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WHICEB 2016 Proceedings
Wuhan International Conference on e-Business

Summer 5-27-2016

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# Research on the Distribution of Freight with Time Windows in Consideration of Traffic Congestion

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**Abstract:** Since the implementation of the regulations on the limit-driving of truck in urban areas of big cities, the study on route and time of city distribution gradually gets more attention. To improve the efficiency of distribution transport, not only the length of the routes need to be considered, but also the traffic conditions as well, even along with freight station locations and etc. Based on the traffic data of Beijing as an example, this paper analyze the differences in traffic distribution in aspect of time and areas, which will be taken into considered the distribution selection strategy with time window, so that we can ensure the freight trucks in delivery and pick-up processing avoids peak congestion. Finally take company A as an example, introduce the dynamic replenishment method to different districts considering their own particular congestion status. We expect to bring some inspiration to the vehicle allocation decision of online freight companies.

Keywords: traffic congestion, time window, urban freight distribution

## 1. INTRODUCTION

### 1.1 Road traffic evolution in Beijing

Due to the increasing number of motor vehicles in recent years, Beijing as a metropolis, the type of urban logistics mainly involve input directly from the field and municipal distribution from suburbs[1]. In order to reduce congestion and control traffic order and environment in urban areas, Beijing has published a series of policies for urban freight car limit-driving[2], which greatly increase the logistics cost and inhibit the development of the urban logistics. According to the notice issued by the Beijing Municipal Transportation Commission(BMTC)[3], since April 11, 2014, the city's forbidden range has been enacted much tougher. For the trucks which permitted weight is 8 tons or more, the prohibit traffic time in the main roads within the fifth ring road has been settled from 6 am to 12 pm every day[4]. Furthermore, from 0 am to 6 am, the forbidden range for the trucks from other provinces has been expanded to sixth loop. Recently, the forbidden ranges have been extended in both space and time range, which directly leads to the city distribution inconvenience. There are some parts of the logistics nodes chose to relocate outside the urban areas or establish conversion station for outer trucks[5].

### 1.2 Vehicle routing problem with time windows

Vehicle Routing Problem (VRP) was first proposed by Danting and Vehicle in 1959[6]. VRP with Time Window(VRPTW) is an extension of general VRP, which is described as: a number of vehicles for service from the sites for different locations, with diverse goods needs and distinct service time windows, and then return to the sites, which provides a service for each customer. The goal is to provide customers with services within the time windows, so that the time for vehicle's driving and waiting can be optimized to a minimum[7].

### 1.3 Traffic congestion indexes

Traffic Congestion Index, abbreviating traffic index, is also called Traffic Performance Index(TPI) [8], which is a conceptual numerical value initiated by BMTC to synthetically reflect the traffic condition of the road

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network. Table 1 listed its span ranges from 0 to 10 corresponding the average speed.[9]

**Table 1. Ranks of average speed and TRI published by BMCT**

| Rank | Fluent | Basically fluent | Slightly congestion | Middle congestion | Heavy congestion |
|---|---|---|---|---|---|
| Speed(km/h) | >37 | [30,37] | [25,30] | [23,25] | <23 |
| TPI | [0,2] | [2,4] | [4,6] | [6,8] | [8,10] |

The index is calculated by the deep processing of vehicle driving information(referred to as the floating car data) distributing in all city roads [10]. After getting the travel speed from roads of different ranks on the road function and traffic data, the 0-10's index value is indicated by the folks' perception of congestion[11]. It is a well-known fact that TPI does not just denote the speed because road situations are vary and the perception of speed are not the same either[12]. Therefore, TPI is more accurate in the assessment of road traffic conditions.

