# Appointment Scheduling Optimization for Specialist Outpatient Services

**C. K. M. Lee, KKH Ng and M. C. Cheng**
Department of Industrial and Systems Engineering
The Hong Kong Polytechnic University
Hong Kong, China
ckm.lee@polyu.edu.hk, kkh.ng@polyu.edu.hk, mcmtcheng@polyu.edu.hk

## Abstract

Aging population and expecting a higher living standard in the developed countries cause demanding and high quality service in healthcare industry respectively. However, one of the customer requirement is to reduce the waiting time to see the doctor in the high demand of public medical. As a result, service appointment scheduling is the important issue. The poor medical service scheduling may lead to the complaints from patients on waiting time. Researchers tried to minimize the hospital explicit and implicit cost and maximize patient's satisfaction by adopting the appointment scheduling rules. The trade-off is considered in appointment scheduling problem. In general, solving appointment scheduling problem includes simulation and analytical method. The proposed approach allows hospital to take as a reference to further improve the appointment scheduling system. In this research, appointment scheduling optimization model with LINGO software using the exact algorithm is applied into the appointment scheduling problem for the outpatient clinic. The performance of the appointment scheduling optimization model is examined in difference case scenario and performance improvement is realized.

## Keywords
Appointment scheduling optimization model, appointment scheduling problem, LINGO

## 1. Introduction

How do we assign the patients to see which doctor at the particular time-slot? Will hospital consider setup a best appointment system for maximizing profit in one day while minimizing the patient waiting, doctor idle time and overtime? When the patient no-show or cancelled the booking, what will be the new arrangement and how to re-scheduling them? If there are many cases have to see by the same specialist in one-day, how will the hospital take actions to consider this kind of worst-case scenario? There are many challenges faced by the healthcare industry which needed to be solved. Besides, in the healthcare industry, the purpose of the hospital is not only to cure the patient, but also to consider about the customer satisfaction. Customer satisfaction has become the most important concern, as it can reveal the quality of healthcare services. With the problem of aging population, the elderly has become the most demanding group with a large amount of patients who requires all types of medical services (MacLeod et al., 2014). For instant, the elderly patients have high risk of suffering chronic disease. Therefore, they would more concern whether they can have the timely and appropriate treatment (Xie & Lawley, 2015).

Furthermore, treatment-processing time can be extended when the disease becoming pro-longed without taking care, so patient have to address for a longer period of recovering time in the hospital (Hall, 2006). To maintain an outstanding performance while balancing the resource equally, effective resources allocation and planning is required so as to assign the number of nurses or doctors in a consultation room. Facilities planning such as utilizing the appropriate number of consultation room in the hospital enable smooth diagnosis operation. Beside excellent service, simulation method is used to enhance service qualities (Mustafee & Katsaliaki, 2015).In case there is not enough nurse in one ward but with a large group of patient. Patients may not satisfy with service because of long waiting time. As usual, this kind of scheduling need to figure out the trade-off between waiting time of patient and hour rate of doctors (Saremi, 2013). For hospital point of view, maximizing the profit, margin and resource usages is the goal. On the other hand, doctors expect the less overtime hours or idle time to serve all booked patients within the clinic operation hours. For patient, they are expecting shortest waiting time as well as quality medical care services (Lailomthong & Prichanont, 2014). Therefore, a well-planning schedule for the doctor and patient is important to maintain a satisfied environment. Oppositely, poor planning like a long waiting time for treatment or a high overtime rate for the doctors would cause health's deterioration or misdiagnosis respectively, as the doctor would like to quickly finishing their work and so unclear explanation will be happened. It in turn will harm to the patient health (Hall, 2006). Moreover, if the patient experienced long waiting time like they just seat in the hospital more than 1 hour while they seek for medical consultation advice only for few minutes, they will feel bad at that moment. If they need to wait for more than 1 year to see the doctor for the next stage, they need to take the risk of getting worst. Consequently, complaint will become more and the customer satisfaction will be decreased (Pakdil & Harwood, 2005). Besides, Norris et al. (2014) indicated that this kind of situation will proportionally increase the medical care cost and decrease the treatment effectiveness. In addition, doctor's idle time would be treated it as a non-used of resources in the industry. When the doctor is being idle, hospital needs to be reschedule the appointment which is a kind of administration cost (Huang, Zuniga, & Marcak, 2014). Resources should be well-planned so that the hospital will be beneficial for the patients. Operation research is applied to provide an optimal solution for different kinds of medical service problem.

