Junzo Watada
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Editors



SMART INNOVATION, SYSTEMS AND TECHNOLOGIES 10

# Intelligent Decision Technologies

Proceedings of the 3rd International Conference on Intelligent Decision Technologies (IDT´2011)

Springer

Junzo Watada, Gloria Phillips-Wren, Lakhmi C. Jain, and Robert J. Howlett (Eds.)

Intelligent Decision Technologies

## Smart Innovation, Systems and Technologies 10

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# Intelligent Decision Technologies

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# Preface

Intelligent Decision Technologies (IDT) seeks an interchange of research on intelligent systems and intelligent technologies which enhance or improve decision making in industry, government and academia. The focus is interdisciplinary in nature, and includes research on all aspects of intelligent decision technologies, from fundamental development to the applied system.

The field of intelligent systems is expanding rapidly due, in part, to advances in Artificial Intelligence and environments that can deliver the technology when and where it is needed. One of the most successful areas for advances has been intelligent decision making and related applications. Intelligent decision systems are based upon research in intelligent agents, fuzzy logic, multi-agent systems, artificial neural networks, and genetic algorithms, among others. Applications of intelligence-assisted decision making can be found in management, international business, finance, accounting, marketing, healthcare, medical and diagnostic systems, military decisions, production and operation, networks, traffic management, crisis response, human-machine interfaces, financial and stock market monitoring and prediction, and robotics. Some areas such as virtual decision environments, social networking, 3D human-machine interfaces, cognitive interfaces, collaborative systems, intelligent web mining, e-commerce, e-learning, e-business, bioinformatics, evolvable systems, virtual humans, and designer drugs are just beginning to emerge.

In this volume we publish the research of scholars from the Third KES International Symposium on Intelligent Decision Technologies (KES IDT'11), hosted and organized by the University of Piraeus, Greece, in conjunction with KES International. The book contains chapters based on papers selected from a large number of submissions for consideration for the symposium from the international community. Each paper was double-blind, peer-reviewed by at least two independent referees. The best papers were accepted based on recommendations of the reviewers and after required revisions had been undertaken by the authors. The final publication represents the current leading thought in intelligent decision technologies.

We wish to express our sincere gratitude to the plenary speakers, invited session chairs, delegates from all over the world, the authors of various chapters and reviewers for their outstanding contributions. We express our sincere thanks to the University of Piraeus for their sponsorship and support of the symposium. We thank the International Programme Committee for their support and assistance. We would like to thank Peter Cushion of KES International for his help with

organizational issues. We thank the editorial team of Springer-Verlag for their support in production of this volume. We sincerely thank the Local Organizing Committee, Professors Maria Virvou and George Tsihrintzis, and students at the University of Piraeus for their invaluable assistance.

We hope and believe that this volume will contribute to ideas for novel research and advancement in intelligent decision technologies for researchers, practitioners, professors and research students who are interested in knowledge-based and intelligent engineering systems.

Piraeus, Greece
20–22 July 2011

Junzo Watada
Gloria Phillips-Wren
Lakhmi C. Jain
Robert J. Howlett

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# Part I
# Modeling and Method of Decision Making

# A Combinational Disruption Recovery Model for Vehicle Routing Problem with Time Windows

Xuping Wang, Junhu Ruan, Hongyan Shang, and Chao Ma

**Abstract.** A method of transforming various delivery disruptions into new customer-adding disruption is developed. The optimal starting time of delivery vehicles is analyzed and determined, which provides a new rescue strategy (starting later policy) for disrupted VRPTW. Then the paper considers synthetically customer service time, driving paths and total delivery costs to put forward a combinational disruption recovery model for VRPTW. Finally, in computational experiments, Nested Partition Method is applied to verify the effectiveness of the proposed model, as well as the strategy and the algorithm.

**Keywords:** VRPTW, combinational disruption, disruption management, rescue strategies, nested partition method.

## 1 Introduction

There are various unexpected disruption events encountered in the delivery process, such as vehicles break down, cargoes damage, the changes of customers' service time, delivery addresses and demands. These disruption events, which often make actual delivery operations deviate from intended plans, may bring negative effects on the delivery system. It is necessary to develop satisfactory recovery plans quickly for minimizing the negative effects of disruption events.

Vehicle routing problem (VRP), initially proposed by Dantzig and Ramser (1959), is an abstraction of the vehicle scheduling problem in real-world delivery systems. A variety of solutions for VRP have been put forward (Burak et al 2009), and a few researchers took delivery disruptions into account. Li et al (2009a, 2009b) proposed a vehicle rescheduling problem (VRSP), trying to solve the problem vehicle breakdown disruption. The thought of disruption management, which aims at minimizing the deviation of actual operations from intended plans with minimum costs, provides an effective idea to deal with unpredictable events (Jeans et al 2001). Several researchers have introduced the thought into logistics delivery field. Wang et al (2007) developed a disruption recovery model for the vehicle breakdown problem of

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VRPTW and proposed two rescue strategies: adding vehicles policy and neighboring rescue policy. Wang et al (2009a) built a multi-objective VRPTW disruption recovery model, studied the VRP disruption recovery model with fuzzy time windows (2009b), and carried out a further study on the vehicle breakdown disruption (2010). Mu et al (2010) developed Tabu Search algorithms to solve the disrupted VRP with vehicle breakdown disruption. Ding et al (2010) considered human behaviors to construct a disruption management model for delivery delay problem.

Existing literatures have produced effective solutions for disrupted VRP with some certain disruption event, but the existing models and algorithms can handle only a certain type of uncertainty. It is difficult to solve actual vehicle routing problems with the reality that various disruption events often occur successively or even simultaneously. The purpose of the paper is to develop a common disruption recovery model for VRPTW, which may handle a variety and a combination of disruption events. Meanwhile, existing models for disrupted VRP did not consider the optimal starting time of delivery vehicles. Vehicles may arrive at delivery addresses early, but they can not serve until customers' earliest service time. If the starting time is optimized for each vehicle, waiting costs may be reduced and a new rescue strategy may be provided for some disruption evens.

The paper is organized as follows. A transformation method of delivery disruption events is developed in Section 2. Section 3 determines vehicles' optimal starting time from the depot. Section 4 builds a combinational disruption recovery model for VRPTW. In Section 5, computational experiments are given to verify the effectiveness of the proposed model. Conclusions are drawn in Section 6.

## 2 A Transformation Method of Delivery Disruption Events

### *2.1 Preview of VRPTW*

The original VRPTW studied in the paper is as follows. One depot has *K* delivery vehicles with the same limited capacity. A set of customers *N* should all be visited once in requested time intervals. Each vehicle should leave from and return to the central depot. The target is to determine the delivery plan with the shortest total delivery distance. Notations used in the following are defined in Table 1.

**Table 1** Notations for original VRPTW

| Notations | Meanings |
|---|---|
| $N$: | A set of customers, $N$={1,2,…,n} |
| $N_0$: | A set of customers and the depot, $N_0=\{0\}\cup N$ |
| $K$: | The total number of vehicles |
| $Q$: | The limited capacity of each vehicle |
| $c_{ij}$: | The distance between node $i$ and $j$, $i,j\in N_0$ |
| $t_{ij}$: | The travel time between node $i$ and $j$, $i,j\in N_0$ |
| $d_i$: | The demand of node $i$, $d_0=0$ |
| $ser_i$ | The service time at node $i$ |
| $q_{ijk}$: | The available capability of vehicle $k$ between node $i$ and node $j$ |
| $x_{ijk}$: | A binary variable; $x_{ijk}=1$ mens vehicle $k$ travels from node $i$ to node $j$; otherwise $x_{ijk}=0$ |
| $u_{ik}$: | A binary variable; $u_{ik}=1$ means that customer $i$ is served by vehicle $k$; otherwise $u_{ik}=0$ |
| $Rsta_i$: | The starting service time for customer $i$ |
| $[sta_i, end_i]$: | The time window of customer $i$; $sta_i$, earliest service time, $end_i$, latest service time |
| $M$: | A large positive number |

The mathematical model of above VRPTW is:

$$\min \sum_{k=1}^{K} \sum_{i=0}^{N_0} \sum_{j=0,\, j\neq i}^{N_0} c_{ij} x_{ijk} \tag{1}$$

*s.t.*

$$x_{ijk} = \{0,1\} \qquad i, j \in N_0, k \in \{1,...,K\} \tag{2}$$

$$u_{ik} = \{0,1\} \qquad i \in N, k \in \{1,...,K\} \tag{3}$$

$$\sum_{k=1}^{K} u_{ik} = 1 \qquad i \in N, k \in \{1,...,K\} \tag{4}$$

$$\sum_{k=1}^{K} u_{0k} = \sum_{k=1}^{K} u_{k0} \le K \quad k \in \{1,...,K\} \tag{5}$$

$$\sum_{l=0, i\neq l}^{N_0} x_{lik} = \sum_{j=0, i\neq j}^{N_0} x_{ijk} = u_{ik} \qquad i \in N_0, k \in \{1,...,K\} \tag{6}$$

$$\sum_{i=1}^{N_0} d_i \times u_{ik} - \sum_{j=1}^{N_0} q_{0jk} = 0 \qquad k \in \{1,...,K\} \tag{7}$$

$$q_{ijk} \le Q \times x_{ijk} \qquad i, j \in N_0, k \in \{1,...,K\} \tag{8}$$

$$Rsta_j \ge Rsta_i + ser_i + t_{ij} - (1 - x_{ijk}) \times M \qquad i, j \in N, k \in \{1,...,K\} \tag{9}$$

$$sta_i \le Rsta_i \le end_i \qquad i \in N \tag{10}$$

where the objective function (1) is to minimize total delivery distance; constraint (4) ensures each customer is served only once by one of the vehicles; (5) ensures each vehicle should leave from and return to the depot; (6) represents the vehicle which arrives at customer *i* should leave from customer *i*; (7) and (8) represent any vehicle shouldn't load more than its limited capability.

## *2.2 Delivery Disruption Events Transformation*

In order to develop a combinational disruption recovery model for VRPTW, the paper tries to transform different disruption events (involving the changes of customers' requests) into new customer-adding disruption event.

(1) Change of time windows

Assuming that the service time of customer *i* is requested earlier, its original time window [$sta_i$, $end_i$] will become [$sta_i$-$\triangle t$, $end_i$-$\triangle t$] where $\triangle t$ is a positive number. If $\triangle t$ is so small that the vehicle *k* planned to serve customer *i* can squeeze out some extra time longer than $\triangle t$ by speeding up, the request will be ignored. If $\triangle t$ is large and vehicle *k* can't squeeze out enough time, the request will be regarded as a disruption and customer *i* will be transformed into a new customer *i'* with time window [$sta_i$-$\triangle t$, $end_i$-$\triangle t$].

Assuming that the service time of customer *i* is requested later, its time window [$sta_i$, $end_i$] will be [$sta_i$+$\triangle t$, $end_i$+$\triangle t$]. If $\triangle t$ is relatively small and vehicle *k* can wait for the extra time at customer $i$ with the precondition that it will bring no effects on remaining delivery tasks, the request will be ignored and no disruption is brought to the original plan. If $\triangle t$ is large and vehicle $k$ can't wait for customer $i$, the request will be regarded as a disruption and customer $i$ will be transformed into a new customer $i'$ with time window [$sta_i+\triangle t$, $end_i+\triangle t$].

(2) Change of delivery addresses

If delivery addresses change, the original plan can't deal with the changes which will be regarded as disruptions. For example, the delivery coordinate $(X_i,Y_i)$ of customer $i$ is changed into $(X_i',Y_i')$, customer $i$ will be transformed into a new customer $i'$ with delivery coordinate $(X_i',Y_i')$.

(3) Change of demands

Changes of customers' demands include demand reduction and demand increase. The demand reduction of some customer won't bring disruptions on the original delivery plan. Vehicles can deliver according to their planed routing, so the demand reduction isn't considered as a disruption in the paper.

Whether the demand increase of customer $i$ will be regarded as a disruption depends on the occurrence time $t$ and the increase amount $\triangle d$. If vehicle $k$ which will serve customer $i$ has left from the depot at $t$ and no extra cargoes more than $\triangle d$ is loaded, the increase will be regarded as a disruption; If vehicle $k$ has left from the depot at $t$ and loads extra cargoes more than $\triangle d$, the increase would not be regarded as a disruption. If vehicle $k$ hasn't left from the depot at $t$ and can load more cargoes than $\triangle d$, there will be no disruption on the original plan ; If vehicle $k$ hasn't left from the depot at $t$ but can't load more cargoes than $\triangle d$, the demand increase is also looked as a disruption. After the demand increase being identified as a disruption, a new customer $i'$ whose demand is $\triangle d$ will be added.

(4) Removal of requests

Customers may cancel their requests sometimes because of a certain reason, but the planed delivery routing needs no changes. When passing the removed customers, delivery vehicles just go on with no service.

(5) Combinational disruption

Combinational disruption refers to that some of above disruption events occur simultaneously on one customer or several customers. For one customer $i$ with coordinate $(X_i,Y_i)$ and demand $d_i$, if its delivery address is changed into $(X_i',Y_i')$ and extra demand $\triangle d$ is requested, a new customer $i'$ can be added with coordinate $(X_i',Y_i')$ and demand $\triangle d$. For several customers, time window of customer $i$ is requested earlier, from [$sta_i$, $end_i$] to [$sta_i-\triangle t$, $end_i-\triangle t$]; delivery address of customer $j$ is changed, $(X_i,Y_i)\rightarrow(X_i',Y_i')$; extra demand $\triangle d$ is requested by customer $m$. The transformation of these disruptions is shown as Table 2.

**Table 2** Transformation of combinational disruption from multi-customers

| **Original customers** | **Disruption events** | **New customers** |
|---|---|---|
| $i$ | [$sta_i$, $end_i$] $\rightarrow$[$sta_i-\triangle t$, $end_i-\triangle t$] | $i'$: [$sta_i-\triangle t$, $end_i-\triangle t$] |
| $j$ | $(X_i,Y_i)\rightarrow(X_i',Y_i')$ | $j'$: $(X_i',Y_i')$ |
| $m$ | $d_m\rightarrow d_m+\triangle d$ | $m'$: $\triangle d$ |

**Note that:** After being transformed into new customers, original customers won't be considered in new delivery plan except the customers with demand increase disruption.

## 3 Determination of the Optimal Starting Time for Vehicles

Most existing researches on disrupted VRP assumed that all assigned vehicles left from the depot at time 0. Although delivery vehicles may arrive early at customers, they have to wait until the earliest service time, which will result in waiting costs. In fact, the optimal starting time of each vehicle can be determined according to its delivery tasks, which may decrease total delivery costs and provide a new rescue strategy for some disruption events.

Some new notations used in the following are supplemented. $N_k$: the set of customers served by vehicle $k$, $k\in\{1,...,K\}$; $w_i$: the waiting time at node $i$, $i\in N_k$; $BST_k$: the optimal starting time of vehicle $k$.

$[sta_i, end_i]$ is the time window of customer $i$; $t_{i\text{-}1,i}$ is the travel time between node $i$-1 and $i$. $Rsta_i$, the starting service time for customer $i$, equals to the larger between the actual arrival time $arr_i$ and the earliest service time $sta_i$, that is,

$$Rsta_i = \max\{arr_i, sta_i\},\ (i \ge 1, i \in N_k) \tag{11}$$

where $arr_i$ depends on the starting service time for node $i$-1, the service time at node $i$-1 and the travel time $t_{i\text{-}1,i}$ between node $i$-1 and $i$. Thus, the actual arrival time $arr_i$ at node $i$:

$$arr_i = Rsta_{i-1} + ser_{i-1} + t_{i-1,i},\ (i \ge 1, i \in N_k) \tag{12}$$

$w_i$, the waiting time at node $i$, equals to $Rsta_i$-$arr_i$. The waiting time which can be saved by vehicle $k$ is $\min\{Rsta_i\text{-}arr_i\}$, which will equal to 0 when $arr_i$ is bigger than $sta_i$ for all the customers in $N_k$.

When the actual finishing time $Rsta_i$+$ser_i$ is later than the latest service time $end_i$, the extra time at node $i$ will be 0. When $Rsta_i+ser_i \le end_i$, that is, the latest service time $end_i$ isn't due when vehicle $k$ finished the service for customer $i$, an extra time interval $[Rsta_i+ser_i, end_i]$ will exist. The total extra time of vehicle $k$ in the delivery process, $TFTL_k$, equals to:

$$\mathrm{TFTL_k} = \min\left\{\sigma[end_i - (Rsta_i + ser_i)]\right\},\ \sigma = \begin{cases} 0, & Rsta_i + ser_i > end_i \\ 1, & Rsta_i + ser_i \le end_i \end{cases};\ i \ge 1, i \in N_k \tag{13}$$

To sum up, the optimal starting time of vehicle $k$ can be calculated by the following conditions and equations:

(1) If the earliest service time of the first customer served by vehicle $k$ is earlier than or equal to the travel time from the depot to the customer, that is, $sta_1 \le t_{0,1}$, the optimal starting time of vehicle $k$ equals to 0, that is, $BST_k$=0.

(2) If $sta_1 > t_{0,1}$ and $\min\{Rsta_i\text{-}arr_i\}$=0, then

$$BST_k = (sta_1 - t_{0,1}) + TFTL_k, k \in \{1,...,K\} \tag{14}$$

(3) If $sta_1 > t_{0,1}$ and $\min\{Rsta_i\text{-}arr_i\}$>0, then

$$BST_k = (sta_1 - t_{0,1}) + \min\{\min\{Rsta_i - arr_i\}, TFTL_k\},\ i \in N_k, k \in \{1,...,K\} \tag{15}$$

## 4 Combinational Disruption Recovery Model for VRPTW

Disruption Management aims at minimizing the negative effects caused by unexpected events to original plans, so the effects should be measured quantitatively before being taken as the minimization objective, which is called disruption measurement. The effects of disruption events on VRPTW mainly involve three aspects: customer service time, driving paths and delivery costs (Wang et al 2009a).

In Section 2, the paper has transformed different disruption events into new customer-adding disruption event, so the disruption measurement on disrupted VRP, which will focus on measuring the new customer-adding disruption, is relatively simple. In disruption recovery plan, the number of customers, delivery addresses, time windows and other parameters may change, so some notations in original VRPTW are labeled as new notations correspondingly: $N_0 \to N_0'$, $x_{ijk} \to x_{ijk}'$, $sta_i \to sta_i'$, $Rsta_i \to Rsta_i'$, $end_i \to end_i'$, and so on. However, there are some notations unchanged, such as the number of vehicles $K$, the limited capability of vehicle $Q$.

(1) Disruption measurement on customer service time

The disruption on customers' service time refers to that the actual arrival time is earlier than the earliest service time or later than the latest service time. The service time deviation of customer $i$ is:

$$\lambda_1 (sta_i' - arr_i') + \lambda_2 (arr_i' - end_i'),\ \lambda_1, \lambda_2 \in \{0,1\} \tag{16}$$

where, if $arr_i' < sta_i'$, then $\lambda_1 = 1$ and $\lambda_2 = 0$; if $arr_i' > end_i'$, then $\lambda_2 = 1$ and $\lambda_1 = 0$; if $sta_i' \leqq arr_i' \leqq end_i'$, then $\lambda_1, \lambda_2 = 0$. The total service time disruption is:

$$\theta \sum_{i=1}^{N'} (\lambda_1 (sta_i' - arr_i') + \lambda_2 (arr_i' - end_i')),\ \lambda_1, \lambda_2 \in \{0,1\} \tag{17}$$

Where $\theta$ is the penalty cost coefficient of per unit time deviation.

(2) Disruption measurement on driving paths

Total driving paths disruption is:

$$\sigma \sum_{i=0}^{N_0'} \sum_{j=0}^{N_0'} c_{ij} (x_{ij}' - x_{ij}) + \mu \sum_{i=0}^{N_0'} \sum_{j=0}^{N_0'} (x_{ij}' - x_{ij}),\ i, j \in N_0', x_{ij}, x_{ij}' \in \{0,1\} \tag{18}$$

where $\sigma$ is delivery cost coefficient of per unit distance; $\mu$ is the penalty cost coefficient of increasing or reducing a delivery path; $x_{ij}$, $x_{ij}' \in \{0,1\}$, if there is a delivery path between node $i$ and node $j$, $x_{ij}=1$, $x_{ij}'=1$, otherwise, $x_{ij}=0$, $x_{ij}'=0$.