## 2. METHODOLOGY

### 2.1 Data acquisition and preprocessing

The data used throughout this paper are collected by a web crawler based on VBA(Visual Basic for Applications)[13], which gather the traffic data from the official website of BMCT round the clock since 2013. However, due to system maintenance, network failure, or system updating etc., data are lost at some time points. So just take the day of relatively completed record into consideration. Therefore, with the help of Excel or MATLAB to do a data filtering to select those days [12]. The processes of implementation are as follows: (1) import the data set to MATLAB; (2) select the data which have relatively complete data in a day; (3) if there is one or two blanks in a serial data, the interpolation will be performed; and (4) finally the new data set will be updated to create a new data table.

### 2.2 Analysis of the temporal and spatial distribution of congestion

We respectively analyze the temporal and spatial distribution of traffic congestion. From the time aspect, extracted the data of the ordinary working days in different months to study the seasonal changes of traffic congestion[13] (refer Figure 2); from the space aspect, selected a certain day to compare difference of congestion degree and time distribution at the same time points.(refer Figure 4)

### 2.3 Impact on distribution of regional congestion

Distribution is a process during which the road conditions are always changing. We can not guarantee to avoid congestion, save fuel consumption and thus benefit the best just depending on the traffic congestion table to provide a general view of the road[14][15]. Take the distribution of transferring warehouses and urban demand nodes for example, according to the regularity of historical data, we can judge whether it will encounter congestion or not. And then use Lingo to update the dynamic matching.

## 3. RESULTS ANALYSIS

### 3.1 Analysis of time serial

Take a specific day(Oct. 14th, 2014) as an example to clarify the details of data processing analysis. The data in that day missed three groups, respectively at 9:30, 9:45 and 13:15. To acquire the new data by the MATLAB curving fitting function, with a chart of the curve drawing (the default value taken is Null) and another about numerical value distribution. As Figure 1, There are two broken pieces before treatment. During this small interval, the mutation is not likely to occur as a big probability event. So the smooth transition is more realistic. There are totally 96 points in time axes which represents the time points in every 15 minutes per day.

**(a)before the curve**

**(b)after the curve**

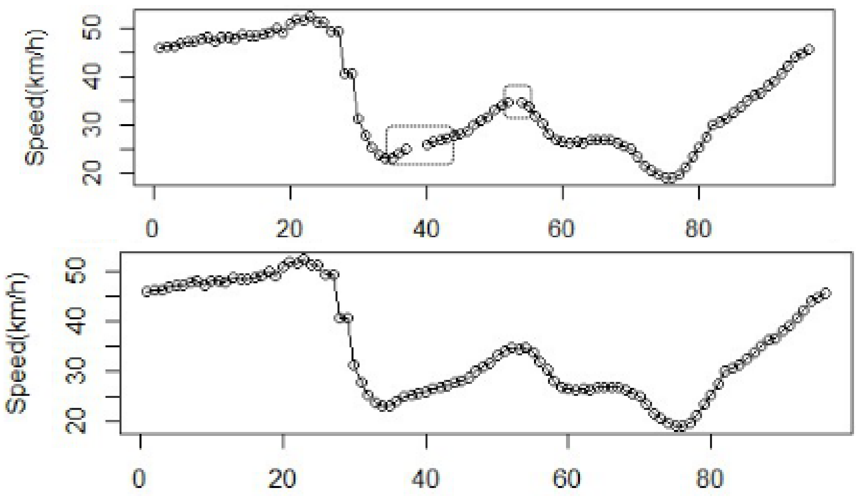



**Figure 1. Comparison of original data and curved data(cubic interp1, Oct. 14th, 2014, whole network)**

As for the speed distribution, generally the speed above 35km/h is thought to be frequent. It showed the characteristic of polarity that the points less than35km/h or the points more than 45km/h account for more than 80% of total points. Next, we selected a few typical dates which are relatively complete and are work days. Then Figure 2 compared the time series of those speed data.

