2010 International Conference on Computer Application and System Modeling (ICCASM 2010)

A Simulation Based Verification Method for Elevator Traffic Planning

Yang Zhenshan
College of Information Science and Engineering
Bohai University
Jinzhou, P. R. China
e-mail: ydlut @163.com

Zhang Yunli
Computer Teaching and Research Section
Liaoning Medical University
Jinzhou, P. R. China
e-mail: zhyunli @163.com

Abstract—**Elevator traffic systems are the main vertical transportation facilities in high-rise buildings which play a vital role in modern life. A well-designed elevator traffic system should provide passengers with both sufficient quantity and satisfactory quality of service. Considering that the classical elevator traffic planning theory focuses, mainly, on the quantity of service, ignoring the quality of service, a simulation based verification method for elevator traffic planning is proposed, in which the object oriented discrete event driven technique, based on an improved multi-server batch service queuing discipline, is employed to describe the dynamic behaviors of both passengers and elevators to evaluate the service level of elevator traffic system. The initial configuring results by the classical calculation model are adjusted on simulation to meet both the expected passenger handling capacities and the expected service level. The proposed method perfects the classical elevator traffic planning theory which shows better results than the classical methods.**

Keywords-elevator traffic planning; service quality; multi-server batch service; event driven; average waiting time

I. INTRODUCTION

The sufficient passenger handling capacity and high-quality service is the indispensable necessary conditions for a well designed elevator traffic system. The traffic planning is the prerequisites to implement elevator group control [1-3]. How to determine the basic elevator configuration parameters are the principal research problems in the elevator traffic planning. But the classical elevator traffic planning theory focuses mainly on the quantity of service [4-5], i.e., the handling capacity of passengers during the heaviest 5 minutes of the up-peak traffic condition, ignoring the quality of service, Namely, how well must the elevator system deal with its passengers. The quality of service is represented by passenger waiting time which is the best indicator of the quality of service that an elevator system could provide, that is to say, the shorter the waiting time, the better the service. Findings show that [6], passengers tend to be upset if they are made to wait too long, say, over 30s. However, passenger waiting time cannot be easily measured analytically by classical approaches.

As stated previously, there are the following problems with the classical elevator traffic planning theory.

1) The design method does not take into account how the elevator services passengers.

2) The quality of service can not be determined, as measured by passenger waiting time.

3) Passenger behavioral description and the statistics for an elevator system is deficiency.

Thus the classical elevator traffic planning procedure, to some extent, is a static analytic method with no close attention to the quality of service.

The domestic research on simulation verification study about elevator traffic planning for high-rise buildings is not sufficient and concrete, and there are little literatures on this aspect. Elevate^{TM} [7], developed by Dr. Richard Peters, is a international publicly available software package for elevator traffic analysis & simulation evaluations, but the cost of the package is very expensive and limited only to general introduction in literatures without opening it's source code.

To the deficiency of classical elevator traffic planning theory and the research magnitude of the problem, a simulation based verification method for elevator traffic planning is proposed to effectively evaluate the elevator traffic system service level in this thesis.

The dynamic performance parameters of the existing elevator traffic configuration are verified by simulation test. The elevator traffic system is taken as a special stochastic service system. Accordingly, the general structure of the elevator traffic planning is established based on an improved multi-sever batch service queuing discipline. In order to describe the dynamic behaviors of both the passenger and the elevator, the object oriented discrete event driven technique [8] is employed. The initial calculation results for elevator traffic planning are regarded as the simulation input to verify the traffic service level.

If the comparative result does not meet the expected criteria, the initial configuring results will be adjusted until the service level criteria are achieved.

The remainder of this thesis is organized as follows. In Section II, the modeling for the service of elevator traffic is conducted based on the behavioral characteristic of both passengers and elevators. In Section III, the global structure design and algorithm process of simulation is discussed in detail. In Section IV, the simulation results and discussions are presented, and the conclusions are drawn in Section V.

II. SERVICE MODELING OF ELEVATOR TRAFFIC SYSTEME

As highlighted above, elevator traffic system is a special stochastic multi-server batch service system. But if the service discipline for multi-server batch service (MSBS) system is employed in service modeling of the elevator traffic system, the problems encountered are as follows.

1) Due to complexity of the problem, it is difficult to obtain the analytical solutions.

2) The service procedure the model expressed doesn't totally conform to the elevator traffic system.

For the classical MSBS model, passengers arrive individually according to a Poisson process, but they are served in batches under the following threshold policy [9].