This research proposes a method of operation research (1) to deal with the appointment scheduling which may be better than some of the others method like analytical approach, exact method is suggested by the other researches. The advantage of this approach is using the algorithm to deliver possible solutions for solving problems for hospital (Saremi, 2013). (2) to develop a model for solving the uncertain real-world situation like the stochastic service duration. (3) to develop an appointment scheduling approach in outpatient clinic with the use of LINGO and (4) to minimize the waiting time in the outpatient specialist clinic, as a result which will increase the customer satisfaction. The reminder of this paper is organized as follows: the literature related to operation research in healthcare will be shown in Section 2, while the problem description and formulation will be put in Section 3, Section 4 study different case study and provide the result using the proposed solver, and the conclusion will be put in Section 5.

## 2. Literature review

Mathematical model is built to find a better result for the appointment systems (Saremi, 2013), and the Appointment Scheduling Rules are applied in order to reduce the doctor's idle time and overtime as well as the patient waiting time.

### 2.1 Traditional appointment scheduling rules

To evaluate the performance in the clinic, patients' waiting time would be a suitable indicator. Cayirli and Veral (2003) showed that it can be classified into several kinds of block: individual block, multiple block and variable block with two kinds of interval: fixed and variable. Different kinds of scheduling rules will result in a trade-off among of the patient waiting time, doctor idle time and the doctor overtime. For instant, one of the scheduling rules is that, all patient is assigned to the same time-slot (i.e. All patients are put at 9:00 am), which can prevent the doctor from idle but it will lead to excessive waiting time for patient.

Another rule is to fixed interval with individual block (i.e. 1 patient in 1 session). It could reduce the waiting time; however, the doctor's idle time would be occurred when cancellation or no show of the patients. To reduce the doctor's idle time, giving more amount of patient in the first session would be proposed, which is an example of individual block with a fixed interval for an initial block. While waiting time would be occurred when patients are coming on time and no cancellation occurred.

For the problem of large number of patients use the medical services, hospital now is adopted the rules of multiple block in a fixed interval rules (i.e. 10 patients are put in the same hour session) or variable-block in a fixed interval rules (i.e. 10 patients in 9:00 am and 6 patients in 10 am) or individual block in a variable interval rules (i.e. Patient A in 9:00 am, patient B in 9:05 and patient C in 9:30 am according to their consultation time). These rules could reduce the doctor idle time and the excessive waiting time of patients, but the waiting time would still be occurred, so a better scheduling with this rule could be adjusted to obtain a better result.

### 2.2 Methods used for OR on appointment scheduling

There are different methods which have been applied to find the solution of appointment scheduling in the outpatient clinic. Researchers usually proposed the method for OR including queuing theory optimization and simulation.

For queuing theory, literature would like to consider the scheduling problem as a queuing problem, which means that using the queuing models to show the systems and environment. Mardiah and Basri (2013) considered the scheduling problem as a queuing problem. They present the queuing models of clinic environment and appointment system. They suggest that patient flow is the major element to improve the efficiency. By using some calculation and simulation to find the condition that may affect patient waiting time, like room capacity or the behavior of doctor.

Queuing model provides a solution in the appointment scheduling system, but the disadvantage is to assume the system is stable (Saremi, 2013) This assumption may not suitable to the situatoin of public hospital as it contains lots of uncertainty like the doctor has to see the patient late or the queue is too long,. Besides, the paper usually considers with a distribution of service time, like exponential or discrete distribution for service time is used while some suggested that lognormal distribution would be more appropriate (Mak, Rong, & Zhang, 2014). However, there are lot of uncertainties have to be faced like stochastic service duration, cancellation or no show of booking, uncertain capacity of resource and patient flow in reality. Peak hour would make the scheduling even worse (Ahmadi-Javid, Jalali, & Klassen, 2017). Consequently, there is a distinctive difference between planned operations and actual one.