(3) Disruption measurement on delivery costs

Delivery costs depend on total travel distance and the number of assigned vehicles, so total delivery costs disruption is:

$$\sigma (\sum_{k=1}^{K} \sum_{i=0}^{N_0'} \sum_{j=0, j \neq i}^{N_0'} c_{ij} x_{ijk}' - \sum_{k=1}^{K} \sum_{i=0}^{N_0} \sum_{j=0, j \neq i}^{N_0} c_{ij} x_{ijk}) + \sum_{k=1}^{K} C_K (v_k' - v_k) \tag{19}$$

where $\sum_{k=1}^{K}\sum_{i=0}^{N_0'}\sum_{j=0,j\neq i}^{N_0'} c_{ij}x_{ijk}'$ represents the total delivery distance of the recovery plan; $\sum_{k=1}^{K}\sum_{i=0}^{N_0}\sum_{j=0,j\neq i}^{N_0} c_{ij}x_{ijk}$ represents the total delivery distance of the original plan; $C_k$ is the fixed cost of a vehicle and $\sum_{k=1}^{K} C_K(v_k'-v_k)$ represents the change of vehicle fixed costs, where $v_k$, $v_k'\in\{0,1\}$, if vehicle $k$ is assigned in the original plan or in the recovery plan, $v_k$ or $v_k'=1$, otherwise, $v_k$ or $v_k'=0$.

To sum up, a combinational disruption recovery model is developed:

$$\min(\theta\sum_{i=1}^{N'}(\lambda_1(sta_i'-arr_i')+\lambda_2(arr_i'-end_i'))) \tag{20}$$

$$\min(\sigma\sum_{i=0}^{N_0'}\sum_{j=0}^{N_0'} c_{ij}(x_{ij}'-x_{ij})+\mu\sum_{i=0}^{N_0'}\sum_{j=0}^{N_0'}(x_{ij}'-x_{ij})) \tag{21}$$

$$\min(\sigma(\sum_{k=1}^{K}\sum_{i=0}^{N_0'}\sum_{j=0,j\neq i}^{N_0'} c_{ij}x_{ijk}'-\sum_{k=1}^{K}\sum_{i=0}^{N_0}\sum_{j=0,j\neq i}^{N_0} c_{ij}x_{ijk})+\sum_{k=1}^{K} C_K(v_k'-v_k)) \tag{22}$$

*s.t.*

$$x_{ijk}'=\{0,1\},\quad i,j\in N_0',k\in\{1,...,K\} \tag{23}$$

$$u_{jk}'=\{0,1\},\quad j\in N',k\in\{1,...,K\} \tag{24}$$

$$\sum_{k=1}^{K} u_{ik}'\begin{cases}=1, d_i'=d_i\\ \leq 2, d_i'>d_i\end{cases},\quad i\in N' \tag{25}$$

$$\sum_{k=1}^{K} u_{0k}'=\sum_{k=1}^{K} u_{k0}'\leq K \tag{26}$$

$$\sum_{l=0,i\neq l}^{N_0'} x_{lik}'=\sum_{j=0,i\neq j}^{N_0'} x_{ijk}'=u_{ik}',\quad i\in N_0',k\in\{1,...,K\} \tag{27}$$

$$\sum_{i=1}^{N_0'} d_i'\times u_{ik}'-\sum_{j=1}^{N_0'} q_{0jk}'=0,\quad k\in\{1,...,K\} \tag{28}$$

$$q_{ijk}'\leq Q\times x_{ijk}'\quad i,j\in N_0',k\in\{1,...,K\} \tag{29}$$

$$Rsta_j'\geq Ksta_k+Rsta_i'+ser_i'+t_{ij}'-(1-x_{ijk}')\times M,\ i,j\in N',k\in\{1,...,K\} \tag{30}$$

$$Ksta_k=BST_k, k\in\{1,...,K\} \tag{31}$$

$$\lambda_1,\lambda_2\in\{0,1\},\ x_{ij},x_{ij}'\in\{0,1\},\ v_k',v_k\in\{0,1\} \tag{32}$$

Objective (20), (21) and (22) is to minimize the disruption on customers' service time, driving paths and delivery costs respectively. Constraint (30) and (31) ensure vehicles leave from the central depot at their optimal starting time, where $Ksta_k$ is the actual starting time of vehicle $k$ and $BST_k$ is the optimal starting time determined in Section 3.

# 5 Computational Experiments

The paper applied Nested Partitions Method (NPM) to solve the proposed model. NPM, proposed by Shi (2000), is a novel global optimization heuristic algorithm. The designed NPM algorithm for the combinational recovery model integrates three rescue strategies: (1) Adding vehicles policy. The strategy means some new vehicles which haven't delivery tasks according to the original plan are added to meet requests of new customers. (2) Starting later policy. As vehicles don't leave from the depot until their optimal starting time, there may be some vehicles still staying at the depot when disruption events occur. (3) Neighboring rescue policy. The strategy uses in-transit vehicles which adjoin new customers to deal with the disruptions.

## *5.1 Original VRPTW and Combinational Disruption Data*

The original VRPTW studied in the paper is from [7]: one depot owns 8 vehicles with the limited capacity 5*t*; the distance between two nodes can be calculated according to their coordinates; the speed of each vehicle is 1 *km/h*; coefficients $\theta$, $\sigma$ and $\mu$ are given 1, 1 and 10 respectively; detailed original data can be seen in [7]. By using improved genetic algorithm, [7] attained the optimal initial routing: vehicle 1: 0-8-2-11-1-4-0; vehicle 2: 0-10-5-13-0; vehicle 3: 0 -9-7-6-0; vehicle 4: 0-3-14-12-15-0. The total driving distance is 585.186.

After the initial scheduling, there are still four spare vehicles in the depot. At time 32.65, change requests are received from customer 4, 8, 11, 14 and a new customer 16 occurs. The detailed change data are shown in Table 3.

**Table 3** Data of changes

| Customers | Original coordinates | Original time windows | Original demands | New coordinates | New time windows | New demands |
|---|---|---|---|---|---|---|
| 4 | (53,19) | [96,166] | 0.6 | *(53,29)* | *[10,54]* | *1.6* |
| 8 | (56,4) | [9,79] | 0.2 | Unchanged | Unchanged | *1.4* |
| 11 | (41,10) | [74,174] | 0.9 | Unchanged | Unchanged | *1.9* |
| 14 | (73,29) | [56,156] | 1.8 | Unchanged | *[20,70]* | Unchanged |
| 16 | - | - | - | *(55,60)* | *[30,75]* | *2.0* |

## *5.2 Results and Findings*

According to Section 2, above disrupted nodes can be transformed into new customer nodes: from 4, 14, 8, 11 to 16, 17, 18, 19. A new customer 20 is added. There are three in-transit vehicles which are transformed into virtual customers 21, 22, 23 (A vehicle has not left when the disturbance occurred). Data after transformation are shown as Table 4.

NPM algorithm with neighboring rescue policy produced the new routing: 0-17-18-8-2-0, 0-10-5-13-0, 0-9-7-6-0, 0-3-1-19-11-16-12-0, 0-20-15-0. NPM algorithm with starting later policy produced the new routing: 0-8-2-11-1-0, 0-10-5-13-0, 0-9-7-6-0, 0-16-3-18-12-15-0, 0-20-17-19-0.

**Table 4** Data after transformation

| Customers | X (km) | Y (km) | $d_i$ (t) | $sta_i$ (h) | $end_i$ (h) |
|---|---|---|---|---|---|
| 0 | 50 | 50 | 0 | 0 | +∞ |
| 1 | 19 | 0 | 1.0 | 74 | 144 |
| 2 | 33 | 3 | 1.8 | 58 | 128 |
| 3 | 35 | 21 | 1.1 | 15 | 85 |
| 5 | 70 | 94 | 1.9 | 47 | 177 |
| 6 | 27 | 44 | 1.4 | 85 | 155 |
| 7 | 10 | 69 | 1.2 | 21 | 91 |
| 8 | 56 | 4 | 0.2 | 9 | 79 |
| 9 | 16 | 81 | 1.7 | 37 | 107 |
| 10 | 68 | 76 | 0.8 | 21 | 121 |
| 11 | 41 | 10 | 0.9 | 74 | 174 |
| 12 | 83 | 43 | 0.8 | 58 | 158 |
| 13 | 25 | 91 | 1.9 | 15 | 125 |
| 15 | 70 | 18 | 0.9 | 87 | 187 |
| 16 | 53 | 29 | 1.6 | 10 | 54 |
| 17 | 73 | 29 | 1.8 | 20 | 70 |
| 18 | 56 | 4 | 1.2 | 9 | 79 |
| 19 | 41 | 10 | 1.0 | 74 | 174 |
| 20 | 55 | 60 | 2.0 | 30 | 75 |
| 21 | 54 | 18 | 0 | 0 | 400 |
| 22 | 57 | 61 | 0 | 0 | 400 |
| 23 | 43 | 57 | 0 | 0 | 400 |

**Table 5** Comparison of results

| Methods | Total distance | Paths deviation | Total Time deviation | Number of Vehicles |
|---|---|---|---|---|
| Rescheduling | 840.76 | 16 | 210.75 | 7 |
| Disruption Management by GA | 841.69 | 9 | 37.03 | 6 |
| Disruption Management by NPM with neighboring rescue policy | **679.79** | 19 | 66.76 | **5** |
| Disruption Management by NPM with starting later policy | 737.11 | **7** | **33.30** | **5** |

The comparison of results with [7] is shown as Table 5. From the comparison, the paper finds: (1) Disruption Management by GA is superior to the Rescheduling in **Paths deviation**, **Total Time deviation** and **Number of vehicles**; Disruption Management by NPM with neighboring rescue policy produced better results in **Total distance**, **Total Time deviation** and **Number of vehicles** than the Rescheduling; Disruption Management by NPM with starting later policy outdoes the Rescheduling in all aspects. This verifies the advantage of Disruption Management in dealing with disruption events for VRPTW. (2) In **Total distance** and **Number of vehicles,** Disruption Management by NPM with neighboring rescue policy is superior to the Rescheduling and Disruption Management by GA; Disruption Management by NPM with starting later policy produced better results than the Rescheduling and Disruption Management by GA. This gives some evidences on that the transformation of disruption events and the designed NPM algorithm are effective to the combinational disruption recovery model. (3) Disruption Management by NPM with neighboring rescue policy is better than Disruption Management by NPM with starting later policy in **Total distance** but worse than the later in **Paths deviation** and **Total Time deviation**, which proves that considering the optimal starting time of vehicles may provide a new rescue strategy for disrupted VRP.

## 6 Conclusions

Disruption Management provides a good idea to minimize the negative effects of disruption events on the whole delivery system. For the reality that a variety of delivery disruptions often occur successively or simultaneously, the paper proposed a method of transforming various disruption events into new customer-adding disruption, which can facilitate to develop a combinational VRPTW disruption recovery model. The paper considered vehicles' optimal starting time from the central depot, which can not only reduce the waiting costs of vehicles in transit but also provide a new rescue strategy for the disrupted VRP. The paper focused on the customer disruption events, but didn't give enough consideration to vehicle disruption events and cargoes disruption events, which needs further efforts.

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# A Decision Method for Disruption Management Problems in Intermodal Freight Transport

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**Abstract.** In this paper, we propose a new decision method for dealing with disruption events in intermodal freight transport. First of all, the forecasting decision for the duration of disruption events is presented, which decides whether a rearrangement is needed. Secondly, a network-based optimization model for intermodal freight transport disruption management is built. Then an improved depth-first search strategy is developed, which is beneficial to automatically generating the routes and achieving the recovery strategies quickly. Finally, a numerical example is applied to verify the decision method. The new decision method supports the real-time decision making for disruption management problems.

**Keywords:** Decision method, Disruption management, Intermodal freight transport.

## 1 Introduction

Many power facilities are delivered by multiple modes of transport. Uncertainties and randomness always exist in freight transportation systems, especially in intermodal freight transportation. Intermodal freight transportation is the term used to describe the movement of goods in one and the same loading unit or vehicle which uses successive, various modes of transport (road, rail, air and water) without any handling of the goods themselves during transfers between modes (European Conference of Ministers of Transport, 1993) [14]. It is a multimodal chain of transportation services. This chain usually links the initial shipper to the final consignee of the container and takes place over long distances. The whole

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transportation is often provided and finished by several carriers. Almost all types of freight carriers and terminal operator may, thus, be involved in intermodal transportation, either by providing service for part of the transportation chain or by operating an intermodal transportation system (network) [5]. Therefore, the satisfied flow continuity and transit nodes compatibility of the multimodal chain of transportation services is significant while making modal choice decision once multiple transport modes, multiple decision makers and multiple types of load units are included.

Unexpected events (e.g. Hurricane, the snow disaster, traffic accidents) happening in one link of the multimodal chain could result in the disturbance of pre-decided transportation activities. A new strategy used to handle disruptions is disruption management. Its objective is the smallest disturbances the entire transportation system encounters with the new adjustment scheme, rather than the lowest cost. How to real-timely deal with the disruption events and achieve the coping strategies quickly and automatically is an important problem. It is necessary to present a new solution approach to improve the rationality and efficiency of disruption management in intermodal freight transportation.

The remainder of this paper is organized as follows: Section 2 briefly reviews the related solution approaches and applications. In Section 3, the forecasting decision method for the duration of disruption events is presented, and an optimization algorithm for intermodal freight transport disruption management is constructed. A numerical example is given in Section 4. Finally, concluding remarks and future research directions are summarized in Section 5.

## 2 A Brief Review of Related Literature

The research on the planning issues in intermodal freight transport has begun since the 1990s. Macharis and Bontekoning [15] conducted a comprehensive review on OR problems and applications of drayage operator, terminal operators, network operators and intermodal operators. Related decision problems for intermodal freight concern some combinations of rail, road, air and water transport. Following this approach, Caris et al. [3] provide an update on the review in Macharis and Bontekoning, with a stronger orientation towards the planning decisions in intermodal freight transport and solution methods.

In the current results on intermodal transportation system, we find most of them are related with planning transportation activities. We divide them into 4 categories from the perspectives of intermodal carrier selection, transportation mode selection, transportation routes, and terminal location. For the aspect of intermodal carrier selection, Liu et al. [12] establish an improved intermodal network and formulate a multiobjective model with the consideration of 5 important characteristics, multiple objective, in-time transportation, combined cost, transportation risks and collaboration efficiency. Ma [16] proposes a method for the optimization of the carrier selection in network environment by inviting and submitting a tender based on multi-agent. With respect to transportation mode selection, Liu and Yu [11] use the graph-theory technique to select the best combination of transportation modes for shipment with the consideration of 4 characteristics, multiple objective, in-time transportation, combined cost and transportation risks. Shinghal and Fowkes [19] presents empirical results of determinants of mode choice for freight services in India which shows that frequency of service is an important attribute determining mode choice. For transportation route selection, Huang and Wang [7] analyze the evaluation indicators (transportation cost, transportation time, transportation risk, service quality, facility level) of intermodal transportation routes, establish the set of alternatives, incorporate the perspectives of quantitative and qualitative analysis to compare and select the route alternatives. Chang [4] formulate an international intermodal routing problem as a multi-objective multimodal multi-commodity flow problem with time windows and concave costs. Yang et al. [23] present a goal programming model for intermodal network optimization to examine the competitiveness of 36 alternative routings for freight moving from China to and beyond Indian Ocean. For the aspect of terminal location, in the area of hub location problems, Campbell et al. [2] review various researches on new formulations and better solution methods to solve larger problems. Arnold et al. [1] investigate the problem of optimally locating rail/road terminals for freight transport. A linear 0-1 program is formulated and solved by a heuristic approach. Sirikijpanichkul et al. [20] develop an integral model for the evaluation of road-rail intermodal freight hub location decisions, which comprises four dominant agents, hub owners or operators, transport network infrastructure providers, hub users, and communities. Meng and Wang [17] develop a mathematical program with equilibrium constraints model for the intermodal hub-and-spoke network design problem with multiple stakeholders and multi-type containers.

The existing results on intermodal transportation system are related with planning transportation activities. They just put emphasis on planning in advance. However, they lack the research on disruptions possibly occurred in each transport mode and can not achieve an operational scheme with overall smallest disturbances quickly. It is more important to ensure flow continuity and transit nodes compatibility.

We have seen a number of results in disruption management in urban distribution system where only one mode of transport is used. Most of them are focused on the study of the disruption caused by customer requests or by dynamic travel time. The work of Potvin et al. [18] describes a dynamic vehicle routing and scheduling problem with time windows where both real-time customer requests and dynamic travel times are considered. In terms of the disruption caused by dynamic travel time, Huisman et al. [8] present a solution approach consisting of solving a sequence of optimization problems. Taniguchi et al. [21] use dynamic traffic simulation to solve a vehicle routing and scheduling model that incorporates real time information and variable travel times. Du et al. [6] design a solution process composed of initial-routes formation, inter-routes improvement, and intra-route improvement. Besides the above, there are some other results. The study of Zeimpekis et al. [24] present the architecture of fleet management system. Li et al. [10]

develop a prototype decision support system (DSS) [11]. Wang et al. [22] propose a transformation method for the recovery of the vehicle routing. The results above investigate the distribution system with only one transport mode. For example, in urban areas, only the transport mode of road is utilized to accomplish the delivery. Therefore, the disruption management in urban distribution system puts emphasis on the satisfaction of the customers. Meanwhile, in intermodal freight transport, it focuses on the choice of transportation modes and carriers.

Therefore, it is necessary to provide a solution approach with the ability of qualitative and quantitative processing to disruption management problems in intermodal freight transport system.

## 3 A Decision Method for Intermodal Freight Disruption Problems and a Solution Algorithm

### *3.1 The Forecasting Decision for the Duration of Disruption Events*

The disruption management problems in intermodal freight transport system can be described as follows: after the cargos start from the origins according to the plan, unexpected events (e.g. Hurricane, the snow disaster, traffic accidents) happen in one link of the multimodal chain, which might result in the interruption of one transport mode. The pre-decided transportation activities might need to be rearranged. If necessary, a rescue scheme with smallest deviation which is measured by the cost and the time of the routes should be achieved in an efficient way.

The duration of a disruption event, also means the delay of current transport activity, is used to decide whether a new arrangement should be made. If the delay is within the next carrier's tolerance, then no rearrangement is needed, otherwise, rerouting with smallest deviation should be made. It is assumed the effect of the delay on the one after the next carrier has been considered in the next carrier's tolerance. The way to achieve the duration of disruption events is to collect historic statistic data of typical disruption events in the specific transport mode.

We take the accidents happened on freeways as an example to illustrate the study of disruption event duration. According to the causes of disruption events, the accidents on freeways can be divided into 7 types [13], vehicle crash, bumping into the objects, vehicle breakdown, injuring-causing accident, vehicle burning accident, death-causing accident, and dangerous stuff accident. The distribution of each kind of disruption event's duration could be obtained by statistical analysis of historic statistic data. The forecasting decision tree for the duration of disruption event (vehicle crash) is shown in Figure 1. We use 3 parameters to illustrate an event's duration, average duration ( $\overline{A_i}$ ), the lower and the upper of four quartiles ( $Q\min_i$ , $Q\max_i$ ) as the upper bound and lower bound of confidence interval. They can be calculated according to historic statistic data.

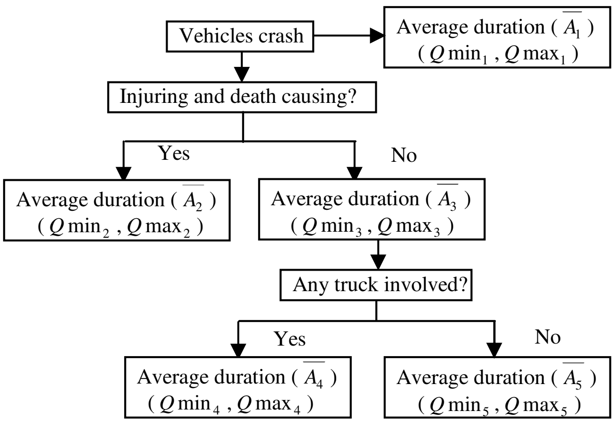


**Fig. 1** The forecasting decision tree for the duration of disruption event

## *3.2 An Optimization Algorithm for Intermodal Freight Transport Disruption Management*

According to the forecasting duration or delay in Sect. 3.1, if the delay is out of the range of the next carrier's tolerance, then rerouting with smallest deviation should be made. The deviation of $s^{\text{th}}$ route, denoted by $D_s$, can be calculated as follows.

$$D_s = \alpha_1 \frac{c_s - c_0}{c_0} + \alpha_2 \frac{t_s - t_0}{t_0} \tag{1}$$

The variables and parameters in Eq. (1) are explained below.

