PREDICTING THE PROBABILITY OF PARKING VEHICLE BASED ON DYNAMIC SIMULATION

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Abstract: Parking is one of the facilities that smoothes operation of vehicle flow. The availability of parking spaces in urban transport system, especially in Central Business District, becomes an urgency since there are a lot of mixed activities that generate vehicles to come to and leave the office buildings. Lack of parking space increases in parking duration that is function of activities. This situation is not experienced by cities in developing countries but also some of developed countries that rely mostly not on public transport systems. This paper deals with the development of simulation model for parking system that emphasises on the performance, namely the parking probability. Information on vehicle flow to and out from parking space is collected on certain parking system in CBD area in Jakarta. Putting such information to the case a probability model is then developed and analysed based on a dynamic state. The developed simulation model represents the situation and can be used to examine various parameters in the design of parking systems.

1. INTRODUCTION

In many cities of developing as well as developed countries parking system is crucially required to accommodate vehicles and so the activities. Scarce of parking areas is extremely true in the CBD areas with more space for working employees but less for vehicles. The problem of high land cost has worsened the situation and resulted in more traffic congestion in the vicinity. On the other hand, the concept of designing a parking system has traditionally relies on the conventional approach of counting the potential generated traffic rather than random behaviours of car users to occupy the parking space.

Stimulated by such problems this research tempts to develop a simulation model that could represent some of random behaviours of car users in the parking systems as well as its operations. The simulation model can further be expected to perform various design parameters and variables in the parking systems for optimal design. Flows of vehicles entering the parking systems as well as exiting the system are information that may be considered to estimate the performance of system. However, there are some other parameters that behave randomly and influence the probability of users in getting parking lot. Such random behaviour can be observed in the operation, and potentially be represented by certain distribution.

In the normal operation of parking system tariff is imposed regularly and charged to the users once they enter the system with certain additional tariff for graduated time spent in the system. However, less attention is included in the design to the situation in which users may or may not get a parking lot and possibly leave the system without a chance to park at all. It is the prime concern of the paper in developing a system dynamics based simulation in the search for optimal design where chance of users to get parking lot is strictly considered. In the ensuing sections the development of simulation model is explained, and based on such a simulation case is conducted which is based on observed data. Some results are discussed to comprehend the performance of the model and eventually some remarks are drawn in the conclusions.

2. MODEL DEVELOPMENT

2.1. Parking System Simulation Model

Simulation model is to be developed in this research since it is expected that such model could reduce the complexity of problems and risks. So it is one of the aims that a comprehended performance of complex parking system is to be simulated prior to any detail or engineering designs. Various variables and parameters are to be considered to evaluate their importance and relation to adjust parking performance. In some extent, to provide fair parking operation, it is preferable to the users to have complete information of the availability of the parking space where users may decide firmly whether to enter or to leave the system.

Control to such information for fair parking can be done by, say, imposing variable parking fee based on the space availability, or by intermittent closure and disclosure of the gate for such availability. This research would ultimately develop such real time control of parking service based on availability, however, in the first development of the model availability of parking space is of prime consideration and to be developed in the basis of system dynamics. System dynamics is adopted as a tool to simulate related variables that would influence the space availability. In a more complex situation the interrelation of variables should be evaluated in the progress of demand change, parking duration, available space, and so forth. Progress of such variables is, of course, time-dependent and system dynamics is considered fit to such analysis.

Space availability is the focus of the analysis and best represented in terms of parking probability that means the chance of a user to get a parking lot once he/she enters the system. Furthermore, in order to develop reasonable simulation model, a set of parking data was collected to determine real characteristics of parking. Furthermore, flowchart of research illustrated in Figure 1 is adopted.

As can be seen in Figure 1, model is developed based on existing data of a mall in Jakarta that shows in general the characteristics of parking flows, demand and supply and other information. The data is analysed statistically for the model and tested for its compatibility of parking system. Once compromised values are achieved the parking model and its figures for supply and demand can be determined for its possible values of probabilities and then structured in firmer model for simulation. In the process of structuring the model some calculations are surely required to achieve realistic value for simulation. The complete package of parking performance analysis would, however, include the system control able to provide feedback to modified model or changes to scenarios in concern. Although, such system control is proposed in the whole model it is not included in the paper. This control is beyond the paper's scope but its development is being undertaken.

