Planning the Capacity of a Hospital Lift System

Jonathan W. C. Ng and Carrie K. Y. Lin

***Abstract*—A regional general hospital in Hong Kong has a plan to construct a new high-rise block to provide a comprehensive range of ambulatory medical services. The objective of this paper is to determine the capacity of the lift system in the new block to meet a specific service standard. As the demand for lift services in a building varies significantly with the number of lift users and their movement within the building, the paper identifies the major user types, studies the essential characteristics of each user type, models their movement in the block and plans the capacity of the system using simulation. The management of the hospital can make use of the simulation results to determine the required capacity.**

***Index Terms*—Capacity planning, hospital, simulation, lift.**

I. Introduction

A regional general hospital in Hong Kong, established about 40 years ago, has an expansion plan to construct a new 23-storey block to provide a comprehensive range of ambulatory medical services. In the building design stage of the hospital lift system (HLS) in the new block, the designer has classified the lifts in HLS into 3 types - public, staff/bed and service, and designed HLS to serve various types of users. It is common in a large hospital that staff, patients and visitors spend a considerable amount of time on waiting for lift service as a result of heavy lift traffic. A higher standard of lift service offered would require a larger HLS capacity with a higher operating cost. To achieve a good balance between providing good lift service and keeping lift operating cost low, the hospital has placed a special emphasis on the design of HLS. One major design challenge is to plan the capacity of HLS to provide a reasonable level of lift service.

Capacity planning of HLS is a difficult planning problem as a hospital is one of the most complex systems in our society. The foot traffic, generated from interaction among various hospital departments and between the departments and outside world, often requires the service of HLS. Indeed, a detailed analysis is needed in order to develop the most appropriate capacity plan for HLS.

This paper aims at determining the capacity of HLS to meet the projected demand for lift service. Section II reviews the literature related to HLS capacity planning problem. Section III describes the demand model and simulation model for HLS. Simulations results are discussed in Section IV. Concluding remarks are given in Section V.

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II. Literature Review

Butcher and Wilson [1] have pointed out that "the difficulty in planning lift installation is not in calculating its probable performance, but in estimating the likely passenger demand". Various methods for estimating lift passenger traffic have been proposed by Peters *et al.* [2]. The main focus of these methods is on commercial buildings. Passenger arrival rates to specific floors are expressed as percentages of the building's population and the inter-floor traffic is usually assumed to be a certain percentage of the population.

Researchers have developed different analytical models and derived lift performance measures (e.g. round trip time, number of stops and number of passenger per trip) and these models have been discussed in details in Barney and Santos [3] and Barney [4]. However, all these models require simplifying assumptions on the passenger movement, which are unlikely to be valid in a hospital.

Simulation is a popular tool to study the performance of lift systems. Ladany and Hersh [5] have used simulation to examine various elevator-operating schemes for a commercial building. Lustig [6] has suggested using simulation for improving lift system design. Chu *et al.* [7] have developed a simulation model for studying the performance of lift systems with various control rules.

III. Model Development

A. Lift Service Demand

To plan the HLS capacity, we need to determine a good match between service demand and service supply. It is clear that service supply depends on the capacity of HLS. Vertical movements of people and materials in the new block often generate the service demand for HLS. The demand can be measured in terms of number of service requests and each service request can be characterized by its arrival time, arrival location, loading time (the amount of time required for a user to enter a lift), departure location, unloading time (the amount of time required for a user to leave a lift) and capacity consumption.

There are six types of users for HLS, namely, outpatient, staff, visitor, beds/stretcher, trolley and wheelchair. Thus, the demand for HLS is generated by people flow, resulting from the movement of patients, staff and visitors, and material flow, resulting from the movement of beds/stretchers, trolleys and wheelchairs. The total volume of the two flows depends on the operations scale of the new block and the movement sequence of people and materials. The estimate for the operations scale is expressed in terms of daily demand profile of outpatients, daily number of visitors, daily number of staff, and daily number of trips

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made by bed/stretcher, trolley and wheelchair movement in each department in the block.

It is noted that material flow is relatively simple, typically with one arrival location and one departure location when moving materials from one department to another. On the other hand, people flow often involves multiple arrival and departure locations. A typical 7-stage flow of an outpatient is shown in Fig. 1. In the figure, an outpatient enters the new block, takes a lift to go to Shroff to pay consultation fee, takes a lift to go to a clinical department to attend a medical appointment, stays in the clinical department for the consultation, takes a lift to go to Shroff after the consultation to pay medication fee, picks up the medication, and takes a lift to leave the new block. As illustrated in the above flow, an outpatient needs to use HLS to go to several locations in the block for completing the trip for a medical service. The arrival of an outpatient at the block sequentially triggers various HLS service requests at different visit locations at different times and the sequence of these requests follows the outpatient's movement sequence.

