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Planning the capacity of hospital lifts for a new ambulatory block

Jonathan Wing Cheong Ng [1] and Carrie Ka Yuk Lin [2]
[1] Department of Industrial and Manufacturing Systems Engineering, The University of Hong Kong, Hong Kong, China
ngwc@hku.hk
[2] Department of Management Sciences, City University of Hong Kong, Hong Kong, China
mslincky@cityu.edu.hk

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Abstract

In a regional acute general public hospital, a new multi-storey ambulatory care block is under construction to accommodate specialty out-patient clinics to meet future growth in patient demand. Hospital lifts play a key role in vertical transportation and are an expensive long-term investment. The building design includes several lift groups each serving different floors and targeting user groups in the new ambulatory block. The main objective of this study is to decide on the capacity in terms of number of lifts needed in each group. Statistical forecasting provides demand estimates for comparison with projected figures from staff. A simulation model is developed to study the performance of different capacities under three demand scenarios to find the right level of service in terms of lift waiting time performance. Sensitivity analysis of the capacities has provided comprehensive information for multiple stakeholders, including the Hospital Authority Head Office, hospital management and the building contractor, to finalize the capacity decision which would have a long-term impact on service quality and cost.

Introduction

The study arises from an on-going hospital expansion project and was initiated as a consultancy project by the Hospital Authority Head Office (Ng & Lin, 2014). The objective is to decide on the number of lifts required to meet a given service standard of lift waiting time performance. The structure of the new ambulatory block is different from that of other lift studies in healthcare or non-healthcare environments. In several local public hospitals, specialist out-patient clinics are co-located with other supporting services in the same building, called the ambulatory care centre or block, usually ranging from 6 to 9 storeys. The day care services typically serve a large number of outpatients, generating complex, significant traffic flow during morning and afternoon sessions. In the current hospital, the new ambulatory block under construction is 17 storeys and is expected to be completed in 2021. The stacking diagram in Figure 1 shows two types of vertical transportation, including 3 types of lifts (for the public, staff/bed and service users) and 5 pairs of escalators. The 3 types of lifts are divided into 9 lift groups in the study.

When making capacity decisions, a common consideration is the trade-off between service quality and cost (installation, long-term operation and maintenance). Another challenge in this project is to decide on the service standard for finding the required capacity. During the on-going hospital expansion project, the building contractor has provided a set of capacity estimates from standard lift traffic calculations, given the projected number of people and material flow expected in 2021 by the hospital staff. The estimated total number of lifts required is 31 based on the design criterion of less than 45 seconds of lift interval (average time between lifts departing from the main terminal floor). At this point, the Head office introduced the authors to the project stakeholders as an independent party with the following objectives:

(i) Analyze the projection for the demands of lift users in 2021, including human (staff, patients, visitors) and materials (beds, stretchers and wheelchair) flow, given by hospital staff. Compare with other forecasting approaches.
(ii) Develop a simulation model for planning the capacity (number) of lifts in each group.
(iii) Determine the capacity requirement under different demand scenarios satisfying various levels of service standards for lift performance.

The main objective of this project is (iii) through developing (ii), while (i) serves as an important input.