The coefficients $\alpha_1$ and $\alpha_2$ denote the decision maker's preference. They are equal or greater than 0, and $\alpha_1 + \alpha_2 = 1$. $c_s$ denotes the total cost of $s^{\text{th}}$ route; $t_s$ the total transport time of $s^{\text{th}}$ route; $c_0$ the total cost of the initial plan; $t_0$ the total transport time of the initial plan. Therefore, Eq. (1) is equivalent to Eq. (2).

$$D_s^{'} = \alpha_1 \frac{c_s}{c_0} + \alpha_2 \frac{t_s}{t_0} \tag{2}$$

Fig.2 shows a network of intermodal freight transport. The nodes represent the cities (*A*, *B*, ……, *H*) which cargos need to pass through. In each city, there are several carriers providing different modes of transport respectively. For example, from the origination node, there are *k* modes of transport ($A_1$, $A_2$, ……, $A_k$) for the cargos to choose to arrive at City A.

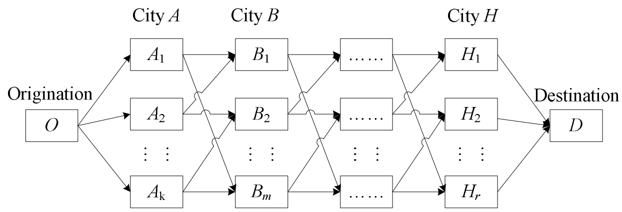


**Fig. 2** The virtual network of disruption event

The decision for the routing problem of intermodal freight transport can be turned into path searching through the graph shown in Fig. 2. Considering the characteristics of search strategies, we adopt an improved depth-first search strategy to generate the routing schemes.

## *3.3 An Improved Depth-First Search Strategy*

From Fig. 2, we observe that the network of intermodal freight transport corresponds to a State Space for decision-making, in which a transshipment location is a search node. An initial route is a path spanning through the State Space from the initial node (origination) to the goal node (destination), and an operational disruption recovery scheme with deviation is a path spanning through the State Space from the disrupted location to the goal node. Considering the characteristics of search strategies and the problem, we apply the principle of depth-first search strategy and improve it to generate the routing schemes.

The improved depth-first search algorithm includes three factors: state sets, operators, and goal state. The details of state-space search based on the improved depth-first search algorithm for disruption management problems in intermodal freight system are given below.

- State sets: are described by three elements, which are $P_i$ (the cargos' current location, where the disruption happens), $i = A, B, C, \cdots\cdots$; $c_{sij}$ (accumulative cost of $s^{\text{th}}$ route when the cargos arrive at $i^{\text{th}}$ city by $j^{\text{th}}$ transport mode); $t_{sij}$ (accumulative transport time of $s^{\text{th}}$ route when the cargos arrive at $i^{\text{th}}$ city by $j^{\text{th}}$ transport mode).
- Operators: cargos move from the current location (a search node) to the next location (a search node).
- Goal state: As the nodes are searched, the goal state (destination) can be reached. Until to this state, $c_{sij}$ is the total cost of $s^{\text{th}}$ route ($t_s$), and $t_{sij}$ is the total transport time of $s^{\text{th}}$ route ($t_s$).

After the search process is finished, the feasible recovery schemes are generated. And $D_s^{'}$ can be calculated by Eq. (2).

# 4 A Numerical Example

A numerical example is constructed to illustrate and verify the above decision method. The description of the example is given as follows. Suppose there are 10 ton of cargos to be transported from City *A* to City *D*, which should pass through City *B* and City *C*. The example intermodal transportation network is described in Fig. 3, which shows the available transport modes between two cities. And its corresponding operational intermodal transportation network is presented in Fig. 4. Transport cost per unit (1000RMB/ton) and required transport time (h) are listed in Table 1. Transshipment cost (1000RMB/ton) and time (h) between different transport modes are listed in Table 2.


**Fig. 3** An example intermodal transportation network

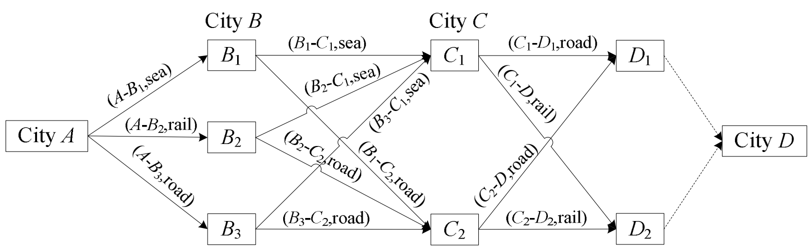


**Fig. 4** The operational intermodal transportation network

**Table 1** Transport cost per unit/required time

| | A-B | B-C | C-D |
|---|---|---|---|
| Rail | 9/20 | -- | 6/18 |
| Road | 6/15 | 10/18 | 7/16 |
| Sea | 3/28 | 4/30 | -- |

**Table 2** Transshipment cost/time between different transport modes

| | Rail | Road | Sea |
|---|---|---|---|
| Rail | 0/0 | 0.1/0.5 | 0.2/0.5 |
| Road | 0.1/0.5 | 0/0 | 0.1/1 |
| Sea | 0.2/0.5 | 0.1/1 | 0/0 |

We assume the decision maker has the same preference on the cost and the transport time, that is, $\alpha_1 = 0.5$, $\alpha_2 = 0.5$.

According to the improved depth-first search strategy in Sect. 3.3, the initial feasible routes can be generated. And the optimal one is achieved as $A$-$B_3$-$C_1$-$D_2$, with the total cost of 163 and the total transport time of 64.5.

If there is a disruption event happened in the link $A$-$B_3$, and a delay of 8 hours occurred. The transport mode of sea in the link $B_3$-$C_1$ in Fig. 4 will not be available for the cargos. The recovery schemes have to be generated by the improved depth-first search strategy. And the scheme with smallest deviation will be chosen to deliver the cargos. Here the optimal recovery scheme is $B_3$-$C_2$-$D_2$, with a deviation 0.98.

## 5 Concluding Remarks

We present a new decision method for disruption problems in intermodal freight transport, which comprises the forecasting decision for the duration of disruption events, network-based optimization model, and improved depth-first search strategy. The forecasting for the duration of disruption events helps make a decision whether a rearrangement is need. The introduction of improved depth-first search strategy can be beneficial to automatically generating the initial routes and recovery routes. The method can compete with rapid decision-making in disruption management problems. Furthermore, it provides a new solution idea for other disruption management problems. Some specific work remains to be further studied, for example, large scale case study network should be selected to verify the decision method.

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# A Dominance-Based Rough Set Approach of Mathematical Programming for Inducing National Competitiveness

Yu-Chien Ko and Gwo-Hshiung Tzeng

**Abstract.** The dominance-based rough set approach is a powerful technology for approximating ranking classes. Analysis of large real-life data sets shows, however, decision rules induced from lower approximations are weak, that is supported by few entities only. For enhancing the DRSA, the mathematical programming is applied to support the lower approximations with entities as more as possible. The mathematical coding such as unions of decision classes, dominance sets, rough approximations, and quality of approximation is implemented in Lingo 12. It is applied on the 2010 World Competitiveness Yearbook of International Institute for Management Development (WCY-IMD). The results show the business finance and attitudes & values matter achieving the top 10 positions in the world competitiveness.

**Keywords:** dominance-based rough set approach (DRSA), Mathematical programming (MP), national competitiveness.

## 1 Introduction

DRSA is a powerful technology to process the relational structure, which has been successfully applied in many fields [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. However, it has rarely been used in the analysis of national competitiveness due to skewed dimensions and unique characteristics among nations. Up to today the annular reports, World Competitiveness Yearbook (WCY) and Global Competitiveness Report (GCR), publish the competitiveness ranks with statistical descriptions instead of relational structure, thus inferring of competitiveness structure still cannot be elaborated for policy makers and national leaders. This research adopts mathematical programming to design

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and develop unions of decision classes, dominance sets, rough approximations, and quality of approximation [11, 12, 13]. Finally, induction rules based on WCY 2010 are generated for stakeholders to help policy making and verification.

WCY collects figure data and expert opinions together into in 4 consolidated factors, i.e. Economic Performance, Government Efficiency, Business Efficiency, and Infrastructure. Their details are divided into 20 sub-factors. Totally there more than 300 criteria are collected in the 20 sub-factors. The report provides the weakness, strength, trends of nations from a view of individual nation instead of crossing over nations [14, 15]. This research partitions nations into 2 parts i.e. at least $10^{th}$ and at most $11^{th}$, shown in Figure 1, then induces rules. It discovers the facts how the top nations outperformed than the others.

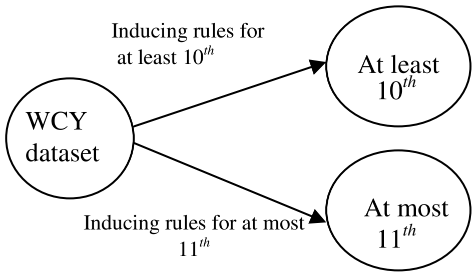


**Fig. 1** Competitiveness model

The remainders of this paper are organized by presenting the rough set and DRSA in Section 2, propositions of mathematical programming for DRSA in Section 3, application of the proposed DRSA on national competitiveness in Section 4, discussion of competitiveness criteria and the future work in Section 5. The last section concludes the paper and remarks.

## 2 Review on DRSA

Measures or evaluations of competitiveness crossing over nations have not been deeply explored in the fields of dominance-based rough set. This section starts from the concept of rough set then extends to the dominance-based rough set.

### A. Rough Set

The rough set can discover important facts hidden in data, and has the capacity to express decision rules in the form of logic statements "if conditions, then decision". The conditions and decision in the statement specify their equivalence relations based on respective criteria. The degree of satisfying the rule is measured with entities contained in the relations such as coverage rate, certainty, and strength [16, 17, 18, 19]. Generally, it performs well at classification in many application fields but cannot handle preference inconsistency between condition and decision for choice, ranking, and sorting. Therefore, the rough set is extended by applying dominance principle on the preference-ordered rough set [3, 4]. The extension substitutes indiscernibility relations by dominance-based relations. The approximation of dominance-based relations has involved the preference function, dominating and dominated entities, rough approximation, and unions of decision classes [1~10] below.

### B. Information System of DRSA

A data table with preference information $IS = (U, Q, V, f)$ is presented with $U = \{x_1, x_2, ..., x_n\}$, $Q = C \cup D$, $f : X \times Q \rightarrow V$, and $V = \{V_1, V_2, ..., V_q\}$ where $n$ is the number of entities, $C$ is the set of condition criteria, $D$ is the set of decision criteria, $X$ representing a subset of $U$ that decision makers have willing to tell their preference on criteria, and $f$ representing a total function such that $f(x, q) \in V_q$ for all $q \in P$. The information function $f(x, q)$ can be regarded as a preference function when its domain is a scale of preference for criterion $q$ (Greco *et al.,* 2000). Thus the pair comparison of $x$, $y \in U$, $f(x,q) \geq f(y,q) \Leftrightarrow x \succsim_q y \Leftrightarrow f_q(x) \geq f_q(y)$, means '$x$ is at least as good as $y$ in the preference strength with respect to criterion $q$'. The outranking relations not only make sense in data structure but also in mathematical functions. The rough approximation related to the mathematical structure is described below.

### C. Rough Approximation by Dominance Sets

The dominance-based rough approximations can serve to induce entities assigned to $Cl_t^{\geq}$ (an upward union of classes) or $Cl_t^{\leq}$ (a downward union of classes) where $Cl$ is a cluster set containing ordered classes $Cl_t$, $t \in T$ and $T$={1, 2,…, $n$}. For all $s$, $t \in T$ and $s \geq t$, each element in $Cl_s$ is preferred at least as each element in $Cl_t$, which is constructed as

$$Cl_t^{\geq} = \bigcup_{s \geq t} Cl_s$$

$$Cl_t^{\leq} = \bigcup_{s \leq t} Cl_s$$

$P$-dominating and $P$-dominated sets are the rough approximations by taking object $x$ as a reference with respect to $P$, $P \subseteq C$.

***P*-dominating set:** $D_P^+(x) = \{y \in X, yD_Px\}$

***P*-dominated set:** $D_P^-(x) = \{y \in X, xD_Py\}$

where $y \succsim_q x$ for $D_P^+(x)$, $x \succsim_q y$ for $D_P^-(x)$, and all $q \in P$. Explaining the approximation of decision classes by $P$-dominance sets is the key idea of rough set to infer one knowledge by another knowledge, which has been implemented in DRSA as

$$\underline{P}(Cl_t^{\geq}) = \{x_i \in Cl_t^{\geq}, D_P^+(x_i) \subseteq Cl_t^{\geq}\}$$
$$\overline{P}(Cl_t^{\geq}) = U - \underline{P}(Cl_{t-1}^{\leq})$$
$$\boldsymbol{B}np(Cl_t^{\geq}) = \overline{P}(Cl_t^{\geq}) - \underline{P}(Cl_t^{\geq})$$
$$\underline{P}(Cl_t^{<}) = \{x_i \in Cl_t^{<}, D_P^-(x_i) \subseteq Cl_t^{<}\}$$
$$\overline{P}(Cl_t^{<}) = U - \underline{P}(Cl_{t+1}^{<})$$
$$\boldsymbol{B}np(Cl_t^{<}) = \overline{P}(Cl_t^{<}) - \underline{P}(Cl_t^{<})$$
$$t = 1, \ldots, n$$

where $\boldsymbol{B}np(Cl_t^{\geq})$ and $\boldsymbol{B}np(Cl_t^{\leq})$ are $P$-doubtful regions.

Analysis of large real-life data sets shows, however, that for some multi-criteria classification problems, the application of DRSA identifies large differences between lower and upper approximations of decision classes. In consequence, decision rules induced from lower approximations are weak, that is supported by few entities only [7]. For this reason a DRSA method is designed and developed in the mathematical programming to search entities for the lower approximation.

## 3 Mathematical Programming for DRSA

This section covers unions of decision classes, dominance sets, rough approximations, and quality of approximation, which starts from propositions then uses them to build formulae.

### A. Propositions

Reduction of criteria is expressed in a Proposition (A.1) by setting a coefficient $w_j$ to 0; otherwise $w_j$ equals to 1.

$$\textbf{(A.1)} \quad L = \sum_{j=1}^{m} w_j, w_j \in \{0,1\},\ j \in \{q_1, q_2, \ldots, q_m\}$$

where $m$ is the number of criteria in $C$, $L$ is the number of criteria in the sub set $P$ after reduction. For the entities assigned to $Cl_t^{\geq}$, Proposition (A.2) sets $u_i = 1$ when $x_i \in Cl_t^{\geq}$ and $x_i \in D_t^{\geq}$; otherwise $u_i = 0$,

$$\textbf{(A.2)} \quad u_i \times L \leq \sum_{i \in Cl_t^{\geq}, j=1}^{m} w_j * u_{ij},\ u_i \in \{0,1\}$$

where $u_{ij} = 1$ when $f(x_i, j) \geq r_{ij}, \forall j \in P$; otherwise $u_{ij} = 0$; $r_{ij}$ is the low boundary of $j$ for $D_t^{\geq}$. For the entities assigned to $Cl_t^{<}$, Proposition (A.3) sets $\overline{u}_i = 1$ when $x_i \in Cl_t^{<}$ and $x_i \in D_t^{<}$; otherwise $\overline{u}_i = 0$.

**(A.3)** $\overline{u}_i \times L \leq \sum_{i \in Cl_t^{<}, j=1}^{m} w_j * \overline{u}_{ij}, \ \overline{u}_i \in \{0,1\}$

where $\overline{u}_{ij} = 1$ when $f(x_i, j) \leq r_{ij}$ otherwise $\overline{u}_{ij} = 0$; . $r_{ij}$ is the high boundary of $j$ for $D_t^{<}$.

## B. Mathematical Formulae for Rough Approximation

By following the propositions above, dominance set, rough approximation, and quality of approximation are constructed in mathematical formula as below.

- *P*-dominating set $D_P^{+}(x_i) = \left\{ x_i \in Cl_t^{\geq}, \ L = \sum_{i \in Cl_t^{\geq}, j=1}^{m} w_j * u_{ij} \right\}$

- *P*-dominated set
$D_P^{-}(x_i) = \left\{ x_i Cl_t^{<}, \ L = \sum_{i \in Cl_t^{<}, j=1}^{m} w_j * \overline{u}_{ij} \right\}$

- Rough Approximation

$$| \underline{P}(Cl_t^{\geq}) | = \sum_{i=1}^{|Cl_t^{\geq}|} u_i$$

$$| \overline{P}(Cl_t^{\geq}) | = | U | - \sum_{i=1}^{|Cl_t^{\geq}|} u_i$$

$$| \underline{P}(Cl_t^{<}) | = \sum_{i=1}^{|Cl_t^{<}|} \overline{u}_i$$

$$| \overline{P}(Cl_t^{<}) | = | U | - \sum_{i=1}^{|Cl_t^{<}|} \overline{u}_i$$

For sustaining the quality of rough approximations, consistency constraints are designed to restrict the scope of dominance sets, i.e. $D_p^{+}(x)$ could not contain entities in the $D_p^{-}(x)$ and vice versa.

- Consistency Constraints

$$L - 1 \geq \sum_{i \in Cl_t^{\geq}, j=1}^{m} w_j * \overline{u}_{ij}$$

$$L - 1 \geq \sum_{i \in Cl_t^{<}, j=1}^{m} w_j * u_{ij}$$

### C. Evaluation of Rough Approximation

According to Pawlak (2002) and Greco *et al.*, (2000), there are 2 frequent measures of approximation.

- Coverage rate for $Cl_t^{\geq}$ and $Cl_t^{<}$ approximation

$$CR_P(Cl_t^{\geq}) = \frac{|\underline{P}(Cl_t^{\geq})|}{|Cl_t^{\geq}|}, CR_P(Cl_t^{<}) = \frac{|\underline{P}(Cl_t^{<})|}{|Cl_t^{<}|}$$

It expresses '*the probability of entities in the unions of decision classes relatively belonging to the lower approximation*'.

**Table 1** 4 factors and 20 sub factors of WCY

| Economic Performance | |
|---|---|
| $q_1$ | Domestic Economy |
| $q_2$ | International Trade |
| $q_3$ | International Investment |
| $q_4$ | Employment |
| $q_5$ | Prices |
| Government Efficiency | |
| $q_6$ | Public Finance |
| $q_7$ | Fiscal Policy |
| $q_8$ | Institutional Framework |
| $q_9$ | Business Legislation |
| $q_{10}$ | Societal Framework |
| Business Efficiency | |
| $q_{11}$ | Productivity & Efficiency |
| $q_{12}$ | Labor Market |
| $q_{13}$ | Finance |
| $q_{14}$ | Management Practices |
| $q_{15}$ | Attitudes and Values |
| Infrastructure | |
| $q_{16}$ | Basic Infrastructure |
| $q_{17}$ | Technological Infrastructure |
| $q_{18}$ | Scientific Infrastructure |
| $q_{19}$ | Health and Environment |
| $q_{20}$ | Education |

- Quality of approximation for $Cl$

$$\gamma_P(Cl) = \frac{|\underline{P}(Cl_t^{\geq})| + |\underline{P}(Cl_t^{<})|}{|U|}$$

It expresses classification performance with '*the probability of the entities being covered by all the lower approximations* (*partitions*)'.

**D. Decision Rules based on Rough Approximation**

The unions of decision classes and rough approximations can serve to induce rules that are expressed in terms of '*if..., then...*'. Here are 2 exemplary rule types below.

