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IMPROVING EMERGENCY DEPARTMENT OVERCROWDING IN MALAYSIAN GOVERNMENT HOSPITAL

(Menambah Baik Kesesakan Jabatan Kecemasan di Hospital Kerajaan Malaysia)

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ABSTRACT

There have been a marked increase in emergency department (ED) visits. This has led to healthcare problems in ED, particularly overcrowding. This paper aims to contribute towards ED overcrowding by increasing the efficiency level of the department through eliminating ED bottlenecks and reallocating ED resources. An ED located in Kuala Lumpur was chosen as the study setting. Integration of Discrete Event Simulation (DES) and Data Envelopment Analysis (DEA) were adopted in this study. DES is used to model the ED system and to identify the system bottlenecks. Meanwhile, DEA is applied to select the best alternative to resources allocation. We also present a novel mathematical equation for generating resources allocation alternatives based on the hospital budgets. The new configuration number of ED resources constructed in this study improved the system bottlenecks. Patients' waiting time was reduced by 52%. The utilisation rate among Red Zone Doctors, Green Zone Doctors and Yellow Zone Nurses was reduced successfully from 89% to 85%, 98% to 90% and 91% to 89%, respectively. In conclusion, the finding in this study has produced better results in patient waiting time and resource utilisation and thus, enhance the hospital efficiency. Hopefully, in future the hospital will become a role model for other hospital in improving their services.

Keywords: emergency department; overcrowding; efficiency problem; discrete event simulation; data envelopment analysis

ABSTRAK

Dewasa ini peningkatan ketara pesakit ke jabatan kecemasan (JK) telah mendatangkan pelbagai masalah seperti kesesakan di JK. Justeru, kajian ini dijalankan bertujuan untuk menyelesaikan masalah kesesakan di JK dengan meningkatkan tahap kecekapan jabatan dengan menghapuskan kesendatan dan menyusun atur kembali sumber-sumber JK. Sebuah JK yang terletak di Kuala Lumpur telah dipilih sebagai lokasi kajian. Kaedah Simulasi Peristiwa Diskret (SPD) dan Analisis Penyampulan Data (APD) telah digunakan dalam kajian ini. SPD digunakan untuk memodelkan sistem JK dan mengenal pasti kesendatan yang wujud. APD pula digunakan untuk memilih alternatif penambahbaikan yang optimum bagi pengagihan sumber. Suatu rumus matematik baharu juga telah dibina bagi menjana alternatif-alternatif penambahbaikan tersebut menggantikan sistem manual yang digunakan sebelum ini. Hasil kajian menunjukkan tatarajah baharu sumber JK yang dibina berjaya menambah baik kecekapan sistem. Masa menunggu pesakit juga telah berjaya dikurangkan sebanyak 52%. Manakala peratusan penggunaan Doktor Zon Merah, Doktor Zon Hijau dan Jururawat Zon Kuning masing-masing telah berkurangan daripada 89% kepada 85%, 98% kepada 90% dan 91% kepada 89%. Kesimpulannya, penemuan dalam kajian ini telah menghasilkan masa menunggu pesakit dan peratusan penggunaan sumber yang lebih baik dan seterusnya meningkatkan tahap kecekapan JK. Semoga hospital ini akan menjadi penanda aras kepada hospital lain dalam meningkatkan kecekapan perkhidmatan mereka pada masa akan datang.

Kata kunci: jabatan kecemasan; kesesakan; masalah kecekapan; simulasi peristiwa diskret; analisis penyampulan data

1. Introduction

A major problem facing EDs around the world is overcrowding (Fatimah & Mona 2020; Ahmad *et al.* 2020). ED overcrowding can be described as an extremely busy situation in ED in which the ED is being forced to work beyond its capacity (Lowthian *et al.* 2010). Overcrowding is the product of a shortage of ED medical staff and an excessive number of patients in ED seeking medical treatment (Lowthian *et al.* 2010) especially among inappropriate ED users (Selasawati *et al.* 2004). Inappropriate ED users can be defined as ED patients who have been triaged as non-emergency cases and suffering minor problems such as mild headaches, mild fevers not more than three days, minor cuts, diarrhoea, or itching which can be treated in other primary health care services (Selasawati *et al.* 2004). Overcrowding can lead to multiple negative effects such as long waiting time (UK Department of Health 2021; Khairie 2019), patients leaving without treatment, high utilisation rate among medical staff, medical errors, poor patient outcomes, patient dissatisfaction, increased morbidity and increased mortality (Somma *et al.* 2015).

Several methods have been suggested to overcome ED overcrowding. A study suggested developing more government hospitals to cater for the increasing demand of healthcare services (Mohammed 2012). Some countries use triage patient away policy such as implementing ambulance diversion as a method to improve high demand of ED services. (Nahhas *et al.* 2017). Another approach that is frequently applied is to make intuitive decisions such as modifying the ED flow and the number of resources, especially during peak hours based on trial and error. These approaches should be studied closely since it is unreasonable and involves spending a huge amount of money (Nik *et al.* 2013).

Multiple studies have taken advantage of the power of the DES modelling technique to resolve ED overcrowding (Abbas *et al.* 2014; Ansah *et al.* 2021). DES has been used to solve the ED problem since it is a powerful technique that is capable for modelling a complex system like ED (Baesler *et al.* 2003). DES is the most economical method to test modifications without disturbing the operation of the real system (Brailsford *et al.* 2009). DES can also help researchers understand the operations of the ED in detail (Ahmad *et al.* 2012). By doing so, patient waiting time, patient throughput time, staff utilisation rate, the number of occupied beds and system bottlenecks, as well as causes of ED overcrowding, can be obtained. Consequently, various improvements can be proposed to increase the system's efficiency.

Researchers utilise the flexibility of the DES approach by integrating DES with other techniques such as DEA. In 1978, Charnes, Cooper and Rhodes introduced the basic DEA model, namely CCR. The CCR model applies linear programming technique to measure the efficiency of organisations called decision-making units (DMU) with multiple inputs and outputs (Charnes *et al.* 1978). The model calculates a DMU's efficiency by comparing it to a group of other DMUs that have the same set of inputs and outputs. Examples of DMU include hospitals and airplanes or their components such as jet engines. In research, using the CCR model alone as a method of optimisation is not enough (Ghasemi *et al.* 2015). The model fails to discriminate among efficient DMUs for choosing the best DMU (Ghasemi *et al.* 2015). It may occur that more than one DMU is calculated as efficient. Therefore, the model is used together with other approaches to improve the CCR's drawbacks.

In this study, a method integrating DES and DEA was designed to overcome ED overcrowding. An ED located in Kuala Lumpur suffering from frequent overcrowding was selected for study. This study aims to overcome the ED overcrowding by increasing the efficiency of the ED operations involving all ED patients by eliminating bottlenecks and reallocating the ED resources involving doctors, nurses and beds. The key elements of efficient ED service are having shorter patient waiting times in all ED areas and having an adequate resources utilisation rate (Jun *et al.* 1999; Shao *et al.* 2011). These two elements will be emphasised in this study for increasing the ED efficiency.