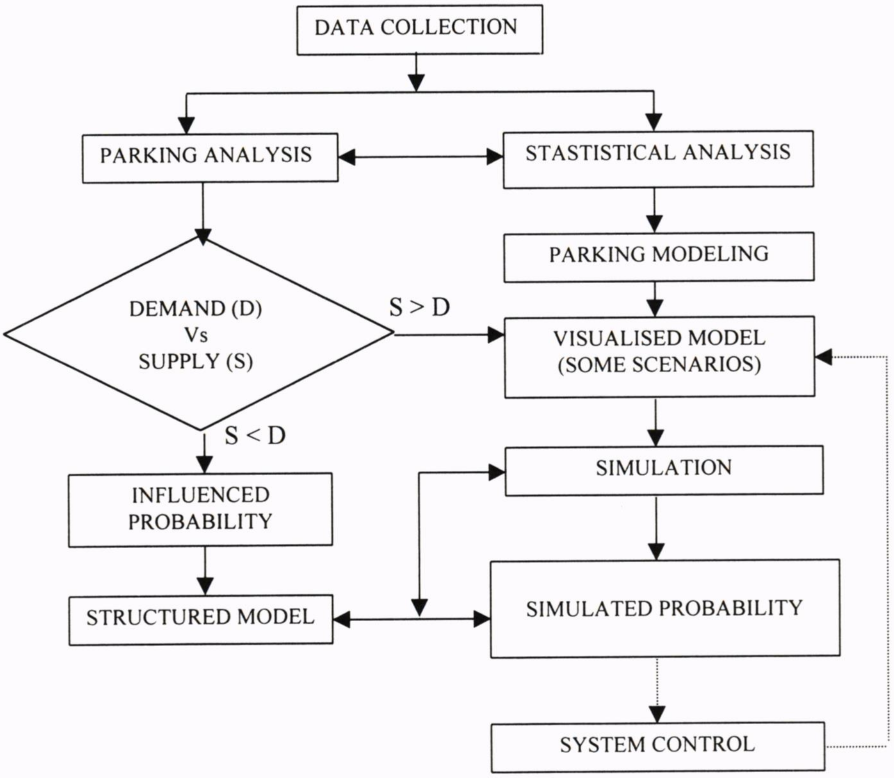

Figure 1: Flowchart of Parking Modelling

2.2. Dynamic State for Parking Simulation

It may already be recognised that car user's behaviour is dynamic in nature, and this behaviour may implicitly be included in the analysis to have accurate prediction of any transport system performance including parking system. This nature has stimulated the research to put such dynamic state in the analysis, and since inclusion of dynamic behaviour may increase complexity to any mathematical model as well as its rigorous computational efforts, the dynamic simulation is adopted.

The dynamic state of parking system comprises of several interacting variables, and out of those variables parking probability may be the focus of planning and designing a reliable parking system. To understand such interacting variables an illustrative causal diagram for the model developed is shown in Figure 2.