If and only if the number of waiting passengers is no less than a threshold θ ($\theta \geq 1$), the server immediately start servicing. If, on the other hand, there are less than θ passengers in the queue, the server remains idle until the number reaches θ.

Therefore, an improvement of batch service discipline for the classical MSBS model will be needed to model the elevator traffic system.

A. Improvement of the Batch Service Discipline

Based on the above analysis, as a special stochastic multi server batch service system, the elevator traffic system's service discipline is improved as flows.

- Here the service mode of the elevator traffic system is considered as the batch service mode, namely, there are ξ ($\xi \geq 1$) passengers served stochastically by the system each time, where ξ is an integer stochastic variable. If there are no passengers waiting for elevators, then the elevator remains idle, i.e., the elevators do not leave without passengers.
- Let c be the car rated capacity in persons. Assume that, at a given time, $1 \leq \xi < c$, new passengers arrive appropriate at this time. According to the behavioral characteristic of passengers [10], the elevator will randomly postpone a time delay γ, to meet the traffic demand for the coming passengers, but the entire number of passengers boarding the car must not exceed the car rated capacity c. Meanwhile, if the passenger in the car has pushed the car button, or for some reasons, the newly arrived passengers can not board the car, then the rest of the passengers have to wait for another elevator.

On the basis of the above improvement, the modeling of the elevator traffic system is conducted in the next section.

B. Modeling for Elevator Traffic

1) Model assumptions

- The elevator systems comprises more than one elevator car, and operates under up-peak traffic condition only, i.e., the dominant traffic flow is in an upward direction, with the majority of passengers entering the elevator system at the main terminal.
- Elevators return to the main terminal, even when there are no calls.
- Empty elevators await orders at the main terminal, and do not leave without passengers considering on VIP service.
- The main terminal has adequate space to accommodate arrival passengers.
- Passengers can select elevators at will;
- Passenger arrivals, at the main terminal, follow the Poisson process and independent of each other.
- The queue service discipline is first come, first served.
- When a passenger arrives at the main terminal, if all the elevators are busy, then he enters into the waiting queue automatically to wait for an elevator to come.
- Service is by batches of size no greater than the size of rated capacity of the elevator.
- The service time for each batch is exponentially distributed with a mean service time of each elevator car.

2) Modeling based on passenger arrival and elevator service

Just as the assumptions in the previous subsection, findings show that [11]: if $N(t)$ is the number of the passengers arrived in $(0, t]$, then $\{N(t), t > 0\}$ is a Poisson process with a mean arrival rate (arrivals per unit time) of λ, which is the best representation of the realistic passenger arrival process and it is generally accepted.

So the passenger arrival time interval follows the exponential distribution with λ.

Modeling of the passenger arrival is conducted based on the above analysis. Assume that, t is the maximum of passenger arrival time interval, τ_{pi}, $\tau_{p(i-1)}$ are the arrival instant of the ith and the $(i$-1)th passenger, respectively. Consequently, the passenger arrival time interval must satisfy (1)

$$P\left\{\tau_{pi} - \tau_{p(i-1)} < t\right\} = \begin{cases} 1 - e^{-\lambda t}, & t \geq 0 \\ 0, & t < 0 \end{cases} \tag{1}$$

The following two steps are employed to determine the passenger arrival time

- Generate arbitrary pseudo-random number r between 0 and l, then the maximum value of passenger arrival time interval is derived from (1)

$$t = \frac{\ln(1-r)}{\lambda} \tag{2}$$

- Generate arbitrary pseudo-random number t_{pi} between 0 and t, as the arrival time interval between the ith passenger and the $(i$-1)th passenger, therefore, the arrival time of the ith passenger is given as

$$\tau_{pi} = \tau_{p(i-1)} + t_{pi} \tag{3}$$

In a similar way, the arrival instant of elevators can be determined.

Let RTT be the round trip time, i.e., the time in seconds for a single car trip around a building from the time the car doors open at the main terminal, until the doors reopen, when the car has returned to the main terminal floor, after its trip around the building, which gives an indication of the quality of service.

Let τ_s be the batch service time, then τ_s follows independent exponential distribution with parameter μ [12], namely

$$P\{\tau_s < t\} = \begin{cases} 1-e^{-\mu t}, & t \geq 0 \\ 0, & t < 0 \end{cases} \tag{4}$$

and

$$\mu = E[\tau_s]^{-1} = RTT^{-1} \tag{5}$$

Where t is the maximum of the batch service time, RTT is an extremely complex random variable which is closely related to many factors: such as the passenger's destination floor, elevator speed, acceleration, door closing or opening time, elevator service mode, etc. For further discussion about RTT, see [4], [6] for details.

