International Journal of Technology (2015) 2: 236-243
ISSN 2086-9614

THE APPLICATION OF OPTIMIZATION MODEL OF OFF-STREET PARKING MANAGEMENT WITH DYNAMIC SIMULATION

Nahry[1*], Tri Tjahjono[1], Tiyana Brotoadi[1]

[1]*Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Kampus UI Depok 16424, Indonesia*

(Received: February 2015 / Revised: April 2015 / Accepted: April 2015)

ABSTRACT

Freight transport plays a very important role in economic activities. However, in some cases, the local transportation authority often disregards its existence, including in parking management issues. This research is aimed at developing an optimization model for off-street parking space management that considers freight cars and passenger cars as two different entities. Optimization aims at minimizing the joint function of the parking index of freight cars and the parking index of passenger cars. Weighting is given to both parking indexes to represent the interest level of parking operator to both types of vehicles. Parking space of both vehicles is at any time is arranged in a dynamic manner based on the inflow and outflow rate of vehicles at previous times. The parking index is limited by the maximum parking index desired by the management. The proposed model is applied to the parking activity in Jatinegara Trade Center (JTC), Jakarta, and shows that the model solution provides a better parking index than the actual parking index (without optimization).

Keywords: Dynamic simulation; Freight car; Optimization; Parking management; Passenger car

1. INTRODUCTION

Parking is a compulsory activity for people or goods transport using vehicles. Any motorized trip definitely requires a place for parking. Space limitation, particularly in the city center, has made the parking problem a central issue in urban traffic management. Many studies relating to parking have been conducted, all of which aim at seeking the most effective and efficient way to manage parking space. Wei Liu et al. (2014) manage parking lots with user's time management schemes (parking duration and parking time) and aim to reduce travel costs. Arnott et al. (2013) manage the use of parking space in the city center by taking into account the heterogeneity of the individual user and by considering the value of time and parking duration. Parking solutions utilizing information systems have also been the object of many studies. Jong-Ho Shin et al. (2014) provide a solution to drivers to use ICTs to monitor the availability of parking space based on censorship. This is due to limited parking space and high parking costs, especially in the city center. Some information are generated from the solution, such as distance to parking facility, walking distance from the parking facility to the point of destination, parking cost, and condition of road congestion in reaching the parking facility. In this method, data communication uses VANETs (Caliskan et al., 2007) to transfer information on the parking status to the parking manager, which is then passed on to the drivers through a communication set. Klappenecker et al. (2014) predict the total number of available parking spaces in a parking facility using a method developed by Caliskan and Marlov.

[*] Corresponding author's email: nahry@eng.ui.ac.id, Tel. +62-21-7270029, Fax. +62-21-7270028
Permalink/DOI: http://dx.doi.org/10.14716/ijtech.v6i2.974

Based on the information from various alternative parking lots, users are informed through a vehicular network about the number of occupied spaces, capacity, arrival, and parking rate. Hence, users can obtain information on the available parking space upon arrival and can save costs and fuel. Nourimejad et al. (2014) studied the parking policy on city trucks, including time limit, price policy, space management, and law enforcement, by developing a method which considers any potential impact of the policy on truck and passenger car parking on the road shoulder in urban areas. Using an econometric method based on the type and parking location, it can be concluded that the searching time for parking space for a freight car is shorter than that for a passenger car.

Previous studies show the importance of regulation of parking management, particularly in the city center, due to limited space. In most cases, the study does not distinguish the user of the parking space between freight and non-freight (passenger car). However, the freight activities in trade centers, which often take place in the city center, are usually somewhat intensive. Due to the characteristics of their dimensions, maneuvering, or loading, unloading freights tend to require more time and wider spaces for parking than passenger cars do. Parking prohibition for vehicles, particularly freight vehicles in trade centers, often has no positive impact on the economy because it is not followed by readily available goods conveyance infrastructure. On the other hand, several studies relating to urban freight highlight the need for more effective solutions to handling city freight, including solutions through parking management (Taniguchi et al., 2014; Munuzuri et al., 2005). Due to the increase in the role of city freight, it is necessary to specifically study city freight, particularly with regard to its parking activities. The initial concept of optimization of off-street parking space with dynamic simulation has been done by Nahry and Sumabrata (2013).

The model is aimed at optimizing the use of parking space by considering the characteristics of parking usage in real time and dynamically. In this concept, the user of the parking space is specifically distinguished between freight car and passenger car. The concept is based on the parking management techniques that utilize information about the availability of parking space through the information board in order to reduce parking searching time. Through this concept, we can give priority to freight vehicles or passenger vehicles according to the arrival and departure rate in real time and dynamically.