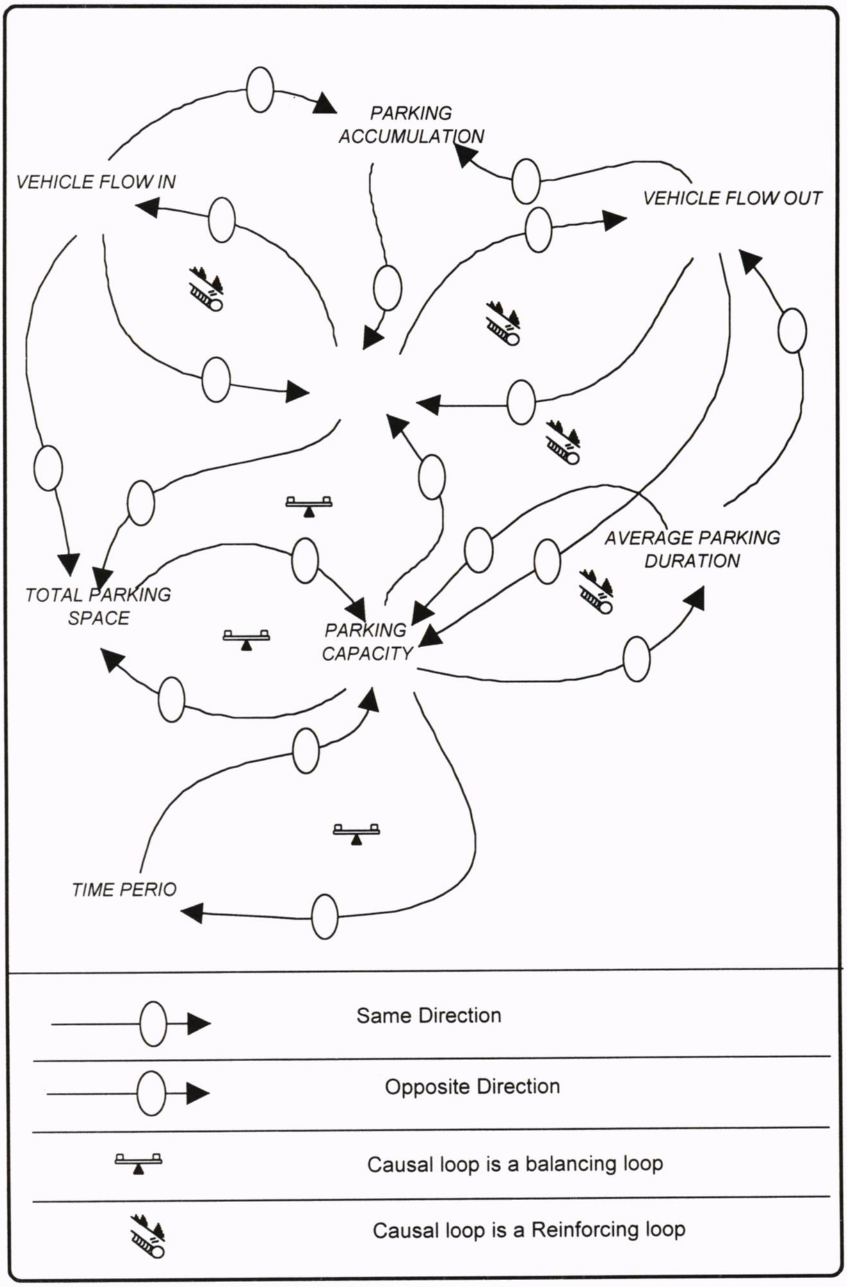

Figure 2: Causal Loop Diagram for Parking Probability

As can be seen from Figure 2 there are some variables that interact and influence the parking probability as a focused performance variable. Some variables may interact in a same direction but some may interact in the opposite direction. These interactions are uncommon in practice because same direction of interaction may increase/decrease in quantity and/or quality of other variables, but of course, such increase/decrease may be limited to a certain level and achieve an equilibrium state. To counter the monotonic increasing/decreasing of interacting variables requires counter-action of other variables, and this is the term called negative feedback in the dynamic state. Through such counter-action the equilibrium may be achieved. Although it can be argued that such equilibrium may not happen in reality but it can be determined theoretically where indeed it occurs very instantly and then back to unsteady state within the dynamic progress.

2.3. Parking Probability Model

Although parking probability is focused as performance indicator in this model, there are some relevant variables that influence the probability as would be simulated, and are defined as followings:

Parking accumulation; is total number of vehicles in the system which are approaching to and parking in the lot.
Parking index; is the ratio between the number of parking vehicles and total number of parking lots.
Parking duration; is time length spent by a vehicle in the parking lot.
Turn-over; is the number of vehicles entering the parking area, up to certain time to leave, divided by total number of parking lots.
Occupancy rate; is an average accumulation number of vehicles parked within a certain period (T) divided by total number of lots.
Practical capacity; is total number of lots available (Cap), and formulated as,

Practical capacity is identified as number of vehicles parked, and could be expressed by following equation;

$$Cap(T) = \{(1 - R_f) \times \sum PS \times T\} / D_{av}(T) \quad \text{.................................} (1)$$

where; R_f is reduction factor (%), PS is total number of parking lots, $D_{av}(T)$ denotes average duration of parking vehicle within a period of T, and equation (1) can be calculated within a certain operational period of T. Furthermore, theoretical capacity of parking system is denoted by $R_f = 0$.