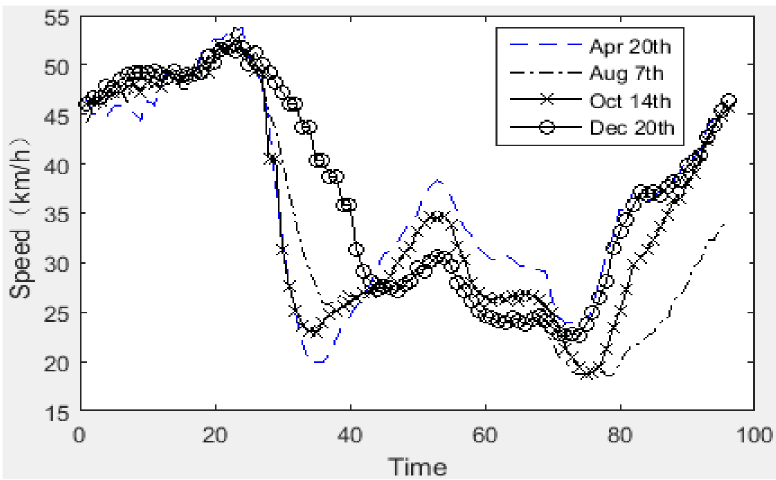



**Figure 2. Comparison of speed in different seasons (whole network)**

As Figure 2, (1) In spring(Apr. 20$^{th}$) and autumn(Oct. 14$^{th}$), the curve tendencies are similar. During the eve-peak, the congestion is more serious in autumn, the speed of whole network in average is less than 25km/h between the 70th point to 80th point. (2) In winter(Dec. 20$^{th}$), there is a strong characteristic of the early peak period lagging behind. Because of the climatic conditions, some commercial and transportation workers are less inclined to travel in the extreme temperatures of winter before sunrise. For large vehicles in Beijing or distribution vehicles for multi-zones with licenses, the most suitable choice is to unload and load after 10 pm or during the early morning. For small vehicles in short urban distance, choose the period before 7 am or two hours after 12 am in summer to complete to avoid congestion. According to Table 1, speed above 30km/h as fluent. Table 2 recommend the suitable period for freight distribution. The main differences reflected the delay of morning peak in winter and the extension of the afternoon free time in summer.

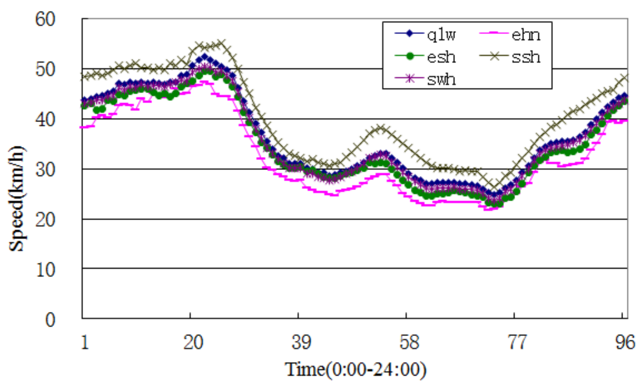
**Table 2. The suitable period for freight distribution for all seasons (whole network)**

| | Spring | Summer | Fall | Winter |
|---|---|---|---|---|
| AM | 0:00 ~7:00 | 0:00~7:00 | 0:00~7:00 | 0:00~7:00 |
| PM | 12:30 ~14:00 | 11:00~17:00 | — | 12:30~14:00 |
| Night | 20:00~24:00 | 20:30~24:00 | 20:30~24:00 | 19:30~24:00 |

### 3.2 Regional analyses

On the whole, the highest average speed of all day is between the fourth ring road and the fifth ring road, basically above the 30km/h all the time.(Refer Figure 3) The rest of them decline from the outside gradually. If the cross regional delivery is during the daytime, choose the routes outside the forth ring road is less likely to encounter congestion.

The same method is used to compare the speeds of different districts. The severe degrees of the congestion in different districts are shown in different colors in Figure 3 and 4 to visually illustrate the difference of all urban districts in geography and time. Green represents the fluent traffic. And red represents the jam. The deeper the color, the more fluent(in green) or jamming(in red) they were. The traffic index table of Figure 4 choose three days' data randomly in both spring and autumn, as the distributions of them are similar.