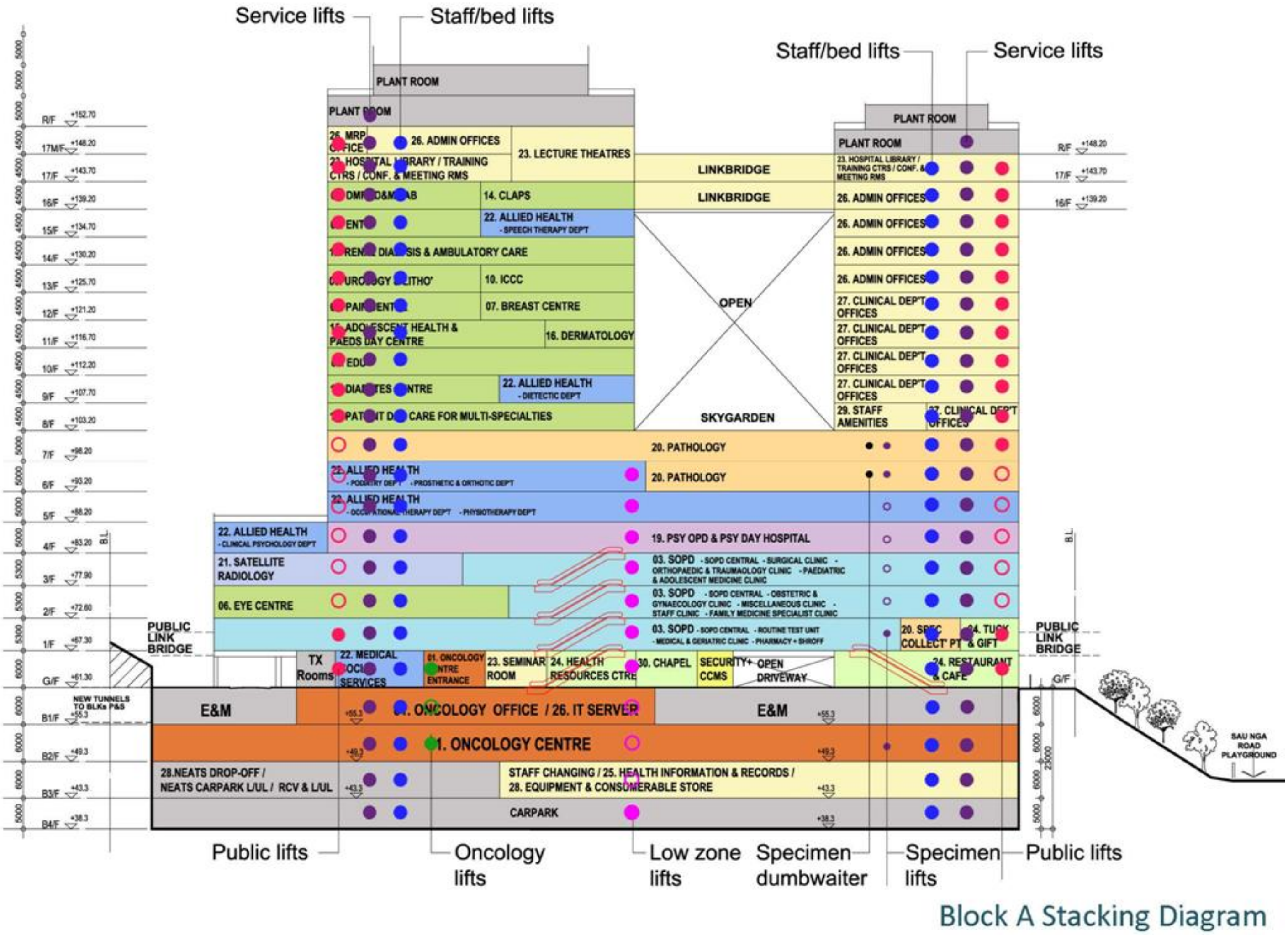


Figure 1. Stacking diagram of the new ambulatory care block

Demand analysis and forecasting

During the planning for the expansion project, the current hospital staff in different specialties and departments has provided a set of demand projections for 2021. They are expressed in terms of the daily demand profile for outpatients, daily number of visitors, number of staff, and number of trips made by bed/stretcher, trolley and wheelchair movement in each department of the new ambulatory block. These projections are important inputs for planning the capacity of different lift groups. For outpatients, the projection made reference to the actual daily patient attendance in 2013, and accounted for various quantitative and qualitative factors in different departments, e.g., population growth, past trends in patient demand, service growth, new services, and shortening of waiting time, etc. The majority of the daily traffic is generated by out-patient departments. A sample is shown in Table 1 for departments with a large projected daily patient attendance of over 500 in 2021. Other categories include departments with a moderate or small projected daily patient attendance of 200 – 300, and less than 200, respectively. Their subtotals are 1,170 and 629, respectively, giving a projected total of 9,011 daily patient attendance in 2021 from all three categories.

