A Practical Solution for Vehicle Dispatching Problem on Cooperative Deliveries

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***Abstract*¾ In order to solve the vehicle dispatching problem for cooperative deliveries from multiple depots (VDP/CD/MD), a hierarchical multiplex structure calculation model is proposed. It takes advantages of object-oriented modeling, heuristic method, and fuzzy inference in 3 layers, so it can find a utility decision (vehicles plan) close to expert dispatcher. Since the vital input parameters are few and the computational engine is packaged into a software component, the proposed model is provides a convenient tool for the VDP/CD/MD. The model and its optimization algorithm are implemented on PC using object-oriented paradigm. The performance of the proposed model is evaluated through experiments using 3 days oil delivery data taken from an actual dispatching center in Tokyo area. To save a running cost, a total of 27 tank lorries are available for daily cooperative deliveries from 3 depots to about 30-60 destinations with different owners. The experimental results and the evaluations by human experts confirm that the proposed model are better than the results of experienced dispatchers in six evaluation objectives, and that it can be applied to the planning support system for the VDP/CD/MD.**

***Index Terms*¾ cooperative deliveries, multiple depots, calculation model, vehicle dispatching problem.**

I. Introduction

Vehicles dispatching problem for cooperative deliveries is becoming a new and important issue in the real-world [1,2,3,4]. Furthermore, with the growth of personal computers and the spread of geographic information systems, the requirements for a calculation model that can solve practical transport problems in a flexible and feasible way have been increasing. The cooperative delivery problem is one of these practical transport problems. In this paper, a concept of the vehicles dispatching problem for cooperative deliveries from multiple depots (VDP/CD/MD) is introduced. In order to solve the VDP/CD/MD, a practical calculation model of hierarchical multiplex structure is proposed. The proposed calculation model consists of 3 layers: atomic layer (system cost is controlled by a heuristic method), molecular layer (system state is adjusted by a heuristic method and an optimal calculation), and individual layer (a system plan is modified by fuzzy inference). The calculation model is implemented as a software component using object-oriented paradigm, and the corresponding optimization algorithm based on heuristic methods and fuzzy inference is also proposed. Experiments using the 3 days order data taken from an actual dispatching center in Tokyo area are done. A total of 27 tank lorries are available for daily cooperative deliveries from 3 depots to about 30-60 destinations. The transport area is in the Tokyo metropolitan area. Based on the experimental results, a detailed analysis is done from viewpoints of algorithm, system application, and practical implementation. The results and the evaluations by human experts confirm that the calculation model is a feasible, fast, efficient, and can be applied to the planning support system for the VDP/CD/MD in the real-world.

A concept of the VDP/CD/MD and its formulation using fuzzy set theory are proposed in II. The structure and operation criteria of the calculation model are formalized in III. Experimental results and their evaluations are shown in IV.

II. A Concept of VDP/CD/MD

A new style daily delivery problem: Vehicles Dispatching Problem for Cooperative Deliveries from Multiple Depots (VDP/CD/MD) is introduced in Fig. 1. L vehicles $\{V_l\}$ from several companies are hired for delivery jobs in some depots D_p's (the depots which hold all goods in stock). Although the beginning position (start depot) of each vehicle is not fixed to consider the delivery cost, its end position (garage) is usually fixed into garage depot (a carport in a specified depot). When M orders $\{O_m\}$, needs for some goods in a certain time window, are obtained from N users $\{U_n\}$, consumers of some orders with constraints, a dispatching plan of vehicles will be made for deliveries on the next day. The problem is how a suitable dispatching plan can be made for these depots, while having an optimum routing and efficient scheduling for all delivery jobs, and satisfying some constraints.

