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Urban Freight Service Capacity Dynamic Coordination System

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Abstract: In big cities with the serious traffic congestion problem and environmental challenges, strict regulations are enforced on trucks in operation. Therefore an Urban Freight Service Capacity Dynamic Coordination System (UFSC-DCS) as a Decision Support System (DSS) was proposed. It integrated a simulation model with optimization objectives and balanced the interests of various participants. This UFSC-DCS provides regulators with candidate solutions under different spatial-temporal traffic resources constraints.

Key words: Urban freight, trucks regulation, decision support system

INTRODUCTION

Policymakers face a clear challenge with respect to addressing trade-offs between the essential role of trucking in the economy and our daily lives and negative externalities associated with on-road goods movement (Kanaroglou and Buliung, 2008). So most cities ban or at least strictly regulate truck traffic. In Spain urban freight policies included the access restrictions (always depend on truck weight), load zones (truck parking is normally up to 30 min and then only as long as load/unload operations are being carried out), access time windows and noise regulations (night distribution is banned in all major cities, except for very specific cases) (Munuzuri *et al.*, 2012). In the United Kingdom, delivery trucks assigned the congestion pricing tax (£5 a day). Some northern European cities (Amsterdam, Copenhagen, Stockholm and Goteborg) applied truck access restrictions based on environmental criteria (Dablanc, 2007).

As a candidate policy, evening deliveries have potential benefits, on behalf of carriers, such as reduced travel time and fuel consumption, accompanying the adverse factors like increased costs for staff and security issues as well as noise impact for urban residents. Moreover, time restrictions may cause a decrease in the efficiency of deliveries in terms of number of trips or load factor (Stathopoulos *et al.*, 2012). Holguin-veras *et al.* (2006) assessed the impacts of the Port Authority of New York and New Jersey's (PANYNJ) time of day pricing initiative on the behavior of carriers and the nature of the response is determined by the balance of power between carriers and receivers.

All the routes in the city are not really congested during every hour of the day and some roads definitely can allow a few freight trucks to go through for their destinations (Bhuiyan *et al.*, 2010). For example, the time

of day pricing initiative by PANYNJ classified the peak hours are 6-9 AM and 4-7 PM on weekdays and 12 noon-8 PM on weekends, the overnight period (trucks) is from midnight to 6 AM on weekdays; the remaining hours are classified as off-peak hours (Holguin-veras *et al.*, 2006). On the contrast, Beijing almost carries out the consistent delivery windows (e.g., 6 AM-11 PM) for trucks except with some special freight permits. But with widely practice of Intelligent Transportation Systems, urban freight transportation structure can be greatly changed to meet clients dynamic demand with the fluctuation of traffic (Grzybowska and Barcelo, 2012). For example, Holguin-veras (2000) proposed the Integrative Freight Market Simulation, focusing on producers, consumers, carriers, while the government is divided in a regulatory body and a Traffic Management Center that provided real time traffic information and exercised traffic control. Bhuiyan *et al.* (2010) proposed an iterative bidding framework for better traffic management and socioeconomic benefit while dealing with the decentralized urban freight management problem. In brief, being able to predict and anticipate preferences should help policy design, prevent negative reactions and avoid unwanted policy outcomes. The microscopic simulation model is successfully calibrated to reflect the observed and to produce realistic congestion patterns, representing queuing formation/dissipation and bottlenecks and allowing for separate analysis of performance (Abdelgawad *et al.*, 2011). Yang *et al.* (2010) simulated operation time schedule and the truck arrival pattern within an operation time window.

This study presents an Urban Freight Service Capacity Dynamic Coordination System (UFSC-DCS). As a Decision Support System (DSS), it integrates a simulation model with optimization objective, to balance the interests of various participants. In the next section,