This set of projected figures is defined as Demand Scenario 1 in our analysis. The hospital staff has also provided another set of projected figures for the maximum number of lift users per day based on the function rooms in the new block to anticipate a worst-case condition. This is considered as Demand Scenario 2 in our analysis. The 8-year time gap poses a great challenge in demand forecasting. To achieve objective (i), we focus on analyzing the quality of the estimates in Demand Scenario 1 as these represent the future normal condition. Other forecasting methods are applied for comparison.

One public source that could provide objective data for an alternative estimation is the annual Hospital Authority Statistical Report (2007/08 − 2012/13). The annual actual patient attendance breakdown by clinical department in the 5-year period 2007/08 – 2011/12 can be used to construct two demand growth models, namely, constant growth and compound growth rate, described in equations (1)−(3) and (4), respectively.

Constant growth model:

$$Y_t = Y_{t-1} + \beta = Y_0 + \beta \cdot t, \; t = 1, 2, \ldots, n \quad (1)$$

$$d = \beta / w \text{, where } w = (270\text{, number of workdays per year}) \quad (2)$$

$$r_1 = \beta / \overline{Y} \text{, where } \overline{Y} = \sum_{t=1}^{n} Y_t \Big/ n \quad (3)$$

Compound growth rate model:

$$Y_t = (1 + r_2) \cdot Y_{t-1} = (1 + r_2)^t \cdot Y_0, \; t = 1, 2, \ldots, n \quad (4)$$

Table 1. Departments with a large projected daily patient attendance > 500

Department	*Actual daily patient attendance in 2013*	*Projected daily patient attendance in 2021*
Specialist Out-Patient Department	2,367	3,587
Allied Health Departments	725	1,159
Eye Centre	473	718
Oncology Centre	-	690
Satellite Radiology Service	402	534
Psychiatric Out-Patient Department and Psychiatric Day Hospital	205	524
		Subtotal: 7,212

Both models can be represented by simple linear regression models with the sample regression line estimated from the 5-year actual patient attendance data $\{Y_t, t = 1,\ldots, 5\}$. The estimated growth (daily growth d and annual rate r_1; compound annual growth rate r_2) can be compared with those derived from Table 1 when the two models are applied to the two years' data, 2013 (actual) and 2021 (projection from staff). Furthermore, the forecast attendance for 2013 from the best model using the previous 5-year data can be compared with the actual attendance of 2013 for reference. Table 2 displays the results for departments where data were available in the past statistical reports. For the two largest departments (Specialist Out-Patient Department and Allied Health Departments), the growth rates between projected figures from the staff and the 5-year data from 2007−12 are close. Besides this, the forecast error for attendance in 2013 is within ±13%. The natural grouping of related clinics into these large departments helped reduce forecast error. However, the data from the other two departments do not match so well, probably due to a recent growing trend and anticipated structural changes. We only validated the patient forecasts generated from the two largest departments which already contribute to over 50% of the daily patient attendance (9,011) in 2021. The projected maximum number of staff on the day shift is only half the patient attendance and the staff are allowed to use any lift group. In a way, the hospital staff provided more comprehensive estimates with front-end information on qualitative factors (e.g., future scale of operations). Our results from quantitative forecasting on the two largest departments have helped convince the Head Office that the projected figures from the staff are acceptable as input for the simulation model.

To examine the impact of demand uncertainty on the results, the two demand scenarios given by the staff are considered: Scenario 1 with the demand level set to the projection for 2021, and Scenario 2 with the demand level set to the projected maximum number of lift users in 2021. Scenario 3 has been created in this study as an intermediate case to average the demand level between Scenarios 1 and 2.