For simulation, many researches are using simulation models to solve the scheduling in outpatient clinic. As the simulation model like FlexSim can have a lot of different factors such as cancel of booking, no shows or lateness that put all into the model as a situation based, and it can generate different performance measures (Nordgren, 2003). In addition, it can help the researcher to do some experiment analysis when considering or proposing a better scheduling rules to evaluate the performance. Mustafee and Katsaliaki (2015) used simulation to modify the scheduling problem, as this kind of simulation program contains a lot of resource and data which can interpret the real situation, so it is easy to generate the result and to conduct what-if analysis

There would be some advantages of simulation especially for complex situation, like setting the priority of the patient. Some patients needs to be set as the priority case with a various service time duration. Besides, when comparing to the queuing theory, assumption of the simulation is to contain the random behavior in the model. However, Saremi (2013) pointed out that it is lacking of optimization strategy which means the result is not the optimal solution. Employing more doctors may be a good solution to reduce the waiting time but it may not be applicable in a real situation. A combined simulation with other technique such as mathematical programming could help to improve the problem.

For optimization, it is a kind of mathematical programming that computes the result using the mathematical model. Among the evolutionary computing approaches, most researchers apply generic algorithm to the outpatient appointment scheduling problem (Qu, 2006) Kaandorp and Koole (2007) applied dynamic programming with branch and bound algorithm, which is another algorithm that considering different branch of solution and find the best solution in one particular branch and solve the static scheduling problem in their research. Jebali and Diabat (2015) solved the problem by considering the exponential distribution and providing the distribution in a special phase-type. In order to minimize the total cost in the company the doctor makespan and the patient waiting time are calculated using the characteristics of phase-type distributions,. They realized that a dome shape pattern would be the most appropriate solution during the clinic session. The consultation session is increasing in the first few sessions and then decreasing at the end, while the middle is the longest service time in that period.

To conclude, operation research has been proposed in a lot of research and provides some important insights to the scheduling problem, not limited to the application of outpatient scheduling. This study is to formulate a model for Hong Kong outpatient clinic by considering the practical scheduling rules for real life problem.

## 3. Problem description and formulation

Appointment scheduling optimization model considers the scheduling with large amount of patients of an outpatient clinic in a single day during the office hour (ie. 9am-5pm). The problem is firstly considering the overall makespan in the outpatient clinic. As a result, the makespan in the clinic can be minimized to ensure that the doctor can evenly distributed the work in the. Some data should be obtained such as number of patient, number of doctor, the service duration corresponding to the patient towards the doctor, the arrival time to the patient, and the leaving time of doctor. The model is further modified by minimizing the waiting time of patient and minimizing the overtime of doctor.

A hypothetical specialist outpatient clinic would be presented in Figure 1 to show the similar properties in the outpatient clinic in Hong Kong. The clinic contains different stages including arrival, reception, nurse visit, waiting seat, and doctor consultation. When the patients come, they received the booking number after paying money in the reception The next step is that the nurse will call the patient to check the booking number or ID card number to validate the patient, identify. And then the booking number will be shown on the screen. The patients are seat in the waiting area. If the patient booking number is displayed on the screen, then the patient will see the doctor. By considering the historical record of the patient, the doctor can then provide medical consultation to the patient. Finally, the patient will be discharged if the consultation is finished. The notations and decision variables used in this model are consolidated in Table 1.