2. Data and Methodology

This study concentrates on minimising the waiting time of all patients inside the ED as well as improving the utilisation of the ED resources to increase the ED efficiency. The methodology that will be adopted to achieve the objectives is outlined in the following steps:

Step 1: Data collecting.
Step 2: Modelling the ED system.
Step 3: Identify the ED bottlenecks and proposing alternatives to resources allocation.
Step 4: Evaluating resources allocation alternatives using DEA.
Step 5: Comparing the results in step 4 with the current state.

Step 1 involves with data collection process at the ED. At the initial stage of Step 1, approval was obtained from the hospital's Research Ethics Committee to conduct this study. After obtaining permission, we started the data collection process by performing several visits to the ED and interviewing their staff. By doing so, it helped us to understand the operation system, and the process involved and required data for developing the ED model. After that, a comprehensive survey was carried out to collect data on the patients' arrival time, the number of patients in each triage zone, the doctors' final decisions for each patient and the service time at triage, registration desk and each treatment room. A special form was designed and used by the data collection team to fill in such data.

Step 2 is the development of the ED model by using DES method. Step 2 also involves performing verification test and validation test to the model to make sure that it is valid and represent the actual ED operation system. After modelling process, the next step (Step 3) is analysing the DES results to identify the system's bottlenecks. Besides, alternatives improvement will be recommended to enhance the bottlenecks.

In Step 4, every alternative is evaluated by measuring its efficiency using the DEA model. The DEA model that used are CCR model, Reference Set and Super Efficiency. Reference Set and Super Efficiency methods are used to improve the CCR drawbacks. Lastly, all efficient alternatives are compared to the current ED state to find the best (optimum) resources allocation alternative that able to improve ED overcrowding.

2.1. *Discrete event simulation*

2.1.1. *System description*

ED in Malaysian government hospitals can be classified into three colour triage zones, namely the Red Zone, Yellow Zone and Green Zone. The Red Zone is responsible for treating critical cases in which life is at stake, while the Yellow Zone is in charge of treating all semi-critical cases. Meanwhile, the Green Zone is used to treat all non-critical cases. Patients attending the ED undergo a triage process to determine the urgency of the cases. After the triage process, patients in the ED will be attended to by the treatment team at each zone, according to the target time mentioned in Table 1. The target time was taken from Saiboon *et al*. (2021) and Nora *et al*. (2011).

Table 1: Triage categorisation system and target time

Triage zone	Case	Target time
Red Zone	Critical (Resuscitation)	Immediate
Yellow Zone	Semi-critical (Emergency)	Within 30 minutes
Green Zone	Non-emergency	Within 3 hours

The current operation of the ED can be divided into three working shifts, namely the morning shift, evening shift and night shift. The morning shift starts at 0700 until 1400. Meanwhile, the evening and night shifts start at 1400 to 2100 and 2100 to 0700. Three nurses are allocated at the triage counter for every shift. The number of doctors and nurses allocated in each zone for every shift are mentioned in Appendix A (Please refer DMU1). All staff were working according to the shifts mentioned above, except for the Green Zone Doctors. Their working hours were based on Schedule 1(denoted by S1); one doctor worked from 0700 to1000, three doctors from 1000 to 1700, three doctors from 1700 to 2300, and two doctors from 2300 to 0700.

2.1.2. *Model design*

Figure 1 shows the flowchart of the development of simulation model applied in this study. The overall process of the ED had been modelled by a DES software, namely ARENA. After performed data collection process, ARENA Input Analyzer was used to fit the appropriate distribution of the data. Table 2 gives the distributions of the service times at each activity in the ED. For example, service time at registration follows a triangular distribution in an average of three minutes or a minimum and maximum time of two and five minutes respectively. The distributions obtained were included in modules in the ARENA. The modules were linked together and run between three to five replications to get the average and accurate results (Law & McComas 1991). An animation of the model was also developed for the purpose of verification checking on the next step.

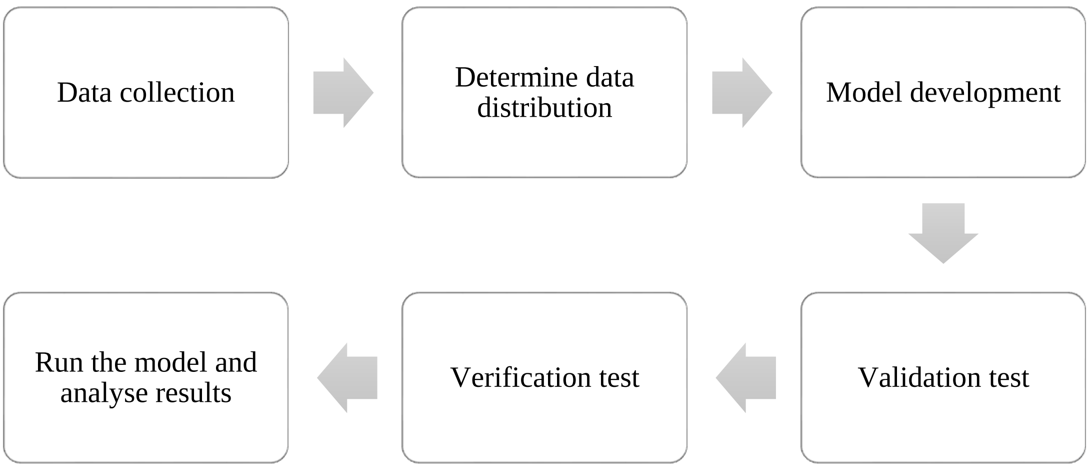

Figure 1: Steps to develop a simulation model

Table 2: Distributions of service time at each activity

Activity	Distribution
Patient Arrival	-0.5 + LOGN(7.98, 6.39)
Primary Triage	0.5 + GAMM(0.844, 1.89)
Secondary Triage	TRIA (5,10,20)
RedBox	0.5 + WEIB(8.09 , 1.46)
Registration	TRIA(2,3,5)
Red Zone Treatment Area	TRIA(510, 627, 1667)
Yellow Zone Treatment Area	UNIF(21, 553)
Green Zone Treatment Area	TRIA(10,17, 64)

2.1.3. *Model verification and validation*

After developed the ED simulation model, verification test and validation were conducted. Verification test can be defined as a process of ensuring that the ED model is correctly constructed according to the ED flow and free from any logical error (Kelton *et al.* 2010). Therefore, the ED model along with the animation was presented to the ED management and verified by them. Validation test is the process to make sure that the model imitated the real operations of the ED (Kelton *et al.* 2010). All the results were presented to the ED management, and they decided the validity of all the results. Moreover, we carried out another validation test to reinforce the validity of the model and provide additional confidence to the proposed ED model. We performed comparisons between the simulated and actual results based on the following mathematical formula suggested by Altiok and Melamed (2007):

$$Difference\ (\%) = \frac{|\,Simulation\ output - Actual\ data\,|}{Actual\ data} \times 100\%, \tag{1}$$

Based on the recommendation put forward by Carson (2002), the difference must be less than 10% to achieve the level of sufficient accuracy. Table 3 shows that all comparisons being done were less than 10%. Therefore, we concluded that the proposed ED model was valid and all results produced by the model are relevant to be used for conduct this study.

