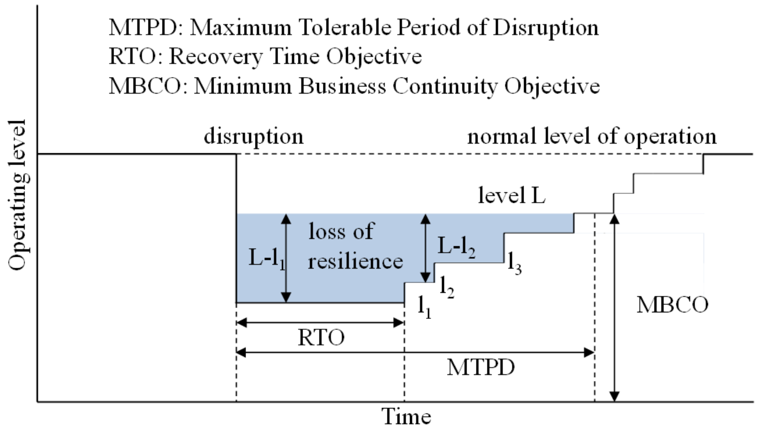


FIGURE 2. Business continuity terminologies

for each critical product, current inventory level and the financial liquidity of the firm. MBCO is set considering the firm's strategic, operational goals. With MBCO and MTPD set, recovery strategy and resource allocation procedures are planned. These terms are illustrated in Figure 2. In Figure 2, shaded area is called the loss of resilience or resilience triangle [5]. Many recovery plans in BCM try to minimize the loss of resilience area for the quick recovery.

3. **Mathematical Model for BCM Plan.** In this section, we introduce a mathematical model formulating resource allocation problem for multiple critical processes trying to reach MBCO level of operation during MTPD time periods. During BIA, we identified K critical processes and its P resources and BCM planning horizon is set between $[0, T]$. We suppose that a critical process k's normal operating level is at L and when a disruption d occurs, operating level is reduced to the level l_k^d. We denote CP k's MBCO and MTPD as γ_k and ξ_k, respectively. Suppose that with recovery effort during $[t_1, t_2]$, the level increases to l_2 at t_2. If this recovery process continues at times $t_2, t_3, \ldots, t_n$ and the levels increase to $l_3, l_4, \ldots, l_n$, then the loss of resilience (LR) in Figure 2 is computed as $LR = \sum_{i=1}^{n} \Delta_i$, where $\Delta_i = (L - l_i)(t_{i+1} - t_i)$.

In Figure 3, we denote two time instances t_i and t_j with their operating levels l_i and l_j. Each circle in Figure 3 represents a (time, level) pair and we call this pair as a node $i = (t_i, l_i)$. The resource cost c_{ijk}^p was paid between two nodes i and j and $s_{ij}^k = (L - l_i)(t_j - t_i)$ denotes LR region in interval $[t_i, t_j]$. In the following, indices i, j always denote above (time, level) pairs. We denote R_{pt} as the amount of resource available at time t. The resources considered in this paper are number of personnel, area of facility, number of equipment, or monetary unit. We suppose that R_{pt} is an increasing function of time while the unit recovery cost c_{ijk}^p is a decreasing function of time. The recovery planning process is to select resources for recovering from level l_1 to level ξ_k during MTPD for each critical process k. The equivalent mathematical model (RP) is the following integer program.

$$\text{Minimize } \sum\nolimits_i \sum\nolimits_j \sum\nolimits_k s_{ij}^k x_{ijk}$$

subject to

$$\sum\nolimits_j x_{ijk} - \sum\nolimits_j x_{jik} = \begin{cases} 1 & t_i = 1,\ l_i = l_k^d \\ -1 & t_i = T,\ l_i = L \\ 0 & \text{otherwise} \end{cases} \quad \forall i, k$$

$$\sum\nolimits_i \sum\nolimits_{j \in S_k} x_{ijk} \geq 1 \quad \forall k$$

$$\sum\nolimits_{k \in K(p)} \sum\nolimits_{i:t_i = t} \sum\nolimits_j c_{ijk}^p x_{ijk} \leq R_{pt} \quad \forall p, t$$

$$x_{ijk} \in \{0,1\} \quad \forall i,j,k,$$

where $S_k = \{j | l_j \geq \xi_k, t_j = \gamma_k\}$ and $K(p)$ denotes the set of critical processes that use the resource p.

Problem (RP) is a variant of multi-commodity network flow model with additional constraints. Due to the resource allocation nature of the model, all variables are binary variables. In (RP), each node is a (time, level) pair and each arc connects these nodes in (time, level) expanded network as illustrated in Figure 3.

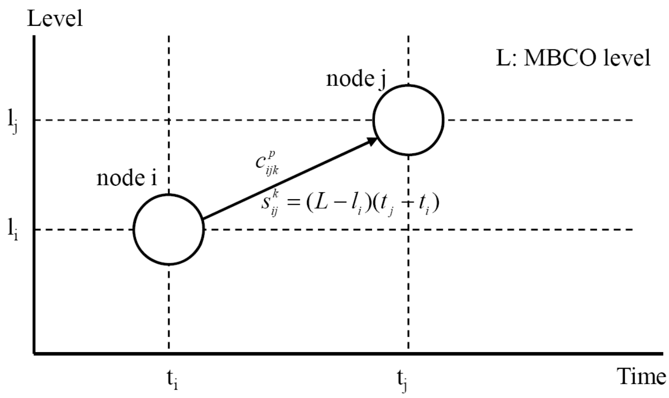


FIGURE 3. Time-level expanded network

4. **Computational Results.** In the computation, we consider a scenario where 5 critical processes (CP) are recovered using 6 resources during $[1, 13]$ time intervals between levels 1 to 10. Each CP has its own MTPD and MBCO goals. We generated random cost parameters c^p_{ijk} and random resource availability R_{pt}. In the first set of data, we set R_{pt} grows 5% in each time period and in the second set of data, R_{pt} grows 20% per each time period with much lower initial value than the first one.