Table 2. Comparison of growth between the projection from staff and the 5 years of past data (2007-12)

Department	*Constant growth (Daily growth d; annual rate r_1)*		*Compound growth rate (Annual rate r_2)*	
	Projection from staff 2013→2021	*Using 5-year data 2007-12 (R^2 from regression)*	*Projection from staff 2013→2021*	*Using 5-year data 2007-12 (R^2 from regression)*
Specialist Out-Patient Department	152.5; 5.12%	105.16; 6.01% (0.95)	5.33%	6.19% (0.955)
Allied Health Departments	54.3; 5.76%	34.96; 5.09% (0.83)	6.04%	5.38% (0.822)
Ophthalmology Specialist Out-patient Clinic	28.4; 4.84%	27.43; 11.49% (0.818)	5.02%	11.56% (0.856)
Psychiatric Out-Patient Department and Psychiatric Day Hospital	39.9; 10.94%	23.5; 8.08% (0.989)	12.45%	8.5% (0.985)

Operation flow

Another important input is the movement sequence of various types of people and the flow of materials. The patient flow sequence is the most complex. On seeking consensus from the hospital manager, it was agreed that the typical movement of outpatients could be modelled by Figure 2, an 8-stage flow sequence of an outpatient visiting multiple locations. Depending on the floor level of each location, multiple service requests for lifts and/or escalators would be generated during the entire movement sequence.

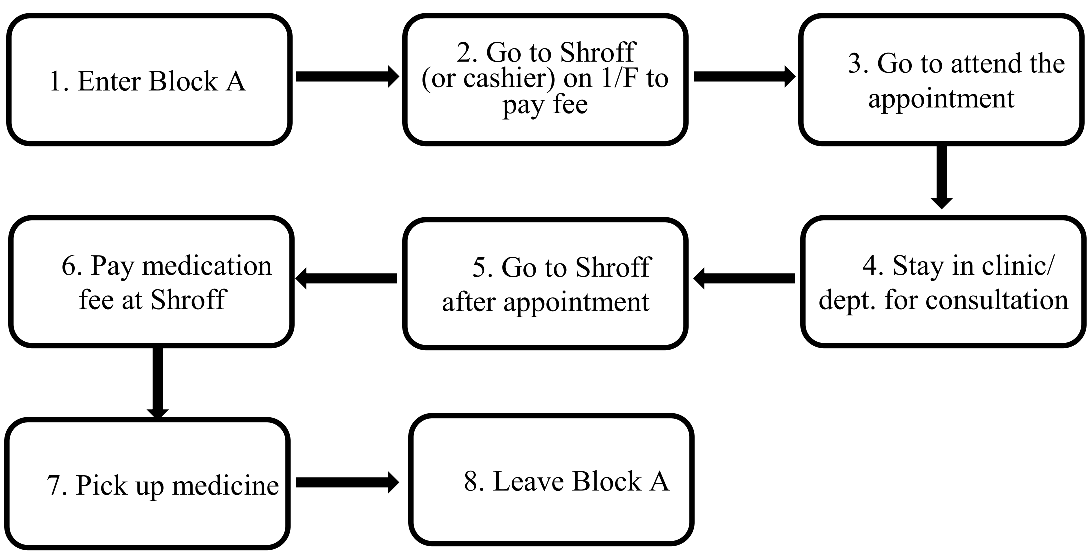


Figure 2. Typical flow sequence of an outpatient

(This approach could be applied to model the movement of outpatients of a particular specialty which involves visiting other diagnostic facilities. Accordingly, it would require more data collection and preparation time.) The movement sequence of different user types together with the time spent at each visit location can be used to determine the time for each lift service request, the arrival location and departure location.