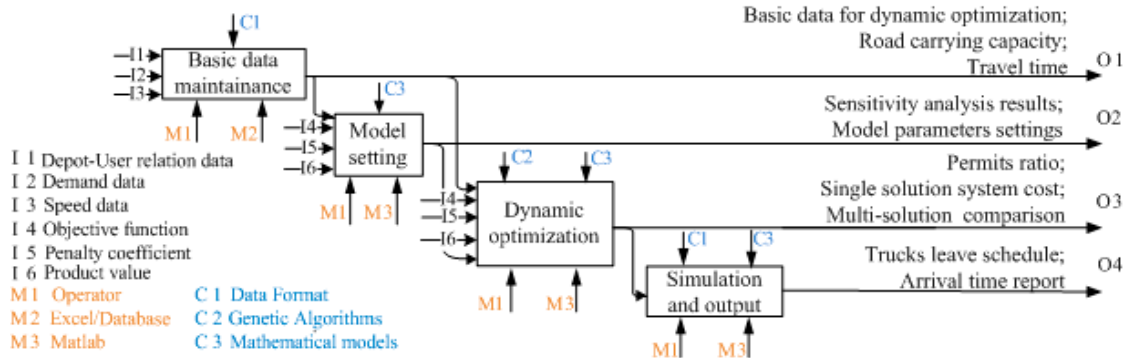


Fig. 1: System IDEFO diagram of UFSC-DCS

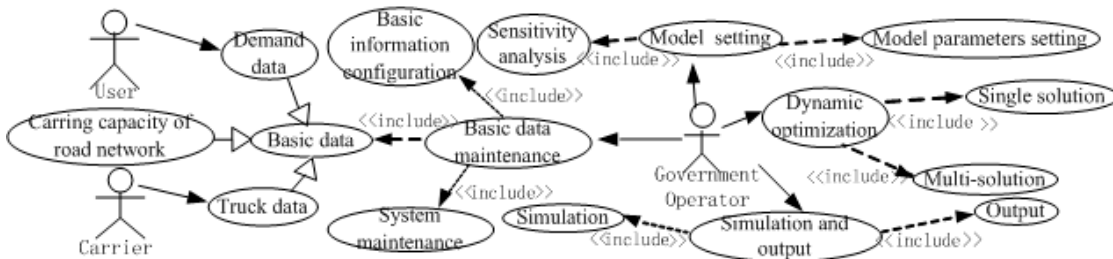


Fig. 2: Use case diagram of UFSC-DCS

after the illustration of the main scheme of the UFSC-DCS, a detailed object-oriented system design method is described, followed with results and conclusion.

MAIN SCHEME OF UFSC-DCS

The UFSC-DCS took the type of goods and trucks’ waiting time into account and dynamically distributed the freight trucks permits to coordinate the urban freight service capacity. According to the software engineering theory, Fig. 1 presents the IDEFO diagram of UFSC-DCS with its functions and links.

The UFSC-DCS tries to meet the demand of urban freight as well as reduce traffic congestion and economically regulate freight trucks to access downtown areas. It has four modules as following.

Basic data maintenance prepares input data like Depot-User relation, demand, travel speed and calculates the road carrying capacity and travel time.

Model setting has two sub-modules. One is model parameters settings, deciding product value, penalty coefficient and objective function. The other is sensitivity analysis comparing and selecting the proper model parameters.

Dynamic optimization now employs a genetic algorithm (GA) to calculate the optimal permits ratio, system cost and conduct multi-solution comparison.

Simulation and output module includes simulation optimization program, trucks leave schedule and arrival time report, etc.

OBJECT-ORIENTED SYSTEM ANALYSIS OF UFSC-DCS

UFSC-DCS’s static models: The specific use cases diagram includes government operator, user and carrier as Fig. 2. Figure 3 illustrates entities in the system class diagram UFSC-DCS.

UFSC-DCS’s dynamic models: Sequence diagram describes the dynamic interactions between objects, emphasizing the chronological order between dissimilar objects. Figure 4 presents the sequence diagram of government operator adding basic data. Figure 5 is the dynamic optimization activity diagram.

State diagram describes all possible states and state transition events in the system life cycle. All objects have a state, which usually has certain time stability and is the result to perform a series of activities.