In the current building design, the three types of lifts in HLS are further classified into 9 lift groups according to physical locations and the set of floors they served. Table I gives the major operational characteristics of the 9 lift groups and the lifts in each lift group are identical except in Group 4. Table II gives the major characteristics of the users. The travelling time of lifts depends on physical dimensions of the new block and the relevant building data is given in Table III. For the six types of users, there are some restrictions on the use of different lift groups in HLS. These restrictions are given in Table IV. In Table IV, √ (X) denotes a user-type can (cannot) use a lift group.

TABLE I: CHARACTERISTICS OF LIFT GROUPS

Lift Group	Lift Capacity	Set of Floors Served
Group 1	1600kg	5, 6, 13-23
Group 2	1600kg	1, 5-10
Group 3	1600kg	5-10
Group 4	2500kg / 4350kg	1-23
Group 5	2500kg	1-23
Group 6	1600kg	3, 5
Group 7	1600kg/	5, 6, 13-23
Group 8	2500kg	1-22
Group 9	2500kg	1-23

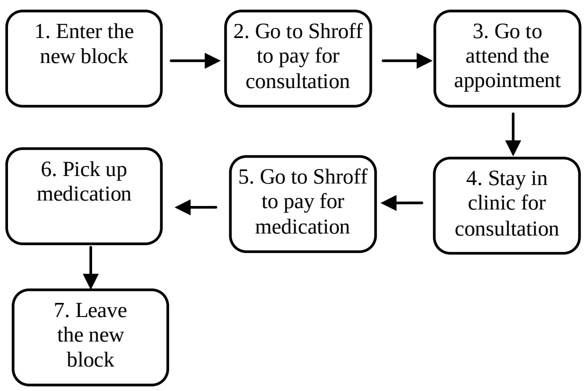

Fig. 1. Typical movement of an outpatient.

TABLE II: CHARACTERISTICS OF LIFT USERS

Lift Users	Values
Staff/Visitor/Outpatient	
Unit Load	1 unit
Loading time	0.9 second
Unloading time	0.5 second
Trolley	
Unit Load	4 units
Loading time	2.0 seconds
Unloading time	2.0 seconds
Wheelchair	
Unit Load	3 units
Loading time	3.0 seconds
Unloading time	3.0 seconds
Bed/Stretcher	
Unit Load	16 units
Loading time	5.0 seconds
Unloading time	5.0 seconds

TABLE III: BUILDING DATA

Floor	Floor Height
1	5.0m
2-4	6.0m
5-8	5.3m
9-12	5.0m
13-23	4.5m

TABLE IV: USER-LIFT RESTRICTIONS

	Lift group								
User-type	1	2	3	4	5	6	7	8	9
Visitor	X	X	√	√	√	X	√	X	X
Outpatient	X	X	√	√	√	X	√	X	X
Staff	√	√	√	√	√	√	√	√	√
Wheelchair	√	√	√	X	√	X	√	√	X
Trolley	√	√	X	X	X	√	X	√	√
Bed/ Stretcher	√	√	X	X	X	X	X	√	X

B. Simulation Model

A simulation model is developed in this paper to simulate the operation of HLS and to capture operational performance data for different levels of capacity. It is noted that the physical dimensions of all the lifts have been specified in the building design stage. Hence, the capacity of HLS mainly depends on the number of lifts in the system, and hence, the capacity can be expressed in terms of the number of lifts in each lift group of HLS. Fig. 2 shows the major inputs and output of the simulation model.

The major inputs to the simulation model are as follows:

1) Performance indicator
   The primary performance indicator for HLS is mean lift waiting time.
2) HLS capacity
   The HLS capacity is expressed in terms of number of lifts in each lift group.
3) Operational characteristics

These operational characteristics mainly include the flow of lift users.

4) Building data
The building data mainly includes the number of floors and the set of floors served by each lift group.

5) User data
User data includes the loading and unloading data and the number of users projected by the hospital.

The key output of the simulation model is the statistics of performance indicator collected in simulation runs.