$(D_{\geq})$ **if** $f(x, j) \geq r_j^{\geq}$ **... and** $f(x, j') \geq r_{j'}^{\geq}$ **then** $x \in Cl_t^{\geq}$

$(D_{<})$ **if** $f(x, j) \leq r_j^{<}$ **... and** $f(x, j') \leq r_{j'}^{<}$ **then** $x \in Cl_t^{<}$

$j, j' \in P$

Based on the propositions, mathematical formula, and exemplary rule types, national competitiveness is induced next.

## 4 Applying the Proposed DRSA to National Competitiveness

According to 20101 WCY, 58 nations are listed in Appendix I. This section starts from description of data set then the algorithm of induction.

**A. WCY Data Set**

Table 1 presents 4 factors and 20 sub factors. The left column is the symbols for the sub factors. The ranks of nations in 2009 and 2010 are presented in Appendix I. Australia, Canada, Hong Kong, Malaysia, Norway, Singapore, Sweden, Switzerland, Taiwan, and USA are the top 10 nations. The followings will induce the dominance sub factors, called as dominance criteria, for nations. Also the boundaries of dominance criteria are called as dominance boundaries in the following context.

**B. An Algorithm of Competitiveness Induction**

An algorithm is designed to solve the optimal coverage rates for both $Cl_t^{\geq}$ and $Cl_t^{<}$ approximations simultaneously. It can prevent the difference in supporting approximations i.e. avoiding one support is high and the other support is low. Before executing the algorithm, users might remove some criteria that have low coverage rates of $CR_j(Cl_{10th}^{\geq})$ or $CR_j(Cl_{10th}^{<})$, which can reduce computing tasks and time.

**Objective**

$$\mathbf{Max}\ CR_P(Cl_{10th}^{\geq}) + CR_P(Cl_{10th}^{<}) - 0.01 \times L$$

**Constraints**

$$CR_P(Cl_{10th}^{\geq}) = \frac{|\ \underline{P}(Cl_{10th}^{\geq})\ |}{|\ Cl_{10th}^{\geq}\ |} = \frac{\sum_{i=1}^{m} u_i}{|\ Cl_{10th}^{\geq}\ |}$$

$$CR_P(Cl_{10th}^{<}) = \frac{|\ \underline{P}(Cl_{10th}^{<})\ |}{|\ Cl_{10th}^{<}\ |} = \frac{\sum_{i=1}^{m} \overline{u}_i}{|\ Cl_{10th}^{<}\ |}$$

$$L = \sum_{j=1}^{m} w_j,\ w_j \in \{0,1\},\ 1 \leq L \leq 3,$$

$$u_i \times L \leq \sum_{i \in Cl_t^{\geq}, j=1}^{m} w_j * u_{ij},\ u_i \in \{0,1\}$$

$$\overline{u}_i \times L \leq \sum_{i \in Cl_t^{<}, j=1}^{m} w_j * \overline{u}_{ij},\ \overline{u}_i \in \{0,1\}$$

$$L - 1 \geq \sum_{i \in Cl_t^{\geq}, j=1}^{m} w_j * \overline{u}_{ij}$$

$$L - 1 \geq \sum_{i \in Cl_t^{<}, j=1}^{m} w_j * u_{ij}$$

This algorithm intends to find out the dominance criteria and boundaries for both lower approximations at one time. The results are presented next.

## C. Induced Rules of $D_{10th}^{\geq}$ and $D_{10th}^{<}$

The induced rule is presented with ‘if…,then…’, which comprises the dominance criteria and boundaries as below.

Rule I:

**if** $(f(x, q_{13}) \geq 64.91) \wedge (f(x, q_{15}) \geq 62.30)$ **then** $x \in Cl_{10th}^{\geq}$

$r_{i \in Cl_{10th}^{\geq},13} = 64.91,\ r_{i \in Cl_{10th}^{\geq},15} = 62.30$

Dominance criteria and boundary of Rule I: (64.91/Finance, 62.30/Attitudes & Values)

Rule II:

**if** $(f(x, q_{13}) \leq 60.08) \wedge (f(x, q_{15}) \leq 62.30)$ **then** $x \in Cl_{10th}^{<}$

$r_{i \in Cl_{10th}^{<},13} = 60.08,\ r_{i \in Cl_{10th}^{\geq},15} = 62.30$

Dominance criteria and boundary of Rule II: (60.08/Finance, 62.30/Attitudes & Values)

**Table 2** Evaluation parameters

| | $CR_P(Cl^{\geq}_{10th})$ | $CR_P(Cl^{<}_{10th})$ | $\gamma_P(Cl)$ |
|---|---|---|---|
| Rule I | 0.80 | | 0.78 |
| Rule II | | 0.77 | 0.78 |

This algorithm generates Rule I and II that separate the nations into $D^{\geq}_{10th}$ and $D^{<}_{10th}$ in Figure 2.

**D. Dominance criteria (sub factors)**

The dominance criteria of $D^{\geq}_{10th}$ and $D^{<}_{10th}$ are Finance and Attitudes & Values in business. They are listed in Table 3 next.

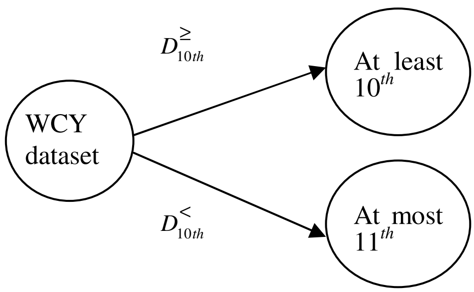


**Fig. 2** Induced model

**Table 3** Dominance criteria (sub factors)

| sub-factor | description in WCY 2010 |
|---|---|
| $q_{13}$ | banking and financial services, financial institutions' transparency, finance and banking regulation, stock markets, stock market capitalization, value traded on stock markets, shareholders' rights, credit is easily available for businesses, and venture capital. |
| $q_{15}$ | attitudes toward globalization are generally positive in the society, the image abroad of a country encourages business development, the national culture is open to foreign ideas, flexibility and adaptability of people are high when faced with new challenges, the needs for economic and social reforms is generally well understood, and the value system in the society supports competitiveness |

## 5 Discussion and the Future Work

This section has 3 parts for discussing the proposed method.

**A. Rough approximation**

The proposed DRSA have 80% of the top 10, 77% of the rest, and totally 78% covered in the lower approximations. In the analysis of rank changes during 2009~2010, top 10 nations in $\underline{P}(Cl^{\geq}_{10th})$ have 8 nations covered by Rule I; 6 of them made progress and 2 of them sustained the same positions (please refer to Appendix I). The induced rules and the rank change of Appendix I deliver a message that 100% nations in $\underline{P}(Cl^{\geq}_{10th})$ performed dominance over others. USA, a member of the top 10 but out of $\underline{P}(Cl^{\geq}_{10th})$ , adversely degenerated.

In this case the rough approximation is applied to get inside knowledge of national competitiveness. The discussion about rule generation is presented next.

**B. Rule generation**

Two rules composed of dominance criteria and boundaries are backwardly and optimally solved at one time by the proposed method, which separate nations by dominance boundaries (64.91/Finance, 62.30/Attitudes & Values) for $\underline{P}(Cl^{\geq}_{10th})$ and (60.08/Finance, 62.30/Attitudes & Values) for $\underline{P}(Cl^{<}_{10th})$ .

The shorter length of dominance boundaries is easier for users to understand the knowledge of the approximations. To approaching the shortest length, subtracting 0.01*$L$ in the objective function is designed for the rules. Therefore, only two criteria compose the induced rules.

**C. Rule validation**

The binary variables $w_j$ control whether criteria $j$ is dominance or not. Their solved $w_j$ and dominance boundaries are substituted into constraints

$u_i \times L \leq \sum_{i\in Cl_t^{\geq}, j=1}^{m} w_j * u_{ij}$ , $\overline{u}_i \times L \leq \sum_{i\in Cl_t^{<}, j=1}^{m} w_j * \overline{u}_{ij})$ , $L-1 \geq \sum_{i\in Cl_t^{<}, j=1}^{m} w_j * u_{ij}$ ,

and $L-1 \geq \sum_{i\in Cl_t^{\geq}, j=1}^{m} w_j * \overline{u}_{ij}$ , to validate the supports and exceptions for the rough approximations. If a nation satisfies then it supports otherwise it plays as an exception. The validation results are shown as below.

Top 10 nations, Australia, Canada, Hong Kong, Malaysia, Singapore, Sweden, Switzerland, and Taiwan, support the Rule I except Norway and USA.

Nations beyond top 10, Argentina, Austria, Belgium, Brazil, Bulgaria, China Mainland, Colombia, Croatia, Czech Republic, Estonia, France, Germany, Greece, Hungary, Iceland, Indonesia, Italy, Jordan, Kazakhstan, Korea, Lithuania, Mexico, New Zealand, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russia, Slovak Republic, Slovenia, Spain, Turkey, Ukraine, United Kingdom, and Venezuela, support the Rule II except Chile, Denmark, Finland, India, Ireland, Israel, Japan, Luxembourg, Netherlands, South Africa, and Thailand.

**D. The future work**

DRSA provides a good technology for processing relational structure and the proposed method implements DSRA into a mathematical tool. In the future work the mathematical programming can be applied to equivalent relations, flow network, and so forth. Hopefully there will be more insides to be discovered and help decision making.

## 6 Concluding Remarks

The rule generation for the lower approximations is designed and implemented in this research. The proposed DRSA inferring the relational structure by the mathematical programming makes optimal solutions available for objectives. In the results not only the rough approximations but also the dominance criteria and boundaries are provided. Based on the WCY 2010, the business finance and attitudes & values are inferred as the dominance criteria for the top 10 nations. Nations higher than or equal to the dominance boundaries at least sustain positions or made progress during 2009 ~ 2010.

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# Appendix (I)

**Table 4** Competitiveness ranks during 2009 ~ 2010

| nations | competitiveness ranks | | progressing | degenerating | the top 10 nations |
|---|---|---|---|---|---|
| | 2009 | 2010 | | | |
| Argentina | 55 | 55 | | | |
| Australia | 7 | 5 | 1 | | 1 |
| Austria | 16 | 14 | 1 | | |
| Belgium | 22 | 25 | | 1 | |
| Brazil | 40 | 38 | 1 | | |
| Bulgaria | 38 | 53 | | 1 | |
| Canada | 8 | 7 | 1 | | 1 |
| Chile | 25 | 28 | | 1 | |
| China Mainland | 20 | 18 | 1 | | |
| Colombia | 51 | 45 | 1 | | |
| Croatia | 53 | 56 | | 1 | |
| Czech Republic | 29 | 29 | | | |
| Denmark | 5 | 13 | | 1 | |
| Estonia | 35 | 34 | 1 | | |
| Finland | 9 | 19 | | 1 | |
| France | 28 | 24 | 1 | | |
| Germany | 13 | 16 | | 1 | |
| Greece | 52 | 46 | 1 | | |
| Hong Kong | 2 | 2 | | | 1 |
| Hungary | 45 | 42 | 1 | | |
| Iceland | - | 30 | | 1 | |
| India | 30 | 31 | | 1 | |
| Indonesia | 42 | 35 | 1 | | |
| Ireland | 19 | 21 | | 1 | |
| Israel | 24 | 17 | 1 | | |
| Italy | 50 | 40 | 1 | | |
| Japan | 17 | 27 | | 1 | |
| Jordan | 41 | 50 | | 1 | |
| Kazakhstan | 36 | 33 | 1 | | |
| Korea | 27 | 23 | 1 | | |
| Lithuania | 31 | 43 | | 1 | |
| Luxembourg | 12 | 11 | 1 | | |
| Malaysia | 18 | 10 | 1 | | 1 |
| Mexico | 46 | 47 | | 1 | |
| Netherlands | 10 | 12 | | 1 | |
| New Zealand | 15 | 20 | | 1 | |

**Table 4** (*continued*)

| | | | | | |
|---|---|---|---|---|---|
| Norway | 11 | 9 | 1 | | 1 |
| Peru | 37 | 41 | | 1 | |
| Philippines | 43 | 39 | 1 | | |
| Poland | 44 | 32 | 1 | | |
| Portugal | 34 | 37 | | 1 | |
| Qatar | 14 | 15 | | 1 | |
| Romania | 54 | 54 | | | |
| Russia | 49 | 51 | | 1 | |
| Singapore | 3 | 1 | 1 | | 1 |
| Slovak Republic | 33 | 49 | | 1 | |
| Slovenia | 32 | 52 | | 1 | |
| South Africa | 48 | 44 | 1 | | |
| Spain | 39 | 36 | 1 | | |
| Sweden | 6 | 6 | | | 1 |
| Switzerland | 4 | 4 | | | 1 |
| Taiwan | 23 | 8 | 1 | | 1 |
| Thailand | 26 | 26 | | | |
| Turkey | 47 | 48 | | 1 | |
| Ukraine | 56 | 57 | | 1 | |
| United Kingdom | 21 | 22 | | 1 | |
| USA | 1 | 3 | | 1 | 1 |
| Venezuela | 57 | 58 | | 1 | |

# A GPU-Based Parallel Algorithm for Large Scale Linear Programming Problem

Jianming Li, Renping Lv, Xiangpei Hu, and Zhongqiang Jiang

**Abstract.** A GPU-based parallel algorithm to solve large scale linear programming problem is proposed in this research. It aims to improve the computing efficiency when the linear programming problem becomes sufficiently large scale or more complicated. This parallel algorithm, based on Gaussian elimination, uses the GPU (Graphics Processing Unit) for computationally intensive tasks such as basis matrix operation, canonical form transformation and entering variable selection. At the same time, CPU is used to control the iteration. Experimental results show that the algorithm is competitive with CPU algorithm and can greatly reduce the computing time, so the GPU-based parallel algorithm is an effective way to solve large scale linear programming problem.

**Keywords:** Linear Programming, Parallel Algorithm, GPU, CUDA (Compute Unified Device Architecture).

## 1 Introduction

Linear programming problem is a basic branch of operational research. Linear programming algorithm was first presented by Dantzig in 1947. It plays a very important role in many kinds of economic activities such as allocation of funds and task scheduling [1-2]. It is mainly used to solve how to utilize existing resources to make the prospective goal achieving optimum. Although the existing linear programming problem algorithms are effective in solving many practical problems,

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they have to run a long time to find solutions to large scale problems. To overcome this limitation, researchers have proposed some methods for improvement, such as the infeasible exterior point simplex algorithm for assignment problems[3] and the efficient search direction for linear programming problems[4]. These methods reduce the iterative times successfully, but fail to improve the efficiency of iterative process. Recently a more promising approach has attracted a lot of attention which parallelizes these algorithms on parallel or distributed computers[5-7]. It has advantages of reducing iteration times, speeding up the solving process. However these existing parallel algorithms have brought the users a lot of inconvenience due to the following drawbacks: (1) For most researchers, the parallel machines are too expensive, and the usage and management of parallel machines is relatively complex. (2) The frequent communications between CPUs in parallel machine are hardly acceptable in most parallel machines.

In recent years, the increasing demand of the multimedia and games industries for accelerating 3D rendering has driven the development of graphics processing unit (GPU) [8-10]. These consumer-level GPUs are cost-effective not only for game playing, but also for scientific computing. Many researchers and developers have shown their interest in harnessing the power of commodity graphics hardware for general-purpose parallel computation [11-13]. JIN implements parallel linear programming algorithm on GPU Shader and speedup well. Comparing with GPU Shader, CUDA contains less passes, and it's more efficient and flexible. Based on the analysis above, this paper will propose a linear programming algorithm based on GPU programming with CUDA.

In section 2, we present our parallel linear programming algorithm principle. Then numerical experiment is given in section 3. We will give a conclusion and a description of our future work in the last section.

# 2 GPU-Based Parallel Linear Programming Algorithm

## *2.1 Linear Programming Problem*

Linear programming is the problem of optimizing a linear objective function subject to a set of linear constraints, either equalities or inequalities. The standard form is shown as follows:

$$
\max\ z = c_1 x_1 + c_2 x_2 + \cdots + c_n x_n
$$

$$
s.t \begin{cases} a_{11} x_1 + a_{12} x_2 + \cdots + a_{1n} x_n = b_1 \\ a_{21} x_1 + a_{22} x_2 + \cdots + a_{2n} x_n = b_2 \\ \cdots\cdots \\ a_{m1} x_1 + a_{m2} x_2 + \cdots + a_{mn} x_n = b_m \\ x_j \ge 0,\quad j = 1 \sim m \end{cases}
$$

Simplex algorithm is a classical method to solve the linear programming problem. After getting the standard form of linear programming problem, we can solve it through simplex algorithm. For the past few years, scholars have combined simplex algorithm, genetic algorithm and other integrated algorithm to improve the efficiency of solving linear programming.

The algorithm procedures are illustrated in detail as following:

Step 1. Initialization. Find out the initial feasible base, determine the basic feasible solution, calculate the value of objective function, and build the initial linear programming tableau.

Step 2. Optimality criterion. Calculate check number vectors; test the check numbers of non basic variable $x_j$. $\sigma_j = c_j - \sum_{i=1}^{m} c_i a_{ij}$

Stop if $\sigma_j \le 0$ , so we find the optimum solution, otherwise go to the next step.

Step 3. Insolubleness check. Find out $\max(\sigma_j) = \sigma_k$ among $\sigma_j > 0, j = m+1, \cdots n$ . Identify $x_k$ as entering variable. The problem is insoluble if the counterpart coefficient column vector $A_k \le 0$ , then stop. Otherwise calculate the $\theta$ .

$$\theta = \min\{ \frac{b_i}{a_{ik}} \mid a_{ik} > 0, i = 1, \cdots, m\} = \frac{b_l}{a_{lk}}$$

Identify $x_l$ as s leaving variable and turn to the next step.

Step 4. The leaving variable of $x_l$ and entering variable of $x_k$ . Use Gauss elimination method to process elementary transformation matrices with pivot element $a_{lk}$ . Transform the counterpart column vector of $x_k$ and $A_k = (a_{1k}, a_{2k}, \cdots, a_{lk}, \cdots, a_{mk})^T$ into $A_k^{'} = (0,0,\ldots,1,\ldots,0)^T$ .

Transform $x_l$ from feasible basis $x_B$ into $x_k$ , and get new linear programming tableau. Turn to step 2.

While processing large-scale linear programming problem, each iteration of simplex algorithm takes a lot of computing time. The time complexity of CPU is related to $m * m$ .

### *2.2 Principle of GPU-Based Parallel Algorithm*

Simplex algorithm can be transformed to SIMD process in GPU with adequately utilizing the ability of high speed floating-point calculation and parallel calculation of GPU. Parallel algorithm will improve the efficiency of solving large-scale linear programming problem. Simplex algorithm entirety is iteration process that the calculation of current iteration depends on previous iteration. The parallel simplex algorithm based on GPU is divided into four parts: (1) parallel simplex algorithm of linear programming, (2) parallel calculation of canonical form, leaving and enter variables, (3) implementation of GPU-based parallel algorithm, (4) optimizing the use of GPU memory.

### 2.2.1 Parallel Simplex Algorithm of Linear Programming

In each iteration, computational intensive tasks are concentrated on elementary transformation matrices. The process of coefficient matrix need $m * n$ time-steps on CPU. After attentively considering, we would find that the operation on each element of the coefficient matrix is independent. Mapping the operation on the elements of each row in coefficient matrix to a thread in GPU is feasible. This paper use CPU to control the iteration while use GPU for calculating intensive tasks. So the canonical form and checkout vector $\sigma$ could be calculated by $n$ threads simultaneously that will greatly reduce computation time of each iteration.

### 2.2.2 Parallel Calculation of Canonical Form, Leaving and Entering Variables

Computationally intensive tasks are assigned to GPU, such as entering variable selection, leaving variable selection and calculating canonical form while are concentrated at step 4 in section 2.1. Calculation of canonical form is divided into two steps: changing pivotal element to one and rotate variable. We change pivotal element to one through dividing the element of the pivot row by pivotal element. It needs n time-steps in CPU while one time-step in GPU through mapping element i to thread blocks $T_i$ ($0 <= i < n$). The figure 1 shows the process of changing pivotal element to one.