Table 3: Differences between simulated and actual data

Phase	Simulation output	Actual data	Difference (%)
Total arrival patients	1356	1400	3.0
Number of patients in Red Zone	49	51	4.0
Number of patients in Yellow Zone	429	438	2.0
Number of patients in Green Zone	875	892	2.0

2.1.4. *Design of alternatives to resources allocation*

Once the developed model was judged as valid, the model was run. Then, the DES outputs are analysed to identify the system bottlenecks. As mentioned before, the situation considered as bottlenecks is long waiting times among ED patients and inappropriate utilisation rate of ED resources. Several alternatives were designed to improve the bottlenecks. These alternatives to resource allocation contained new configurations of resources for the ED. This was done by reallocating the ED resources, for instance adding recourses at the appropriate location, reallocating the resources and rescheduling the existing staff timetable.

As mentioned by Gedmintas *et al.* (2010) and Rossetti *et al.* (2013), each staff at ED has different workloads depending on the number of patients treated and their condition. Staff who treated a high volume of patients daily will incur a greater workload. There was also a significant increase in staff workloads to see higher acuity patients rather than least severe patients in ED. These show that every staff at each triage zone area possess different utilisation rate and should be considered as a separate control variable. The control variables in this study are detailed as follow, Red Zone Doctor, Yellow Zone Doctor, Green Zone Doctor, Red Zone Nurse, Yellow Zone Nurse and Bed. The design of alternatives in this study was based on considering the above control variables. The present control variable can be considered as a contribution to studies of ED.

Modifications were not implemented for the Green Zone Nurse since only one nurse was allocated for every shift. We also did not make any changes during the night shift due to fewer attendants among the ED patients as revealed by (Wan Malissa *et al.* 2016). The quality management team at the ED was interested in finding an economical approach to increasing the ED efficiency. They would like to find the new configuration of the ED resources that achieved the above objectives by increasing their resources within their budgetary constraints. After discussion, they agreed to perform the ranges of changes in each variable as shown in Table 4. Schedule 2 and Schedule 3 were the new working schedules proposed in this study. Schedule 2 was denoted as S2 {three doctors work from 0700-1400, three doctors work 1400-2100 and two doctors work from 2100-0700} while Schedule 3 was denoted as S3 {four doctors work from 0700-1400, three doctors work from 1400-2100, and two doctors work from 2100-0700}.

Table 4: Range of changes for developing alternatives based on hospital budget

Variable	Current staff number	Possible range of change	
		Minimum	Maximum
Red Zone Doctor	1	1	2
Yellow Zone Doctor	2	2	3
Green Zone Doctor	Using Schedule 1	Schedule 1	Schedule 3
Red Zone Nurse	5	4	5
Yellow Zone Nurse	6	6	7
Bed	17	17	19
TOTAL	32	31	39

To ease the process of generating all possible resource allocation alternatives, a novel mathematical formula was developed. The total number of resource allocation alternatives that should be produced based on the above range of change was also able to be calculated from the equation. Thus, it can prevent the occurrence of missing alternative if the process of generating the alternatives was done manually as performed by other researchers. The equation formula is below:

$X_{r,y,g,i,f,h,e} \leq N$, where

$$r = a,..,R,\ y = b,..,Y,\ g = c,..,G,\ i = d,..,I,\ f = j,..,F,\ h = k,..,H,\ e = l,..,E, \quad (2)$$

r is the index for Red Zone Doctor, *y* is the index for Yellow Zone Doctor, *g* is the index for Green Zone Doctor Schedule, *i* is the index for Red Zone Nurse, *f* is the index for Yellow Zone Nurse, *h* is the index for Green Zone Nurse, *e* is the index for ED bed, *R* is the total number of Red Zone Doctor, *Y* is the total number of Yellow Zone Doctor, *G* is the total number Green Zone Doctor (for this study, it was considered as Schedule 1 until Schedule 3), *I* is the total number of Red Zone Nurses, *F* is the total number of Yellow Zone Nurses, *H* is the total number of Green Zone Nurses, *E* is the total number of ED beds and *N* is the maximum number of range of changes.

Based on the formula, 144 alternatives were obtained (refer to Appendix A) and solved using the LINGO software. Each resource allocation alternative is treated as a DMU starting from DMU1 representing alternative 1 until DMU144 representing alternative 144. DMU 1 contained the configuration number of ED resources in the current ED system. Meanwhile the configuration number of ED resources shown in the DMU2 until DMU 144 are proposed in this study. For instance, in DMU2 this study suggests to allocating only one Red Zone Doctor in every working shift and remain the similar number of ED staffs and beds at Yellow Zone and Green Zone as recent situation.

2.2. *Data envelopment analysis: the CCR model*

In this study, CCR model based on input-oriented version is used in order to calculate efficiency score for each DMU. The CCR model is expressed as:

$$\text{Max } \theta_0 = \sum_{j=1}^{m} u_j\, y_{j0}$$

Subject to

$$\sum_{i=1}^{s} v_i\, x_{i0} = 1$$

$$\sum_{j=1}^{m} u_j\, y_{jk} - \sum_{i=1}^{s} v_i\, x_{ik} \leq 0$$

$$v_i \geq 0,\ u_j \geq 0,\ u_0 \text{ free in sign}, \quad (3)$$

θ_0 is the efficiency score for DMU_0, x_{i0} is the input vector at DMU_0, y_{j0} is the output vector at DMU_0, x_{jk} is the value of input *i* used by DMU_k, y_{jk} is the value of output *j* used by DMU_k, *v* is the weight attached to inputs and *u* is the weight attached to outputs. DMU is considered as efficient if $\theta_0 = 1$.

The input and output used in the study, as well as value of input and output for all 144 DMUs, are displayed in Appendix B. In the table, the unit of waiting time patients at Yellow Zone, Green Zone and waiting for second assessment are in minutes. Meanwhile, utilisation of ED beds, nurses and doctors are represented by percentage (%) of beds, percentage (%) of nurse and percentage (%) of doctor.

The values shown in Appendix B are generated from the ED model by running each DMU to the model separately. DEA will operate more powerfully when the number of DMUs that were being used was larger than the value of the total number of inputs and outputs multiplied by two (Minwir 1999). Since the total number of DMUs used in this study exceeded the value, a better result will be provided

2.3. *Reference set*

Reference set was an efficient DMU that was being referred to by the inefficient DMU (Peng *et al.* 2021). It can be interpreted as a target level of operation of inputs and outputs that indicated how the inefficient DMU could be improved. In DEA, we can determine how many times each DMU was referred to by the inefficient DMUs. The more often the efficient DMU was referred to by the inefficient DMU, the higher the ranking of the efficient DMU in the list of reference set (Ang *et al.* 2019). Therefore, the DMU that has highest total number of reference sets will be rank in the first rank and be selected as the optimum DMU. In this study, the DEAP Software will be used to determine the reference set as it able to list down the reference set of each efficient DMU effectively. Besides, the software will also be used to calculate the efficiency score of each DMU.