Assumptions

In modelling users' traffic and lift service requests in this complex ambulatory block, certain assumptions are made about its future operations. These include (1) the percentage of staff working in the building who will drive to work is 6% (based on the policy that 90% of the 200 parking spaces in the new block is to be shared by about 3000 staff), (2) the morning peak period for staff arrival and afternoon peak period for departure after work each lasts for 30 minutes, (3) the staff lunch hour is between 12:30 and 13:30, (4) a certain proportion of users with both their origin and destination on lower floors (between G/F and 4/F) will use escalators instead of lifts, and (5) for a department that is assigned to a given set of n (> 1) possible locations, there is an equal chance ($1/n$) of the department being assigned to any one of these locations. In addition, each user type is restricted to use one (or more) specific type of lifts/escalators (e.g., outpatients and visitors can use either public lifts or escalators, while staff can use all types of lifts or escalators).

Simulation model

The Hospital Authority Head Office has applied simulation modelling in the past to study and improve the performance of lifts in a number of local hospitals (Chu *et al*, 2003). The unique characteristic of this project is the building structure mainly consists of ambulatory care services with no in-patients, and the flow sequence of each user type needs to be determined (e.g., Figure 2) for tracking the service request time for lifts/escalators, and arrival and destination floors. Figure 3 shows the major inputs and outputs for the customized simulation model.