The current research is based on the application of this concept at one of the wholesale trade centers of Jakarta that is dominated by freight vehicles, namely Jatinegara Trade Center (JTC). Its parking lot is has a high proportion of freight vehicles, with a composition of 49% and 51% for freight vehicles and passenger cars, respectively. The land transport authority of Jakarta prohibits on-street parking by giving solutions of alternative parking lots, but they are not effectively utilized by the freight cars that are going to JTC, because they are too far and there is a lack of goods conveyance facilities to JTC. Due to the limited area of the JTC parking building, efforts should be made to manage the parking area according to the real time characteristics of the arrival and departure of vehicles and by specifically distinguishing freight vehicles and passenger vehicles, so that the parking services may be enhanced.

2. MODEL DEVELOPMENT

Basically, the optimization model is based on the information of the parking characteristics during a particular time period, in relation to flow-in (F_{in}) and flow-out (F_{out}). In this case, the vehicles are distinguished between the freight vehicles and passenger vehicles. This information may be obtained through the records of vehicle flow at the entrance and exit of the parking building.

The optimization principle is intended to manage the parking space in such a way that it is divided into two zones, namely freight zone (with the number of parking spaces R_{FC}) and non-freight zone (with the number of parking spaces R_{PC}). This partition results in two parking indexes: parking index of freight cars (PI_{FC}) and parking index of non-freight cars (PI_{PC}). Parking index denotes the ratio of parking accumulation to total parking space provided. For two conditions with the same parking inflow and outflow, the lower the parking index, the more efficient is the utilization of the parking area. Optimization aims at minimizing the Z-value, where Z-value is the joint function of PI_{PC} and PI_{FC}. R_{PC} and R_{FC} are dynamically managed for each time interval during the parking operation period. The space management (R_{PC} and R_{FC}) at any time is based on the amount of the previous F_{in} and F_{out}.

R_{PC} and R_{FC} arrangement are limited by PI_{max} determined by the parking management. PI_{max} illustrates the allowable maximum parking index and represents the service level desired by the parking system. The illustration of the amount of PI_{max} is given in Table 1. Due to the change in parking spaces of both types of vehicle from time to time, it is likely that there will be a condition where vehicles are prohibited to enter because no more parking spaces are available. This requires the aid of the announcement board at the entrance gate, so that vehicles that enter may change their plan at once. Immediately after a parking space has been made available, vehicles may be allowed to enter.

Table 1 Limitation of PI_{max}

Class	Limit	Note
1	$PI_{max} \leq 1$	Circulation corridor is vacant, movement of vehicle is unobstructed
2	$1 \leq PI_{max} \leq 2$	Circulation corridor is used for parking and vehicle movement is obstructed

The minimization program of this optimization model is as follows (Nahry & Sumabrata, 2013):

$$Min\ Z(\alpha;\beta) = \alpha\ (PI_{FC})_t\ +\ \beta\ (PI_{PC})_t\quad \forall\ t\ \in T \tag{1}$$

subject to:

$$(R_{FC})_t + (R_{PC})_t = 1 \tag{2}$$

$$(\mathrm{PI_{FC}})_t \leq \mathrm{PI_{FC}}_{\mathrm{max}} \tag{3}$$

$$(PI_{PC})_t \leq PI_{PC\,max} \tag{4}$$

where:

$$(PI_{FC})_t = \frac{(ACC_{FC})_t}{(R_{FC}\ )_t\ .\ Cap} \tag{5}$$

$$(PI_{PC})_t\ = \frac{(ACC_{PC})_t}{R_{PC}\ .\ Cap} \tag{6}$$

$$(ACC_{FC})_t = (ACC_{FC})_{t-1}\ + (Fin_{\ FC})_t - (Fout_{\ FC})_t \tag{7}$$

$$(ACC_{PC})_t = (ACC_{PC})_{t-1}\ + (Fin_{\ PC})_t - (Fout_{\ PC})_t \tag{8}$$

$(PI_{FC})_t, (PI_{PC})_t$	:	Parking index of freight car and passenger car, respectively, during time t
$(ACC_{\ FC})_t\ ,\ (ACC_{\ PC})_t$	:	Accumulation of freight car and passenger car, respectively, during time t
Decision variables	:	$(R_{FC})_t$ and $(R_{PC})_t$
where $(R_{FC})_t\ ,(R_{PC})_t$	:	Proportion of area of freight car parking space and passenger car parking space, respectively, during time t