In the time-level expanded network, we assume each node has six outgoing arcs depicted in Figure 4. We assume that costs $c_1 > c_2 > c_3 > c_4 > c_5 > c_6$ and each cost c_j is a decreasing function of time and level. Table 1 shows the objective values of the problem (RP) and its linear programming (LP) relaxation. For two cases, the LP relaxation bound is relatively tight. In each data set, next to LP objective bound, initial values of R_{pt}, MTPD and MBCO values for five critical processes are shown. Figure 5 shows the recovery plan for two data sets in Table 1. Compared with the data set 1, MBCO of the data set 2 in Figure 5(b) is lower than data set 1 in Figure 5(a).

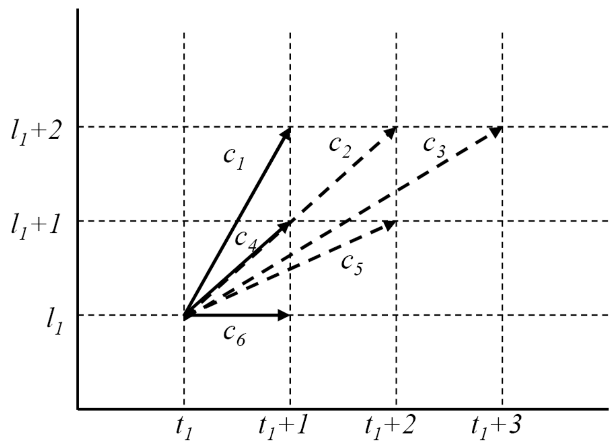
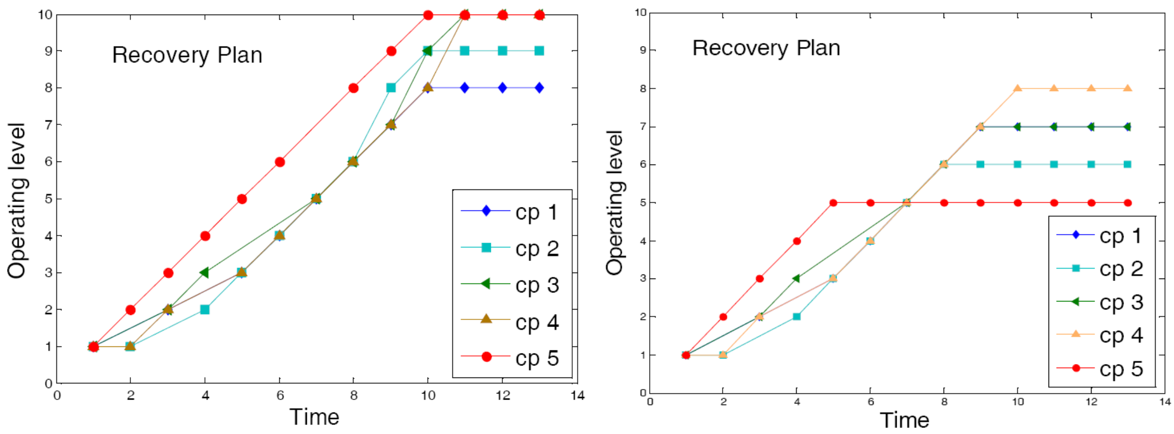


FIGURE 4. List of outgoing arcs



(a) Data set 1 (b) Data set 2

FIGURE 5. Recover plan using data sets 1 and 2

TABLE 1. Computational results

Data set 1	Obj. value (RP)	289.0
	Obj. value (LP)	278.4
	R_{pt}	$\{250, 353, 424, 322, 730, 420\}$
	MTPD	$\{10, 11, 12, 13, 14\}$
	MBCO	$\{7, 8, 9, 8, 7\}$
Data set 2	Obj. value (RP)	335.0
	Obj. value (LP)	318.0
	R_{pt}	$\{250, 353, 424, 322, 730, 420\}$
	MTPD	$\{10, 11, 12, 13, 14\}$
	MBCO	$\{7, 8, 6, 8, 5\}$

5. **Conclusions.** Business impact analysis (BIA) is the most important step when implementing a business continuity plan and vast data collection and detailed analysis are required for a successful execution of BIA. The key parameters MTPD, MBCO of each critical process are estimated reflecting the organization's risk appetite level. In this paper, given key parameters of the recovery plan, we developed a variant of the multi-commodity network optimization model to minimize the loss of resilience during BCM recovery plan.

The proposed model provides a general framework that can be applied to general BCM plan and the type of resources and the determination of MTPD and MBCO in the particular context of different supply chain organization requires organization-specific methodology. More tailored BIA methodology for specific organization categories will be a good future research direction.

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