2.4. *Super efficiency*

Super Efficiency is a technique used to rank the efficient DMUs. This technique modified the CCR model by eliminating constraints related to the DMU that was being calculated. This made the efficiency score for each efficient DMU greater than one ($\theta_0 > 1$), and thus the ranking for the DMU can be established (Bajec *et al.* 2021; Sojoodi *et al.* 2021). The efficient DMU that scored the highest value of θ_0 had been identified as the best alternative to be applied to the system. Lingo Software will be used to perform this task. The super efficiency model is as follow:

$$\varphi_0 = \min \sum_{i=1}^{m} v_{ik}\, x_{ij_0} - v_0$$

Subject to

$$\sum_{r=1}^{s} u_r\, y_{rj_0} = 1$$

$$\sum_{r=1}^{s} u_r\, y_{rj} - \sum_{i=1}^{m} v_{ik} x_{ij} + v_0 \leq 0$$

$$v_0 \text{ free}, u_r, v_i \geq \varepsilon, r = 1, \dots, s_i = 1, \dots, m_j = 1, \dots, n. \tag{4}$$

3. Results

As calculated according to the CCR model, 100 DMUs out of the 144 DMUs were efficient. Since more than one DMU was calculated as efficient, Reference Set and Super Efficiency were used to select the best DMU to be applied to the ED system to increase the ED efficiency.

Based on the reference set, the results give that DMU5 and DMU54 had the highest total number of reference sets which were 13. DMU5 are referred by DMU18, DMU19, DMU20, DMU23, DMU25, DMU27, DMU29, DMU30, DMU33, DMU34, DMU40, DMU44 and DMU45. Meanwhile, DMU54 are referred by DMU16, DMU24, DMU26, DMU41, DMU45, DMU56, DMU85, DMU87, DMU131, DMU139, DMU140, DMU142 and DMU143. This shows that DMU5 and DMU54 were the most suitable alternatives to be applied to the ED as recommended by the reference set technique.

DMU5 suggested adding a Yellow Zone Doctor and allocating only four nurses in the Red Zone while maintaining the number of resources in the other zone. DMU54 proposed allocating a doctor in the Red Zone, two doctors in the Yellow Zone and substitute S1 to S2 for the work schedule of the Green Zone Doctor. In terms or nurses, DMU54 mentioned that four nurses were enough to take care of Red Zone patients at every shift instead of the current five nurses. However, a nurse should be added to the Yellow Zone to improve the ED's efficiency.

The Super Efficiency method ranked DMU117 as the highest score followed by DMU97, DMU53 and DMU113 as shown in Table 5. DMU117 recommended adding a doctor, a nurse and an additional bed at the Yellow Zone Treatment Area. Furthermore, a new Green Zone's doctor working schedule as explained in S3 was suggested to replace the current schedule. The DMU also planned to allocate only four nurses to the Red Zone instead of five nurses. Therefore, based on the Super Efficiency method, DMU117 was selected to improve the efficiency level of the ED.

Table 5: Top 4 ranking

DMU	CCR Efficiency Score	Super-Efficient Score	Rank
117	1	1.45	1
97	1	1.13	2
53	1	1.10	3
113	1	1.08	4

Table 6 summarises the comparison results among the current ED situations (DMU1), DMU5, DMU54 and DMU117. The comparisons were made based on the waiting time and utilisation rate among ED staff. These two factors were emphasised in this study as they were the most important factors that influenced the change of efficiency level in healthcare. The question which then arose was which alternative or DMU should be chosen as the best resource allocation to be applied to the ED for improving its efficiency?

Referring to Table 6, DMU117 was more practical to be applied in the ED to improve their efficiency. Patient waiting times were reduced significantly in every part of the ED compared to other DMUs. The obvious reduction in DMU117 was notified in the Green Zone Treatment Area. The average waiting time in the zone was reduced by 58% compared to the average waiting time in the current system. Despite the obvious reduction that also occurred in DMU5, by applying the DMU, this will lead to an increase in the average waiting time of Yellow Zone patients up to 10 minutes.

Based on the utilisation rates among the ED resources, DMU5 can be considered an inappropriate alternative. By implementing the DMU, the utilisation rate of Yellow Zone Doctors will drop to 28% instead of 41%. In contrast, DMU54 and DMU117 were seen to be capable of enhancing the ED efficiency. The utilisation rate among Red Zone Doctors, Green Zone Doctors and Yellow Zone Nurses were reduced successfully. In addition, both DMUs were able to improve and sustain the utilisation rate of the other ED resources. However, as explained previously, DMU54 had failed to reduce the patients' waiting time. Such an error reduces the effectiveness of the DMU for improving the ED efficiency.

This analysis showed that DMU117 is the best alternative. DMU117 can help the ED management to solve all ED bottlenecks and enhanced ED efficiency. Indirectly, the chances of the ED overcrowding to occur frequently can be reduced effectively.

Table 6: Comparison results among DMU1, DMU5, DMU54 and DMU117

Items	DMU1	DMU5	DMU54	DMU117
Waiting Time (minute):				
• Yellow Zone	9.0	5.6	10.0	6.0
• Green Zone	129.7	121.8	66.0	54.3
• Re-assessment	137.2	123.6	65.3	48.3
Utilization (%):				
• Bed	66.0	68.0	66.0	68.0
• Red Zone Doctor	89.0	83.0	80.0	85.0
• Yellow Zone Doctor	41.0	28.0	47.0	49.0
• Green Zone Doctor	98.0	98.0	94.0	90.0
• Red Zone Nurse	18.0	21.0	20.0	18.0
• Yellow Zone Nurse	91.0	90.0	88.0	89.0

4. Discussion

This study focused on increasing the ED efficiency level by solving ED bottlenecks identified from the ED simulation model and proposing several resource allocation alternatives (DMU). In the final analysis, DMU117 was chosen as the best alternative. DMU117 achieved all the study's objectives by minimising waiting times of all patients as well as improving the utilisation rate of the ED resources.

A short waiting time among ED patients for getting treatment from ED staff will reduce patient length of stay in the ED system and avoid the patient's illness from worsening (Nathan & Dominim 2008). Besides a short waiting time, a sufficient resource utilisation rate provides a lot of positive implications for the ED management and services. Utilisation rate is an indicator of how well available resources are used. The sufficient utilisation rate shows that ED staff have been fully utilised and thus, prevent waste of labour and money (Zeinali *et al.* 2015). It also shows that the staff are not suffering from high levels of stress and anxiety due to enormous workload (Ansari *et al.* 2015). They have several periods to rest within each job and are competent to deliver quality medical services to patients.

The finding suggested by this study contrasts with other ED studies. Most of the alternatives proposed by other ED studies produced improvements in their ED by using a large additional number of staff (Jeenanunta *et al.* 2013). However, through this study, only a new doctor and a new bed should be hired by the ED management. A new Green Zone Doctor's working schedule suggested to replace the original schedule does not involve hiring new doctors into the system.

The new schedule has rearranged all nine Green Zone Doctors by allocating more doctors to work during morning and evening shifts. This is effective since those were the peak arrival times by almost all EDs in Malaysian hospitals (Selasawati *et al.* 2004; Wan Malissa *et al.* 2016). An additional nurse at the Yellow Zone which is recommended by DMU117 can also be carried out by replacing the nurse that has been relocated from the Red Zone to the Yellow Zone. By doing so, no additional nurses were hired by the ED management. These findings indicate that the ED will not be burdened by investing lots of money to enhance their efficiency.

An effective approach to managing ED overcrowding has been suggested in this study. Although the simulation model developed and the alternatives considered reflect a particular hospital's ED, it can be used as a diagnostic tool by other EDs and other healthcare providers. They can employ the procedure of creating a simulation model and the alternatives and use the DEA models for optimisation. The hybrid method can serve as a cost-effective method of exploring options to improve ED overcrowding at a time when costs serve as a severe constraint for all healthcare providers.