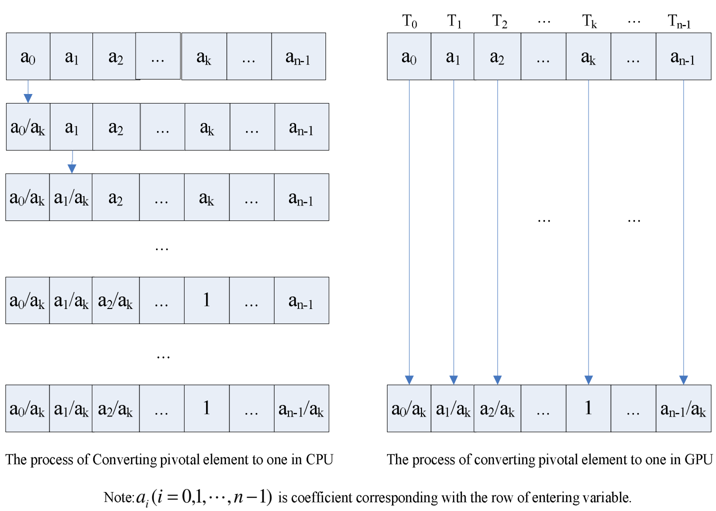


**Fig. 1** The comparison of changing pivotal element to one between CPU and GPU

Entering variable is the largest variable in checkout vector. We use parallel reducing algorithm to find it out as shown in figure 2. The process in CPU need n-1 time-steps while (log n) time-steps in GPU. The process of leaving variable also uses parallel reducing algorithm.

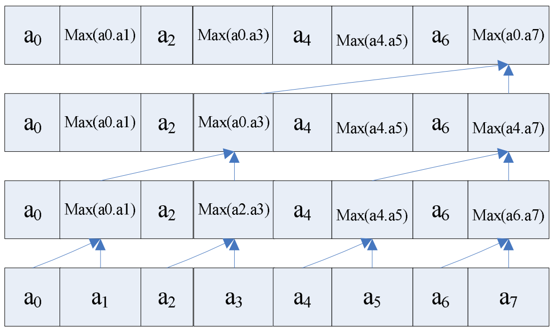


**Fig. 2** Parallel reducing algorithm

## *2.3 Implementation of GPU-Based Parallel Algorithm*

In the part, we realize the parallel linear programming algorithm in GPU using CUDA.

(1) Variable definition:

$n$ : The number of variables in standard form;

$m$ : The number of constraint conditions;

$A[m][n]$ : Coefficient matrix;

$c$ : Cost vector;

$b$ : Right-hand member vector.

(2) The execution step of the program:

*Step 1:* Initialize parameters. Convert linear programming problem to standard form by adding slack variable and surplus variable in CPU; Initialize $m$ and $n$ and matrix $A[m][n]$; Transmit data to GPU.

*Step 2:* Calculate basis feasible solution in GPU.

*Step 3:* Calculate $\max(\sigma_j) = \sigma_k$ in GPU using parallel reducing algorithm, calculate entering variable $x_k$ and judge whether the optimal solution has been obtained in CPU.

*Step 4:* Parallel calculate $\theta$ in GPU, calculate leaving variable $x_l$ and judge whether the problem is unbounded in CPU.

*Step 5:* Make Gauss transformation using $a_{lk}$ as pivotal element, go to *Step 2*.

Following is the flow chart of our algorithm:

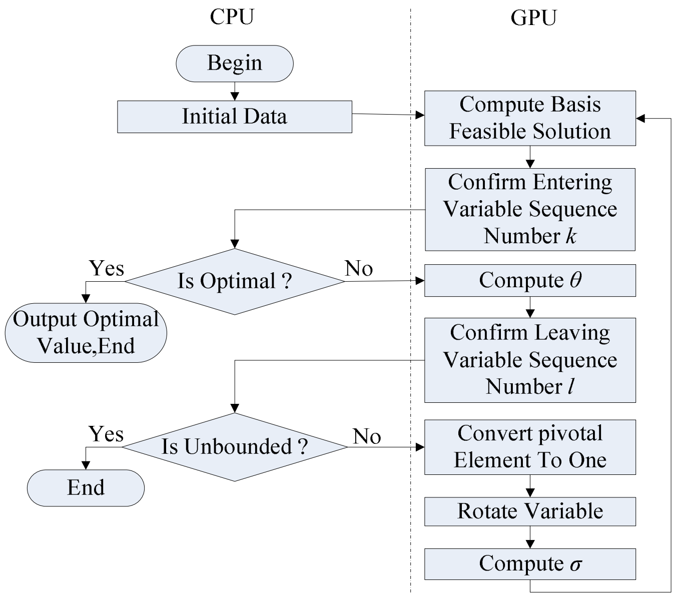


**Fig. 3** Flow chart of the parallel simplex algorithm based on GPU-acceleration

## 2.4 *Optimizing the Use of GPU Memory*

In order to improve the GPU memory use of parallel linear programming algorithm, we propose the following improvement:

(1) Optimizing use of GPU chip memory. Each thread needs to visit column $k$ of coefficient matrix during the Gauss transformation. According to the feature of GPU, the access speed of shared memory is faster than that of global memory. So the column $k$ is copied from global memory to shared memory. Each thread of a block just reads data from shared memory during computing which will reduce the time of fetching data. To make full use of this feature, the number of threads in each block is set to the upmost value.

(2) The back-and-forth transmission of data between CPU and GPU take a negative effect to parallel simplex algorithm. So the frequency and quantity of data transmission should be reduced as far as possible. In this paper, the transmitted data in each cycle just include two integers which are used to judge whether the optimal solution is already obtained and whether the problem is unbounded.

## 3 Experimental Results and Analysis

We apply our algorithm to a set of linear programming problems. In order to analyze the relation between the accelerating effect and the column number $m$, the row number $n$ of coefficient matrix, we performed two experiments on a computer which has 1.6GHz Core 2 Inter 2140 processor, 2048M RAM, NVDIA GeForce 9800GT display card and Windows 7 operation system.

We applied GPU and CPU algorithm to each data group for 100 times and compare the average execution time of each algorithm. Table 1 and table 2 is the experimental results of each group. Logarithmic diagram 1 and diagram 2 show the difference of algorithm execution time between CPU and GPU.

**Table 1** Coefficient matrix m=n

| m | n | CPU times (ms) | GPU times (ms) | Speed-up |
|---|---|---|---|---|
| 100 | 100 | 57 | 50 | 1.1 |
| 200 | 200 | 162 | 72 | 2.3 |
| 500 | 500 | 1004 | 104 | 9.7 |
| 1000 | 1000 | 3912 | 180 | 21.7 |
| 2000 | 2000 | 15123 | 295 | 51.3 |
| 5000 | 5000 | 96413 | 1166 | 82.7 |
| 7000 | 7000 | 192499 | 1604 | 120.0 |

**Table 2** Coefficient matrix m>>n

| m | n | CPU times(ms) | GPU times(ms) | Speed-up |
|---|---|---|---|---|
| 100 | 10 | 41 | 42 | - |
| 200 | 10 | 95 | 67 | 1.4 |
| 500 | 10 | 478 | 81 | 5.9 |
| 1000 | 10 | 1945 | 181 | 10.7 |
| 2000 | 10 | 7410 | 249 | 29.8 |
| 5000 | 10 | 39021 | 530 | 73.6 |
| 7000 | 10 | 64715 | 754 | 85.8 |

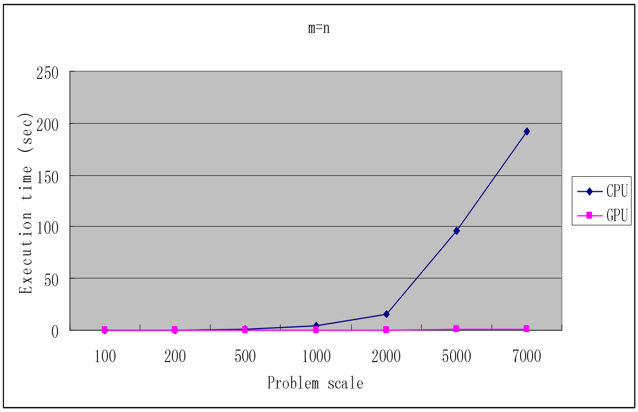


**Fig. 4** Network m=n

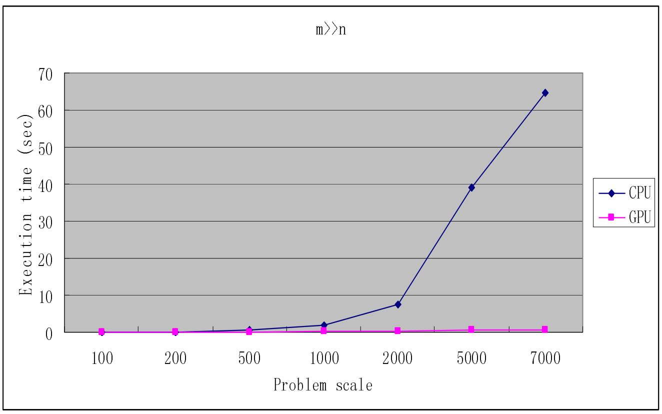


**Fig. 5** m >> n

The results indicate that our parallel algorithm has the following advantages:

(1) Better speed-up. Datum in Table 1 shows the execution time of parallel linear programming algorithm is shorter than CPU method. The speedup ratio is 120 when the scale of coefficient matrix's size reaches to 7000*7000. While the linear programming problem's scale is larger, the effect of acceleration of parallel simplex algorithm is more obviously.

(2) The speed-up ratio linearly correlates with $m$. When $m$ is equal to $n$, Figure 4 indicates that the execution time of CPU is related to $m*m$, and the time complexity in theory is $O(m*(m+n))$. The execution time of GPU linearly correlates with $m$, and the time complexity in theory is $O(m+n)$. In the case

that $m$ is far larger or smaller than $n$, our algorithm doesn't perform well, see Figure 4 and Figure 5. To sum up, our algorithm has the most obvious acceleration result when $m$ and $n$ are both large.

## 4 Conclusions

In this paper, we propose a GPU-based parallel algorithm to solve large scale linear programming problem. From the analysis of experimental results, we can conclude that our algorithm is competitive with CPU algorithm, it can greatly reduce the computing time. Therefore, the GPU-based parallel algorithm is an effective way to solve the large scale linear programming problem.

As pointed out above, the advantages of the results are summarized as follows. From a theoretical perspective, our algorithm is a parallel algorithm other than serial algorithm, so the computing time can be greatly reduced. This research contributes to the literature on the large scale linear programming problem. From a practical perspective, the proposed algorithm provides a helpful decision-making tool to ordinary users who are hard to contact with parallel machine, to solve large scale problems, such as production planning problems, inventory control, etc.

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# A Hybrid MCDM Model on Technology Assessment to Business Strategy

Mei-Chen Lo, Min-Hsien Yang, Chien-Tzu Tsai, Aleksey V. Pugovkin, and Gwo-Hshiung Tzeng

**Abstract.** The wave of globalization, and government's policy towards joining regional market with boundary-less. The entire market becomes a fair and fully competitive market environment, and in order to develop feasible technology strategies. Technology Assessment (TA) is being increasingly viewed as an important tool to aid in the shift towards technology development. The paper aims at to reflect different aspects of technology assessment and their relative importance for future business strategy. We adopt the hierarchical model with multiple criteria to evaluate the alternative concepts in approaching technology assessment process for business strategy (BS). This paper use DANP methods includes DEMATEL, and ANP to establish the investment model. The preference of strategies is demonstrated by VIKOR for selecting appropriate alternatives. The relationship of interdependence and feedback from criteria to influence the setting priority of strategies are discussed. The presented model appears to be comprehensive, flexible and easy to implement in managerial practice. The numerical example is illustrated.

**Keywords:** Technology Assessment, Business Management (BS), Multiple Criteria Decision Making (MCDM), DEMATEL (Decision Making Trial and Evaluation Laboratory), Analytic Network Process (ANP), VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje).

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## 1 Introduction

Technology Assessment (TA) is as an important tool to aid in the shift towards technology development. TA is a wide concept and evolving at the different levels: national, industrial and corporate. This article aims to provide some clarification by reflecting on the different aspects described in the literature as the forms of TA, and evaluating them in terms of their potential contributions to business performance.

For a growing international business, it is facing to the increasingly complex operations in many aspects, including finance, general administration, logistic, sales and marketing, and manufacturing. Although multinational cooperation has ample resources and well experienced in cross-nation management, they have to integrate their global information technology and establish and unified strategy for universal implementation, so as to enable monitoring and assisting the operations of all subsidiaries around the globe in an effective and timely manner. As such, TA starts to play an increasingly important role in developing responsive technology compatibility and innovative strategies under the intense local market competition. Both Russian and Taiwanese multinational corporations face the issues of the application business deployment and system integration and maintenance architecture, regardless of the management style of the regional cultures – organization (business units) and information architecture is centralized, decentralized, or both. This study discusses multinational corporations' business modes – functions, organization, system on integration and maintenance, and related theories with hybrid Multiple Criteria Decision Making (MCDM) for performance evaluation toward to guidance business strategies. The numerical example is presented to ensure the method is feasible and useful for the illustrations.

## 2 Technology Assessments

There are many empirical studies on TA (Coates, 1980; Schot and Rip, 1997; Van Den Ende et al., 1998; Van Eijndhoven, 1997). Pope et al. (2004) presents a conceptualizing sustainability assessment and uses a concept of "integrated assessment" to achieve the impact of strategic assessment. Smits and Leijten (1991) focus on TA as a process consisting of analyses of technological development and its consequences and of debate in relationship to these consequences. It provides information that could help the company involved in developing their strategies. Coates (1980) presents that TA is a class of policy studies which systematically examine the effects on society that may occur when a technology is introduced, extended or modified. It emphasizes those consequences that are unintended, indirect or delayed. Cetron and Connor (1972) attempt to establish an early warning system to detect, control, and direct technological changes and developments so as to maximize the public good while minimizing the public risks. Pretorius and de Wet (2000) define a framework by the hierarchical structure of the enterprise to assess the impact of manufacturing technology on the productivity and competitiveness of the enterprise.

Following the previous findings, Lo (2010) and Lo et al. (2007) presents the attributes of TA and the hierarchy structure of evaluation model (as Fig. 1) on corporate level that are important to users and investors, including capability-R&D, competition-rivalry, competence-manufacturing, and customer-market. In this approach we incorporate the four-aspect of TA accordingly to the concepts of multiple criteria quantitative modeling. The main goal TA is divided into four aspects at the second level of the hierarchy. Every aspect is divided into three or four criteria at the next level.

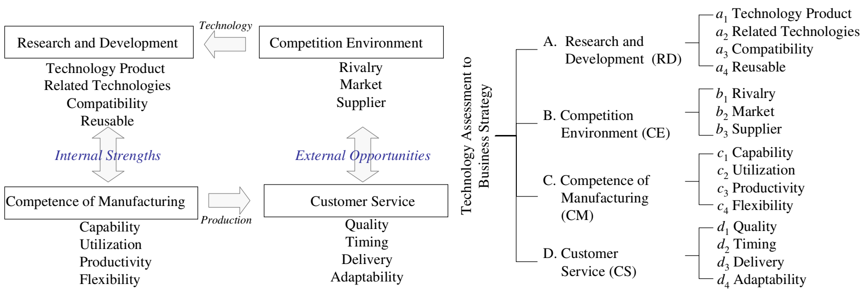


**Fig. 1** Framework to Hierarchy Structure for Technology Assessment

## 3 Assessment Model

This paper is combining DEMATEL, ANP and VIKOR for solving the dependence and feedback problems (relationship map, weighted, and ranking) to reflect to the real world. Across this method we recognize the gaps and guide the direction for business strategies of potential partners from Taiwan and Russia. This study aims to decide the sub-factors that would affect mutual influence of four perspectives and sub-factors, and to establish a more complete business strategy evaluation framework of TA.

### *3.1 A Hybrid MCDM Model for Business Opportunity Evaluation*

The evaluation procedure of this study consists of several steps. First, we identify the aspects (dimensions) and criteria that managers (people who concerns the business opportunities with Taiwan and Russia) consider the most important. After constructing the evaluation criteria hierarchy, we manipulate DEMATEL technique to build an network-relationship map (NRM) and an ANP method is then used to obtain the relative importance of weightings in preferences for each criterion. The measurement of performance corresponding to each criterion is conducted under surveying the domain experts. Finally, we conduct VIKOR method and to index criteria of identifying a way to achieve the aspired outcomes as well as the ranking results. The ANP method currently deals with normalization in the supermatrix by assuming each cluster has equal weight. Although the method to normalize the supermatrix is easy, using the assumption of equal weight for each cluster to obtain the weighted supermatrix seems to be irrational because there are different degrees of influence among the criteria in real world (Ou Yang et al., 2008).

### *3.2 About the Methodologies*

The DEMATEL technique was developed by the Battelle Geneva Institute: (1) to analyze complex 'real world problems' dealing mainly with interactive map-model techniques; and (2) to build qualitative and factor-linked aspects of societal problems (Gabus & Fontela, 1972). The DEMATEL technique was used to investigate and solve the complicated problem group. DEMATEL technique was developed with the belief that the pioneering and proper use of scientific research methods could help to illuminate specific and intertwined phenomena and contribute to the recognition of practical solutions through a hierarchical structure. The methodology, according to the concrete characteristics of objective affairs, can verify interdependence among variables/ attributes and confine the relationship that reflects the characteristics with an essential system and evolutionary trend. DEMATEL has been successfully applied in many situations such as marketing strategies, e-learning evaluations, control systems, safety problems, and environment watershed plans (Liou et al., 2007; Tzeng et al., 2007).

The ANP is the general form of the analytic hierarchy process (AHP) (Saaty, 1980) which has been used in MCDM to release the restriction of hierarchical structure. The ANP method is expressed by a unidirectional hierarchical relationship among decision levels. The top element of the hierarchy is the overall goal for the decision model. The hierarchy decomposes to a more specific criterion, until a level of manageable decision criteria is met. Under each criterion, sub-criteria elements relative to the criterion can be constructed. The ANP separates complex decision problems into elements within a simplified hierarchical system. This study adopt the concept of ANP and combing DEMATEL and ANP method using in obtaining the relationship between each dimension/criteria and the relative weight of criteria.

The VIKOR method was developed for multi-criteria optimization of complex system. It determines the compromise ranking list, the compromise solution, and the weight stability intervals for preference stability of the compromise solution obtained with the initial given weights. This method focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria. It introduces the multi-criteria ranking index based on the particular measure of "closeness" to the "ideal" solution (Opricovic & Tzeng, 2004). Assuming that each alternative is evaluated according to each criterion function, the compromise ranking could be performed by comparing the measure of closeness to the ideal alternative. The multi-criteria measure for compromise ranking is developed which used as an aggregating function in a compromise programming method.

## 4 Numerical Example

This research involves several objects both from Taiwan and Russia, which are High-Tech manufacturing related leaders, telecom experts from different function which includes top management, senior R&D, the senior administrative personnel and marketing functions. The questionnaire of TA evaluation mainly was composed of two parts: questions for evaluating the relative importance of criteria and company's performance corresponding to each criterion.