C. *The system performance evaluation criteria*

In order to evaluate the quality of service for elevator traffic system, the major dynamic performance criteria are considered as follows.

1) Average waiting time, AWT

$$AWT = \frac{1}{n}\sum_{i=1}^{n} W_i \tag{6}$$

Where W_i is the waiting time of the ith hall call, n is the total number of hall calls who accept service.

2) Long waiting percent, LWP

$$LWP = \frac{n_{60}}{n} \times 100\% \tag{7}$$

Where n_{60} is the number of hall calls who wait more then 60(s).

As dynamic performance parameters, AWT and LWP are the key criteria to evaluate the passenger service level.

To measure the quality of service, AWT is the critical performance criterion. The tolerance level of passengers for long waiting time is different from both building type and one's travel purpose. Dr. Barney G C proposed the evaluation criteria for average waiting time [13]: in an office building AWT should not exceed 30(s) and in residential building, 60(s).

LWP, caused by poor passenger service, should be controlled at an acceptable range, say, no less than 20%.

III. GLOBAL STRUCTURE DESIGN AND ALGORITHM PROCESS OF SIMULATION

A. *Global Structure Design of Simulation*

1) Structure and composition of simulation: as shown in Fig.1, the global structure of simulation consists of the following parts.

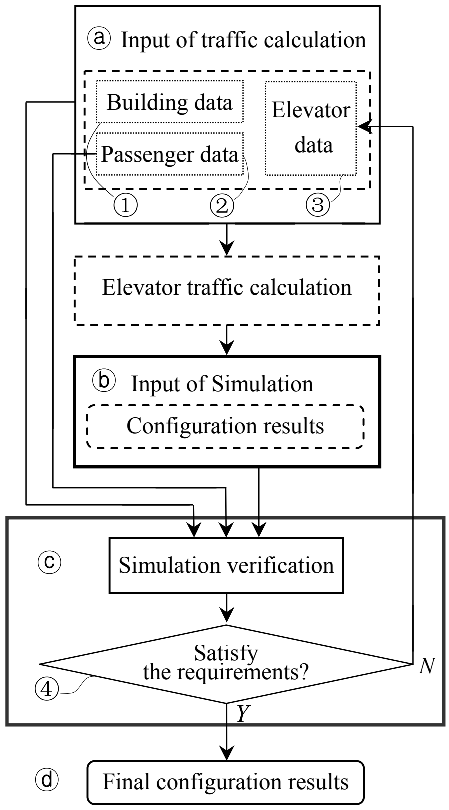

Figure 1. Global structure of simulation flow chart

ⓐ *The basic input of elevator traffic planning:* consisting of three parts to dealing with the initial elevator traffic calculation.

- ① Building data: building type, number of floors, covered area, occupant, home floor, floor height.
- ② Passenger data: traffic distribution and arrival rate of passenger arrival process, by which the passenger data sequence of elevator traffic is generated.
- ③ Elevator data which are divided into two categories: the dynamic data, decided on simulation, including the number of cars, contract speed of cars, rated capacity of cars, acceleration, and so on, and fixed data, including door type, door operation time, acceleration, passenger transfer time, etc.

ⓑ *The input of simulation:* referring to the configuration results from the elevator traffic calculation.

ⓒ *The simulation verification unit:* this is the main part of the global structure of simulation, and the main emphasis of research in this thesis, in which the initial elevator traffic calculation (or the existing elevator traffic configuration) is verified by simulation.

- ④ indicates that the result of simulation is compared with the specified dynamic performance criteria, if it is not satisfied with the specified criteria, then adjust the elevator data, until the specified criteria is satisfied.

ⓓ *The final configuration results by simulation verificationt:* consisting, mainly, of number of cars L, contract speed of cars V_e, rated capacity of cars c, etc.

2) Execution mechanism of simulation model

If the elevator traffic system is taken as an entity, it can be seen from outside the system, two kind of events occurs: passenger arrivals, and passenger departures; from inside the system, only one kind of event occurs: dequeue events. Since the change of state is triggered by random event, the change of state occurs at random instants of time.

Therefore, the discrete event driven approach is employed to simulate dynamic behavior of elevator traffic system for accurately observing and control the system state.

The simulation time advancing is determined by the instant of time of the next event occurrence, the time clock is conducted with driving method. Namely, the random occurrences are inserted in the event list in chronological order, simulation clock advancing is determined by the next earliest event in the event list. Simulator responds to the passenger requests for elevators from the main terminal by the event driven mode, to deal with passenger arrival events to complete system simulation.