In addition, some believe that improving the performance of ED might lead to perverse outcomes such as increasing demand. More patients will come to ED once they identify that they will get faster treatment in ED. This increasing demand cannot be avoided as countries like Malaysia have a policy of not rejecting patients even though they attend the ED for non-emergency conditions (Azhar *et al.* 2000; Khairie 2019). Hence, continuous public awareness campaigns should be conducted by the hospital along with other organisations to offer explanations regarding the true functions of the ED and educate them about the different roles between an ED and other primary health clinics. Hopefully, such programs will be able to lead community members to head for the appropriate place whenever they need to get treatment in future.

The main limitation of this study is obtaining empirical data for simulation models. Although arrival patterns of patient and patient volume can be obtained from ED system database, service time of ED activities and ED resources can only be obtained through observation. Hannan *et al.* (1974) recommended to pay ED staff for collecting such data meanwhile Rossetti *et al.* (1999) used self-reported work sampling approaches to gather such data. Incorrect data collection will cause to inaccurate simulation results. As a result, it can lead to inaccurate decision making for improving ED. Moreover, it should be noted that this study did not consider variables outside the ED such as consultants and therapists. This is because the study only focuses on improving the operation inside the ED by eliminating the obvious bottlenecks in the system.

Besides, lack of standardisation such as patient flows across EDs, care practices, ED resources and triage categories make it hard to design a generic model of an ED for use in a simulation. Sinreich and Marmor (2004) try to develop a generic ED model by classified EDs into two factors namely ED physician type and patients' condition. However, the classification done by them may not be sufficient. Due to that, most simulation studies had to create their own ED models, which in turn lead to ED specific solutions that could not be generalised to other EDs.

5. Conclusion

This study was an optimisation resource allocation research for the ED. This study was carried out by the researchers due to the overcrowding issues that occur regularly in the ED as reported by the Ministry of Health. This study overcomes the hospital bottlenecks successfully by allocating a new configuration number of the ED resources based on the agreed budget by the hospital management. This was important to ensure that the number of staff was sufficient to treat all patients quietly and efficiently, especially during peak hours. As a result, the patient waiting time can be reduced. The ED staff will also not be burdened with heavy workloads. Therefore, the ED will operate smoothly offering excellent quality healthcare services to all patients

For future work, we plan to perform a further investigation into the input and output factors used in the DEA model. We plan to include the cost of each alternative as the input factor of the model. Additionally, other DEA models will be used for choosing the most efficient resources allocation alternative. By doing so, this may provide hospital management with a relatively fast method to determine which resource allocation alternative performs better with minimum cost.

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Appendix A. List of 144 alternatives generated by the mathematical equation formula

DMUs	DR Red	DR Yellow	DR Green	Nurse Red	Nurse Yellow	Bed	DMUs	DR Red	DR Yellow	DR Green	Nurse Red	Nurse Yellow	Bed
1	(1[a],1[b],1[c])	(2,2,2)	S1	(5,5,5)	(6,6,4)	17	73	(1,1,1)	(3,3,2)	S2	(5,5,5)	(7,7,4)	18
2	(2,2,1)	(2,2,2)	S1	(5,5,5)	(6,6,4)	17	74	(2,2,1)	(2,2,2)	S2	(4,4,4)	(7,7,4)	18
3	(1,1,1)	(3,3,2)	S1	(5,5,5)	(6,6,4)	17	75	(2,2,1)	(3,3,2)	S2	(4,4,4)	(7,7,4)	18
4	(2,2,1)	(3,3,2)	S1	(5,5,5)	(6,6,4)	17	76	(2,2,1)	(3,3,2)	S2	(5,5,5)	(7,7,4)	18
5	(1,1,1)	(3,3,2)	S1	(4,4,4)	(6,6,4)	17	77	(1,1,1)	(2,2,2)	S2	(5,5,5)	(6,6,4)	19
6	(1,1,1)	(2,2,2)	S1	(4,4,4)	(6,6,4)	17	78	(2,2,1)	(2,2,2)	S2	(5,5,5)	(6,6,4)	19
7	(2,2,1)	(2,2,2)	S1	(4,4,4)	(6,6,4)	17	79	(1,1,1)	(3,3,2)	S2	(5,5,5)	(6,6,4)	19
8	(2,2,1)	(3,3,2)	S1	(4,4,4)	(6,6,4)	17	80	(2,2,1)	(3,3,2)	S2	(5,5,5)	(6,6,4)	19
9	(1,1,1)	(2,2,2)	S1	(4,4,4)	(7,7,4)	17	81	(1,1,1)	(3,3,2)	S2	(4,4,4)	(6,6,4)	19
10	(1,1,1)	(3,3,2)	S1	(4,4,4)	(7,7,4)	17	82	(1,1,1)	(2,2,2)	S2	(4,4,4)	(6,6,4)	19
11	(1,1,1)	(2,2,2)	S1	(5,5,5)	(7,7,4)	17	83	(2,2,1)	(2,2,2)	S2	(4,4,4)	(6,6,4)	19
12	(1,1,1)	(3,3,2)	S1	(5,5,5)	(7,7,4)	17	84	(2,2,1)	(3,3,2)	S2	(4,4,4)	(6,6,4)	19
13	(2,2,1)	(2,2,2)	S1	(4,4,4)	(7,7,4)	17	85	(1,1,1)	(2,2,2)	S2	(4,4,4)	(7,7,4)	19
14	(2,2,2)	(3,3,2)	S1	(4,4,4)	(7,7,4)	17	86	(1,1,1)	(3,3,2)	S2	(4,4,4)	(7,7,4)	19
15	(2,2,1)	(3,3,2)	S1	(5,5,5)	(7,7,4)	17	87	(1,1,1)	(2,2,2)	S2	(5,5,5)	(7,7,4)	19
16	(1,1,1)	(2,2,2)	S1	(5,5,5)	(6,6,4)	18	88	(1,1,1)	(3,3,2)	S2	(5,5,5)	(7,7,4)	19
17	(2,2,1)	(2,2,2)	S1	(5,5,5)	(6,6,4)	18	89	(2,2,1)	(2,2,2)	S2	(4,4,4)	(7,7,4)	19
18	(1,1,1)	(3,3,2)	S1	(5,5,5)	(6,6,4)	18	90	(2,2,1)	(3,3,2)	S2	(4,4,4)	(7,7,4)	19
19	(2,2,1)	(3,3,2)	S1	(5,5,5)	(6,6,4)	18	91	(2,2,1)	(3,3,2)	S2	(5,5,5)	(7,7,4)	19
20	(1,1,1)	(3,3,2)	S1	(4,4,4)	(6,6,4)	18	92	(1,1,1)	(2,2,2)	S3	(5,5,5)	(6,6,4)	17
21	(1,1,1)	(2,2,2)	S1	(4,4,4)	(6,6,4)	18	93	(2,2,1)	(2,2,2)	S3	(5,5,5)	(6,6,4)	17
22	(2,2,1)	(2,2,2)	S1	(4,4,4)	(6,6,4)	18	94	(1,1,1)	(3,3,2)	S3	(5,5,5)	(6,6,4)	17
23	(2,2,1)	(3,3,2)	S1	(4,4,4)	(6,6,4)	18	95	(2,2,1)	(3,3,2)	S3	(5,5,5)	(6,6,4)	17
24	(2,2,1)	(3,3,2)	S1	(4,4,4)	(6,6,4)	18	96	(1,1,1)	(3,3,2)	S3	(4,4,4)	(6,6,4)	17
25	(1,1,1)	(2,2,2)	S1	(4,4,4)	(7,7,4)	18	97	(1,1,1)	(2,2,2)	S3	(4,4,4)	(6,6,4)	17
26	(1,1,1)	(3,3,2)	S1	(4,4,4)	(7,7,4)	18	98	(2,2,1)	(2,2,2)	S3	(4,4,4)	(6,6,4)	17
27	(1,1,1)	(2,2,2)	S1	(5,5,5)	(7,7,4)	18	99	(2,2,1)	(3,3,2)	S3	(4,4,4)	(6,6,4)	17
28	(1,1,1)	(3,3,2)	S1	(5,5,5)	(7,7,4)	18	100	(1,1,1)	(2,2,2)	S3	(4,4,4)	(7,7,4)	17
29	(2,2,2)	(2,2,2)	S1	(4,4,4)	(7,7,4)	18	101	(1,1,1)	(3,3,2)	S3	(4,4,4)	(7,7,4)	17
30	(2,2,1)	(3,3,2)	S1	(4,4,4)	(7,7,4)	18	102	(1,1,1)	(2,2,2)	S3	(5,5,5)	(7,7,4)	17
31	(2,2,1)	(3,3,2)	S1	(5,5,5)	(7,7,4)	18	103	(1,1,1)	(3,3,2)	S3	(5,5,5)	(7,7,4)	17
32	(1,1,1)	(2,2,2)	S1	(5,5,5)	(6,6,4)	19	104	(2,2,1)	(2,2,2)	S3	(4,4,4)	(7,7,4)	17
33	(2,2,1)	(2,2,2)	S1	(5,5,5)	(6,6,4)	19	105	(2,2,2)	(3,3,2)	S3	(4,4,4)	(7,7,4)	17
34	(1,1,1)	(3,3,2)	S1	(5,5,5)	(6,6,4)	19	106	(2,2,1)	(3,3,2)	S3	(5,5,5)	(7,7,4)	17
35	(2,2,1)	(3,3,2)	S1	(5,5,5)	(6,6,4)	19	107	(1,1,1)	(2,2,2)	S3	(5,5,5)	(6,6,4)	18