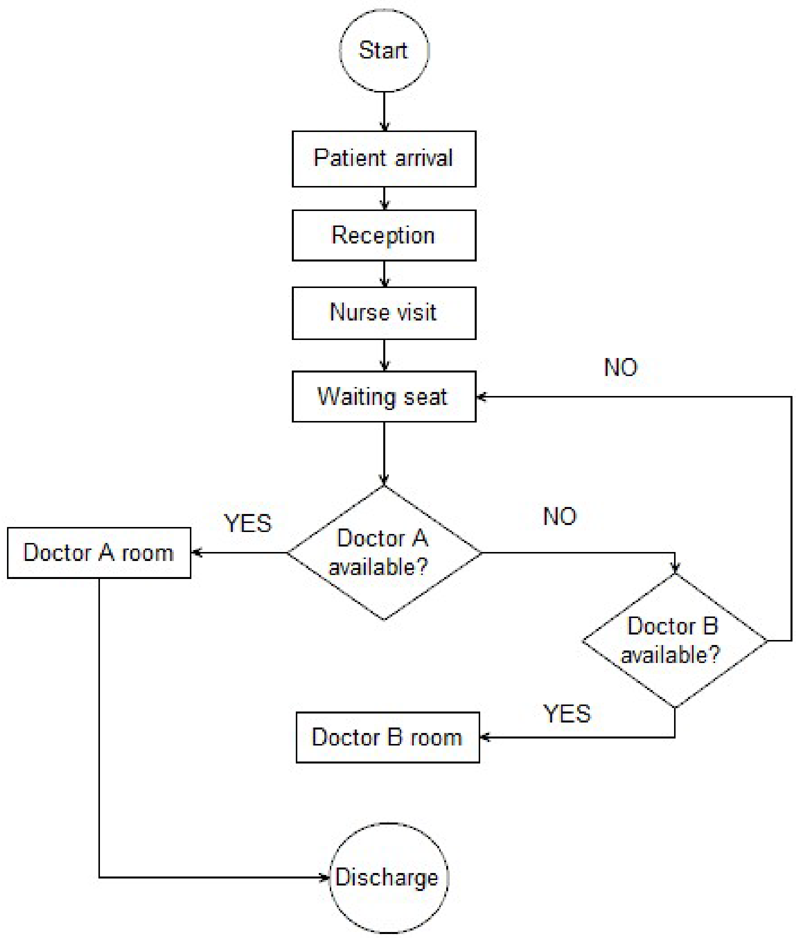


**Figure 1: Process flow in the outpatient clinic**

Table 1: Notation and Decision Variable

| Notations | Explanation |
|---|---|
| j | Patient ID (j = 1,2,…,n) |
| n | The maximum number of patient |
| d | Doctor ID (d = 1,2,…,m) |
| m | The maximum number of doctor |
| $ARVT_j$ | The arrival time of patient j who enters the hospital |
| $PT_{dj}$ | The processing time or the service time of the patient j to the doctor d |
| $LEAT_d$ | The leaving of the doctor d |
| M | Large number associated with the artificial variable |
| **Decision variables** | **Explanation** |
| $x_{dj}$ | 1, if patient j is assigned to doctor d; 0, otherwise |
| $y_{djk}$ | 1, if patient j is assigned before patient k in a consecutive sequence on the same doctor d; 0, otherwise |
| $C_{max}$ | The total makespan of doctor d in the appointment schedule |
| $CT_{dj}$ | The completion time of consultation of the patient j assigned to the doctor d |
| $S_{dj}$ | The starting consultation time of patient j assigned to doctor d |

With these notations and variables, the Appointment Scheduling Optimization (ASO) model can be formulated as below:

$$\text{Min } C_{max} \quad (1)$$

s.t

$$\sum_{d=1}^{m} x_{dj} = 1, \forall j \quad (2)$$

$$y_{djk} + y_{dkj} \leq 1, \forall d, j, k, \forall j \neq k \quad (3)$$

$$y_{djk} + y_{dkj} \geq x_{dj} + x_{dk} - 1, \forall d, j, k, \forall j \neq k \quad (4)$$

$$C_{max} \leq LEAT_d, \forall d \quad (5)$$

$$S_{dj} + PT_{dj} \leq CT_{dj}, \forall d, j \quad (6)$$

$$CT_{dj} \leq C_{max}, \forall d, j \quad (7)$$

$$ARVT_j \times x_{dj} \leq S_{dj}, \forall d, j \quad (8)$$

$$CT_{dj} \leq S_{dk} + M\left(1 - y_{djk}\right), \forall d, j, k, \forall j \neq k \quad (9)$$