TABLE I
CONSTANTS IN VDP/CD/MD

Item	Define	Universal Set
Depot	$D_p = ([Bt_p, Et_p])$	$D = \{ D_1, ..., D_p, ..., D_P \}$
User	$U_n = ([Bt_n, Et_n], SU_n)$	$U = \{ U_1, \ldots, U_n, \ldots, U_N \}$
Order	$O_m = (C_m, [Bt_m, Et_m], U^m_n); C_m \leq SU^m_n$	$O = \{ O_1, \ldots, O_m, \ldots, O_M \}$
Vehicle	$V_l = (SV_\ell, RWt_\ell, EWt_\ell, D^l_p)$	$V = \{ V_1, \ldots, V_l, \ldots, V_L \}$

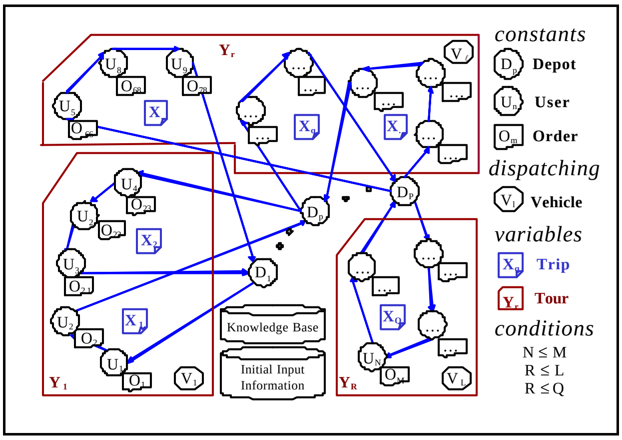

Fig. 1. General description of VDP/CD/MD

TABLE I shows the constant set in the VDP/CD/MD. In the Depot item D_p, the integer interval $[Bt_p,Et_p]$ is a time window during which loading works can be done by vehicles. In the User item U_n, an integer interval $[Bt_n,Et_n]$ is a time window of user's business hours, and SU_n is a max size of the vehicles which can be entered in U_n. In the Order item O_m, the Cm indicates a capacity of O_m, Umn is the user of O_m, and $[Bt_m,Et_m]$ is a desired time window for delivery.

In the Vehicle item V_l, SV_l is a max capacity that the V_l can load, RWt_l is a restriction time that V_l must work as an essential condition, and EWt_l is a max allowed time that the V_l can work more if necessary. D^l_p is the garage depot to which V_l always return after finishing its work. The SU_n, C_m, and SV_l have positive integer values of the same measure, a weight of solid or a volume of liquid. The C_m can be any integer value, while the SU_n and SV_l?are some fixed integer values which correspond to types of vehicle.

TABLE II shows the variables for a trip and a tour used in the VDP/CD/MD. In the Trip item, J_m is a sub-job with order/user pair (a total number is K_q) that represents the order information and the related user's constraints. The Y^q_r is the tour to which X_q belongs, k_q indicates an index number of X_q in the tour Y^q_r. The D^q_L is the loading depot and D^q_R is the rally depot (the next loading depot or garage depot). In the Tour item, Y_r shows a tour carried out by vehicle V^r_l in a day where, $[X^r_{q1}, X^r_{q2},..., X^r_{qKr}]$ is a sequence of trips in Y_r. The SDrp is a start depot which can be variable according to a dispatching plan where, the conditions such as $D^{q1}_R=D^{q2}_L$ are middle shipment conditions, $D^{q1}_L= SD^r_p$ is the start condition, and $D^{qKr}_R=D^{lr}_p$ is the end condition which means vehicles have to return to their garage depot.

All these constant information described above are given in advance, so a solution represented by {X} and {Y} to a certain initial information can be calculated based on both of these constant information and some constraint conditions, which are discussed in the following A.

A. Constraints for VDP/CD/MD

There are some constraints that must be satisfied in the VDP/CD/MD.

1) Vehicle Capacity

The total capacity of orders in a trip can not be over the capacity of a corresponding vehicle.

2) User Condition

A vehicle's size must be equal to or less than all users' parking spaces in the trip it carries out.

3) Depot Condition

All loading works must be done while the depot is open.