Appendix A (*continuation…*)

36	(1,1,1)	(3,3,2)	S1	(4,4,4)	(6,6,4)	19	108	(2,2,1)	(2,2,2)	S3	(5,5,5)	(6,6,4)	18
37	(1,1,1)	(2,2,2)	S1	(4,4,4)	(6,6,4)	19	109	(1,1,1)	(3,3,2)	S3	(5,5,5)	(6,6,4)	18
38	(2,2,1)	(2,2,2)	S1	(4,4,4)	(6,6,4)	19	110	(2,2,1)	(3,3,2)	S3	(5,5,5)	(6,6,4)	18
39	(2,2,1)	(3,3,2)	S1	(4,4,4)	(6,6,4)	19	111	(1,1,1)	(3,3,2)	S3	(4,4,4)	(6,6,4)	18
40	(1,1,1)	(2,2,2)	S1	(4,4,4)	(7,7,4)	19	112	(1,1,1)	(2,2,2)	S3	(4,4,4)	(6,6,4)	18
41	(1,1,1)	(3,3,2)	S1	(4,4,4)	(7,7,4)	19	113	(2,2,1)	(2,2,2)	S3	(4,4,4)	(6,6,4)	18
42	(1,1,1)	(2,2,2)	S1	(5,5,5)	(7,7,4)	19	114	(2,2,1)	(3,3,2)	S3	(4,4,4)	(6,6,4)	18
43	(1,1,1)	(3,3,2)	S1	(5,5,5)	(7,7,4)	19	115	(1,1,1)	(2,2,2)	S3	(4,4,4)	(7,7,4)	18
44	(2,2,1)	(2,2,2)	S1	(4,4,4)	(7,7,4)	19	116	(1,1,1)	(3,3,2)	S3	(4,4,4)	(7,7,4)	18
45	(2,2,1)	(3,3,2)	S1	(4,4,4)	(7,7,4)	19	117	(1,1,1)	(3,3,3)	S3	(4,4,4)	(7,7,4)	18
46	(2,2,1)	(3,3,2)	S1	(5,5,5)	(7,7,4)	19	118	(1,1,1)	(3,3,2)	S3	(5,5,5)	(7,7,4)	18
47	(1,1,1)	(2,2,2)	S2	(5,5,5)	(6,6,4)	17	119	(2,2,2)	(2,2,2)	S3	(4,4,4)	(7,7,4)	18
48	(2,2,1)	(2,2,2)	S2	(5,5,5)	(6,6,4)	17	120	(2,2,1)	(3,3,2)	S3	(4,4,4)	(7,7,4)	18
49	(1,1,1)	(3,3,2)	S2	(5,5,5)	(6,6,4)	17	121	(2,2,1)	(3,3,2)	S3	(5,5,5)	(7,7,4)	18
50	(2,2,1)	(3,3,2)	S2	(5,5,5)	(6,6,4)	17	122	(1,1,1)	(2,2,2)	S3	(5,5,5)	(6,6,4)	19
51	(1,1,1)	(3,3,2)	S2	(4,4,4)	(6,6,4)	17	123	(2,2,1)	(2,2,2)	S3	(5,5,5)	(6,6,4)	19
52	(1,1,1)	(2,2,2)	S2	(4,4,4)	(6,6,4)	17	124	(1,1,1)	(3,3,2)	S3	(5,5,5)	(6,6,4)	19
53	(2,2,1)	(2,2,2)	S2	(4,4,4)	(6,6,4)	17	125	(2,2,1)	(3,3,2)	S3	(5,5,5)	(6,6,4)	19
54	(2,2,1)	(3,3,2)	S2	(4,4,4)	(6,6,4)	17	126	(1,1,1)	(3,3,2)	S3	(4,4,4)	(6,6,4)	19
55	(1,1,1)	(2,2,2)	S2	(4,4,4)	(7,7,4)	17	127	(1,1,1)	(2,2,2)	S3	(4,4,4)	(6,6,4)	19
56	(1,1,1)	(3,3,2)	S2	(4,4,4)	(7,7,4)	17	128	(2,2,1)	(2,2,2)	S3	(4,4,4)	(6,6,4)	19
57	(1,1,1)	(2,2,2)	S2	(5,5,5)	(7,7,4)	17	129	(2,2,1)	(3,3,2)	S3	(4,4,4)	(6,6,4)	19
58	(1,1,1)	(3,3,2)	S2	(5,5,5)	(7,7,4)	17	130	(1,1,1)	(2,2,2)	S3	(4,4,4)	(7,7,4)	19
59	(2,2,1)	(2,2,2)	S2	(4,4,4)	(7,7,4)	17	131	(1,1,1)	(3,3,2)	S3	(4,4,4)	(7,7,4)	19
60	(2,2,1)	(3,3,2)	S2	(4,4,4)	(7,7,4)	17	132	(1,1,1)	(2,2,2)	S3	(5,5,5)	(7,7,4)	19
61	(2,2,1)	(3,3,2)	S2	(5,5,5)	(7,7,4)	17	133	(1,1,1)	(3,3,2)	S3	(5,5,5)	(7,7,4)	19
62	(1,1,1)	(2,2,2)	S2	(5,5,5)	(6,6,4)	18	134	(2,2,1)	(2,2,2)	S3	(4,4,4)	(7,7,4)	19
63	(2,2,1)	(2,2,2)	S2	(5,5,5)	(6,6,4)	18	135	(2,2,1)	(3,3,2)	S3	(4,4,4)	(7,7,4)	19
64	(1,1,1)	(3,3,2)	S2	(5,5,5)	(6,6,4)	18	136	(2,2,1)	(2,2,2)	S1	(5,5,5)	(7,7,4)	17
65	(2,2,1)	(3,3,2)	S2	(5,5,5)	(6,6,4)	18	137	(2,2,1)	(2,2,2)	S2	(5,5,5)	(7,7,4)	17
66	(1,1,1)	(3,3,2)	S2	(4,4,4)	(6,6,4)	18	138	(2,2,1)	(2,2,2)	S3	(5,5,5)	(7,7,4)	17
67	(1,1,1)	(2,2,2)	S2	(4,4,4)	(6,6,4)	18	139	(2,2,1)	(2,2,2)	S1	(5,5,5)	(7,7,4)	18
68	(2,2,1)	(2,2,2)	S2	(4,4,4)	(6,6,4)	18	140	(2,2,1)	(2,2,2)	S2	(5,5,5)	(7,7,4)	18
69	(2,2,1)	(3,3,2)	S2	(4,4,4)	(6,6,4)	18	141	(2,2,1)	(2,2,2)	S3	(5,5,5)	(7,7,4)	18
70	(1,1,1)	(2,2,2)	S2	(4,4,4)	(7,7,4)	18	142	(2,2,1)	(2,2,2)	S1	(5,5,5)	(7,7,4)	19
71	(1,1,1)	(3,3,2)	S2	(4,4,4)	(7,7,4)	18	143	(2,2,1)	(2,2,2)	S2	(5,5,5)	(7,7,4)	19
72	(1,1,1)	(2,2,2)	S2	(5,5,5)	(7,7,4)	18	144	(2,2,1)	(2,2,2)	S3	(5,5,5)	(7,7,4)	19