**Table 1** The total-influence dimensions matrix $T_D$.

| Dimensions | RD | CE | CM | CS | $r_i$ |
|---|---|---|---|---|---|
| RD | 0.292 | 0.387 | 0.342 | 0.596 | 1.616 |
| CE | 0.512 | 0.252 | 0.343 | 0.589 | 1.695 |
| CM | 0.355 | 0.291 | 0.213 | 0.550 | 1.409 |
| CS | 0.728 | 0.620 | 0.644 | 0.924 | 2.915 |
| $s_i$ | 1.887 | 1.549 | 1.541 | 2.659 | |

**Table 2** The sum of influences cause and affected on dimensions and criteria.

| Dimensions/Criteria | $r_i$ | $s_i$ | $r_i + s_i$ | $r_i - s_i$ |
|---|---|---|---|---|
| A. Research and Development (RD) | 1.616 | 1.887 | 3.503 | -0.270 |
| $a_1$ Technology Product | 6.992 | 6.472 | 13.464 | 0.520 |
| $a_2$ Related Technologies | 6.316 | 6.887 | 13.203 | -0.571 |
| $a_3$ Compatibility | 6.599 | 6.808 | 13.407 | -0.209 |
| $a_4$ Reusable | 6.675 | 6.577 | 13.252 | 0.098 |
| B. Competition Environment (CE) | 1.695 | 1.549 | 3.244 | 0.146 |
| $b_1$ Rivalry | 7.012 | 5.407 | 12.419 | 1.605 |
| $b_2$ Market | 6.780 | 6.566 | 13.346 | 0.214 |
| $b_3$ Supplier | 6.313 | 6.199 | 12.512 | 0.114 |
| C. Competence of Manufacturing (CM) | 1.409 | 1.541 | 2.950 | -0.132 |
| $c_1$ Capability | 6.741 | 6.744 | 13.485 | -0.003 |
| $c_2$ Utilization | 6.416 | 6.737 | 13.153 | -0.321 |
| $c_3$ Productivity | 6.810 | 7.543 | 14.353 | -0.733 |
| $c_4$ Flexibility | 7.251 | 6.564 | 13.815 | 0.687 |
| D. Customer Service (CS) | 2.915 | 2.659 | 5.574 | 0.256 |
| $d_1$ Quality | 6.877 | 6.828 | 13.705 | 0.049 |
| $d_2$ Timing | 5.995 | 6.980 | 12.975 | -0.985 |
| $d_3$ Delivery | 5.626 | 6.611 | 12.237 | -0.985 |
| $d_4$ Adaptability | 6.741 | 6.221 | 12.962 | 0.520 |

To gain information that is more valuable for making decisions, we use four dimensions as of Research and Development (RD), Competence of Manufacturing (CM), Competition Environment (CE) and Customer Service (CS) to draw a relationships diagram of business opportunities by TA evaluating and ANP to determine the evaluation criteria weights and rank the priority. As Table 1, Table 2 and Table 3 present the total-influence dimensions matrix, the sum of influences cause and affected on dimensions/criteria and its weights.

By the improvement from the consideration of its interrelationship, influence on cause and affect. Fig. 2 demonstrated the directions for strategic move by priority.

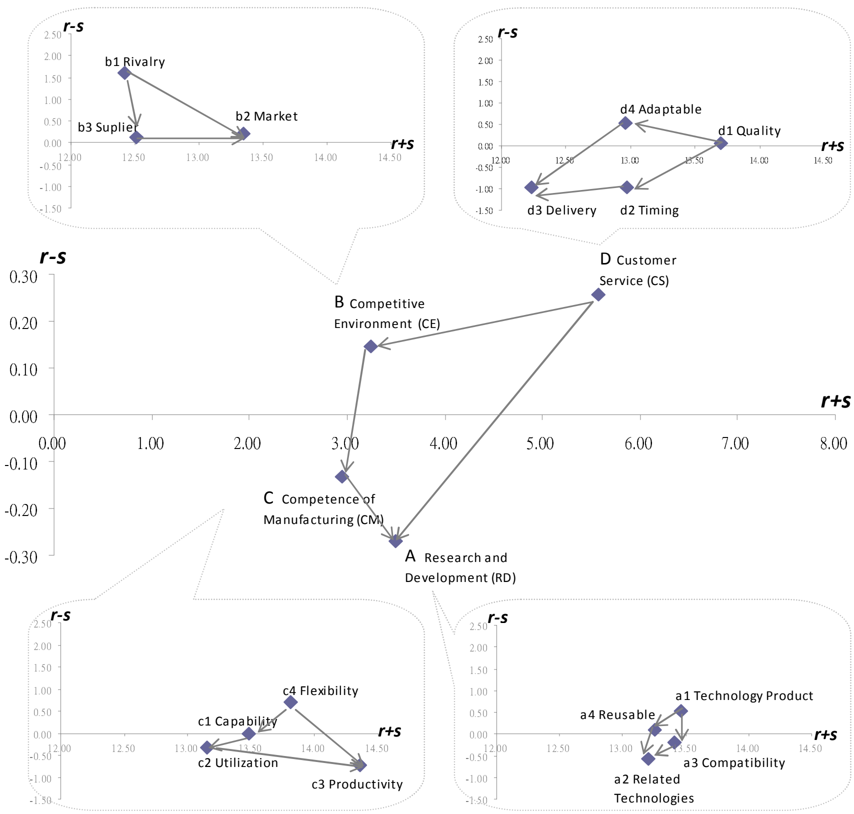


**Fig. 2** The impact NRM of relations

The overall relative weights of the four aspects of TA, which are obtained by applying ANP. Due to the differences of TA environment, construction of the technology platform, business function, industry position and so forth, the various units lead the thought on a difference into the way of analysis by job function. We set several groups to calculate the relative weights as Table 3. Obviously, except administration group, the other groups' shows consistent on the rank with the sequence of RD, CM, CE and CS.

**Table 3** The Weights of Respond TA

| Item | RD $_{[w1]}$ | CE $_{[w2]}$ | CM $_{[w3]}$ | CS $_{[w4]}$ |
|---|---|---|---|---|
| Management | 0.432 (1) | 0.152 (3) | 0.228 (2) | 0.138 (4) |
| R&D | 0.414 (1) | 0.181 (3) | 0.235 (2) | 0.122 (4) |
| Administration | 0.279 (2) | 0.204 (3) | 0.182 (4) | 0.284 (1) |
| Operation | 0.348 (1) | 0.228 (3) | 0.238 (2) | 0.136 (4) |
| Marketing | 0.350 (1) | 0.200 (3) | 0.217 (2) | 0.184 (4) |

From Table 4, the aspect of synthesis performance value for different functions, it shows Management has superior complacency for TA, next is Marketing then Administration, Operational function and the last is R&D, in sequence.

**Table 4** Overall Performance Measure if Different Functions

| Evaluation Criteria | Management | R&D | Administration | Operation | Marketing |
|---|---|---|---|---|---|
| a1 Technology Product | 7.55 (12) | 5.52 (15) | 7.17 (9) | 6.47 (14) | 7.28 (10) |
| a2 Related Technologies | 8.02 (3) | 6.10 (13) | 7.26 (7) | 6.83 (10) | 7.99 (5) |
| a3 Compatibility | 7.97 (5) | 7.04 (7) | 8.39 (1) | 7.05 (7) | 7.16 (12) |
| a4 Reusable | 7.82 (7) | 6.9 0(10) | 7.30 (6) | 7.11 (6) | 7.26 (11) |
| b1 Rivalry | 7.39 (14) | 6.98 (9) | 7.75 (4) | 6.32 (15) | 8.25 (2) |
| b2 Market | 7.06 (15) | 7.09 (6) | 6.49 (15) | 7.20 (4) | 7.80 (8) |
| b3 Supplier | 7.80 (8) | 7.96 (1) | 6.94 (11) | 6.93 (8) | 6.90 (13) |
| c1 Capability | 7.61 (11) | 7.30 (4) | 7.22 (8) | 6.56 (12) | 8.07 (3) |
| c2 Utilization | 7.67 (10) | 7.15 (5) | 6.67 (14) | 7.20 (4) | 7.85 (7) |
| c3 Productivity | 7.44 (13) | 6.06 (14) | 6.94 (11) | 6.63 (11) | 6.76 (14) |
| c4 Flexibility | 8.03 (2) | 6.79 (11) | 7.13 (10) | 6.56 (12) | 6.64 (15) |
| d1 Quality | 7.94 (6) | 6.14 (12) | 7.49 (5) | 7.29 (3) | 8.07 (3) |
| d2 Timing | 8.16 (1) | 7.04 (7) | 6.90 (13) | 8.04 (2) | 7.35 (9) |
| d3 Delivery | 7.76 (9) | 7.63 (2) | 8.39 (1) | 6.87 (9) | 7.99 (5) |
| d4 Adaptability | 8.00 (4) | 7.48 (3) | 7.95 (3) | 8.29 (1) | 8.99 (1) |
| Synthesis value (Rank) | 77.38 (1) | 68.46 (5) | 73.05 (3) | 70.58 (4) | 76.48 (2) |

Remark: synthesis value = performance value *10 * weight.

The strategies/alternatives (Lo et al., 2007) are presented, which emphasizes the business goal of satisfying customers' needs.

– Innovation/Intelligent Property (IIP): Build an innovative environment for continuously technology development achievement;

- Knowledge Platform (KPF): Knowledge accumulation, problem solving, lesson learned and information sharing;
- Response System (RPS): External environmental change to cause Market/Operation strategies to be adjusted;
- Communication System (CMS): a wide channel for customer services in viewing the progress of the on-line production and 24-hour on line service;
- Efficiency Evaluation System (EES): Internal and external factors to move the operation work in effectively;
- Competitiveness Evaluation System (CES): Evaluate the way of technology adoption and shorten the time of technology development into production phase.

Beside, there is no business model or strategies can be applied to the real world all the same, so when adopting a feasible strategies in the changeable business environment, it is necessary to consider as our method which concerns customers' feelings and needs, according to their tendency to find the gap to improve it as well as heading to achieve the ideal solution or aspired level.

For the RD criterion, such priorities include related technologies, compatibility, reusable, and technology product. For the CE criterion, the priorities include market, supplier, and rivalry. For the CM criterion, the priorities include productivity, capability, utilization, and flexibility. For the CS criterion, the priorities include timing, quality, delivery, and adaptability. Combing Fig. 2 and Table 5 which clarify that improvement of priorities in dimensions/criteria should be considered the NRM by thinking whole systems for reducing the gaps to achieve the customers' needs, it is not only care about the weightings but also the influence by direction and indirection to each other.

The performance evaluation has been demonstrated as Table 5 which combining with relative importance of criteria by ANP (global weights). We use the global weight in ANP to compare the performances of each alternative as the ANP provides significant feedback. Respondents were asked to evaluate the level of satisfaction according to each criterion. The performance score and gap (by aspired level) for the possible alternatives of TA concerns is shown in Table 5. Using the performance values, relative results can be obtained. Therefore, the gap identified related to needs-recognition and evaluation of alternatives, which is the same as the DEMATEL of the impact-direction map shown in Fig. 2.

By integrating and calculating the investigated data, we verify the overall performance and determine that RPS surpasses EES, which surpasses CES, KPF, IIP, and then CMS (as of RPS $\succ$ EES $\succ$ CES $\succ$ KPF $\succ$ IIP $\succ$ CMS). The overall performance value of EES (30.814) and CES (30.763) are close, whereas the CMS has a large gap from them. The performance indexes of CMS further demonstrates that the evaluation of alternatives is scored at 28.659 at the lowest point. Relatively, the gap analysis shows the priority (as of CMS $\succ$ IIP $\succ$ KPF $\succ$ CES $\succ$ EES $\succ$ RPS) to problem solving could be the most suggested further of next moves for business strategies.

**Table 5** Performance Evaluation and Gaps Calculation

| Criteria \ Alternatives | Local weight | Global weight (ANP) | Aspired Level | IIP | *Gap* $_{IIP}$ | KPF | *Gap* $_{KPF}$ | RPS | *Gap* $_{RPS}$ | CMS | *Gap* $_{CMS}$ | EES | *Gap* $_{EES}$ | CES | *Gap* $_{CES}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A. Research and Development (RD) | 0.270 | | | 8.083 | (0.147) | 8.500 | (0.076) | 7.384 | (0.114) | 6.520 | (0.225) | 7.943 | (0.137) | 7.296 | (0.226) |
| a1 Technology Product | 0.242 | 0.065 | 10.0 | 9.200 | (0.080) | 9.500 | (0.050) | 9.000 | (0.100) | 6.000 | (0.400) | 9.000 | (0.100) | 5.200 | (0.480) |
| a2 Related Technologies | 0.257 | 0.069 | 10.0 | 7.000 | (0.300) | 8.500 | (0.150) | 8.000 | (0.200) | 7.000 | (0.300) | 8.000 | (0.200) | 8.300 | (0.170) |
| a3 Compatibility | 0.254 | 0.069 | 10.0 | 8.000 | (0.200) | 9.000 | (0.100) | 8.500 | (0.150) | 8.000 | (0.200) | 7.600 | (0.240) | 7.400 | (0.260) |
| a4 Reusable | 0.246 | 0.066 | 10.0 | 8.200 | (0.180) | 7.000 | (0.300) | 4.000 | (0.600) | 5.000 | (0.500) | 7.200 | (0.280) | 8.200 | (0.180) |
| B. Competitive Environment (CE) | 0.251 | | | 7.053 | (0.295) | 7.384 | (0.262) | 8.056 | (0.194) | 7.883 | (0.212) | 7.352 | (0.265) | 7.842 | (0.216) |
| b1 Rivalry | 0.298 | 0.075 | 10.0 | 8.000 | (0.200) | 6.000 | (0.400) | 8.000 | (0.200) | 7.000 | (0.300) | 7.200 | (0.280) | 8.600 | (0.140) |
| b2 Market | 0.361 | 0.091 | 10.0 | 8.400 | (0.160) | 7.000 | (0.300) | 9.100 | (0.090) | 8.500 | (0.150) | 8.000 | (0.200) | 8.200 | (0.180) |
| b3 Suplier | 0.341 | 0.086 | 10.0 | 4.800 | (0.520) | 9.000 | (0.100) | 7.000 | (0.300) | 8.000 | (0.200) | 6.800 | (0.320) | 6.800 | (0.320) |
| C. Competence of Manufacturing (CM | 0.210 | | | 7.762 | (0.175) | 7.190 | (0.199) | 8.165 | (0.129) | 7.015 | (0.244) | 8.129 | (0.116) | 7.544 | (0.175) |
| c1 Capability | 0.245 | 0.051 | 10.0 | 7.200 | (0.280) | 8.000 | (0.200) | 9.000 | (0.100) | 6.000 | (0.400) | 8.400 | (0.160) | 7.000 | (0.300) |
| c2 Utilization | 0.244 | 0.051 | 10.0 | 7.800 | (0.220) | 6.000 | (0.400) | 6.700 | (0.330) | 5.000 | (0.500) | 8.800 | (0.120) | 8.000 | (0.200) |
| c3 Productivity | 0.273 | 0.057 | 10.0 | 8.200 | (0.180) | 7.000 | (0.300) | 8.000 | (0.200) | 8.000 | (0.200) | 7.400 | (0.260) | 7.400 | (0.260) |
| c4 Flexibility | 0.237 | 0.050 | 10.0 | 7.800 | (0.220) | 7.800 | (0.220) | 9.000 | (0.100) | 9.000 | (0.100) | 8.000 | (0.200) | 7.800 | (0.220) |
| D. Customer Service (CS) | 0.269 | | | 7.145 | (0.191) | 7.549 | (0.219) | 8.757 | (0.098) | 7.242 | (0.223) | 7.389 | (0.177) | 8.081 | (0.134) |
| d1 Quality | 0.257 | 0.069 | 10.0 | 7.200 | (0.280) | 8.000 | (0.200) | 9.200 | (0.080) | 5.000 | (0.500) | 7.200 | (0.280) | 7.400 | (0.260) |
| d2 Timing | 0.262 | 0.070 | 10.0 | 6.400 | (0.360) | 9.000 | (0.100) | 9.000 | (0.100) | 8.000 | (0.200) | 6.800 | (0.320) | 7.800 | (0.220) |
| d3 Delivery | 0.247 | 0.066 | 10.0 | 8.200 | (0.180) | 7.000 | (0.300) | 8.000 | (0.200) | 9.000 | (0.100) | 8.200 | (0.180) | 8.600 | (0.140) |
| d4 Adaptable | 0.233 | 0.063 | 10.0 | 6.800 | (0.320) | 6.000 | (0.400) | 8.800 | (0.120) | 7.000 | (0.300) | 7.400 | (0.260) | 8.600 | (0.140) |
| TOTAL | 5.000 | 1.000 | 10.0 | 30.043 | 0.162 | 30.623 | 0.151 | 32.362 | 0.107 | 28.659 | 0.181 | 30.814 | 0.139 | 30.763 | 0.150 |
| Performance Ranking for Alternative (Priority) | | | | 5 | | 4 | | 1 | | 6 | | 2 | | 3 | |
| Priority for Problem Solving | | | | | 2 | | 3 | | 6 | | 1 | | 5 | | 4 |

Based on the findings, CMS should be focused on improving on the way of communication skills (i.e. email, internet contact, satellite system,…,etc.) and more interactivities on human contact will be helpful; IIP should improve on the regulation of intellectual property protection, innovative environment, idea sharing and practice platform (innovation mechanism), and met expectations; and EES, CES, and KPF should improve product availability, market penetration, channel maintenance, feedback system, evaluation mechanism, monitor/auditing system, and knowledge sharing platform. These alternatives provide interaction or trade-off on manipulation business strategies for foreign investment, it should improve their business models to achieve consumers' needs, generate more repurchases, and devise the best marketing strategies for providing the most effective and efficient ways to meet their stage-goal.

## 5 Conclusions

From the analysis result that we can recognize the practice of technology development activities still have large space to promote their business across country via each studied objective in the Taiwan industry. Meanwhile, the analysis of the potential high-tech market force and technology development advantage in Russia reveals the way of collaboration could be taken into businesses considerations from both Taiwanese and Russian.

Technology, marketing and production are the basic elements for TA. Timing to take action gives the opportunities more close to the reality. Using the DEMATEL in conjunction with an ANP, determine the relative weights of specific criteria. The proposed model is suitable for dealing with any complicated and complex decision-making issues whose criteria are interdependent. The analysis result presents several aspects to see the opportunities toward to TA in between Taiwan and Russia. Some issues from this study in technology concerns may also be considered.

1. Via the telecommunication market and equipment analysis, LAN equipment production is the most attractive for investors in Russia.
2. Flexible and fast tool for efficient and prospective investment management skills in a large set of production tasks are required.
3. Middle and small innovation enterprises with government support will be more attractive at point of view of guarantee supplying.
4. For market opportunities, the particular economic zones with economical advantages arisen the big interest (such like in West Siberia - Tomsk and Novosibirsk).

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# A Quantitative Model for Budget Allocation for Investment in Safety Measures

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**Abstract.** The objective of this study was to develop a quantitative model for budget allocation for investment in safety measures in a chemical plant, for determining the sustainability of the company. Developing the model in conjunction with decision-making on strategic investments for safety is complicated because of the subjective factors that enter into the inspection of chemical plants and the choice of appropriate safety measures. This study addressed this problem by applying the Analytic Hierarchy Process (AHP), showing how to quantify inherent risks within a chemical plant for the optimization of the budget allocation for investment in safety measures. A case study was carried out, which clarified the correlation between safety measures and the degree of risk reduction and guided how to allocate budget for safety measures.

**Keywords:** budget allocation, investment in safety measures, percent complete.

## 1 Introduction

With growing interest in global environmental issues, chemical companies need to take responsibility for reducing plant-based risks such as fires, explosions or leakages, given their potentially devastating human and environmental consequences. In addition to taking responsibility, companies need to adopt strategic investment in safety measures, which are inseparable from profit generation, due to the increasing focus on accountability to stakeholders. Developing a quantitative model for budget allocation for investment in safety measures is complicated, particularly in chemical companies, where the introduction of plant safety measures is critical to the success of risk management. In designing such a quantitative model for chemical plants, plant inspections by safety supervisors should form the core, taking into account intangible factors as well as objective plant data. In addition, safety managers must evaluate and choose safety measures in making decisions about strategic investments, which are usually costly and surrounded by uncertainty. Managers in chemical companies continually face such difficulties.

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The difficulties arise mainly from the subjective factors that enter into the inspection of chemical plants and the evaluation and choice of appropriate safety measures. First, the intangible factors include features such as smell, color and sound, which should be reflected in the output of the quantitative model but are rather difficult to quantify, often dependent on safety supervisors' intuition after many years of experience. They would be able to refer to the quantitative data, such as the progression of number of accidents; those data, however, are not enough to capture the depth and richness of risk of the plant. Second, the evaluation and choice of appropriate safety measures is often beset by uncertainty over the likely effects of the different measures available, particularly given the rapidly changing technological environment. Thus, the design of the model and decision-making for budget allocation, relying heavily as it does on experience, knowledge, as well as intuition, means that the evaluation and choice of appropriate safety measures often lacks transparency and traceability.