B. Simulation Procedures

The simulation verification procedures are as follows

1) Input the building data and the initial calculation results for elevator traffic planning.
2) Judge if the number of passenger departures reaches the stated number of simulated passengers, if yes, then go to 11), otherwise go to 3).
3) Check to see whether there are service requests for the time being, if yes, then go to 4), otherwise go to 5).
4) Set the arrival instant of the next passenger as the present moment.
5) Check to see whether the number of passengers exceeds the handling capacity of the system, if yes, then go to 6), otherwise go to 7).
6) According to the first come, first served service discipline, calculate the current service elevators' next arrival times, and update.
7) If there is free space in an elevator after all the arrivals have entered, exactly at this time, if there are passengers to come, then go to 8), otherwise go to 9)
8) The service elevator delay a random time to load the coming passengers.
9) Calculate the next arrival time of the current elevators, and update.
10) Search for the elevator arrival times: based on the service discipline, set the earliest arrived elevator as the current service elevator and it's arrival time as the present instant, then go to 2).
11) Compare AWT and LWP with the stated expectations of the quality of service, if it is not satisfied, then go to 1) and readjust initial calculation results for elevator traffic planning; if it is satisfied, then go to 12).
12) Export the ultimate result of elevator traffic planning.

The application instance is given in the next section.

IV. Simulation Results And Discussions

A. Simulation Conditions

Building data

- Building type: an imaginary standard office building.
- Covered area: 36000(m^2) (including the equipment floor and basement).
- Number of floors: 24 (floors) (above ground).
- Home floor: 1st F.
- Floor height: 1-3F, 4.8(m), others 3.3(m).

Traffic data

- Traffic type concerned: up-peak traffic with a passenger percentage arrival rates 11%. People are uniformly distributed in the building except the main terminal.

Elevator data (fixed data):

- Door type: center opening.
- Door operation time: opening time, 2(s), closing time, 2.9(s).
- Acceleration: 0.8-1.2(m/s^2).
- Passenger transfer time: 2.5(s).
- Time to load/ unload one passenger: 2(s) .

Other parameters, see [4], [13] for details.

B. Iinitial Calculation Results for Configuration

By classical elevator traffic planning method, the calculation results are obtained as follows: under the one way upwards service mode for up peak traffic conditions (i.e., elevators solely service the passengers at the home floor and answer car calls only on its way upwards with bypassing the landing calls, and then it reverses direction and travels nonstop to the main terminal.), the number of elevators, rated elevator capacity, contract speed, are 5, 20(persons), 2.5(m/s), respectively.

C. Simulation Verification

It can be estimated that the initial calculation results basically meets the demand for the quantity of service, but the quality of service is not quite satisfactory. Considering the quality of service, the elevator data are revised to give two alternative schemes by simulation (called solution 1 and solution 2). Simulations are conducted under the given conditions, the simulation curves of percentage of calls answered against the waiting time are shown in Fig.2 ~ Fig.4.

It is observed that solution 1, in which one elevator is increased compared with the initial calculation results, meets both the demand for quantity of service and quality of service. So one way of reducing average waiting time, of course, is to increases the number of elevators in the system, but this is expensive and also requires greater use of the central core space of the building. While, the number of elevators remains unchanged in solution 2 but the quality of service is satisfied by increasing speed, making up for a deficiency of solution 1. If 30s is taken as a reasonable criterion, 60% of hall calls, shown in Fig.2 ~ Fig.4, will be answered within, 36.4(s), 18.8(s), 23.5(s), respectively, 90% of hall calls, will be within 90.4(s), 62.2(s), 68.1(s), respectively.

The simulation results suggest that solution 1 and solution 2 are both alternative ones. The mechanism of the adjustability of speed makes it possible to adjust elevator speed by increasing no investment. So, solution 2 is the final result without increasing costs for building owners.

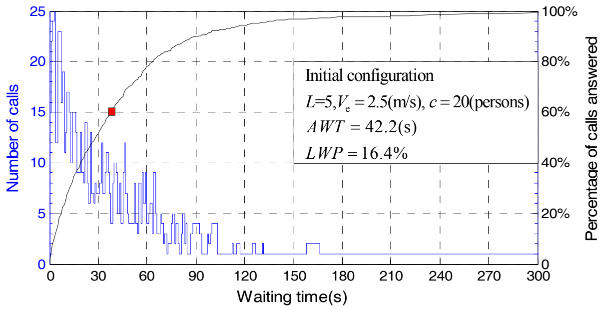

Figure 2. Percentage of calls answered against waiting time for initial configuration