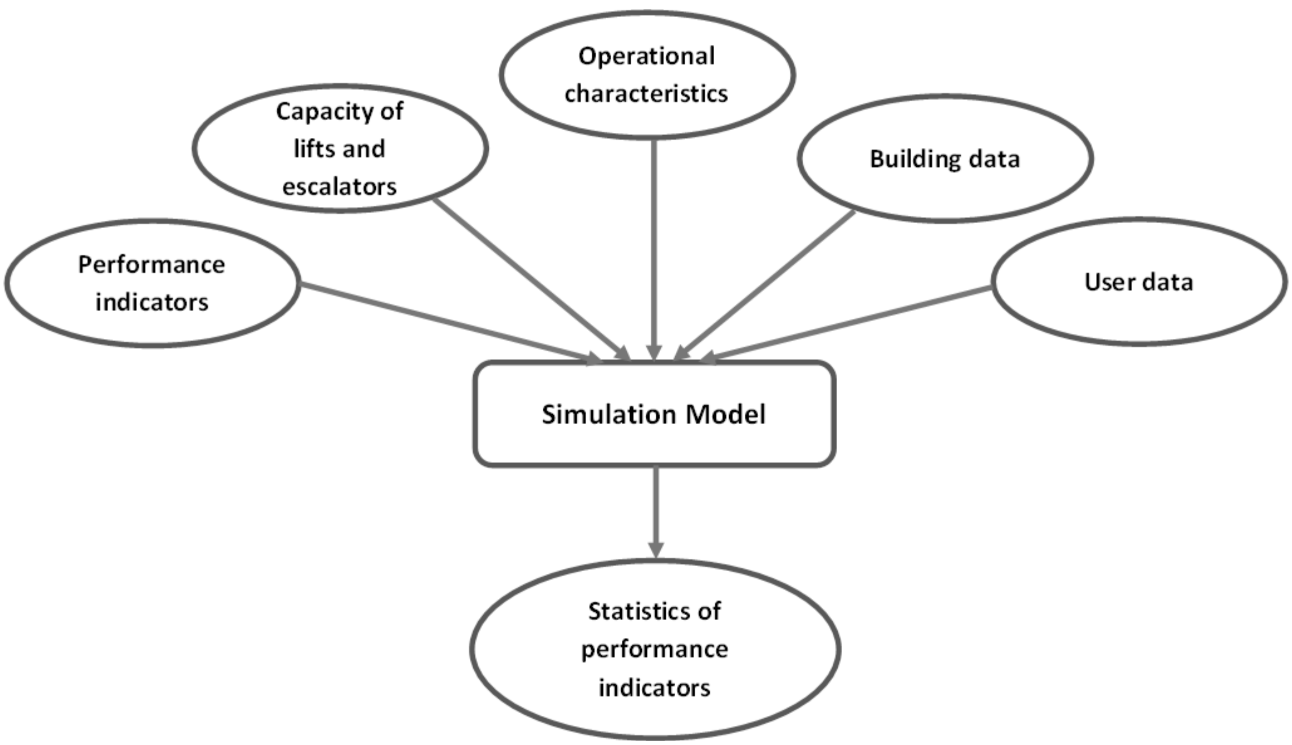


Figure 3. Major inputs to simulation model

The simulation model consists of two modules. The *service request generation module* randomly generates a lift user arrival according to the arrival pattern given by the hospital staff. The lift user's arrival time at each (lift) service request location is then generated randomly. The last step involves demand partitioning which groups the service requests from all users requiring the same lift group into a text file. Each text file stored for a lift group will serve as an input to the second module, *lift and escalator system operation module*, for evaluating the lift performance. The main engine is Elevate, a piece of elevator traffic analysis and simulation software, which can be customized to model the inputs of lift data, building data and user data (Figure 3). The output performance indicators comprise time- and space-measures of lift waiting time, transit time (time spent in lift), system time (sum of lift waiting time and transit time) and the maximum queue length waiting for lifts on each floor. The primary performance indicator used for capacity comparison is mean lift waiting time. Additional statistics of 80 and 90 percentiles of lift waiting time were requested subsequently. The number of replications required in the simulation model has been determined statistically to ensure the error of estimating the mean lift waiting time is not larger than 10%. (This involves increasing the number of replications until the confidence interval of the mean lift waiting time leads to a margin of error, equivalent to half the interval width, not larger than 10% of the sample mean waiting time.) With 95% confidence, 5 replications are required for each given lift group to satisfy the adopted precision of 10%.

Analysis and results of the simulation

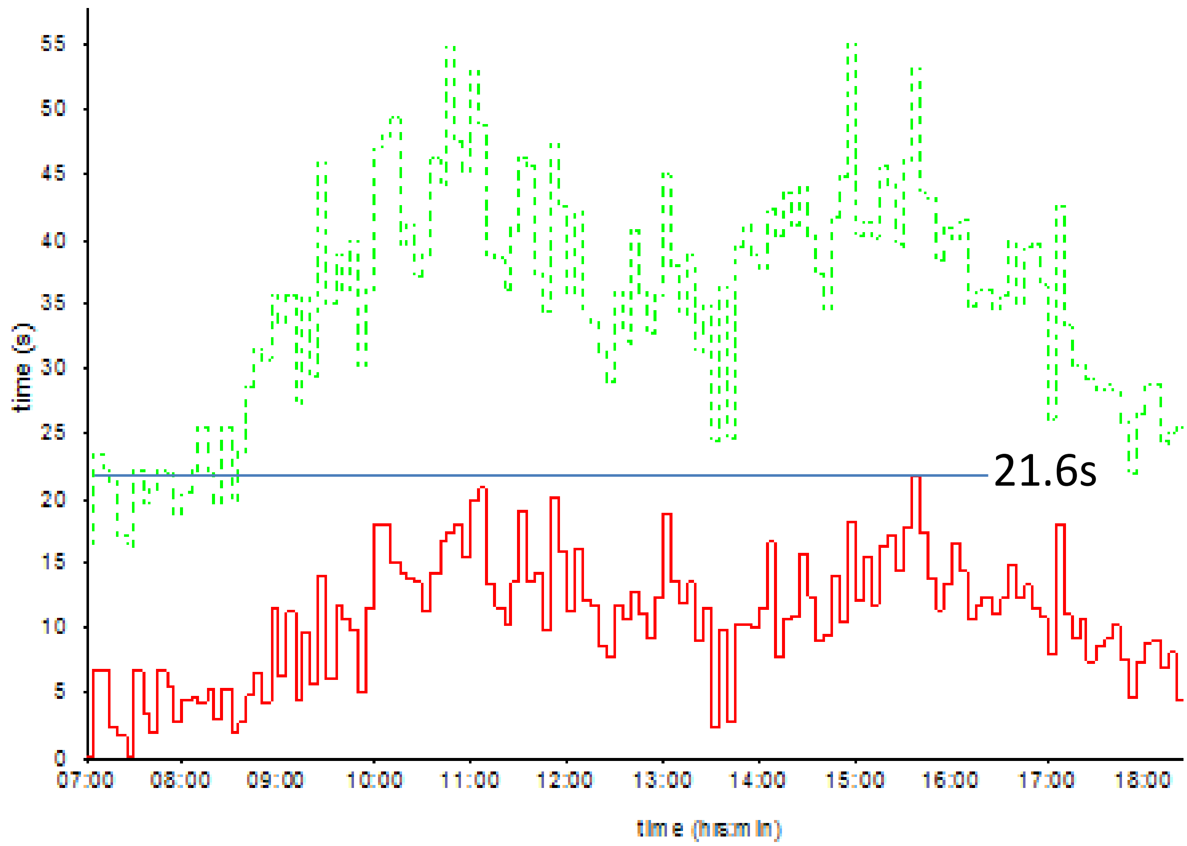
An analysis was first carried out to determine the capacity of each lift group satisfying different levels of service standard in terms of mean lift waiting time. On observing a long waiting time and queue length in the two staff/bed groups, the likelihood of staff taking public lifts was revised from 10% to the ratio of the capacity of the public lifts to the capacity of the staff/bed lifts. Demand Scenario 2 (projected maximum number of users in 2021 as given by the staff) was identified for additional analysis. Capacity results satisfying the mean and the 90-percentile lift waiting time limits are displayed in Table 3.