This paper aims to address this problem; dealing with intangible factors in risk assessment for chemical plants. Unlike previous studies, the quantifying scheme proposed for the intangible risk factors in chemical plants integrates subjective or qualitative information obtained from safety managers into a quantitative model for budget allocation. The quantification of risks is accomplished by an innovative decision support method, the Analytic Hierarchy Process (AHP), which is able to incorporate quantitative and qualitative judgments into evaluations.

## 2 Literature Review

Given the need for necessary and sufficient risk assessment within chemical plants, a variety of approaches have been proposed to date. Six Sigma, a business management strategy first implemented by Motorola in the 1980s and one of the most popular methods for product quality control (Tennant, 2001), can be applied to risk assessment for chemical plants. This method aims to improve the quality of the production process by specifying and eliminating defects in the manufacturing process. Six Sigma employs a set of quality management methods that suit risk management (Snee, 1999), including a statistical analysis method and a quality control method. Even with the wide dissemination of Six Sigma, there have been increasing concerns about its implementation failures. One of the main reasons for the failures is the lack of an appropriate model as to how to effectively guide the implementation of the method (Satya, 2009). In the application of this method to risk management, therefore, how to quantify intangible factors in assessing risks is a critical issue.

Failure Modes and Effects Analysis (FMEA), a procedure in operations management formerly introduced by the U.S. Military Forces in the late 1940s, is also applicable to risk management. Although FMEA was initially developed by the military, the methodology is now extensively employed in a wide variety of industries to examine potential failures in products, processes, designs and services. It is integrated into Advanced Product Quality Planning to provide primary risk mitigation tools and timing in the prevention strategy—both in design and in process formats (Zigmund and Pavel, 2009). While FMEA is powerful tool for the elimination or reduction of failures, how to determine risk priorities of failure modes has been an important issue. Traditional FMEA determines the risk priorities of failure modes by precisely assessing risk factors in terms of the occurrence, severity and detection of each failure mode. This approach, however, is sometimes not feasible in actual application due to the subjectivity in rating the severity, occurrence and detection. Ying-Ming et al. (2007) have proposed treating the risk factors as fuzzy variables and evaluating them by using fuzzy linguistic terms and fuzzy ratings. Besides the subjectivity in judgment, FMEA does not determine the necessity for response, which may blind safety supervisors in risk assessment.

All of these approaches build on the use of models and focus on how frequently failures (the cause of risks) occur, how serious their consequences are, and how easily they can be detected. Any model, however, is simplified and generalized, which means that the model has only a limited region of validity. It is the use of deficient models that actually poses the most serious threat to the validity of risk assessment (Björn, 2003). Even worse is the fact that the assumptions of modelling are often hard coded, which means that not only the validity of the model but also modelling flexibility and modularity are harmed (Zee, 2004).

Furthermore, the number of studies on budget allocation for safety measures within chemical companies is limited because of inherent plant-based risks, which results in a lack of a "standard" scheme of optimization for the budget plan. Chemical companies surrounded by uncertainties such as unexpected loss of disasters and safety measures' envisaged economic effects, therefore, have tried to develop "haute couture" budget optimization by, for instance, consulting professional analysts for safety. While from the perspective of the uncertainty of the results of the investments, such as potential benefits or unexpected costs of early stage manufacturing technology, a budget plan for safety measures is similar to that for new technologies in manufacturing, which serves as a useful reference for this issue. As Beaumont (1999) ascertained, the criteria that firms use to make investment decisions in manufacturing technology are: how firms manage the introduction of new technology; whether firms experience unanticipated effects from new technology; what factors impede or assist its implementation. Some of these factors cannot be clarified before the investments are implemented.

Although decision makers on investments are not completely ignorant of what the future might be, investment decisions are made under conditions of uncertainty. Frank (1998) considered the nature and acceptable level of risk, together with management's personal attitude to risk. O'Brien and Smith (1993) also noted that investments in advanced manufacturing systems must be made while taking into account factors that are difficult to predict. In their paper, how a decision process might be designed and managed was discussed, and the application of the AHP was proposed. Most previous studies, including Frank (1998) and O'Brien and Smith (1993), however, focused solely on the efficacy and efficiency of each safety measure in conjunction with cost minimization; sustainability of a company was not taken into account.

## 3 Model

In this section, a quantitative model for budget allocation for investment in safety measures in a chemical company is developed. The model reflects intangible risk factors while the plan considers global environmental protection issues as well as cost minimization. Although many risk assessments for chemical plants and approaches to budget allocation in risk management have been previously proposed, most have neglected intangible yet critical factors within risk assessment or just focused on cost minimization in risk reduction. Seen in this light, the approach proposed in this research is critical to the sustainability of the company.

A quantitative model of risk assessment must include the intangible risk factors, and the outcome of the model must clarify how to allocate limited resources (e.g., people, goods and capital) to precautionary safety measures. The advantage of the AHP is that it is able to incorporate quantitative and qualitative judgments into assessment. It also makes the evaluation and choice of appropriate safety measures transparent and traceable, even though the design of the model relies heavily on not only experience and knowledge but also intuition.

The quantification of the risks within chemical plants is undertaken using the following two steps, combining the breadth and depth of risks within the plants and incorporating quantitative and qualitative judgments in risk assessment.

1. *Identify and classify risks according to past experience*
   Building on the chemical company's existing accident response manual, an additional review of past accidents within the plants is undertaken. To support the process, interviews would be conducted with the organization maintaining statistics in this field, such as the Ministry of Economy, Trade and Industry in Japan.

2. *Develop a quantitative model of risk assessment reflecting safety supervisors' perceptions*
   A focus group with safety supervisors in the plants is held to capture the depth and richness of risk assessment within the plants. In this process, the issue of risks within the plants would be discussed with the professional analyst for safety. In capturing the safety supervisors' perceptions, questionnaires including AHP-formatted questions would be used. This process facilitates clarification of the priority orders of different risks.

Let $w_D=\{w_{di}\}$ and $w_M=\{w_{mij}\}$, respectively denote the weight of dimensions and that of measures of a risk reduction plan elicited by safety supervisors by using the AHP, where $d_i \in D$ and $m_{ij} \in M$ show a set of dimensions and measures, respectively. Further, let $P=\{p_{ij}\}$ denote percent complete of each measure, which represents the achievement record of each safety measure in comparison with the initial estimate each year. Then the degree of risk reduction can be defined as an index representing how high the risk level of the plants would be one year later:

$$\text{degree of risk reduction} = \sum_i \sum_j w_{di}\, w_{mij}\, p_{ij}. \quad (1)$$

As shown in equation (1), the degree of risk reduction is calculated as a ratio of risk level, which is not based on the number of accidents within the plants. The rationale for the definition is the fact that the model studied in this paper considers the predicted risk level based on the evaluation of each safety measure and its expected effect on risk reduction. In equation (1), the weights of each dimension and measure, $d_i$ and $m_{ij}$, were quantified through discussion among the focus group within the plants, reflecting the consensus of safety supervisors. Percent complete $p_{ij}$, on the other hand, was estimated by the highly experienced safety supervisors in charge of each section. As a result, the risk level of the plants one year later can be predicted as:

$$1 \text{ - (degree of risk reduction)} = 1 - \sum_i \sum_j w_{di} \, w_{mij} \, p_{ij}. \quad (2)$$

## 4 A Case Study in a Japanese Chemical Company

This section demonstrates an application of the quantitative model of risk assessment proposed in this paper as used in a Japanese chemical company (whose name cannot be revealed due to a confidentiality agreement). Although the chemical company has tried to reduce the number of accidents, the current safety status of the plants is not satisfactory. Each division causes some type of accident, and facility error has become a major cause of accidents. What is worse is that the number of accidents increased 80% from 2007 to 2008, after they had succeeded in reducing the number of accidents in 2007. These situations require that the company takes preventive action immediately.

To reduce risks, the company undertook case studies for shareholders, and consulted a professional analyst for the safety of chemical plants. A focus group with safety supervisors in the plants classified risks within the plants into three dimensions as follows: Equipment (hazardous object facilities, poisonous object facilities, utility facilities, construction); Human (education and training, unsafe actions, security); Regulation and others (compliance, design review, inspection system). Based on the classification, concrete measures for risk reduction were proposed as shown in Table 1, consisting of company-wide projects and activities within the plants, and the risk reduction scheme was developed based on the safety measures listed in Table 1.

**Table 1** Safety measures for risk reduction.

| Dimensions | Measures | |
|---|---|---|
| | Projects | Activities |
| Equipment | Emergency inspection<br>Static electricity measure<br>Tank preservation<br>Failure Mode and Effect Analysis | Electricity intentional preservation<br>Environmental risk hedge activity<br>Incinerator abolition |
| Human | Superintendent arousal<br>Security intensification | Natural calamity measure<br>License institution<br>OHSMS (Occupational Health and Safety Management System) |
| Regulation | Equipment measurement system<br>Fire code observance<br>Inspection system establishment | Zero-emission activity<br>5S activity |

In developing the quantitative model for budget allocation for investment in safety measures for chemical plants, plant inspections by safety supervisors should form the core, taking into account intangible factors as well as objective plant data. Intangible factors such as smell, color and sound included in the inspection that should be reflected in the output of the model, however, are often difficult to quantify and often dependent on safety supervisors' intuition based on many years of experience.

In order to quantify these factors for the risk assessment, the AHP was applied in this study. Safety supervisors were required to answer a series of questions formatted by the AHP to derive the weights for the dimensions and measures. Omitting the details of the procedure here, they conducted pairwise comparisons of all possible combinations of dimensions, such as "Which dimension do you think is more important for the risk reduction of our plants, Equipment or Regulation?" Within the chemical plants, the safety supervisors were required to evaluate the degree of importance of dimensions $w_D$ and that of measures $w_M$, first. Then, the safety supervisors in each section measured the percent complete of each measure from the year 2007 to 2008. Lastly, the total degree of risk reduction from the year 2007 (set 1) to 2008 was calculated.

Table 2 summarizes the results obtained from the questionnaire formatted by the AHP. The numbers in the $w_D$ and $w_M$ columns represent the weights for measures normalized by the $l_1$-norm within each dimension. In terms of the importance of dimensions, some supervisors emphasized the importance of Equipment, and others that of Human. In the aggregate, the safety supervisors weighted Human ($w_{d2}$) most, 0.390. For the measures, tank preservation ($w_{m13}$) ranked highest, 0.201, among the measures for Equipment; OHSMS (Occupational Health and Safety Management System) ($w_{m25}$) ranked highest, 0.303, among those for Human; and fire code observance ($w_{m32}$) ranked highest, 0.329, among those for Regulation. Thus, the degree of risk reduction was estimated to be 0.392, as of the end of 2008, according to the percent complete of each measure from 2007 to 2008.

Based on these results obtained from the quantitative model, safety supervisors would be able to rationally allocate budget for safety measures. Being clarified the correlation between safety measures and the degree of risk reduction, safety supervisors may relate the investment amount for safety measures and the percent complete $p_{ij}$ in this paper. Then the budget allocation could be optimized such as by linear programing or other optimization methods. In case LP would be applied to the optimization, cost minimization problem with objective function minimizing investment amounts and with budget constraints could be formulated. In the optimization, a budget allocation for investment entails not only minimizing costs for risk reduction but also integrating the economic, legal and social engineering perspectives, such as "Zero-emission activity" or "5S activity," within the framework shown in Table 1.

**Table 2** Risk assessment: a case within the chemical company.

| Dimensions | $w_D$ | Measures | $w_M$ | $P$ | $w_D * w_M * P$ |
|---|---|---|---|---|---|
| | | Emergency inspection | $w_{m11}$ : 0.161 | $p_{11}$ : 0.95 | 0.0560 |
| | | Static electricity measure | $w_{m12}$ : 0.135 | $p_{12}$ : 0.69 | 0.0340 |
| | | Tank preservation | $w_{m13}$ : 0.201 | $p_{13}$ : 0.50 | 0.0366 |
| Equipment | $w_{d1}$ : 0.365 | FMEA | $w_{m14}$ : 0.114 | $p_{14}$ : 0.30 | 0.0125 |
| | | Electricity intentional preservation | $w_{m15}$ : 0.190 | $p_{15}$ : 0.20 | 0.0139 |
| | | Environmental risk hedge activity | $w_{m16}$ : 0.124 | $p_{16}$ : 0.40 | 0.0181 |
| | | Incinerator abolition | $w_{m17}$ : 0.0745 | $p_{17}$ : 0.10 | 0.00272 |
| | **sub total** | | | | **0.174** |
| | | Superintendent arousal | $w_{m21}$ : 0.190 | $p_{21}$ : 0.50 | 0.0371 |
| | | Security intensification | $w_{m22}$ : 0.186 | $p_{22}$ : 0.00 | 0.000 |
| Human | $w_{d2}$ : 0.390 | Natural calamity measure | $w_{m23}$ : 0.161 | $p_{23}$ : 0.30 | 0.0188 |
| | | License institution | $w_{m24}$ : 0.161 | $p_{24}$ : 0.30 | 0.0188 |
| | | OHSMS | $w_{m25}$ : 0.303 | $p_{25}$ : 0.90 | 0.106 |
| | **sub total** | | | | **0.181** |
| | | Equipment management system | $w_{m31}$ : 0.196 | $p_{31}$ : 0.20 | 0.00960 |
| | | Fire code observance | $w_{m32}$ : 0.329 | $p_{32}$ : 0.00 | 0.000 |
| Regulation | $w_{d3}$ : 0.245 | Inspection system establishment | $w_{m33}$ : 0.128 | $p_{33}$ : 0.20 | 0.00629 |
| | | Zero emission activity | $w_{m34}$ : 0.130 | $p_{34}$ : 0.00 | 0.000 |
| | | "5S" activity | $w_{m35}$ : 0.217 | $p_{35}$ : 0.40 | 0.0213 |
| | **sub total** | | | | **0.0371** |
| | | | | **Degree of risk reduction:** | **0.392** |
| | | | | **Estimated risk level 1 year later:** | **0.608** |

## 5 Concluding Remarks

This paper focuses on a quantitative model of risk assessment for a chemical company, and the correlation between safety measures and the degree of risk reduction are clarified by applying the AHP. Inherent risks of the chemical plants are quantified based on both concrete measures for risk reduction and the consensus of safety supervisors in the plants. In addition, the degree of risk reduction is evaluated based on the importance and the percent complete of safety measures for risk reduction, which guides the allocation of budget for investment in safety measures.

Two open-ended questions remain. First, how to approximate the percent complete of each safety measure for actual cases within chemical companies. The relationship between investment amounts and percent complete of each safety measure just might not lend itself to linear approximation. In such cases, the process of a safety measure needs to be segmented so as to formulate an LP problem. Second, how to establish a feedback system to refine the safety supervisors' subjective judgments in risk assessment. Since the quantitative model of risk assessment developed in this paper is based on plant inspections by safety supervisors, improving the predictive accuracy and taking on broad intangible factors in addition to the objective plant data is crucial.

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# Adapted Queueing Algorithms for Process Chains

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**Abstract.** Process chains are a common modeling paradigm for analysis and optimization of logistic processes, and are intensively used in many practical applications. The ProC/B toolset is a collection of software tools for modeling, analysis, validation and optimization of process chains. The ProC/B models can be translated into queueing networks or Petri nets, which can be solved by effective techniques and algorithms to evaluate performance metrics. The base queueing model with Mean-Value Analysis evaluation algorithm, and their adaptations for modeling thread pool and queue limit have been verified and validated for multi-tier software systems. The goal of our work is to adapt these models and algorithms for process chains to model parallel processes and queue limit.

## 1 Introduction

Process chains are a common modeling paradigm for analysis and optimization of logistic processes [1], and are intensively used in many practical applications.

Different useful approaches have been developed to model the behavior and performance of systems composed from many interacting components with known

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characteristics. In case of logistic systems the components stand for processes related to the collection of steps in the supply chain. As an other example the multi-tier software systems can also be mentioned, where components are related to requests corresponding to certain tiers of the system. There is a demand for researching the ways how performance models of such systems can become more efficient as well as validated.

In most of the cases these systems can advantageously be represented for instance by queueing networks or Petri nets, which support effective techniques and algorithms to determine their performance metrics. However, in logistic systems instead of the mentioned models mainly the process-chain based specification is applied, which cannot directly be utilized by techniques developed for queueing networks or Petri nets.

When talking about process-chains the ProC/B formalism [2] can be mentioned as a modeling language designed to the needs of logistic networks, accompanied by the so called ProC/B tool, aimed for modeling, analysis, validation and optimization of process oriented systems [3, 4]. Furthermore, with the help of the ProC/B tool the mapping of ProC/B models onto queueing networks or Petri nets can also be performed [5, 6], such a way indirectly allowing the application of performance models and algorithms designed for them. The general scheme of mapping ProC/B models onto queueing networks is fairly natural. A standard queueing network is characterized by a set of queues and a set of routing chains as capturing system structure and behavior, respectively.

The paper is organized as follows. Section 2 covers the background and related work. Section 3 provides and analyzes a novel algorithm to model parallel processes. Section 4 proposes and investigates an adapted model and algorithm with queue limit. Finally, Section 5 reports conclusions and future work.

## 2 Background and Related Work

Queueing theory [7, 8] is one of the key analytical modeling techniques used for information system performance analysis [9]. Queueing networks and their extensions (such as queueing Petri nets [10]) have also been proposed to model web-based software systems[11, 12, 13].

This section discusses the base queueing network model and the Mean-Value Analysis evaluation algorithm for multi-tier software systems used in this paper as basis for modeling process chains.

**Definition 1.** The base queueing model is defined for multi-tier information systems [13, 14], which are modeled as a network of $M$ queues $Q_1,\ldots,Q_M$ illustrated in Fig. 1. Each queue represents an application tier. $S_m$ denotes the service time of a request at $Q_m$ ($1 \leq m \leq M$). A request can take multiple visits to each queue during its overall execution, thus, there are transitions from each queue to its successor and its predecessor, as well. Namely, a request from queue $Q_m$ either returns to $Q_{m-1}$ with a certain probability $p_m$, or proceeds to $Q_{m+1}$ with the probability $1-p_m$. There are only two exceptions: the last queue $Q_M$, where all the requests return to the previous queue ($p_M = 1$) and the first queue $Q_1$, where the transition to the preceding queue denotes the completion of a request. Internet workloads are usually session-based. The model can handle session-based workloads as an infinite server queueing system $Q_0$ that feeds the network of queues and forms the closed queueing network depicted in Fig. 1. Each active session is in accordance with occupying one server in $Q_0$. The time spent at $Q_0$ corresponds to the user think time $Z$.

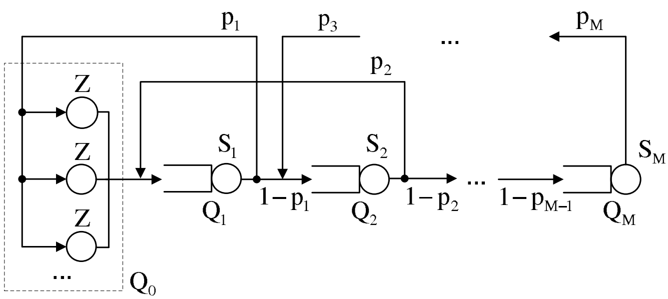


**Fig. 1** Modeling a multi-tier information system using a queueing network

A product form network should satisfy the conditions of job flow balance, one-step behavior, and device homogeneity [9]. The job flow balance assumption holds only in some observation periods, namely, it is a good approximation for long observation intervals since the ratio of unfinished jobs to completed jobs is small.

The MVA algorithm for closed queueing networks [9, 15] iteratively computes the average response time and the throughput performance metrics. The model can be evaluated for a given number of concurrent sessions $N$. A session in the model corresponds to a customer in the evaluation algorithm. The algorithm uses visit numbers instead of transition probabilities, and visit numbers can be easily derived from transition probabilities.

The algorithm introduces the customers into the queueing network one by one ($1 \leq n \leq N$). The cycle terminates when all the customers have been entered. The pseudo code of the MVA algorithm is as follows.