**(a)based on ring roads**


**(b) different districts**

Notes: qlw: the whole network; ehn: within the 2nd ring road; esh: between the 2nd and 3rd ring road; ssh; between the 3rd and 4th ring road, swh: between the 4th and 5th ring road.

**Figure 3. Congestion distribution map of different districts (average of all year)**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dongcheng | 1.1 | 1.6 | 8.5 | 6.7 | 4.6 | 7.9 | 8.6 | 5.7 | 1.6 |
| Xicheng | 1.0 | 1.3 | 7.4 | 5.1 | 2.9 | 5.7 | 8.7 | 6.3 | 1.8 |
| Haidian | 1.1 | 1.3 | 7.2 | 3.7 | 1.6 | 2.5 | 4.7 | 3.9 | 1.2 |
| Chaoyang | 1.0 | 1.1 | 6.3 | 6.8 | 2.7 | 3.8 | 6.5 | 6.0 | 1.8 |
| Fengtai | 0.8 | 1.3 | 6.9 | 6.4 | 2.2 | 2.0 | 2.8 | 1.9 | 1.1 |
| Shijingshan | 1.4 | 1.1 | 5.4 | 2.9 | 0.8 | 1.2 | 2.0 | 1.0 | 0.9 |
| area/time window | 0-6:00 | 6:15-7:15 | 7:30-9:00 | 9:15-12:00 | 12:15-14:00 | 14:15-16:00 | 16:15-19:00 | 19:15-20:15 | 20:30-24:00 |

**Figure 4. Congestion distribution time sequence chart(average of spring and autumn)**

The trucks of which route need to pass these districts have better choose the time period above to drive through. In order to check the universality of the fluent period, we choose the data of other months to test, such as the data in Nov. 18th. We take the TPI index 4 as the benchmark to determine the non-congested boundaries.

On the National Day and other holidays, as the urban areas had implemented the traffic control, and there are no work peak, so the jams are not obvious. We just ignore those situations. The fluent time windows are as Table 3.

**Table 3. Fluent period of all districts**

| District | Work day | On weekends |
|---|---|---|
| Dongcheng | 20：00~7：15(next day, the same below) | 20：00~9：00 |
| Xicheng | 20：00~7：15 | 20：00~ 9：00 |
| Haidian | 19：30~7：30　　10：30~17：30 | 19：30~ 14：00 |
| Chaoyang | 19：30~8：00　　11：00~16：30 | 20：00~ 14：00 |
| Fengtai | Except 8：00~9：00 | 20：00~ 10：00 |
| Shijingshan | All day | All day |

### 3.3 Distribution terminal allocations

Freight distribution of company A from the suburbs stations to the demand points is certain as Figure 5.


**Figure 5. Location of warehouses and demand nodes**

When all the warehouses need the replenishment at the same time, the distribution of end node not only need to consider their route distance to upstream supply warehouses, but also the congestion of route. However, congestion and route distance will greatly increase the computational complexity and the difficulty of solving.

Chose the traffic congestion in the areas on the routes, and approximated to get the time needed for each distribution route. Then updated the time utility matrix, so as to give the optimal allocation scheme under the current situation. The overall idea is as Figure 6.