4) Dispatching Condition

The user must have at least one order in a day, the number of tours must be equal to or less than the total number of vehicles, and each tour must have at least one trip.

TABLE II
VARIABLES IN VDP/CD/MD

Item	Define	Universal Set
Trip	$J_m = (O_m, U^m{}_n)$ $X_q = ([D^q_L, J^q_{m1}, J^q_{m2}, .., J^q_{mKq}, D^q_R], Y^q_r, k_q);$ $K_q \geq 1,\ 1 \leq k_q \leq K^q_r$	$X = \{ X_1, .., X_q, , X_Q \}$
Tour	$Y_r = (SD^r_p, [X^r_{q1}, X^r_{q2}, .., X^r_{qKr}], V^r_\ell);\ K_r \geq 1$ $D^{q1}_R = D^{q2}_L, \ldots, D^{qKr-1}_R = D^{qKr}_L,$ $D^{q1}_L = SD^r_p;\ D^{qKr}_R = D^{\ell r}_p$	$Y = \{ Y_1, \ldots, Y_r, , Y_R \}$

B. Evaluation Functions

1) Total Working Cost

$$T_{cost} = \sum_{q=1}^{Q} T^q_{cost} \quad \Rightarrow \quad \min \tag{1}$$

$$T^q_{cost} = t^q_{DL,U_1} + \sum_{i=1}^{K_q-1} t^q_{U_i,U_{i+1}} + t^q_{U_{K_q},DR} + t^q_{load} + \sum_{i=1}^{K_q} (t^q_{unloadU_i} + t^q_{waitU_i}) \tag{2}$$

Eq(1) defines a total working cost. Eq(2) calculates the running cost (time, distance, etc) of X_q. The $t^q_{a,b}$ $(a,b \in \{U_n\} \cup \{D_p\})$ is a moving cost between a and b, t^q_{load} is a loading cost, t^q_{unload,U_i} and t^q_{wait,U_i} are an unloading cost and a waiting cost at the user U_i, respectively. Where, U_i indicates the user who has the order O^q_{mi}. Those cost information can be calculated based on the database containing depot, user, and road network information.

2) Average Loading Rate

$$C_{cost} = (\sum_{q=1}^{Q} C^q_{cost}) / Q \quad \Rightarrow \quad \max \tag{3}$$

$$C^q_{cost} = (\sum_{j=1}^{K_q} C^q_{mj}) \Big/ SV^r_l \quad (\in [0,1]) \tag{4}$$

Eq(3), and Eq(4) represent an average loading capacity rate for all trips. Higher value of C_{cost} is always preferable for transporting efficiency.

3). Working Balance

$$B_{cost} = \sum_{r=1}^{R} | B^r_{cost} - B^{mean}_{cost} | \Big/ R \quad \Rightarrow \min \tag{5}$$

$$B^r_{cost} = \sum_{i=1}^{K_r} T^{qi}_{cost} \tag{6}$$

$$B^{mean}_{cost} = (\sum_{r=1}^{R} B^r_{cost}) \Big/ R \tag{7}$$

A working balance of each vehicle is also considered, which is important for equality in a labor condition among all drivers. The B^r_{cost} is a working cost for a tour Y_r, and T^{qi}_{cost} is a running cost of a trip X^r_{qi}, which is defined by Eq(2).

4). Working Capacity

$$V_{cost} = L - R \quad \Rightarrow \quad max \tag{8}$$

In the case of cooperative deliveries, it is better to reduce the number of working vehicles if possible. This criterion Eq(8) is called the working capacity.

5). Service 1(appointed time)

$$S_T = \sum_{q=1}^{Q} S_T^q / Q \quad \Rightarrow \quad \max \tag{9}$$

$$S_T^q = \sum_{j=1}^{K_q} m_o^{mj} \Big/ K_q \tag{10}$$

An order from a user usually has an appointed time for delivery, which must be satisfied as much as possible.