- ***Parking Probability Model***

In general ratio between number of vehicles entering parking system and total number of available (unoccupied) parking lots may reflect the chance of a vehicle to get a parking lot or space. In other words, it can be assumed that such probability is represented by available lots or $Cap(t - \partial t)$ deducted by number of accumulative vehicles entering the system, $[\sum(V_{in}-V_{out})_{t-\partial t}]$, where $V_{in}(t-\partial t), V_{out}(t-\partial t)$ denote number of vehicles entering and exiting from parking system within the smallest discrete time observed, ∂t, plus number of vehicles exiting from the system at instant $t, V_{out}(t)$, and then divided by total accumulated number of vehicles entering the system at instant *t*, $[\sum(V_{in}-V_{out})_t]$. Furthermore, the parking probability [*Pr(t)*]can be formulated as;

$$\Pr(t) = \frac{[Cap_{t-\partial t} - \sum(V_{in}-V_{out})_{t-\partial t}] + V_{out(t)}}{\sum(V_{in}-V_{out})_t} \qquad \text{..........................} (3)$$

and

$$0 \le \Pr(t) \le 1 \rightarrow \forall t \qquad \text{..........................} (4)$$

By observation the available parking lots, $Cap_{(t-\partial t)}$ would be analogue to;

$$Cap_{(t-\partial t)} = \frac{[1-Rf] \times \sum PS \times T}{D_{(t-\partial t)}} \rightarrow t \le T \qquad \text{..........................} (5)$$

, and so combining equation (3) and (5) would reproduce [*Pr(t)*];

$$\Pr(t) = \frac{\dfrac{(1-Rf) \times \sum PS \times T}{D_{(t-\partial t)}} - \sum(V_{in}-V_{out})_{t-\partial t} + V_{out(t)}}{\sum[V_{in}-V_{out}]_t} \qquad \text{..........................} (6)$$

Where the following notations may be redefined;

$V_{in(t)}$; volume of vehicles entering parking system at instant *t*
$V_{out(t)}$; volume of vehicles exiting from the system at instant *t*
$[V_{it}-V_{out}]_t$; number of vehicles requires to get parking lots at instant *t*
$\sum(V_{in}-V_{out})_t$; total accumulated number of vehicles at instant *t*
$Cap_{(t-\partial t)}$; available parking lots at within $t-\partial t$
$\sum PS$; total fixed capacity of parking system
$D_{(t-\partial t)}$; average duration time of parking vehicle within $(t-\partial t)$

The developed model is then evaluated based on some data collected from one of the busiest CBD areas in Jakarta to confirm the model. It is found that the most difficult problem to solve is to measure the parking duration of each vehicle, in which such information is very prominent in determining parking lots availability and so parking probability.

To relieve problems of measuring duration time, an average value of duration time is then adopted for all vehicles within a certain period $(t-\partial t)$. This average value is evaluated for its fitness with other variables derived in the model. Afterward average duration time becomes an essential and influencing variable in the model since it represents users' behaviour as well as demand characteristics of the study area of parking system being evaluated or designed. This is one of the aims to evaluate performance of parking system by explicit inclusion of duration time of parking vehicle, and to enable such evaluation in the simulation $D_{(t-\partial t)}$ can easily be reformulated by simple manipulation of previous equations and results in;

$$D_{(t-\partial t)} = \frac{[(1-Rf)\times\sum PS\times T]}{\{[\sum(V_{in}-V_{out})_t\times \Pr_{(t)} - \sum(V_{in}-V_{out})_{t-\partial t} + V_{out(t)}\}} \quad \text{................ (7)}$$

- ***Dynamic Simulation***

It is considered that to evaluate such dynamic changes of variables for parking system would require a simulation process. To such requirements *Powersim* is adopted to simulate dynamically the interrelation among variables and their impact to the core of parking probability performance. Each variable may be included in different level and significance, and to such requirements some dynamic states are defined as follows;

Level and Rate; level (denoted by a box) is defined as process to gather and add a level with inflows or deduct with outflows from a state of related discrete time of simulation. Rate (denoted by a circle valve) is defined as growth of flow that has unit per certain time dependency.

Auxiliary; (denoted by circle) is defined as related variable where is normally required when a model is developed.

Constant; (denoted by a rectangular) is defined as a certain constant value as parameter.

Flow; (denoted by arrow) is defined as unit movement of a certain variable from one state to the other state or variable.

Having all the dynamic states formulated in a interrelating form as can be illustrated in Figure 3, *Powersim* is able to perform any simulation scenario to quantify any progressive interrelating states. It can be noticed from Figure 3 that not all variables should be deterministic, but some may follow certain random behaviour such as shown by reduction factor (Rf). Determining the value of Rf is hard and it normally follows certain random distribution, and it can easily be performed in the simulation by putting it as random variable denoted by a die.