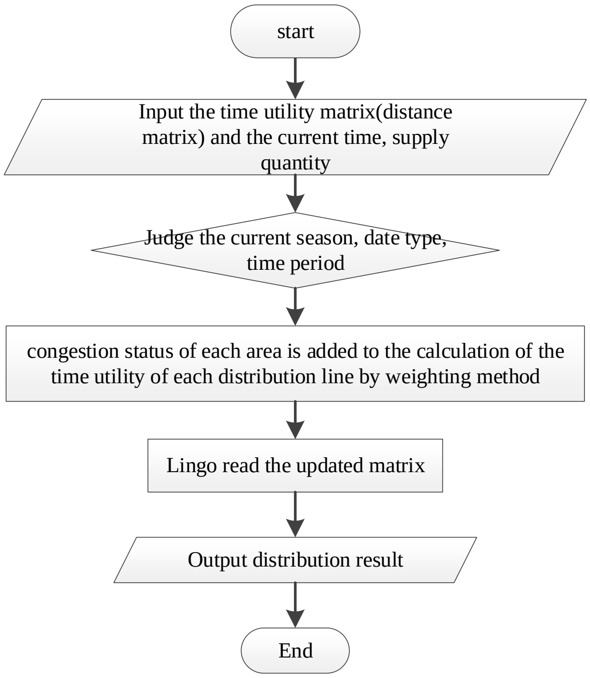



**Figure 6. Flow chart for processing**

In accordance with this idea, we used Lingo to test the case of company A, assuming that the current supply time is Oct. 14th, 2 pm. Figure 7 presents the supply and demand data.

$$\min \quad z = \sum_{i=1}^{5}\sum_{j=1}^{12}(\cos t_{ij} \times volumn_{ij}) \qquad (1)$$

$$s.t. \quad ca_i = \sum_{j=1}^{12} volumn_{ij} \qquad (2)$$

$$wa_j = \sum_{i=1}^{5} volumn_{ij} \qquad (3)$$

$\cos t_{ij}$ : the time utility index from warehouse i to end node j;

$volumn_{ij}$ : the supply quantity from warehouse i to end node j;

$ca$ , $wa$ : warehouse supply capacity and node demand respectively.

As the congestion situation has been taken into consideration, we use the product of time cost and tons to represent the meaning of ton-kilometers. Named after as ton-time utility value, the objective function is to minimize the total time utility. Lead the original time utility matrix into MATLAB, and enter the date and time. According to the statistical characteristics, the speed in the congestion is mainly about 20~25km/h, the speed of the flow is more than 35~45km/h. To simplify the calculation, the time value of the congestion period is multiplied by 2 times as the update value, thus speeding up the speed of the solution.

```
model:
sets:
  warehouses/w1..w5/: capacity;
  vendors/v1..v12/: demand;
  links(warehouses,vendors): cost, volume;
endsets

 [obj] min=@sum(links:cost*volume);
!demand constraint;
@for(vendors(J):
    @sum(warehouses(I): volume(I,J))>=demand(J));
!output constrant;
  @for(warehouses(I):
    @sum(vendors(J): volume(I,J))<=capacity(I));
data:
!haidian3 chaoyang4 xicheng1 dongcheng1 fengtai2 shijingshan1;
  capacity=95 87 146 120 75;
           !100 90 150 130 80;
  demand=41 30 46 37 32 49 47 64 69 38 42 26;
  cost=@OLE('C:\Users\Administrator\Documents\MATLAB\timedis1.xls',f);
       !3 4 6 8 10 12 15 7.5 10 9 12 6
       9 12 7 6 4 3 3 13 11 14 12 16
       12 10 11 8 7 6 5 7 5 6 4 8
       9 7 10 11 9 11 8 5 6 2 3.5 3
       7 5 8 11 10 12 10 6 8 4 6 2;
enddata
```

**Figure 7. Lingo source code with settings and source data**

Then input the updated matrix and used Lingo distribution tasks, and the total ton-time utility value is 2985.5, which is much less than the value of the original distribution plan with the timing congestion considered, at the value of 3576.

## 4. CONCLUSIONS

We collect and process the real-time data processed by the BMTC. We study the time and space of the congestion change by the method of fitting and visualization, which gives a better route planning for the road users, especially for the distribution of the vehicles with more mileage. By using the idea of regional congestion division, different from the traditional research, the advantages are that the data is less, and the response is faster. Here is not able to give a precise forecasting model with learning function, so the distribution result may not be the best result. As for the distribution amount, without considering the specific load capacity, even a small truck, also should be used to load as the goal to save the total ton - mileage, and considering the loading problem.

## ACKNOWLEDGMENT

This work was supported by NSFC (Project: 71303018), Center of Cooperative Innovation for Beijing Metropolitan Transportation.

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