**Algorithm 1.** Pseudo code of the MVA algorithm

**for all** $m$ = 1 to M **do**
    $L_m = 0$
**for all** $n$ = 1 to N **do**
    **for all** $m$ = 1 to M **do**
        $R_m = V_m \cdot S_m \cdot (1 + L_m)$
    $R = \sum_{m=1}^{M} R_m$
    $\tau = n/(Z + R)$
    **for all** $m$ = 1 to M **do**
        $L_m = \tau \cdot R_m$

**Definition 2.** The Mean-Value Analysis (MVA) is defined by Algorithm 1, where the input parameters of the algorithm are the number of customers ($N$), the number of tiers ($M$), the average user think time ($Z$), the visit number ($V_m$) and the average service time ($S_m$) for $Q_m$ ($1 \leq m \leq M$). Moreover, the output parameters are the throughput ($\tau$), the response time ($R$), the response time for $Q_m$ ($R_m$) and the average length of $Q_m$ ($L_m$).

The MVA algorithm for closed queueing networks is applicable only if the network is in product form. In addition, the queues are assumed to be either fixed-capacity service centers or infinite servers, and in both cases, exponentially distributed service times are assumed.

*Remark 1.* Since the base queueing model satisfies the conditions above, the MVA algorithm can evaluate the base queueing model.

*Remark 2.* The computational complexity of the MVA algorithm (Definition 2) is $\Theta(N \cdot M)$, where $N$ is the number of customers and $M$ is the number of tiers.

In this paper adapted models and algorithms for process chains have been introduced in order to model parallel processes and queue limit. The following adapted models and algorithms for modeling thread pool and queue limit have been verified and validated for multi-tier software systems [16, 18, 17]. The verification and validation for process chains are a subject of future work.

## 3 Adapted Algorithm for Parallel Processes

The base queueing model (Definition 1) may be applied also for modeling process chains. The chain elements should be organized into tiers by maintaining the rule, that only elements of neighbouring tiers may communicate. Elements belonging to the same tier should have the same purpose.

The MVA evaluation algorithm (Definition 2) can be adapted in order to model parallel processes, as well. Assume that the actual request contains sequential as well as parallel process elements. Parallel elements can be performed simultaneously with a sequential element.

**Definition 3.** The ***adapted MVA for parallel processes*** (MVA-PP) is defined by Algorithm 2, where the index $s$ is related to a sequential process element index and the index $p$ corresponds to a parallel process element index from $1 \leq m \leq M$.

**Proposition 1.** *The novel MVA-PP (Definition 3) can evaluate the base queueing model (Definition 1).*

*Proof.* Since the MVA evaluation algorithm (Definition 2) can evaluate the base queueing model (Definition 1) shown in Remark 1, and the extensions have not modified the original part of the algorithm, thus, only the extensions have to be proven. In Step 9 of Algorithm 2, the queue length $L_m$ has to be modified to model parallel processes. In Steps 10 and 11 of the algorithm, since the queue length cannot be negative, if the obtained queue length $L_m$ would be negative, it has to be zero.

**Algorithm 2.** Pseudo code of the MVA-PP

1: **for all** $m$ = 1 to M **do**<br>
2: $\quad L_m = 0$<br>
3: **for all** $n$ = 1 to N **do**<br>
4: $\quad$ **for all** $m$ = 1 to M **do**<br>
5: $\quad\quad R_m = V_m \cdot S_m \cdot (1 + L_m)$<br>
6: $\quad R = \sum_{m=1}^{M} R_m$<br>
7: $\quad \tau = n/(Z + R)$<br>
8: $\quad$ **for all** $p$ = 1 to M **do**<br>
9: $\quad\quad$ **if** *p is parallel* **then**<br>
10: $\quad\quad\quad L_p = \tau \cdot R_p - \frac{S_s}{S_p} \cdot L_s$<br>
11: $\quad\quad\quad$ **if** $L_p < 0$ **then**<br>
12: $\quad\quad\quad\quad L_p = 0$<br>
13: $\quad$ **for all** $s$ = 1 to M **do**<br>
14: $\quad\quad$ **if** *s is sequential* **then**<br>
15: $\quad\quad\quad L_s = \tau \cdot R_s$

**Proposition 2.** *The computational complexity of the novel MVA-PP (Definition 3) is $\Theta(N \cdot M)$.*

*Proof.* Assume that each execution of the $i$th line takes time $c_i$, where $c_i$ is a constant. The total running time is the sum of running times for each statement executed. A statement that takes $c_i$ time to execute and is executed $n$ times contributes $c_i \cdot n$ to the total running time.

The worst-case running time of this novel MVA-PP can be seen in below. If $N$ and $M$ is finite, the computational time is finite, the algorithm is terminating.

$$(c_4 + c_5 + c_8 + c_9 + c_{10} + c_{11} + c_{12} + c_{13} + c_{14} + c_{15}) \cdot N \cdot M + \quad (1)$$

$$(c_3 + c_4 + c_6 + c_7 + c_8 + c_{13}) \cdot N + \quad (2)$$

$$(c_1 + c_2) \cdot M + (c_1 + c_3) \quad (3)$$

Consider only the leading term of the formula, since the lower-order terms are relatively insignificant for large $N$ and $M$. The constant coefficient of the leading term can be ignored, since constant factors are less significant than the order of growth in determining computational efficiency for large inputs.

Since the order of growth of the best-case and worst-case running times is the same, the asymptotic lower and upper bounds are the same, thus, the computational complexity is $\Theta(N \cdot M)$.

## 4 Adapted Algorithm for Queue Limit

The base queueing model (Definition 1) and the MVA evaluation algorithm (Definition 2) can be adapted in order to model the queue limit. If the current requests exceed the queue limit, the next incoming requests will be rejected. In these cases, the queue length does not have to be updated.

**Definition 4.** The ***adapted queueing model with queue limit*** (QM-QL) is defined by Fig. 2, where the $Q_{drop}$ is an infinite server queueing system, the $Z_{drop}$ is the time spent at $Q_{drop}$, the $QL$ is the queue limit. If the $QL$ is less than the queued requests sum $\sum_{m=1}^{M} L_m$, the next requests proceed to $Q_{drop}$. Requests from $Q_{drop}$ proceed back to $Q_0$, namely, these requests are reissued.

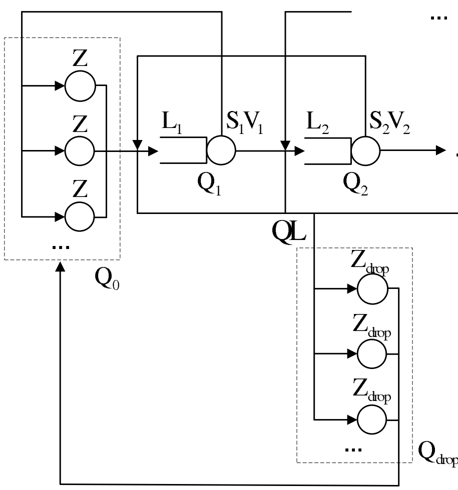


**Fig. 2** Adapted queueing model with queue limit

**Definition 5.** The ***adapted MVA with queue limit*** (MVA-QL) is defined by Algorithm 3, where the $Z_{drop}$ is the time spent at $Q_{drop}$, the $QL$ is the queue limit.

**Proposition 3.** *The novel MVA-QL (Definition 5) can be applied as an approximation method to the proposed QM-QL (Definition 4).*

*Proof.* The QM-QL model does not satisfy the condition of job flow balance (see in Section 2). Thus, the MVA-QL evaluation algorithm can be applied as an approximation method to the QM-QL model.

In Step 8 of Algorithm 3, when it computes the throughput, the $Z_{drop}$ of the model is taken into consideration similarly to $Z$. In Steps 11 and 13 of the algorithm, if the $QL$ is less than the queued requests sum $\sum_{m=1}^{M} L_m$, the next requests proceed to $Q_{drop}$ in the model, the queue length does not have to be updated in the algorithm.

**Algorithm 3.** Pseudo code of the MVA-QL

```
1:  for all m = 1 to M do
2:      L_m = 0
3:  nql = 1
4:  for all n = 1 to N do
5:      for all m = 1 to M do
6:          R_m = V_m · S_m · (1 + L_m)
7:      R = Σ_{m=1}^{M} R_m
8:      τ = nql/(Z + Z_drop + R)
9:      for all m = 1 to M do
10:         L_m = τ · R_m
11:     if Σ_{m=1}^{M} L_m > QL then
12:         for all m = 1 to M do
13:             L_m = oldL_m
14:     else
15:         nql = nql + 1
16:     for all m = 1 to M do
17:         oldL_m = L_m
```

**Proposition 4.** *The computational complexity of the novel MVA-QL (Definition 5) is* $\Theta(N \cdot M)$.

*Proof.* Assume that each execution of the $i$th line takes time $c_i$, where $c_i$ is a constant. The total running time is the sum of running times for each statement executed. A statement that takes $c_i$ time to execute and is executed $n$ times contributes $c_i \cdot n$ to the total running time.

The worst-case running time of this novel algorithm can be seen below. If $N$ and $M$ is finite, the computational time is finite, the algorithm is terminating.

$$(c_5 + c_6 + c_9 + c_{10} + c_{12} + c_{13} + c_{16} + c_{17}) \cdot N \cdot M + \tag{4}$$

$$(c_4 + c_5 + c_7 + c_8 + c_9 + c_{11} + c_{12} + c_{16}) \cdot N + \tag{5}$$

$$(c_1 + c_2) \cdot M + (c_1 + c_3 + c_4) \tag{6}$$

$$\tag{7}$$

Consider only the leading term of the formula, since the lower-order terms are relatively insignificant for large $N$ and $M$. The constant coefficient of the leading term can be ignored, since constant factors are less significant than the order of growth in determining computational efficiency for large inputs.

Since the order of growth of the best-case and worst-case running times is the same, the asymptotic lower and upper bounds are the same, thus, the computational complexity is $\Theta(N \cdot M)$.

These adaptations do not increase the complexity of the evaluation algorithm, because the computational complexity of the original algorithm is the same.

## 5 Conclusions and Future Work

The ProC/B models of process chains can be mapped onto queueing networks or Petri nets, which can be solved by effective techniques and algorithms to evaluate performance metrics.

In this paper novel models and algorithms for process chains have been proposed to model parallel processes and queue limit. It have been shown that the MVA-PP can evaluate the base queueing model, and the MVA-QL can be applied as an approximation method to the QM-QL. The computational complexity of the adapted algorithms have been provided, as well.

The adapted models and algorithms have been verified and validated for multi-tier software systems, the verification and validation for process chains are a subject of future work.

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# An Improved EMD Online Learning-Based Model for Gold Market Forecasting

Shifei Zhou and Kin Keung Lai

**Abstract.** In this paper, an improved EMD (Empirical Mode Decomposition) online learning-based model for gold market forecasting is proposed. First, we adopt the EMD method to divide the time series data into different subsets. Second, a back-propagation neural network model (BPNN) is used to function as the prediction model in our system. We update the online learning rate of BPNN instantly as well as the weight matrix. Finally, a rating method is used to identify the most suitable BPNN model for further prediction. The experiment results show that our system has a good forecasting performance.

## 1 Introduction

### *1.1 Motivation*

Forecasting gold price becomes increasingly important. For a long history, the trading of gold in the international market is continuously active. The derivative of gold trading on the international gold market owns great variety. It mainly contains gold future, gold option, gold forward contracts, and so on[1]. Remarkably, since the price of gold varies within a limited range, this means gold is able to reduce the effect of inflation, control the rise of price and help to carry out constrictive monetary policy. Hence, gold becomes an important risk hedging tool as well as investment tool. Therefore, the works of predicting the price of gold market becomes very significant and important to investors.

However, the current forecasting algorithm has poor precision performance for non-linear problem. We will mainly focus on the artificial neural network (ANN) forecasting algorithm. First, the traditional ANN prediction algorithms employ a

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global fixed learning rate to change the weight matrix. This will cause two problems. On one hand, if the learning rate is too small, the weight matrix will change very slowly. Then, the network training process will take a long time to converge[2].

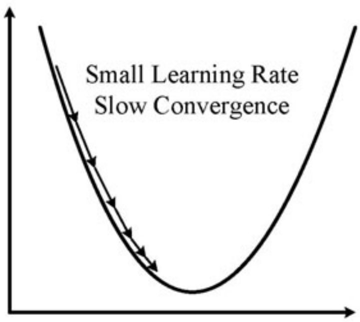


**Fig. 1(a)** Algorithm Convergence of Small Learning Rate.

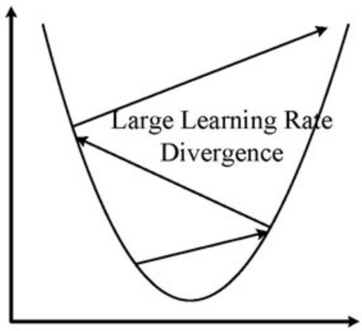


**Fig. 1(b)** Algorithm Convergence of Large Learning Rate.

On the other hand, if the learning rate is too large, we may miss the minimal optimal and cause the algorithm to diverge, like what has shown in Figure 1. Second, unlike the polynomial function, most of the non-linear problems have complex error surfaces. Hence, there will be many local minima. Accordingly, the training process may be trapped in such minima[3]. And the prediction precision will be affected.

## *1.2 Contributions*

In this paper, we propose an improved empirical mode decomposition model(IEMD) to forecast the trend and price of gold market. IEMD model can make efficient use of the history data to predict the future price. During the back-propagation neural network training process, we dynamically change the learning rate by using a global meta-learning rate. Our main contributions are listed as followings:

(1) *High Convergence Speed*. When the trend of history data is downward, we will change the learning rate to increase the weight matrix in the same direction and speed up the decreasing speed of error function. Similarly, when the trend is upslope, the gradient will be increased. And the process will "climb the hill" of error function effectively. Both of methods will speed up the convergence speed of neural network training process.

(2) *High Prediction Precision*. By calculating the gradient of the error function, we minimize the mean square error through changing the weight matrix of prediction model. The novel system we propose is able to update the learning rate of back-propagation neural network instantly, and capture the trend of data series. As a result, our system is able to give a high prediction precision for gold market.

(3) *Significant Application*. Gold plays an important role on the international market. It obtains an increasing attention from investors. Not only it owns the function of risk hedging, but also it can be stored without depreciation. A precise prediction of price on the gold market will help investors to save money. This, therefore, shows the potential significance of our system.

## 2 Related Works

### *2.1 Empirical Mode Decomposition*

What is empirical mode decomposition? The empirical mode decomposition method was firstly proposed by Huang et al[4]. This time series data decomposition technique applies Hilbert transform to nonlinear and nonstationary time series data. The main idea of EMD is to decompose a time series into a sum of oscillatory functions.

The EMD can make highly use of the history data. Since the EMD is able to divide the original time series into several subsets of data by using the intrinsic mode functions(IMF), the characteristics of different subsets of series can be identified through training different BPNNs. We can use these trained BPNNs to predict the future trend of time series and select one of the network model for future prediction.

### *2.2 Online Learning Algorithm*

What is online learning algorithm? In the online learning algorithm, the weight vectors of input data are updated immediately after the presentation of each data point[5]. Therefore, the online learning algorithm is able to adjust the weight of input data and capture the trend of time series instantly.

Online learning algorithm has a number of advantages[5]. As the weight matrix is updated recursively, this algorithm can be use when there is no fixed training set and new data keeps coming in. Besides, as the local minima is a problem for gradient descent in nonlinear models, online learning can easily escape from local minima when a noise data is input. In this paper, we will use online learning algorithm to update the weight matrix. At the same time, we also update the learning rate to make sure the network model can be trained at a fast convergence speed.

## 3 Improved Empirical Mode Decomposition Model (IEMD)

### *3.1 IEMD Model Structure*

Yu et al has proposed an EMD-based neural network ensemble learning model [6, 7]. In this model, presented as EMD-FNN-ALNN for shot, they use forward neural network (FNN) as the prediction model. The time series data is divided into several subsets by using IMF[4]. Each subset is used as an input data to the FNN model for training. The FNN model is finally used to predict future outcome. All the predicted results will be assigned a weight and combined together by using an Adaptive Linear Neural Network (ALNN). This model is pretty good to use the history data. However, prediction results will be greatly affected by the weight of each FNN model. Besides, if one of the FNN models has made a precise prediction, the final prediction may be imprecise because all the predicted results are summed together.

To overcome these problems, we propose an improved EMD online learning-based back-propagation neural network model.

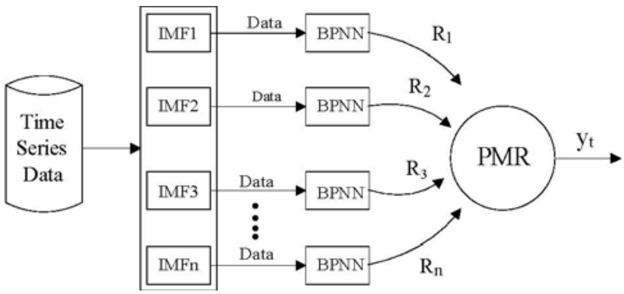


**Fig. 2** An Improve EMD Online Learning-based BPNN Model.

The structure of IEMD-BPNN-PMR model is shown in Fig 2.To make efficient use of the history data, we adopt the EMD method to partition the data into several subsets. Each subset of data is used to train the back-propagation neural network. The time series are decomposed according to the sifting procedure proposed by Yu at el[6]. This procedure is repeated until all the data are divided and each subset of data has only one local minimal or maximal. At the end of the sifting procedure, the data series $x(t)$ can be expressed as follows:

$$x(t) = \sum_{i=1}^{n} c_i(t) + r_n(t) \tag{3.1}$$

Where $n$ is the number of IMFs, namely number of data subsets, $c_i(t)$ is the *ith* IMF, and $r_n(t)$ is the final residue of the procedure. Thus, any time series data can be decomposed by using this EMD method. And the frequency components which are contained in each frequency band are different. They also change the variance of data series $x(t)$, while $r_n(t)$ represent the trend of the data series $x(t)$.

## *3.2 Back-Propagation Neural Network (BPNN)*

Back-propagation neural network is one type of artificial neural network[8], which is a class of typical intelligent learning paradigm and widely used in the field of data forecasting. In this paper, we use a three-layer neural network with error-back-propagation algorithm. And this network model is used as the predicting model of our system. There are many nodes in the hidden layer. Hence, there will be multiple combinations of the weights and data points.

BPNN is able to provide a flexible mapping between inputs and outputs. In the work of Hornik[9], they had proved that a three-layer of feed-forward neural network with an identity transfer function in the output unit and logistic functions in the hidden layer can approximate any continuous function arbitrarily well. Therefore, in this paper, we use the three layer of BPNN as the forecasting model.

Assume that $y_i$ represent the *ith* hidden node, then

$$y_i = \sum_{i=1}^{n} w_i x_i + w_0 \tag{3.2}$$

where $x_i$ is the data input and $w_i$ is the corresponding weight. Meanwhile, $y_i$ is also called a net input, which will be used in the later calculation. After the hidden layer's nodes are generated, we use the activation function $y_j=f(y_i)$ to transform the net input to output, where $j=1,\ldots,m$ and $m$ represents the number of nodes in hidden layer. By using this network model, we finally make the prediction for the time series.

## *3.3 Prediction Model Rating*

We have to ensemble the prediction results from different BPNN models. Thus, the prediction model rating (PMR) method is proposed to handle this problem. In this section, we will calculate the mean squared error $E$ (MSE) of every output of the BPNN model.

$$E_j = \frac{1}{2}(t_j - y_j)^2 \tag{3.3}$$

Where $t_j$ is the target value of the time series; $y_j$ is the predicted outcome from the *jth* BPNN model; $j$ ranges from 1 to $m$. Then, we compare all these $E_j$ and find the minimal one, and increase the rate of *jth* model by 1. This procedure is repeated throughout the training process. Finally, we will get a BPNN prediction model with largest rate for prediction.

# 4 Improved Online Learning Algorithm

## *4.1 Online Weight Update*

In this section, an improved online learning algorithm is proposed. We will start with the mean squared error and make some mathematical methods to deduct the relationship between weight and MSE.

First, we use the chain rule to decompose the gradient into two factors. Then, by using (3.3), we have the following result

$$G = \frac{\partial E_j}{\partial w_{ij}} = \frac{\partial \frac{1}{2}(t_j - y_j)^2}{\partial y_j} \frac{\partial y_j}{\partial w_{ij}} = (y_j - t_j) f'(y_i) x_i \tag{4.1}$$