3. SIMULATION AND SCENARIOS

3.1. CBD Case

To comprehend performance of the dynamic simulation model a case is made for a certain CBD parking area in Jakarta. Some information on vehicle arrival, vehicle departure, parking duration time, total number of parking lots, and initial condition for parking accumulation are recorded as follows;

- Inflows of vehicles at periods (07:00-10:00, 10:00-13:00, 13:00-16:00, 16:00-19:00) = [573,1,352, 1,316, 1,157] vehicles.
- Outflows of vehicles at periods (07:00-10:00, 10:00-13:00, 13:00-16:00, 16:00-19:00) = [197, 927, 1,277, 1,216] vehicles.

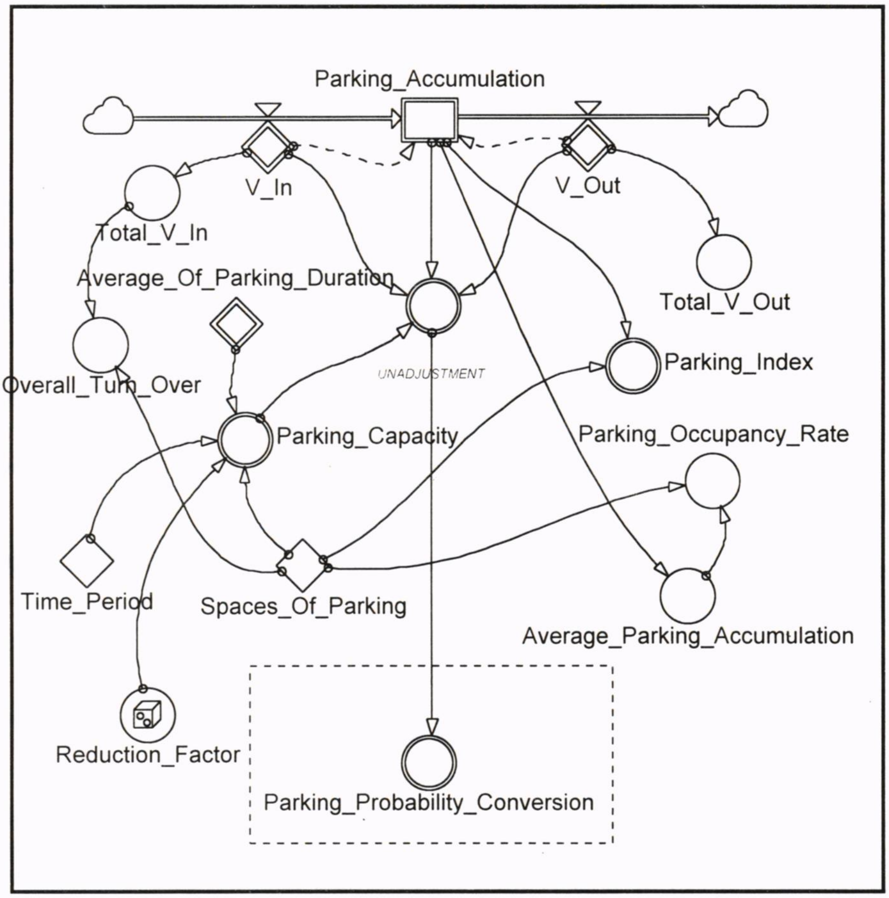

Figure 3: Parking Model Based on Dynamic Simulation

- Average parking duration at periods (07:00-10:00, 10:00-13:00, 13:00-16:00, 16:00-19:00) = [0.92, 1.59, 1.47, 1.44] hours.
- Total number of parking lots = 2,000 lots
- Initial value of parking accumulation = 165 vehicles

Furthermore Table 1 shows records of inflow vehicles and outflow vehicles by time. From the Table 1 can be seen that there are two types of customers, namely casual (non-member) and sticker (member) of the CBD's parking system in which they are charged in different way.