Input Variables:

α	: Weight of Freight Car
β	: Weight of Passenger Car
Cap	: Total number of parking space units
$PI_{FC_{max}}, PI_{PC_{max}}$	: Maximum allowable parking index of freight car and passenger car, respectively
$(Fin_{FC})_t$, $(Fin_{PC})_t$	: Freight car inflow and passenger car inflow, respectively, during time *t*
$(Fout_{FC})_t$, $(Fout_{PC})_t$	: Freight car outflow and passenger car outflow, respectively, during time *t*

We divide the operation time of the parking building (*T*) into several time intervals. Time (*T*) may also be the total period of time where the optimization is done (in case the optimization is not applied at the entire time of the parking operation). The proposed model is aimed at minimization of joint function of PI_{FC} and PI_{PC} during time *t*, while the proportions of area for both types of cars become its decision variables. The coefficients α and β are used for weighting of both types of cars. As the authority intends to give more priority to freight cars, it is able to use any number for α and β provided that α is greater than β. For example, a ratio α/β 10/90 denotes that the parking authority gives priority to passenger cars to occupy a parking area nine times larger than that of freight cars. The bigger the difference between the coefficients, the bigger is the difference of priority given to both types of cars. The objective function is constrained by the total number of parking space units and also the maximum allowable *PI*.
The algorithm of the optimization model is described in Figure 1 as follows.

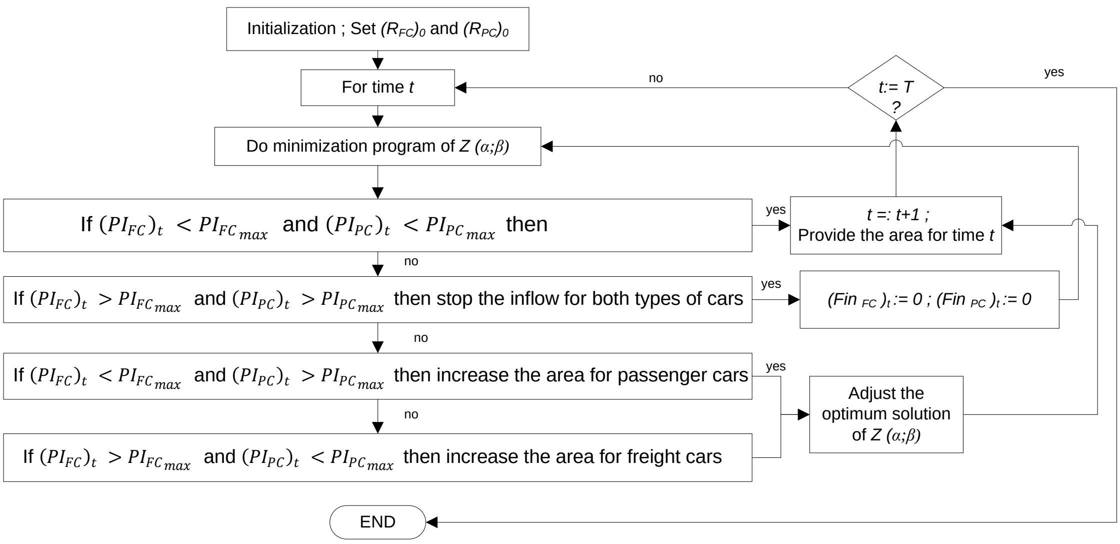

Figure 1 Algorithm of the optimization model

3. MODEL SIMULATION

The model is applied at the JTC wholesale trade center, in the form of simulation using real data. JTC's parking building is a four-storey parking building with a total static capacity of 250 parking space units. The input data used in this simulation model takes the form of parking data for five hours from 09:00 am to 14:00 pm. Video cameras are placed at the entrance and exit of the parking building. This records and calculates the number of vehicles entering and exiting the parking building automatically, using the method of motion capture. Any vehicle entering the capture area is calculated and recorded directly by the system, and then the data is entered into the computer database to be processed and further used for the SQL program simulation database server. In this application, the accumulation of freight car and passenger car is calculated per 30 minutes for five hours. The recorded inflow and outflow data and their accumulation, as well as parking index of the condition before optimization, are given in Table 2. Since the parking management currently gives the same priority to both freight cars and passenger cars, the α/β ratio used in Table 2 is only 50/50.