5). Service 2 (labor condition)

The driver's labor condition, called the service 2 The constraint about vehicle working, which is formulated by Eq(11).

$$s_v = \sum_{i=1}^{l} m_v^l \Big/ L \quad \Rightarrow \max \tag{11}$$

III. CALCULATION MODEL FOR THE VDP/CD/MD

A calculation model with **hi**erarchical **m**ultiplex **s**tructure has been proposed for the VRSDP/SD problem [3]. In this paper, an enhanced version of the **hi**erarchical **m**ultiplex **s**tructure model is proposed (Fig. 2) for the VDP/CD/MD. The calculation model consists of 3 layers: The Atomic layer is a fluctuation area of the system cost (running cost), the Molecular layer is a forming area of the system state (trips and tours), and the Individual layer is a decision area of the system plan (dispatching plan). Compared with [9] model, the calculation model can process two main elements (orders, depots) in the molecular layer, and modify the relations among trips, tours, and depots actively by altering the loading depots.

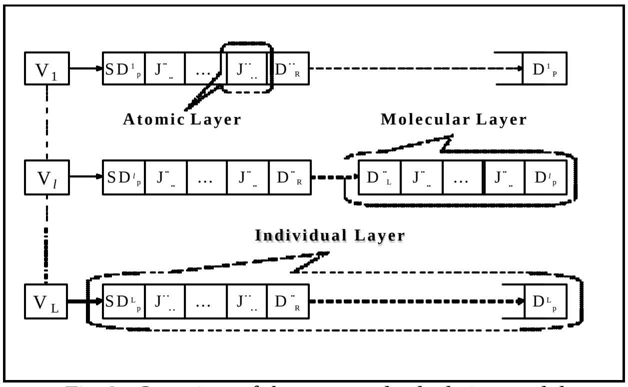

Fig. 2. Overview of the proposed calculation model

The calculation model also imitates a hierarchical calculation and reasoning properties of human experts, and solves the VDP/CD/MD by dividing it into sub-problems, each of which is solved separately in a different layer.

The operating strategy of the calculation model, some measuring and selection functions, and an optimization algorithm are mentioned.

A). Main purpose in Atomic Layer

The main purposes in the Atomic layer are: Minimizing the working cost, improving the loading capacity, and improving the satisfactory degree of Service 2.

A heuristic method like Tabu search [5] is used for applying order Move/Exchange operations and SA [6] for searching the shortest route (X_q).

B). Aims of the Molecular Layer

The aims of the Molecular layer are: Improving the working balance, improving the loading capacity, improving the satisfactory degree of Service 1, and decreasing the running cost.

Tabu search method is also used for applying trip or depot Move and Exchange operations similarly in the Atomic layer. Furthermore, a global search is also used to reorder the trips in the updated tour for improving Service 1 because the number of trips is not so many in a tour.

C). Fuzzy Inference in Individual Layer

The aims in the Individual layer are as follows.

Improving the working balance of vehicles and assigning the appropriate number of vehicles.

The dispatching knowledge from experts is translated to fuzzy membership functions shown in Fig. 3 and Fig. 4. Where, T^T_R is a total restriction time of T type tours (carried out by the vehicles of the same size T) and T^T_{cost} is a total working time of all vehicles of T type. $N(X_T)$ indicates the total number of trips carried out by vehicles of T type, and $N(Y_T)$ is the total number of tours carried out by vehicles of T type.