Table 1: Records of Inflow and Outflow of Vehicles

i-th period	Interval Time (Class)	Number of Vehicles						
		Inflow			Outflow			Accumulation
		Casual	Sticker	Total	Casual	Sticker	Total	
0	Left	8	25	33	0	0	0	33
1	00 – 01	0	0	0	5	0	5	28
2	01 – 02	1	0	1	8	0	8	21
3	02 – 03	0	0	0	6	0	6	15
4	03 – 04	1	0	1	1	1	2	14
5	04 – 05	0	0	0	1	0	1	13
6	05 – 06	3	1	4	1	1	2	15
7	06 – 07	7	7	14	2	1	3	26
8	07 – 08	43	35	78	13	6	19	85
9	08 – 09	89	113	202	34	19	53	234
10	09 – 10	226	67	293	94	31	125	402
11	10 – 11	322	65	387	196	43	239	550
12	11 – 12	384	39	423	263	45	308	665
13	12 – 13	493	49	542	351	29	380	827
14	13 – 14	409	61	470	439	32	471	826
15	14 – 15	440	42	482	380	35	415	893
16	15 – 16	335	29	364	349	42	391	866
17	16 – 17	302	19	321	341	26	367	820
18	17 –18	346	37	383	373	77	450	753
19	18 – 19	435	18	453	355	44	399	807
20	19 – 20	487	18	505	368	30	398	914
21	20 – 21	262	22	284	417	44	461	737
22	21 – 22	65	9	74	499	82	581	230
23	22 – 23	10	5	15	135	34	169	76
24	23 – 24	6	2	8	29	4	33	51
Total		4,674	663	5,337	4,660	626	5,286	9,901
Average		194.8	27.6	222.4	194.2	26.1	220.3	412.5
S.D		189.8	28.2	204.0	181.5	23.9	202.0	370.5
Max.		493	113	542	499	82	581	914
Min.		0	0	0	0	0	0	13

Based on information summarised above, rate of arrival vehicle and leaving vehicle are to be determined. To make an easy and relevant approximation, and related to the peak and off-peak hours within a day, four different time periods are decided that produce rate of arrival and leaving vehicles, (λ) as shown in Table 2.

Table 2: Rate of Inflow and Outflow Vehicles

Time Interval	Rate of Inflow Vehicle (vehicles/minute)	Rate of Outflow Vehicle (vehicles/minute)
Period (1) 07:00 – 10:00	3	1
Period (2) 10:00 – 13:00	8	5
Period (3) 13:00 – 16:00	7	7
Period (4) 16:00 – 19:00	6	7