[a] shift 0700 am to 1400 pm, [b]shift 1400 pm to 2100 pm, [c]shift 2100 pm to 0700 am

Appendix B. Input and output values

	Input, x_i						Output, y_i						
				Waiting Time				% Doctor			% Nurse		
DMU	No. of Bed	No. of Doctor	No. of Nurse	Yellow Zone	Green Zone	Second assessment by doctor	% Bed	Red Zone	Yellow Zone	Green Zone	Red Zone	Yellow Zone	No. of Served Patient
1	17	12	12	9.3	129.7	137.2	66.0	89.3	41.3	98.2	18.0	91.0	120
2	17	13	12	9.8	103.0	105.8	68.7	81.4	41.5	97.8	28.6	90.2	124
3	17	13	12	5.6	121.8	123.7	67.0	83.0	27.9	98.3	16.8	90.8	123
4	17	14	12	6.1	114.4	116.7	68.7	76.5	27.5	98.0	25.1	90.2	124
5	17	13	11	5.6	121.8	123.6	66.9	83.0	27.7	98.3	20.6	90.8	123
6	17	12	11	9.2	129.7	137.2	66.1	89.0	41.3	98.2	22.4	90.5	120
7	17	13	11	9.0	103.0	105.8	68.6	81.4	41.6	97.8	35.6	90.1	124
8	17	14	11	6.1	114.4	116.7	68.8	76.5	27.5	98.0	31.4	90.2	124
9	17	12	12	11.3	129.5	140.5	66.1	87.3	47.0	98.0	21.7	88.9	127
10	17	13	12	6.4	119.9	125.1	67.2	87.2	32.0	97.8	21.6	89.6	126
11	17	12	13	11.3	129.5	140.5	66.1	87.3	47.2	98.1	17.3	89.0	127
12	17	13	13	6.4	119.9	125.1	67.0	87.2	32.0	97.8	17.3	89.7	126
13	17	13	12	13.0	116.8	123.5	68.4	78.9	47.2	98.3	32.2	88.5	128
14	17	14	12	7.0	132.6	132.0	68.2	76.3	32.0	98.3	31.6	88.8	127
15	17	14	13	7.0	132.6	132.0	68.2	76.3	32.0	98.3	25.4	88.9	127
16	18	12	12	9.9	121.0	126.2	66.1	89.3	44.8	97.4	17.7	90.5	123
17	18	13	12	10.3	107.1	105.7	69.1	77.3	43.0	98.3	25.6	89.9	123
18	18	13	12	6.3	118.5	121.5	66.8	78.4	30.1	97.7	15.4	90.7	123
19	18	14	12	6.8	114.8	117.7	68.6	72.6	28.5	96.8	23.7	90.2	121
20	18	13	11	6.3	118.5	121.5	66.8	78.4	30.2	97.7	19.3	90.7	123
21	18	12	11	9.9	121.0	126.2	66.1	89.3	44.8	97.4	22.2	90.3	123
22	18	13	11	10.2	107.1	105.7	69.1	77.3	43.0	98.3	32.0	90.0	123
23	18	14	11	6.7	114.8	117.7	68.6	72.6	28.1	96.8	29.6	90.2	121
24	18	12	12	11.2	129.2	143.5	65.9	80.2	46.9	98.3	19.8	89.0	125
25	18	13	12	7.4	129.7	133.2	66.8	86.9	32.0	98.3	21.4	89.6	124
26	18	12	13	11.2	129.2	143.5	65.9	80.2	46.9	98.3	15.8	89.0	125
27	18	13	13	7.4	129.9	133.2	66.6	86.9	31.6	98.3	17.1	89.6	124
28	18	13	12	12.0	113.3	115.7	67.5	72.6	47.0	97.8	30.0	88.5	128
29	18	14	12	7.8	134.3	135.5	67.3	76.4	30.7	97.8	30.9	88.6	124
30	18	14	13	7.8	134.3	135.3	67.3	76.4	31.3	97.8	24.8	88.6	124
31	19	12	12	11.1	128.0	139.8	65.7	89.3	45.2	97.4	17.6	90.3	126

Appendix B (... *continuation*)