Table 2 Inflow, outflow, accumulation of vehicles, and parking index for actual conditions

No	Time	Freight Cars			Passenger Cars			Total Accumulation	Joint Parking Index	Z – Value *)
		Inflow	Outflow	Accumulation	Inflow	Outflow	Accumulation			
				140			84	224		
1	09.00-09.30	30	15	155	18	15	87	242	0.97	0.97
2	09.30-10.00	10	15	150	17	15	89	239	0.96	0.96
3	10.00-10.30	11	8	153	22	10	101	254	1.02	1.02
4	10.30-11.00	12	10	155	25	12	114	269	1.08	1.08
5	11.00-11.30	14	11	158	22	11	125	283	1.13	1.13
6	11.30-12.00	4	12	150	8	12	121	271	1.08	1.08
7	12.00-12.30	7	13	144	14	23	112	256	1.02	1.02
8	12.30-13.00	15	10	149	19	20	111	260	1.04	1.04
9	13.00-13.30	10	18	141	25	22	114	255	1.02	1.02
10	13.30-14.00	5	16	130	24	18	120	250	1.00	1.00

*) For α/β = 50/50

By assuming that the arrival and departure of vehicles to JTC do not change during the model simulation, using data for five hours with time intervals of 30 minutes, optimization is done using the algorithm as described in Figure 1. Each minimization program of *Z(α,β)* uses Equations (1)~(8). Figure 2 shows the output pattern of the minimization program at $t = 2$ or $t = 09.30–10.00$.

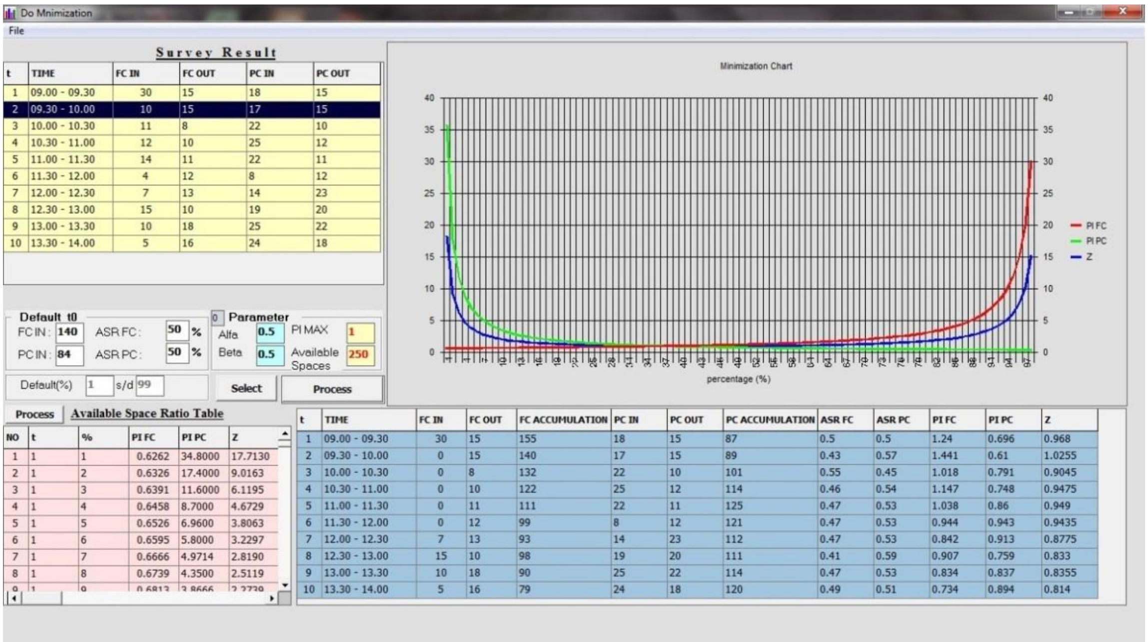

Figure 2 Output presentation of optimization program at *t = 2 (t = 09.30–10.00)*

Every minimization program of $Z(\alpha,\beta)$ at time-t produces optimization output in the form of decision variables $(R_{FC})_t$ and $(R_{PC})_t$ along with the associated parking index $((PI_{FC})_t$ and $(PI_{PC})_t$).