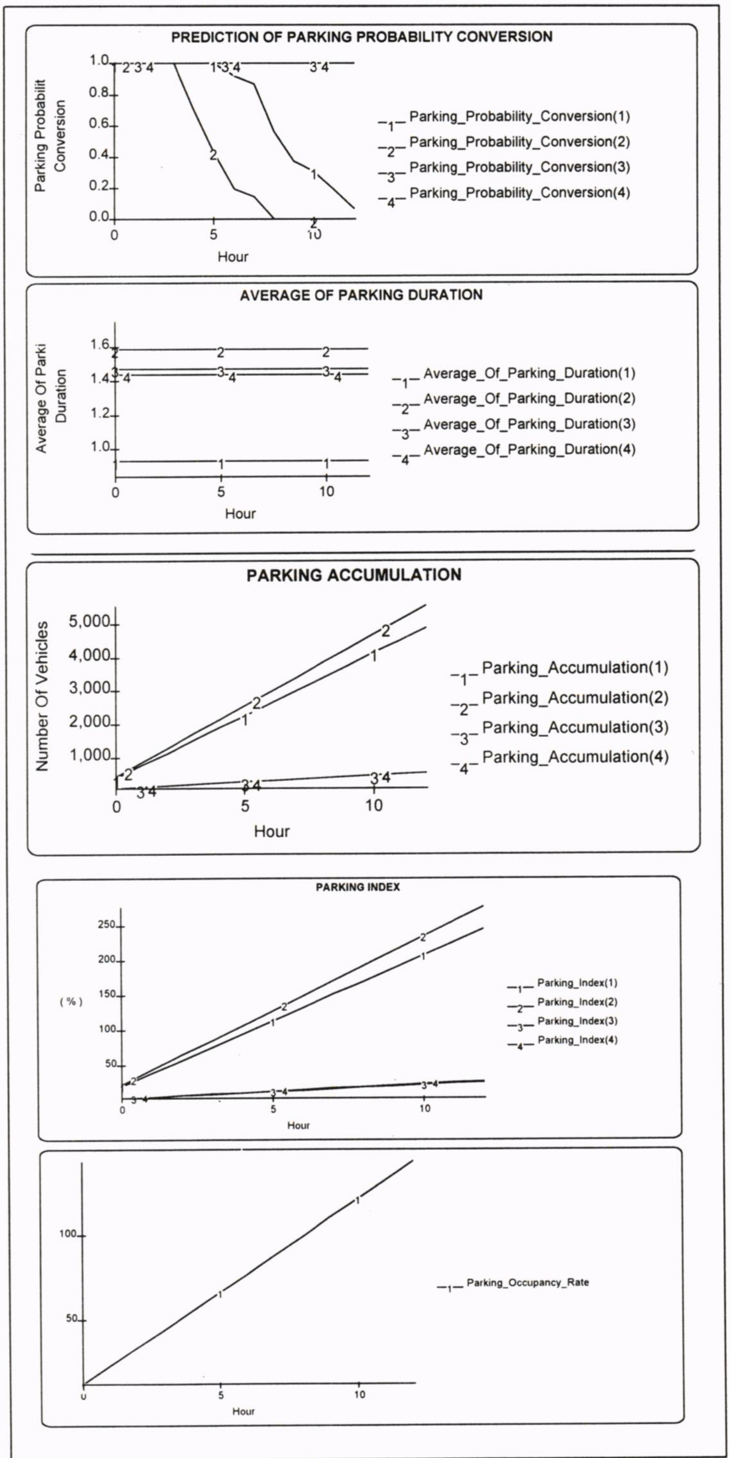

Figure 4. Results of Simulation for Various Performance Criteria

Inputting all related variables and some adjustment to practical conditions to the *Powersim*, some of performance criteria may be evaluated such as parking probability, parking duration, parking accumulation, parking index and occupancy rate shown in Figure 4.

As can be observed that Figure 4 represents a model for observed parking system in a deterministic manner, because all the variables are assumed so. However, short observation of such system may not reflect totally the real situation, and it is not uncommon that a lot of such variables follow some randomness.

Simulation has released a lot of difficulties to include such random variables. The developed model can easily be modified to perform different characters of parking performance. To see parking performance criteria under such random behaviours, other scenario of simulation is developed as shown in Figure 5.

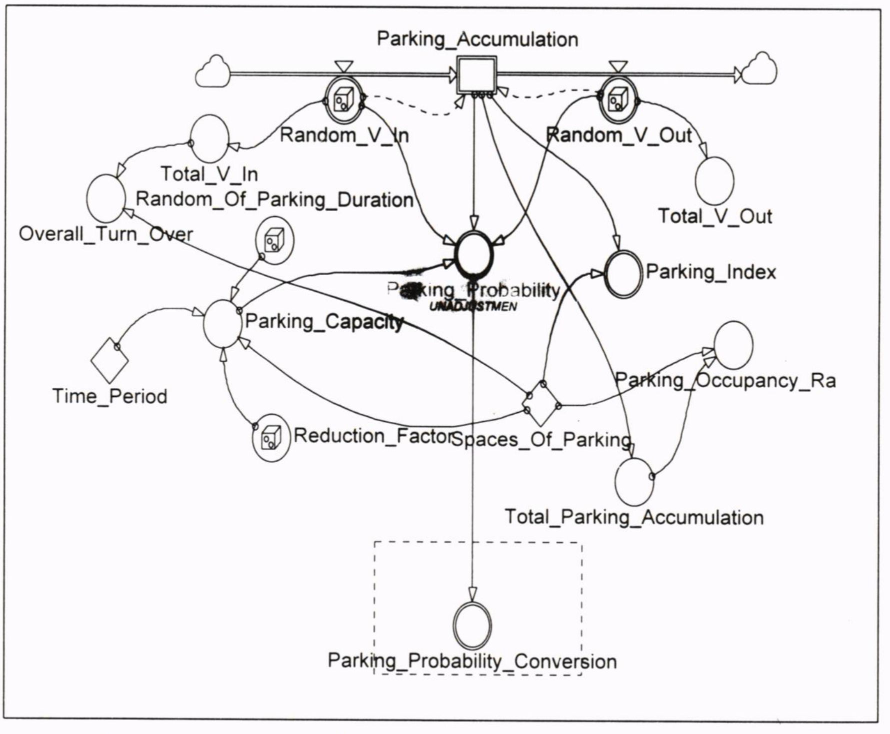

Figure 5: Parking Probability Model with Random Variables

There are some random variables set in the model such as reduction factor, average parking duration in which they can be actually found in the observation so. Furthermore, Figure 6 shows similar performance criteria as the previous simulation. It can be noticed in Figure 6 that almost all of the criteria behave sensitively with random behaviour as can be experienced in practice.