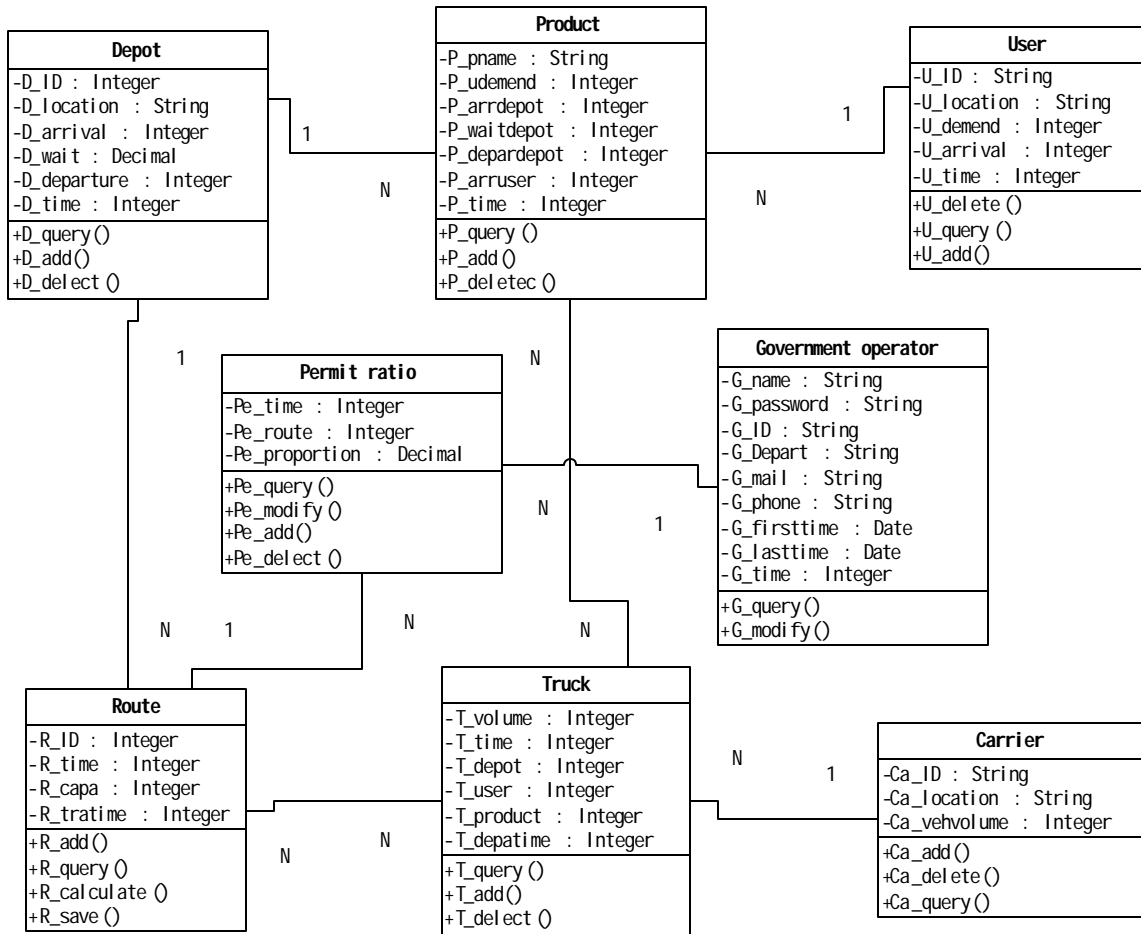


Fig. 3: System class diagram of UFSC-DCS

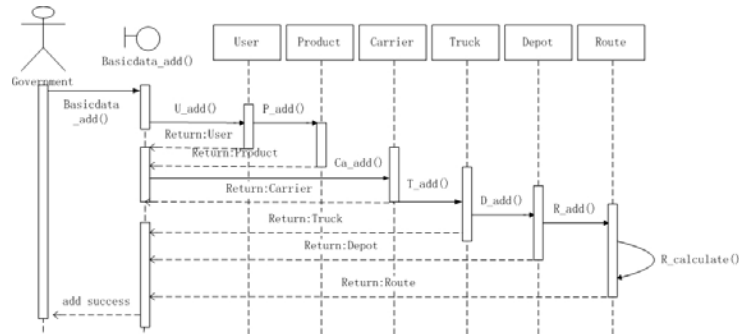


Fig. 4: Sequence diagram of adding basic data

The state transition diagrams of truck and user in system simulation adjustment program module are as Fig. 6 and 7.

RESULTS OF UFSC-DCS

Global parameters and basic data: Figure 8 is global parameters input interface. Input basic system parameters

(①), choose “Generate matrix”, click “Confirm” to generate the depot-user matrix (②), in which the user listed in sequence and depot column is initially 0, here operator fills corresponding depot numbers.

Figure 9 is the demand data maintenance interface. Import the excel to get the non-uniform distribution demand data; For the uniform distribution,