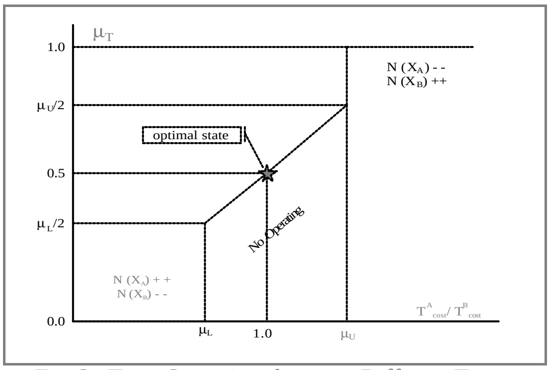

Fig. 3. Trip±Operations between Different Types

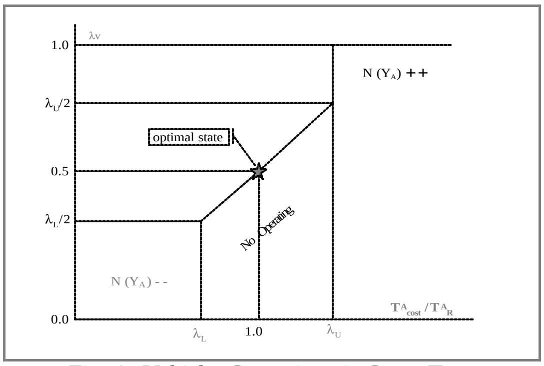

Fig. 4. Vehicle±Operations in Same Type

Fig. 3 shows a trip balance operation between vehicles of different types. The datum lines of a trip balance, μ_L (lower boundary), and μ_U (upper boundary) are given. The current value of trip balance (μ_T) can be used to decide whether to adjust a trip balance or not in the Individual layer. Fig. 4 shows a vehicle balance operation in vehicles of the same type. The datum lines of a vehicle balance, $?_L$ (lower boundary), and $?_U$ (upper boundary) are also given. The current value of a vehicle balance ($?_V$) is used to decide whether to adjust a vehicle balance or not in the Individual layer. By these two fuzzy membership functions used in the Individual layer, not only the relations among trips and tours can be adjusted, but also vehicles of different types can be dispatched appropriately.

D). Measurement and Selection

In this subsection, the measurement criteria of temporary state and the selection criteria for local optimum state of {X} and {Y} are defined.

1) Quality Measurement

(1) Measuring of total working time

$$g_1(X^k) = 1 - T_{cost}^{[k]} / T_{cost}^{[0]} \quad \in [0,1] \tag{12}$$

(2) Measuring of average loading capacity

$$g_2(X^k) = C_{cost}^{[k]} \quad \in [0,1] \tag{13}$$

(3) Measuring of working balance

$$g_3(Y^k) = 1 - B_{cost}^{[k]} / B_{cost}^{[0]} \quad \in [0,1] \tag{14}$$

(4) Measuring of working capacity

$$g_4(Y^k) = 1 - 1/(1 + V_{cost}^{[k]}) \quad \in [0,1] \tag{15}$$

(5) Measuring of service 1

$$g_5(X^k) = S_T^{[k]} \quad \in [0,1] \tag{16}$$

(6) Measuring of service 2

$$g_6(Y^k) = S_V^{[k]} \quad \in [0,1] \tag{17}$$

Eq(12)-Eq(17) describe the measurement criteria of each objective state, where the superscript $^{[0]}$ indicates an initial value of each objective state and the superscript $^{[k]}$ represents a state value of the kth generation (a temporary state). The higher the value of g_x becomes, the better the objective state goes.

$$g(X^k, Y^k) = \sum_{i=1}^{6} r_i \quad g_i(X^k | Y^k) \;\; ; \;\; r_i \in R^+ \tag{18}$$

Eq(18) describes a general measuring formula for all objective item, where $?_i$ is a weighted coefficient which represents an importance degree of each objective item.

E) Selection Criteria

Eq(19) defines a fitness value of the calculation model, which can be used to capture a local optimum state for the VDP/CD/MD problem. Eq(20) indicates whether to record the better state of {X} and {Y} or not, where a_i (i=1,..,6) is the lowest limit value for each measuring objective.

$$eval(k) = \frac{g(X^k, Y^k) - g(X^0, Y^0)}{g(X^*, Y^*) - g(X^0, Y^0)} \tag{19}$$

$$g(X^*, Y^*) = \begin{cases} g(X^k, Y^k) & if \;\; eval(k) > 1 \\ g(X^*, Y^*) & otherwise \end{cases} \tag{20}$$

$$s.t. \quad g_1 \geq a_1, \; g_2 \geq a_2, g_3 \geq a_3, g_4 \geq a_4, g_5 \geq a_5, g_6 \geq a_6$$

F) Implementation of the Calculation Model

A data structure for the calculation model, which is suitable for object-oriented paradigms, is proposed. An optimization algorithm with multiplex heuristic method is also described in this subsection.