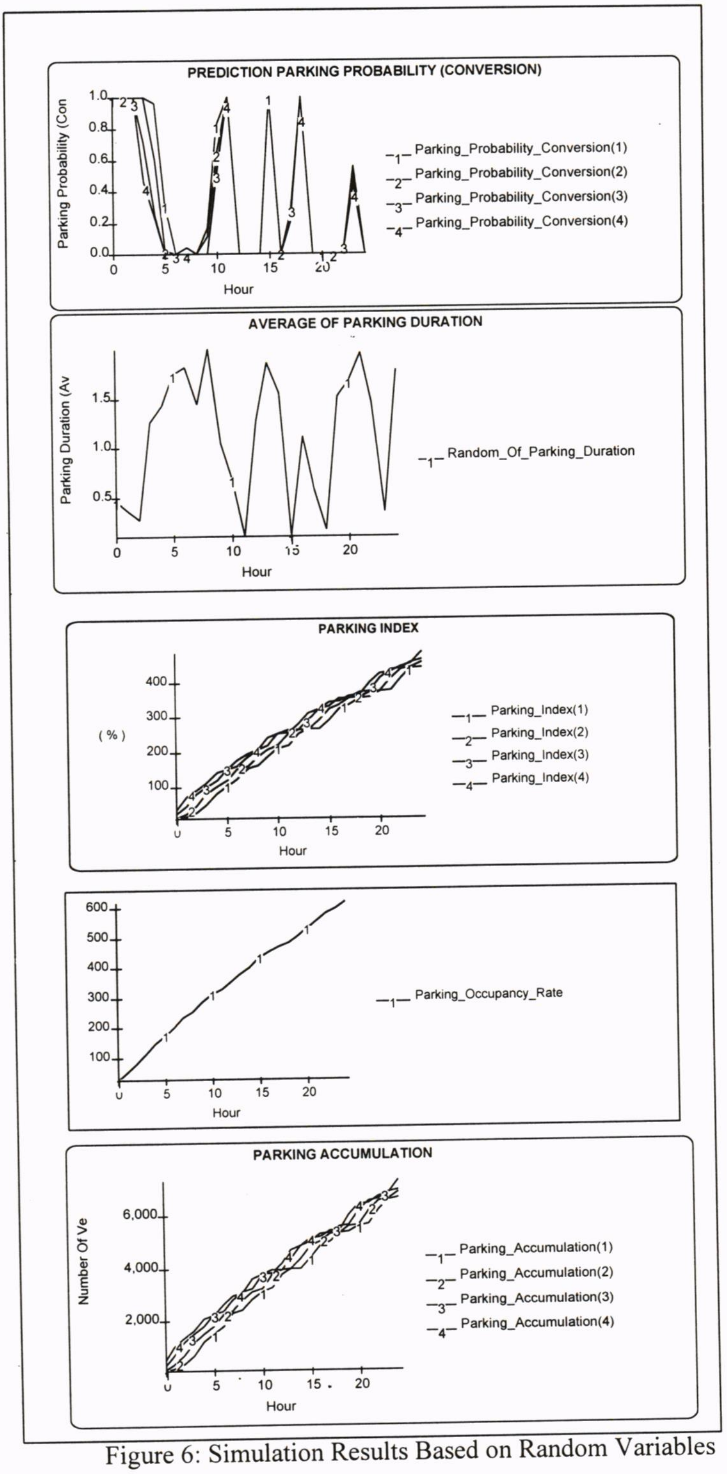

Figure 6: Simulation Results Based on Random Variables

4. CONCLUSIONS

An approach of analysing parking system within a system dynamics environment is developed as simulation model in this research. The model aims at developing an effective tool for quick analysis of various variables involved in the parking system design. To evaluate the performance of the model a case of parking practice of certain CBD's parking area is analysed under the assumptions of deterministic variables as well as random variables. Some conclusions are to be drawn as followings;

- Model has been developed to include various variables, and some exclusion or inclusion of other variables can be done easily to evaluate the sensitivity of the variables.
- Simulation under random variables is found to be more sensitive for various performance indicators, and may reflect the real situation accurately.
- Model may eventually be expected as an evaluation tool for various design parameters and variables of parking system.

REFERENCES

Baugsto, B., et.al. (1993), Powersim, **The Complete Software Tool for Dynamic Simulation**, Modeldata AS.

Drew, DR. (1984), Dynamic Model and Applications, **Course Notes**, Virginia Polytechnic State University.

Meredith, D., et.al. (1985), **Planning and Design of Engineering Systems**, Prentice Hall.

Pignataro, L. (1983), **Traffic Engineering: Theory and Practice**, Prentice Hall.

Robert, N. (1983), **Introduction to Computer Simulation; A System Dynamic Approach**, Addison Wesley.