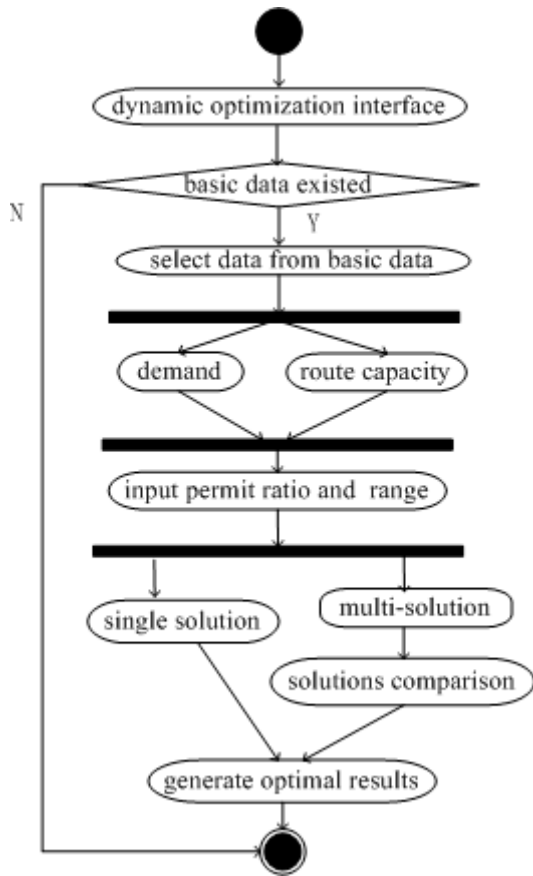


Fig. 5: Dynamic optimization activity diagram of UFSC-DCS

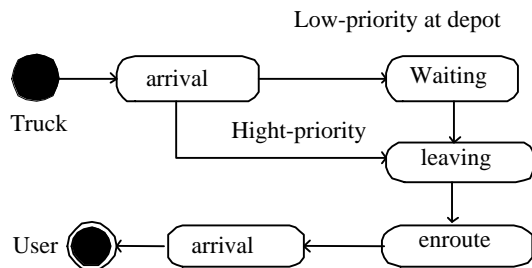


Fig. 6: Truck state diagram

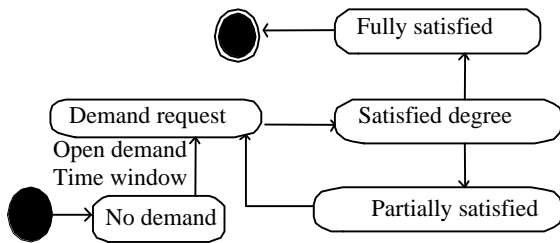


Fig. 7: User state diagram

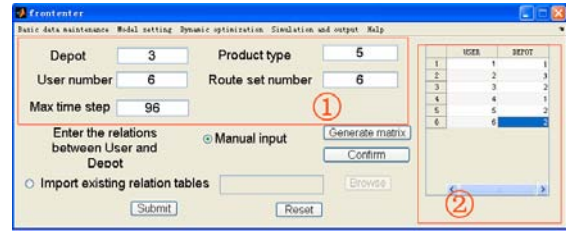


Fig. 8: Global parameters input interface

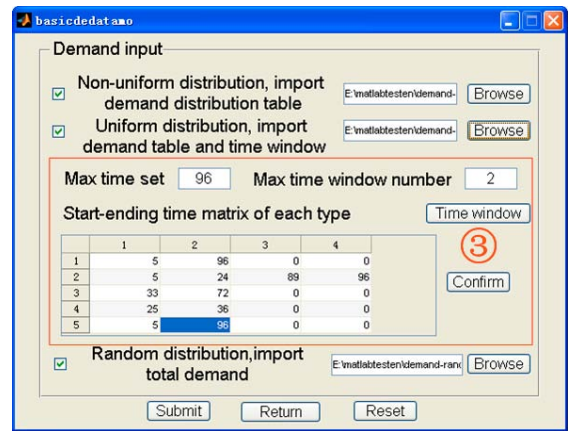


Fig. 9: Demand data maintenance interface

input maximum number of time-windows and its matrix, odd rows filled with start time and the even with ending time (③); Random get by $Rand()$ after read the total demand file.

Figure 10 is the capacity data maintenance interface. If regulate with time window, input the number of time-window and its matrix (④).

Model setting: Indicators to evaluate the simulation system as Eq. 1, 2 and 3.

$$\begin{aligned}
 X_{\text{total system cost}} = & \sum_t \sum_u \sum_p a\beta_1^p \left| \hat{D}_u^p(t_e) - D_u^p(t_e) \right| \\
 & + \sum_t \sum_u \sum_p b\beta_2^p \left| \hat{D}_u^p(t_r) - D_u^p(t_r) \right| \\
 & + \sum_t \sum_u \sum_p cX_{su}^p(t) \times \bar{\tau}_{su}^p(t) \\
 & + \sum_t \sum_u \sum_p dQ_{su}^p(t) \times \bar{\delta}_{su}^p(t)
 \end{aligned} \tag{1}$$

$$X_{\text{travel time}} = \sum_t \sum_u \sum_p X_{su}^p(t) \times \bar{\tau}_{su}^p(t) \tag{2}$$