In order to show the optimization process of a certain time interval, an example of calculation is presented, that is for $t = 2$ or at the interval of 09:30–10:00. For simplicity, the optimization process is shown altogether by simulating three values of ratio α/β: 10/90, 50/50, and 90/10. These ratios represent the extreme values of weighting. In a real situation, any number of ratios can be applied. The simulation is done to show the role of α and β in affecting the composition of freight car parking space (R_{FC}) and passenger car parking space (R_{PC}). This ratio describes the priority weight to be given to both types of vehicles. Obviously, in application, we can either apply only one ratio of α/β during the whole period of parking operation or any various numbers for each time interval. A detailed description of determining the minimum *Z*-value (using Equation 1) at $t = 2$ is illustrated in Table 3 and Figure 3. For a certain α/β ratio used, the minimum Z-value is searched among the 15 possible compositions, and the associated decision variables (i.e., R_{FC} and R_{PC}) are generated from that solution. Obviously, using the SQL program, searching of the minimum Z-value may be done more accurately using the finer increment of R_{FC} and R_{PC}. Table 3 merely presents the increment of 5%.

Table 3 Simulation of *Z*-Value for various compositions of parking space

		Z-Value														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
R_{FC}		**95%**	**90%**	**80%**	**70%**	**60%**	**58%**	**56%**	**55%**	**52%**	**50%**	**40%**	**30%**	**20%**	**10%**	**5%**
R_{PC}		**5%**	**10%**	**20%**	**30%**	**40%**	**42%**	**44%**	**45%**	**48%**	**50%**	**60%**	**70%**	**80%**	**90%**	**95%**
	(10/90)	6.47	3.27	1.68	1.15	0.90	0.87	0.84	0.82	0.78	0.76	0.68	0.66	0.70	0.96	1.54
α/β	**(50/50)**	3.88	2.11	1.27	1.02	0.95	0.94	0.94	0.94	0.95	0.96	1.05	1.25	1.72	3.20	6.19
	(90/10)	1.28	0.96	0.85	0.89	0.99	1.02	1.05	1.06	1.11	1.15	1.41	1.85	2.74	5.44	10.84

Note: Shaded cells show the minimum *Z*-value associated with each ratio of α/β

Figure 3 illustrates the diagram associated with the Z-value and the composition of R_{FC} and R_{PC} for the three values of ratio of α/β.

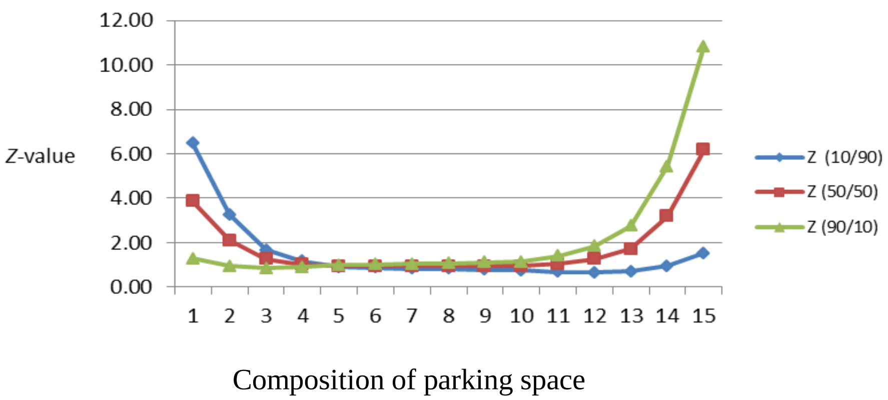

Figure 3 Trend of *Z*-value for three simulations of α/β at $t = 2$

For each simulation, the minimum *Z*-value and the associated composition of R_{FC} and R_{PC} are summarized in Table 4. It shows that the higher the value of α, the higher is the proportion of area of freight car parking space. Table 5 shows a value of *PI* produced from the three simulations at $t = 2$. It shows that the addition to parking space of freight car due to the addition to α will reduce PI_{FC} itself. It shows that PI_{FC} goes down from 2.06 to 0.75 when α increases from 10 to 90. In this case, passenger cars suffer due to the addition to α, where PI_{PC} changes from 0.51 to 1.78. This takes place because the optimization aims at minimizing *Z*-value, not at minimizing PI_{FC} or PI_{PC} separately.