$$x_{dj} \in \{0,1\}, \forall d, j \quad (10)$$

$$y_{djk} \in \{0,1\}, \forall d, j, k \quad (11)$$

In this model, the objective function (1) is to minimize the makespan of each doctor. In the hospital, doctors need to finish all patient of that day in the outpatient clinic, so the division of labor is important such that one doctor need not to handle too may patients while another doctor is being idle. Makespan minimization can result in a better scheduling of division of labor and reduce the doctor's idle time. Constraints (2) ensure that each patient can only consult one doctor only. Constraints (3) and (4) calculate the consecutive sequence in Boolean value. If patient j and k are assigned to doctor d, $y_{djk}$ equals to 1, otherwise, $y_{djk}$ equals to 0. Constraints (5) ensure that the total completion time or makespan of each doctor less than their leaving time, as a result, there will not happen the overtime of doctor, while the problem of overtime will be calculating in the next chapter. It must be true that the completion time of each patient must be greater than or equals to the processing time and the starting time, which is the constraints (6). For constraints (7), it must be ensured that the objective function $C_{max}$ would be lies on the decision variable of completion time and so the total makespan must be larger than the completion time. As a result, the largest value of the completion time would be the value of makespan. Constraints (8) is that the starting time of selected patient to the particular doctor would greater than the arrival time of the patient entering the hospital, to ensure that the programming will not generate the result of the patient start the consultation before the arrival time. In the sequencing problem, if the appointment sequence is patient j before patient k, then patient j must be finished the consultation so that the patient k can be started the consultation in the hospital in constraints (9). The decision variable $x_{dj}$ and $y_{djk}$ could be either 0 or 1 with the constraints (8) and (9).

## 4. Illustrative example, results, and discussion

To evaluate the model, a simulated case studies in Hong Kong public hospital has been considered. The data would be come from the observation and the questionnaire made by the Hong Kong Hospital Authority. From the questionnaire made by Hong Kong Authority, the consultation time of the patient and doctor is around 5-30 minutes in the case. By observation, there are around 10-15 patients in each session. For the structure of specialist, at most three specialists to serve the specific patients (ie. 3 consultation room for Neurology, Otolaryngology or Pediatrics). The model was solved by the LINGO 15.0. As the exact algorithm is adopted, that means it can help to use find the global optimal solution which is the best solution with the objective above. All the scenario will be portrayed in Table 2. The generated solutions will be shown in Table 3 and 4.

Table 2. Case study scenario

| Case Study No. | No. of Patient | No. of Doctor | Service duration | Doctor's Leaving time | Objective | Maximum CPU time |
|---|---|---|---|---|---|---|
| 1 | 30 | 3 | 5-30 minutes/each | 12 noon | Minimize makespan | 10 minutes |
| 2 | 10 | 2 | 5-30 minutes/each | 10:00 am | Minimize waiting time and overtime | 1 hour |

Table 3. Model solution for case study 1

| Patient ID | Assigned Doctor ID | Processing time for taking advice | Stating time | Completion time |
|---|---|---|---|---|
| 1 | 3 | 10 minutes | 9:55am | 10:05am |
| 2 | 1 | 10 minutes | 9:50am | 10:00am |
| 3 (last) | 2 | 20 minutes | 11:30am | 11:50am |
| 4 | 3 | 15 minutes | 11:00am | 11:15am |
| 5 | 2 | 15 minutes | 10:45am | 11:00am |
| 6 | 1 | 15 minutes | 10:45am | 11:00am |
| 7 | 1 | 25 minutes | 11:00am | 11:25am |
| 8 | 2 | 20 minutes | 10:05am | 10:25am |
| 9 | 3 | 10 minutes | 11:15am | 11:25am |
| 10 | 3 | 15 minutes | 11:25am | 11:40am |
| 11 | 2 | 15 minutes | 11:15am | 11:30am |
| 12 (last) | 1 | 10 minutes | 11:40am | 11:50am |
| 13 | 2 | 20 minutes | 9:25am | 9:45am |
| 14 | 1 | 20 minutes | 9:15am | 9:35am |
| 15 (first) | 3 | 20 minutes | 9:00am | 9:20am |
| 16 | 3 | 30 minutes | 9:20am | 9:50am |
| 17 | 3 | 20 minutes | 10:15am | 10:35am |
| 18 | 1 | 20 minutes | 10:00am | 10:20am |
| 19 (first) | 2 | 10 minutes | 9:00am | 9:10am |
| 20 | 2 | 15 minutes | 9:10am | 9:25am |
| 21 | 2 | 15 minutes | 11:00am | 11:15am |
| 22 | 3 | 10 minutes | 10:05am | 10:15am |
| 23 | 1 | 25 minutes | 10:20am | 10:45am |
| 24 | 3 | 20 minutes | 10:35am | 10:55am |
| 25 | 1 | 15 minutes | 9:35am | 9:50am |
| 26 (first) | 1 | 15 minutes | 9:00am | 9:15am |
| 27 | 2 | 20 minutes | 10:25am | 10:45am |
| 28 | 2 | 20 minutes | 9:45am | 10:05am |
| 29 (last) | 3 | 5 minutes | 11:45am | 11:50am |
| 30 | 1 | 15 minutes | 11:25am | 11:40am |