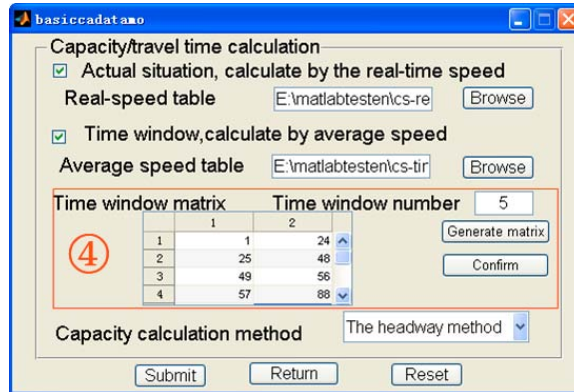


Fig. 10: Capacity data maintenance interface

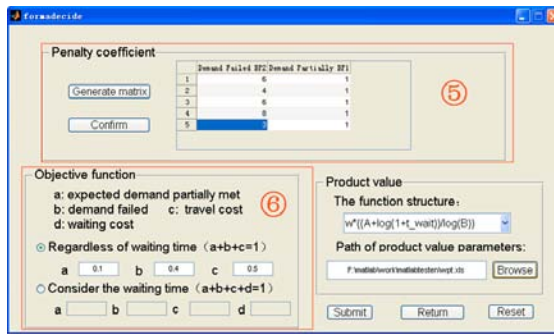


Fig. 11: Model setting interface

Table 1: Compared results between multi-solutions

Solution	1	2	3	4
System cost	61822.0	64012.0	80624	77350
Travel time	105720.0	118195.0	60738	66602
Unsatisfied demand	3721.4	1504.3	20753	18199

$$X_{\text{unsatisfied demand}} = \sum_t \sum_u \sum_p |\hat{D}_u^p(t_f) - D_u^p(t_f)| \quad (3)$$

where, u is users, s is depots; p is products, T is set of time, $t, t_s, t_f \in T$, demand expected time t_s , demand failed time t_f , $Q_{su}^p(t)$ is volume of product p for user u waiting in depot s at time t , $\hat{D}_u^p(t)$ is expect demand of user u for product p at time t , $D_u^p(t)$ is actual arrival volume of product p at time t for user u , $\bar{\tau}_{su}^p(t)$ is average travel time from depot s to user u at departure time t , $\bar{\delta}_{su}^p(t)$ is average waiting time of product p for user u in depot s at time t , $X_{su}^p(t)$ is volume of product p departure time t from depot s to user u .

Figure 11 has three parts. Five types products have penalty coefficients β_1^p and β_2^p (5). The objective function Eq. 1 has parameters a , b , c and d (6). The structure of the product value functions to regulate trucks leaving depot behavior.

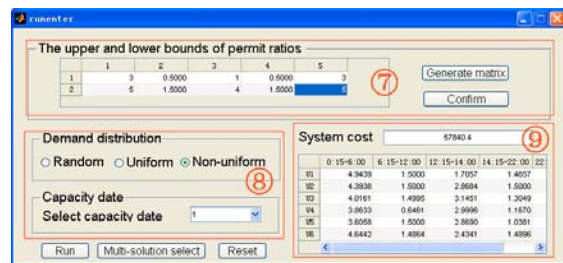


Fig. 12: Single solution optimization interface

Single solution optimization and multi-solution comparison:

In Fig. 12, for GA algorithm input the upper and lower bound of permit ratios (7), choose the demand distribution and capacity data of specified date (8), then get the system cost and permit ratio distribution (9) by optimization calculation.

In Fig. 12, after filled 7 and 8 as solution 1 (basic scenario), click “Multi solution select” compared with the other three scenarios as Table 1.

The unsatisfied demand of solution 3(trucks operate at 22:00-6:00, so the receivers) and 4(trucks are banned during 6:00-12:00 and 14:00-22:00, no receivers as well) are

greater, while the travel time of solution 2 (random distribution of demand and carriers without time restriction) is much longer, so the solution 1 is reasonable in general.

CONCLUSIONS

With Java Web, Matlab and database (/Excel) conducting the mixed-language programming, this paper developed a DSS named as UFSC-DCS, effectively supported the government operator dynamically regulate permits of freight trucks access municipal areas under different spatial-temporal traffic resources constraints, which make full use of the road network capacity as well as meet the urban freight demand.

The embedded simulation model classifies major commodities transported in urban areas into five types and explores the application of sensitivity analysis to adjust the parameters, structure and objective of optimal system model. The objective function considers the different stakeholders' interests and sustainability issues to meet users' expectations in a cost-efficient manner. The simulation model calibrates the behavior of carriers and receivers, assesses the performance changes on travel and waiting time, represents queuing formation/dissipation and bottlenecks.

The ongoing research will classify urban trucks, explore the probability distribution of truck arrivals and traffic demand and employ stated preference methods (Marcucci and Danielis, 2008) to assign depots.

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