Table 3. Capacity of lifts satisfying various service standards under Demand Scenario 2

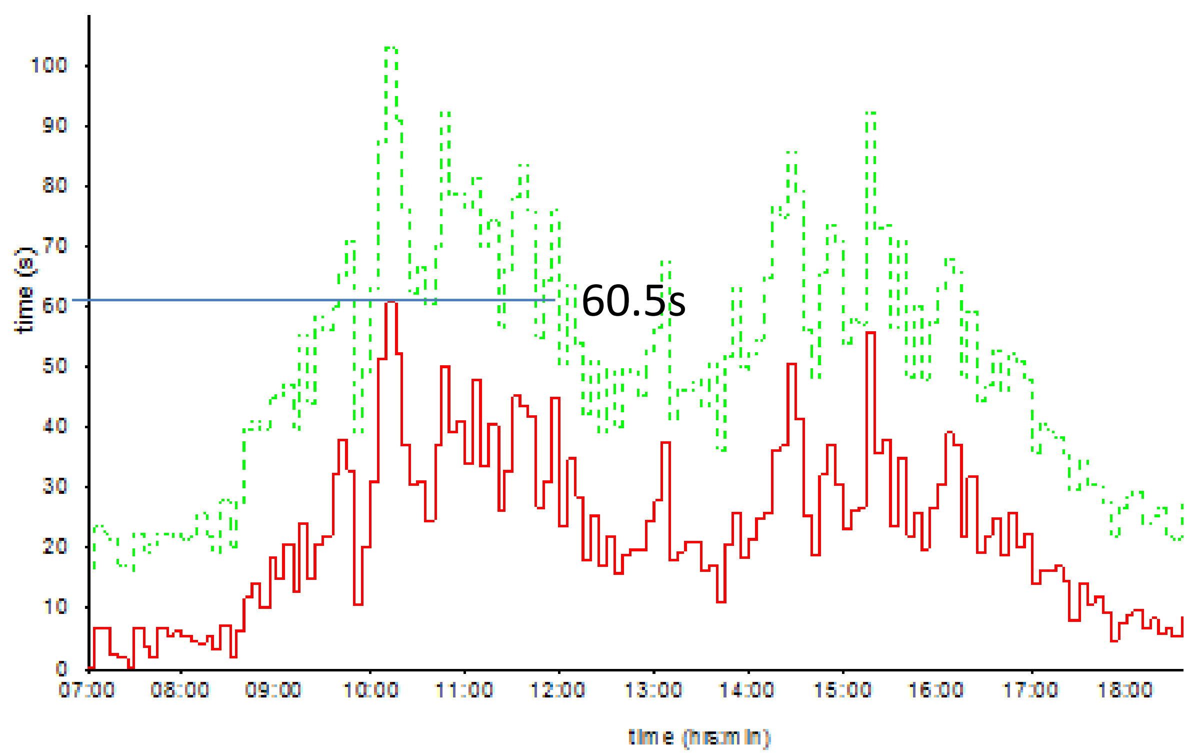
	Current design	*Simulation model: Min. no. of lifts required to achieve mean [and 90-percentile] lift waiting time less than*				
Lift Group		*30 sec*	*45 sec*	*60 sec*	*75 sec*	*90 sec*
North public high zone group	6	6 [>6]	6 [>6]	5 [6]	5 [6]	5 [6]
North public low zone group 1	3	3 [>3]	3 [>3]	3 [3]	2 [3]	2 [3]
North public low zone group 2	3	2 [>3]	2 [3]	2 [3]	2 [2]	2 [2]
North staff/bed group	6	5 [>6]	5 [>6]	4 [6]	4 [5]	4 [5]
North service group	2	2 [>2]	1 [2]	1 [2]	1 [1]	1 [1]
Oncology group	2	2 [2]	2 [2]	2 [2]	2 [2]	2 [2]
South public high zone group	3	3 [>3]	3 [>3]	3 [3]	3 [3]	3 [3]
South staff/bed group	5	5 [>5]	5 [>5]	4 [5]	4 [5]	4 [5]
South service group	1	1 [>1]	1 [1]	1 [1]	1 [1]	1 [1]
Total number of lifts required	31	29 [>31]	28 [>31]	25 [31]	24 [28]	24 [28]