Table 4. Model solution for case study 2

| Patient ID | Assigned Doctor ID | Processing time for taking advice | Stating time | Completion time |
|---|---|---|---|---|
| 1 (first) | 2 | 10 minutes | 9:00am | 9:10am |
| 2 (first) | 1 | 8 minutes | 9:00am | 9:08am |
| 3 | 2 | 20 minutes | 9:43am | 10:03am |
| 4 | 1 | 12 minutes | 9:08am | 9:20am |
| 5 (last) | 1 | 30 minutes | 9:55am | 10:25am |
| 6 | 2 | 15 minutes | 9:10am | 9:25am |
| 7 (last) | 2 | 22 minutes | 10:03am | 10:25am |
| 8 | 2 | 18 minutes | 9:25am | 9:43am |
| 9 | 1 | 15 minutes | 9:20am | 9:35am |
| 10 | 1 | 20 minutes | 9:35am | 9:55am |

For the case study scenario 1, the total makespan of each doctor is 170 minutes, which means that the completion time of each doctor is 11:50am. Comparing to the leaving time, the 10 minutes left of each doctor can handle one more patient for taking an advice or it is one of the buffer zone for the doctor to take rest. As a result, doctor will not getting idle or overtime, the patient's appointment schedule will be shortened due to more patient can be handled for the time left in the buffer zone. This method can provide a base to hospital that the appointment scheduling system can be improved.

For the case study scenario 2, the waiting time for each patient is around 26 minutes and each doctor waiting time is around 25 minutes. While the solver is giving the result for the hospital to know appointment schedule for each patient, and the waiting time could be eliminated or minimized by assigning the patient arrival time of that session (i.e. Assigning patient 1 and 2 come at 9:00am and patient 8 and 9 at 9:15am). For the overtime problem, doctor can put the patient in the next session (i.e. patient 5 and patient 7) and put the other patient in this timeslot to prevent idle or overtime. As a result, the problem would be minimized so as to increase the patient satisfaction and decrease the doctor performance.

## 5. Conclusion

Appointment Scheduling Optimization techniques can solve different problems like manufacturing problem, job-shop scheduling problem or appointment scheduling problem. To sum up, in this research, a formulation of general n-patient, m-doctor outpatient appointment scheduling problem by minimizing the makespan, waiting time and overtime as the criterion. Computational results of the case study are reported using the proposed mixed integer linear programming model to solve the appointment scheduling problem. It would be generated by the method of LINGO and it would be interpreted by tabular representation. As a result, hospital can treat the result as a reference and further develop a better appointment scheduling system. Besides, it can show that a good appointment scheduling leads to different kinds of benefit among doctor, hospital and patients. Patients do not need to stay for a long time to seek the doctor advice;, doctor can clearly answer the question from the patient and increase their own performance; and hospital can increase their patient flow from minimizing the makespan so that the hospital can enhance the efficiency of public health service and alleviate the problem of long waiting time of appointment booking.

Future research in outpatient appointment scheduling problem may summarize as followings. Firstly, the scope of the linear programming model can be extended for other country not limited to Hong Kong. Secondly, more uncertain factors should be determined and should be put into the formulas to ensure the result more close to reality. Thirdly, more data like service time duration should be taken to ensure generating a more accurate result.

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## Biographies

Include author bio(s) of 200 words or less.

**C. K. M. Lee** is currently an assistant professor in the Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hong Kong. She is the program leader of BSc(Hons) Enterprise Engineering with Management. She obtained her PhD and BEng degree from The Hong Kong Polytechnic University. She was awarded Bronze Award of 16th China National Invention Exhibition Award in 2006 and Outstanding Professional Service and Innovation Award, The Hong Kong Polytechnic University in 2006. Dr Lee has authored or co-authored more than 100 journal papers. Her current research areas include logistics information management, smart manufacturing, application of internet of things and data mining techniques.

**KKH Ng** is a PhD student in the Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hong Kong. His interested research areas include aviation management and operation research.

**M. C. Cheng** is a research intern in the Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hong Kong. His interested research areas include healthcare management, operation research.