1) Data Structure of the Calculation Model

The object-oriented programming technique is applied to the implementation of the calculation model. Through object classes and doubly linked pointers, the main elements in the calculation model have hidden link relations among each other so that the information can be obtained directly. The operations in each layer (Atomic, Molecular, and Individual) are performed by meta-programming and the fuzzy inference.

The data structure for the calculation model can resolve a multi-objects synthetic problem like the VDP/CD/MD into sub-problems through hierarchical layer and multiplex data structures. Therefore, the combination of all elements can be searched by meta-programming and the relation among elements can be adjusted by fuzzy inference programming in different layers.

2) Optimization Algorithm

An optimization algorithm for the calculation data structure is shown in Fig. 5.

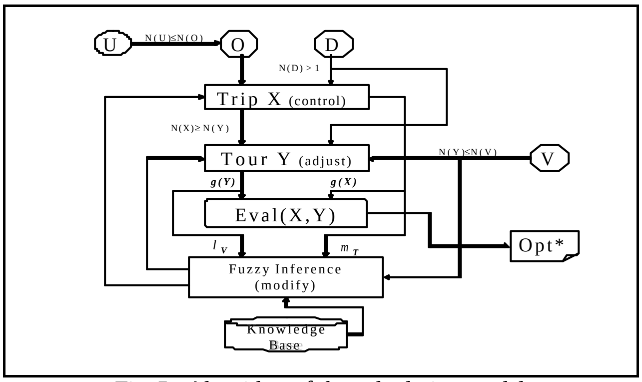

Fig. 5. Algorithm of the calculation model

The heuristic method Tabu search, is used to construct {X} in the Atomic layer (handling a routing problem) from the information of {O}, {U}, and {D}. Based on the information of {X} and {V}, {Y} can also be made by Tabu search in the Molecular layer (handling a scheduling problem). Through an analysis to the relations among {X}, {Y}, and {V}, a synthetic adjustment can be made by fuzzy inference in the Individual layer (handling a dispatching problem). From these operations, the best state for the VDP/CD/SD can be obtained.

IV. EXPERIMENTS USING OIL DELIVERY DATAS

The convergence and effectiveness of the calculation model are shown only by experiments, because it is very difficult to demonstrate these properties of the complicated model such as the calculation model by analytical approaches.

A component of the calculation model is applied to the real data set used in cooperative deliveries by 3 actual oil companies. The cost information can be calculated by Dijkstra algorithm.

Experiments with the order data of 3 days are introduced. Based on the experimental results, the efficiency and flexibility of the calculation model for the VDP/CD/MD are evaluated from several viewpoints.

A) Vehicles Dispatching Experiments

The data set used in the experiments is supplied from an actual dispatching center in Tokyo, in which 27 tank lorries of 2 types (14kl and 20kl) are available for daily cooperative deliveries. It should be noted that the number of vehicles actually used are preferable as small as possible in terms of a transport cost. The delivery jobs are zone forwarding, where 30-60 orders are issued by about 100 users every day. 3 depots with different owners are used for saving a running cost.

The restriction time (RWt) is set to 8 hours and the max extension time (EWt) to 4 hours. The boundaries for trip (μ_T) and vehicle balance ($?_V$) are set to $\mu_T \in [0.45,0.55]$ and $?_V \in [0.45,0.55]$ in fuzzy inference (Fig. 8 and Fig. 4), respectively. The aim of the experiments is to make a dispatching plan with least vehicles while keeping a best balance of all evaluation objectives.