Table 4 Z_{min} and the associated ratio of parking space for three simulations of α/β at $t = 2$

Parameter	Simulation of α/β		
	10/90	50/50	90/10
R_{FC}	30%	56%	80%
R_{PC}	70%	44%	20%
Z_{min}	0.66	0.94	0.85

Table 5 Z_{min} and the associated *PI* for three simulations of α/β at $t = 2$

Parameter	Simulation of α/β		
	10/90	50/50	90/10
PI_{FC}	2.06	1.09	0.75
PI_{PC}	0.51	0.79	1.78
Z_{min}	0.66	0.94	0.85

Further, in order to test the significance of the optimization result, the hypothesis test is done to compare the average *Z*-values of the proposed model to the actual ones (without optimization). Both values are indicated in Table 6. At almost all time intervals, the optimized *Z*-values are lower than the actual ones. Since Z-value is associated with the *PI* and since lower *PI* may correspond to better utilization, it can be concluded that the proposed model could improve parking performance. It is strengthened by the *t*-test with a level of confidence of 95%, which shows that there is a significant difference between the actual result and the optimization one. This significant difference shows that the proposed model significantly improves the system compared to actual conditions.

Table 6 Comparison of actual *Z*-value and Z-value of the optimization

No	**Interval**	***Z* –Value *)**	
		Actual	**Optimization**
1	09.00 - 09.30	0.97	0.97
2	09.30 - 10.00	0.96	0.95
3	10.00 - 10.30	1.02	0.96
4	10.30 - 11.00	1.08	0.93
5	11.00 - 11.30	1.13	0.95
6	11.30 - 12.00	1.08	1.00
7	12.00 - 12.30	1.02	0.95
8	12.30 - 13.00	1.04	0.85
9	13.00 - 13.30	1.02	0.76
10	13.30 - 14.00	1.00	0.75

*) For α/β = 50/50

The results imply that distinguishing the vehicles into two types (i.e., freight vehicles and passenger vehicles), distinguishing their parking capacity, and managing their inflow and outflow according to their available spaces in dynamic real time may result in better parking performance.

4. CONCLUSION

The development of the parking space optimization model is done by optimizing the use of parking space by distinguishing the parking zones of freight car and passenger car. It is aimed to give priority to the type of vehicle that, in actual conditions, is dominating the use of the parking space. The optimization is aimed at minimizing the joint parking index of the two types of vehicle by giving the weight of interest for each type of vehicle. The parking space management of each type of vehicle is dynamic, varying from time to time according to arrival and departure flow. Hence, the method of recording vehicle inflow and outflow becomes important. The application of the proposed model shows a significant improvement in the joint parking index compared to actual conditions (without optimization).

Since the optimization model mostly depends on the data recording of arrival and departure of vehicles, more advanced development is required in the recording set to distinguish the two types of cars more precisely. The use of metal detectors, weighting, and censoring of height at the entrance and exit gates are possible alternatives.

5. REFERENCES

Arnott, R., Rowse, J., 2013. Curbside Parking Time Limits, *Transportation Research Part A 55*, pp. 89–110

Caliskan, M., Barthels, A., Scheuermann, B., Mauve, M., 2007. Predicting Parking Lot Occupancy in Vehicular Ad-hoc Networks. In: *Proceedings of the 65th IEEE Vehicular Technology Conference, VTC 2007*, IEEE Press, Dublin, Ireland, 2007, pp. 277–281

Klappenecker, A., Lee, H., Welch, J.L., 2014. Finding Available Parking Spaces Made Easy, Ad Hoc Networks 12, pp. 243–249

Liu, W., Yang, H., Yin, Y., 2014. Expirable Parking Reservations for Managing Morning Commute with Parking Space Constraints, *Transportation Research Part C 44*, pp. 185–201

Munuzuri, J., Larraneta, J., Onieva, L., Cortes, P., 2005. Solutions Applicable by Local Administrations for Urban Logistics Improvement, *Cities*, Volume 22(1), pp. 15–28

Nahry, Sumabrata, R.J., 2013. An Investigation into the Freight Pick-up Delivery Activities in City Center of Jakarta. In: *Proceedings of the 5th International Conference on Logistics and Transport 2013*, Kyoto, 5–8 November 2013

Nourinejad, M., Wenneman, A., Habib, K.N., Roorda, M.J., 2014. Truck Parking in Urban Areas: Application of Choice Modeling within Traffic Microsimulation, *Transportation Research Part A, 64*, pp. 54–64

Shin J., Jun, H., 2014. A Study on Smart Parking Guidance Algorithm, *Transportation Research Part C 44*, pp. 299–317

Taniguchi, E., Imanishi, Y., Barber, R., James, J., Debauche, W., 2014. Public Sector Governance to Implement Freight Vehicle Transport Management, *Procedia - Social and Behavioral Sciences 125*, pp. 345–357