From Table 3, the capacity requirement for each lift group is observed to decrease moderately as the mean lift waiting time limit is relaxed. The hospital's current design criterion of a lift interval of less than 45 seconds is estimated to correspond to 30 seconds of mean lift waiting time (Peters & Sung, 2000). Further analysis then focused on comparing the 31 lifts (of the current design) with 29 lifts (as proposed from the simulation model). From Table 3, only two lift groups (North public low zone group 2 and North staff/bed group) differ in the number of lifts under the 30 seconds of mean waiting time limit. To examine the situation more closely, the worst mean waiting time in any 5-minute interval over the day and the maximum queue length for each lift group were generated. Figure 4(a) and 4(b) show, in 5-minute intervals, the mean waiting time (solid red line) and mean time to destination (dotted green line) for the North public low zone group 2 for each of the two designs, allowing a comparison between them. This lift group reveals the largest difference in worst mean waiting time between the two designs, 21.6 versus 60.5 seconds, even when the number of lifts differs only by one.

The other lift group, North staff/bed group, with different number of lifts between the two designs (6 versus 5 lifts), shows smaller difference in the worst mean waiting time (41.9 versus 47.6 seconds) in the 5-minute intervals. However, the maximum queue length was recorded to increase from 35 to 55 with 1 fewer lift.



(a) Current design of 3 lifts



(b) Proposed design of 2 lifts (from simulation model)

Figure 4. Mean waiting time in 5-minute intervals for the North Public Low Zone Group 2

Conclusion

A detailed simulation model has been developed to study the requirements of the hospital lifts in the new ambulatory block under three demand scenarios and various levels of lift waiting time performance standards. The future demand of lift users is an important input to the analysis and results. After a comprehensive analysis, the Hospital Authority has finally decided on installing 31 lifts − the current design proposed by the hospital and building contractor. Our study has enabled a better understanding of (mean and extreme) lift waiting time performance and helped bridge the gap in expectations among multiple stakeholders in reaching the final capacity decision. Future work can be conducted to model the patient flow sequence (Figure 2) by specialty.

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