Experiments are done in the same condition as experts do in the real world. The important points are indices of a working cost (T_{cost}), a loading capacity (C_{cost}), and a working balance (B_{cost}). A working capacity is also considered to confirm the validity of fuzzy inference. TABLE III shows the results of these experiments and the best states are recorded in 184, 102, and 71-th generation, respectively.

TABLE III
EXPERIMENTAL RESULTS

Date	$T_{cost([*])}$ (min)	$C_{cost([*])}$ (%)	$B_{cost([*])}$ (min)	$V_{cost([*])}$ (unit)	$S_{T([*])}$ (%)	$S_{V([*])}$ (%)	**Best State**
11/02	9359	90.1	65.8	8	94.9	92.6	184th
11/06	10491	91.4	52.9	6	91.4	92.9	102th
11/08	9059	92.7	56.6	8	94.1	94.7	71th

B) Analysis of Experimental Results

Based on the analysis of calculating processes during above experiments, the advantages of the calculation model from the viewpoints of experimental results, algorithms, and system applications are discussed in this subsection.

1) Discussion about Experimental Results

TABLE IV
COMPARISON ABOUT EXPERIMENTAL RESULTS

Operator (processing time)	T_{cost}	C_{cost}	B_{cost}	V_{cost}	S_T	S_V
Proposed model (20 min)	Better	≥ 90%	≤ 66 min	Better	≥ 90%	Better
Experts (0.5 day)	Good	≥ 83%	≤ 90min	Good	≥ 80%	Good

Considering the properties of actual cooperative deliveries, experiments are done with a condition to minimize the number of vehicles for a transport cost. TABLE IV shows a comparison between the plans made by the calculation model and those done by experienced operators. From the result, it is confirmed that the calculation model is a fast and efficient solver for the VDP/CD/MD and can generate a much better plan than human experts.

2) Discussion about Algorithm

TABLE V
COMPARISON ABOUT OPERATING PROCEDURES

Operator	Process Manner	Data Type	Data Structure	Optimization Means
Proposed model	Synthesis	Fuzzy [0,1]	Object-oriented	Meta + Fuzzy Programming
Experts	Individual	Crisp {0,1}	——	Experience

Experts dispose the VDP/CD/MD with trip, depot, and tour procedures individually. Although the calculation model consists of three operation layers, it integrates these elements into routing, scheduling, and dispatching by a synthetic and multi-objective planning. TABLE V shows the difference of operating procedures between the calculation model and human experts.

3) Discussion about Application

TABLE VI
EVALUATION FOR SYSTEM APPLICATION

Application	Input Parameters	Objective Functions	Objective Balance	Process Time	Flexibility
Proposed model	Fewer	Many	Better	Faster	Better

Another interest is how the calculation model can be used as a software tool for the system applications. TABLE VI shows the advantages of the calculation model from viewpoints of practical system applications.

V. CONCLUSIONS

A new concept of VDP/CD/MD in the real-world is introduced. The enhanced calculation model with hierarchical multiplex structure and its operation strategies based on heuristics, optimization algorithms, and fuzzy inference, are also proposed. The calculation model is implemented as a software component using object-oriented paradigm. Its optimization algorithm is also implemented through meta-programming and fuzzy programming. The experiments with the data set taken from an actual dispatching center are performed to make a dispatching plan with fewer vehicles while keeping the best balance of all evaluation objectives. The experimental results of the calculation model are better than that of experienced dispatchers in six evaluation objectives. Analysis and evaluation results confirm that the calculation component is a feasible, fast, and efficient compared with the results of experts.

Since the calculation model and its algorithm take advantages of object-oriented modeling, heuristic method, and fuzzy inference, it can find a utility decision (vehicles plan) with intelligence and flexibility close to expert dispatcher. Because the vital input parameters are few and the computational engine is packaged into a software component, the calculation model is a convenient tool in system application for the VDP/CD/MD in the real-world.

The proposed calculation model will be able to cover similar transportation problems in the real-world.

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