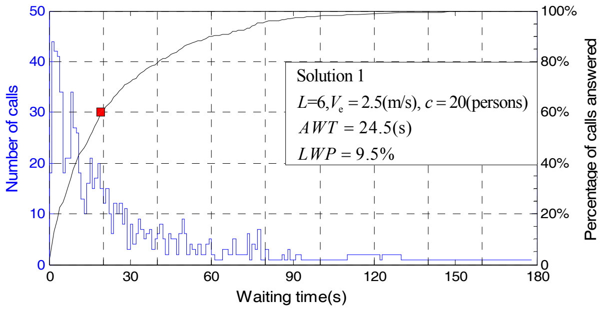

Figure 3. Percentage calls answered against waiting time for solution 1

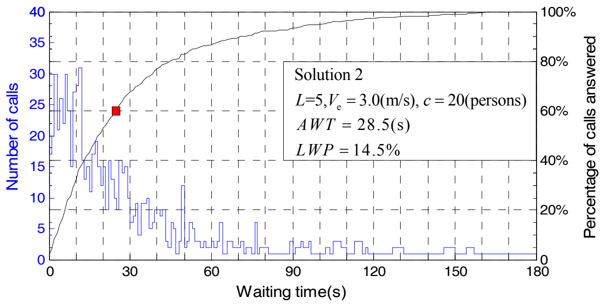

Figure 4. Percentage of calls answered against waiting time for solution 2

V. Conclusion

A verification approach for elevator traffic planning employing the object oriented discrete event driven technique is proposed. To obtain the optimal elevator traffic configuration, the elevator traffic system is taken as a special multi-sever batch service stochastic service system and the dynamic performance parameters, which are important critical criteria to measuring the quality of service, are introduced to the classical elevator traffic planning in this study. The simulation results show that the presented method can be effectively used not only to evaluate new elevator installations at the planning stage and the design stage of a building, but also to modify the existing elevator systems in constructed buildings. Moreover, it provides both a valuable support tool for elevator traffic planning, and a necessary complement to the classical elevator traffic planning.

Acknowledgment

This work was supported in part by the National Natural Science Foundation of China under Grant 69874026, and 60974071.

References

[1] Y. Zhenshan, S. Cheng and M. Haifeng, “Significance-evaluation and forecasting for elevator traffic-demand under unknown distribution,” Control Theory & Applications, Vol. 26, Dec. 12, 2009, pp. 1358–1364.

[2] Y. Zhenshan, S Cheng and L. Guizhi, “Multi-objective optimization for EGCS using improved PSO algorithm,” Proc. ACC Conf. (ACC 07), IEEE Press, July 2007, pp. 5059-5063, doi:10.1109/ACC.2007.4282871.

[3] Z. Yunli, Y, Zhenshan, “Fuzzy logic controller for elevator traffic scheduling,” Lift Report, Jan. 2009, pp. 64, 66-68.

[4] Z. Dwen and N. Zhicheng, Elevator Selection, Configuration and Quantification in Buildings. Beijing, China: China Electric Power Press, 2007.

[5] L, Zhilin, Z, Dewen, and L, Xiaojing, “The Design and Implementation of Elevator Traffic Dispatching,” Proc. 4th Intern. Conf. Computer-Aided Industrial Design and Conceptual Design (CAID & CD’2001), World Publishing Corporation, Oct. 2001, pp. 273–275.

[6] G C. Barney, S M. Dos Santos, Elevator Traffic Analysis: Design and Control. London, U. K: Peter Peregrinus Ltd. 1985.

[7] C. Robert S, “Elevate traffic analysis software (Eliminating the Guesswork), Elevator World, Vol. 48, Jun. 2000, pp. 118-121.

[8] W. Gabriel A, Discrete-Event Modeling and Simulation. Boca Raton, FL: CRC Press, 2009.

[9] I. J. B. F. Adan, J. A. C. Resing, “Multi-server batch-service systems,” Statistica Neerlandica, Vol. 54, Feb. 2000, pp. 202–220.

[10] S. Tuomas, S, Janne, S, Marja-Liisa, “Passenger behaviour in elevator simulation,” Elevatori, Sep. /Oct. 2005, pp. 28–37.

[11] B. Louis G and A. Gilbert, Modelling and Simulation. London, U. K: Springer-Verlag Limited, 2007.

[12] S. Dong, Z. Huiqiao, Z, Changming, “Theoretical modeling and analysis of elevator service system,” Journal of Shanghai Jiaotong University, vol. 30, Mar. 1996, pp. 113–119.

[13] G C. Barney, Elevator Traffic Handbook. London, U. K: Spon Press, 2003.