HLS is a complex system with a maximum design capacity to serve more than 30000 users everyday and most users generate more than one service request. To model the arrival of the users, their operational flow in the new block and the operations of HLS, two major modules are developed for the simulation model. Service Request Generation Module first randomly generates all service requests of each lift group based on the flow of lift users. The details of each service request include arrival time, arrival floor, destination floor, capacity consumption, loading time, and unloading time. HLS Operations Module then schedules and controls the operations of lifts in each lift group to handle all the service requests generated, and collects simulation statistics for performance analysis.

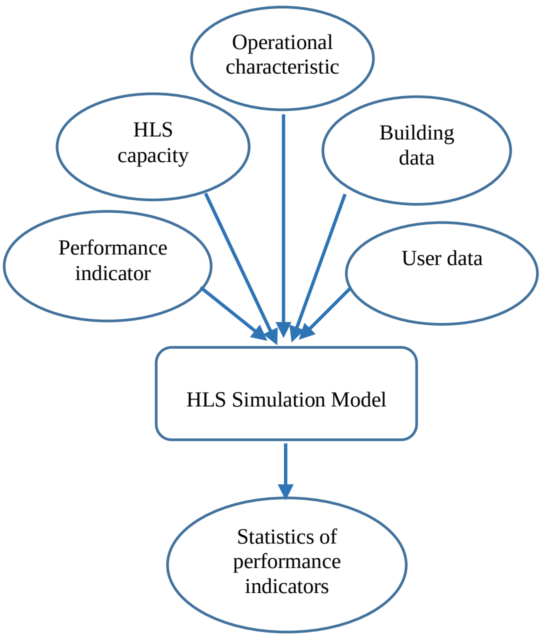

Fig. 2. Inputs and output of simulation model.

IV. Results and Discussions

The capacity levels of each lift group considered in this paper are given in Table V. It is noted that for the capacity level of a lift group smaller than that considered in Table V, the corresponding mean lift waiting time is unacceptably long.

The above simulation model has been run to simulate the operations of HLS to collect necessary performance statistics. The simulation results are presented Table VI.

With the mean lift waiting times given in Table VI, the hospital management can determine the required number of lifts in each lift group to achieve a certain level of lift service. For example, to achieve a mean lift waiting time of not more than 60 seconds for each lift group, the hospital should install a total of 25 lifts, with 5 lifts for Group1, 3 for Group 2, 2 for Group 3, 4 for Group 4, 1 for Group 5, 2 for Group 6, 2 for Group 7, 5 for Group 8 and 1 for Group 9. To achieve a mean lift waiting time of not more than 30 seconds for each lift group, the hospital should install a total of 28 lifts.

TABLE V: Capacity Levels Considered

Lift Group	Capacity Level 1	Capacity Level 2	Capacity Level 3
1	Six 1600kg lifts	Five1600kg lifts	Four1600kg lifts
2	Three 1600kg lifts	Two 1600kg lifts	---
3	Three 1600kg lifts	Two 1600kg lifts	---
4	Five 2500kg and one 4350kg lift	Four 2500kg and one 4350kg lift	Three 2500kg and one 4350kg lift
5	Two 2500kg lifts	One 2500kg lift	---
6	Two 1600kg lifts	---	---
7	Three 1600kg lifts	Two 1600kg lifts	---
8	Five 2500kg lifts	Four 2500kg lifts	---
9	One 2500kg lift	---	---

TABLE VI: Capacity Required For Each Lift Group

	Minimum number of lifts required to achieve mean lift waiting time not more than				
Lift Group	30 sec.	45 sec.	60 sec.	75 sec.	90 sec.
1	6	5	5	5	5
2	3	3	3	2	2
3	2	2	2	2	2
4	5	5	4	4	4
5	2	1	1	1	1
6	2	2	2	2	2
7	2	2	2	2	2
8	5	5	5	5	4
9	1	1	1	1	1

V. Conclusions

The main objective of this paper is to plan the capacity of HLS of a new hospital block in Hong Kong for future operations, based on the planned operational flow, operational characteristics and building data.

A simulation model has been built to study the performance of HLS with different capacity levels. In the paper, the capacity of HLS is expressed in terms of the number of lifts in each lift group and the level of HLS service offered to users is measured in terms of mean lift waiting time. For planning the capacity of HLS, five levels of mean lift waiting time have been considered, namely, 30, 45, 60, 75 and 90 seconds. A comprehensive study has been carried to determine the capacity required to achieve different levels of mean lift waiting time. It is noticed that the capacity required decreases moderately with increasing mean lift waiting time.

Choosing the most appropriate capacity for HLS requires a decision maker's judgment on the level of service offered to users. The decision maker can easily make use of the simulation results to determine the capacity required to meet a specific target level of service.

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