32	19	13	12	11.3	102.5	101.5	69.1	77.6	44.1	97.3	26.7	89.9	125
33	19	13	12	6.7	121.2	126.3	67.3	84.1	31.9	98.3	16.6	90.7	126
34	19	14	12	6.7	120.3	123.7	68.7	75.3	30.7	98.3	24.5	90.2	125
35	19	13	11	6.7	121.2	126.3	67.3	84.1	31.9	98.3	21.7	90.7	126
36	19	12	11	11.1	128.0	139.8	65.7	89.3	44.9	97.4	22.1	90.3	125
37	19	13	11	11.3	102.5	101.5	69.1	77.6	44.1	97.3	33.5	89.9	124
38	19	14	11	6.7	124.4	126.9	68.4	74.8	30.9	98.3	29.8	90.2	125
39	19	12	12	12.5	141.7	151.4	66.2	88.0	50.8	98.0	21.9	89.0	127
40	19	13	12	8.1	118.2	125.0	67.1	84.5	31.7	97.5	21.0	89.6	123
41	19	12	13	12.5	141.7	151.4	66.1	88.0	50.8	98.3	17.5	89.0	127
42	19	13	13	8.1	118.2	125.0	67.1	84.5	31.7	97.5	16.8	89.6	123
43	19	13	12	12.3	133.3	141.0	68.1	80.8	48.8	98.3	32.9	88.3	126
44	19	14	12	8.9	125.1	135.0	66.9	75.5	32.7	97.7	31.9	88.6	126
45	19	14	13	8.9	125.1	135.0	66.7	75.5	32.7	97.7	25.4	88.6	126
46	17	11	12	9.5	71.7	71.8	66.7	86.4	41.6	94.1	17.3	89.7	123
47	17	12	12	9.4	64.8	64.2	68.8	80.2	41.5	95.4	26.2	89.5	125
48	17	12	12	6.0	75.6	75.9	66.1	81.4	28.4	94.0	16.1	90.3	121
49	17	13	12	5.7	79.9	74.1	68.9	74.7	27.7	93.4	25.2	90.0	123
50	17	12	11	6.3	75.6	75.9	66.1	81.4	28.4	94.0	20.2	90.3	121
51	17	11	11	9.5	71.7	71.8	66.4	86.4	41.6	94.1	21.2	89.6	122
52	17	12	11	9.0	63.4	63.3	69.1	80.0	42.0	94.2	32.3	89.6	125
53	17	13	11	5.5	82.0	75.4	69.1	74.3	27.5	93.7	31.2	90.5	121
54	17	11	12	10.6	66.0	65.3	65.7	79.5	47.3	94.1	19.0	88.4	128
55	17	12	12	6.3	73.8	71.9	66.5	86.5	31.5	93.4	21.7	89.3	126
56	17	11	13	10.6	66.0	65.3	65.6	79.5	47.3	94.1	15.4	88.4	128
57	17	12	13	6.3	73.8	71.9	66.5	86.5	31.5	93.4	17.2	89.3	126
58	17	12	12	10.7	64.7	67.0	68.1	74.5	46.3	94.4	30.0	88.3	129
59	17	13	12	6.9	73.3	74.6	69.5	80.0	30.4	91.2	33.8	89.1	122
60	17	13	13	6.8	71.8	71.3	68.9	80.9	31.3	91.4	27.3	88.9	123
61	18	11	12	12.0	67.0	62.3	67.2	86.4	44.5	94.1	17.3	89.7	124
62	18	12	12	11.4	54.8	56.4	69.5	79.2	43.4	93.9	25.5	89.6	125
63	18	12	12	6.6	68.1	65.5	66.6	86.0	29.6	93.2	17.2	90.5	123
64	18	13	12	6.0	61.0	59.5	70.0	80.2	29.2	93.1	28.4	90.2	122
65	18	12	11	6.6	68.1	65.5	66.6	86.0	29.8	93.2	21.5	90.5	123
66	18	11	11	12.0	67.0	62.3	67.2	86.4	44.5	94.1	21.6	89.8	124
67	18	12	11	12.2	57.5	62.1	69.0	76.5	43.7	93.5	30.4	89.8	123
68	18	13	11	6.2	62.8	61.6	70.2	79.5	29.0	93.8	34.6	90.5	122

Appendix B (... *continuation*)

69	18	11	12	9.8	80.6	77.4	66.0	78.4	46.1	94.1	19.6	88.5	125
70	18	12	12	6.7	67.6	61.9	66.9	86.9	31.4	94.6	21.7	89.5	125
71	18	11	13	9.8	80.6	77.4	66.0	78.4	46.1	94.1	15.7	88.5	125
72	18	12	13	6.7	67.6	61.9	66.9	86.9	31.5	94.6	17.4	89.5	125
73	18	12	12	11.6	58.7	57.2	68.5	73.5	46.1	91.6	29.5	88.5	122
74	18	13	12	6.6	64.5	65.6	70.1	80.7	33.2	94.0	36.2	89.4	130
75	18	13	13	6.5	73.0	71.3	69.5	81.3	33.2	94.3	29.0	89.0	130
76	19	11	12	12.3	57.1	51.4	67.4	85.7	45.9	93.3	17.2	89.8	123
77	19	12	12	12.2	70.3	69.3	68.7	78.0	45.3	93.6	25.5	89.6	124
78	19	12	12	7.0	74.0	72.1	66.5	85.5	29.8	93.2	17.1	90.5	122
79	19	13	12	6.6	73.6	72.4	69.3	75.1	30.0	93.8	25.8	90.2	123
80	19	12	11	7.0	74.0	72.1	66.5	85.5	29.8	93.2	21.4	90.5	122
81	19	11	11	12.3	57.1	51.4	67.4	85.7	45.9	93.3	21.5	89.6	123
82	19	12	11	13.5	70.4	69.8	68.9	76.7	45.5	93.4	31.0	89.8	122
83	19	13	11	6.0	74.3	70.5	69.4	74.1	29.2	94.0	30.7	90.5	120
84	19	11	12	11.2	71.8	62.1	66.1	80.4	48.1	93.3	20.1	88.5	125
85	19	12	12	7.7	65.8	68.0	66.9	86.5	33.0	93.4	21.7	89.5	126
86	19	11	13	11.2	71.8	62.1	66.1	80.4	48.1	93.3	16.1	88.5	125
87	19	12	13	7.7	65.8	68.0	66.9	86.5	33.0	93.4	17.3	89.5	126
88	19	12	12	11.9	77.7	81.9	68.5	74.5	47.3	93.1	29.7	88.5	123
89	19	13	12	6.9	67.4	63.0	70.1	82.1	33.7	93.2	36.9	89.4	125
90	19	13	13	6.8	72.1	66.5	69.6	82.7	33.6	93.4	29.8	89.0	126
91	17	12	12	13.1	51.6	48.3	67.8	88.5	41.8	88.5	17.7	90.4	125
92	17	13	12	12.9	54.9	52.1	71.4	81.9	40.8	90.4	30.6	90.1	126
93	17	13	12	7.1	52.4	44.7	67.7	82.0	30.2	87.3	16.4	90.7	124
94	17	14	12	6.8	50.9	42.9	70.8	73.4	28.3	87.5	31.4	90.4	124
95	17	13	11	7.1	52.4	44.7	67.7	82.0	30.2	87.3	20.5	90.7	124
96	17	12	11	13.1	51.6	48.3	67.8	88.5	41.8	88.5	22.1	90.4	125
97	17	13	11	12.5	52.9	51.5	71.6	81.8	40.8	89.6	37.4	90.5	125
98	17	14	11	6.7	52.3	43.1	69.7	71.5	28.4	87.7	30.4	90.8	124
99	17	12	12	13.4	46.9	38.7	68.0	86.3	45.9	87.8	21.7	89.4	128
100	17	13	12	7.3	55.6	54.2	68.1	86.2	31.0	90.5	21.6	89.8	129
101	17	12	13	13.4	46.9	38.7	68.0	86.3	45.9	87.8	17.2	89.4	128
102	17	13	13	7.3	55.6	54.2	62.7	86.2	31.0	90.5	17.3	89.8	129
103	17	13	12	13.7	55.8	50.1	70.2	76.0	47.9	89.4	32.7	89.4	132
104	17	14	12	8.8	59.7	54.8	70.3	74.7	31.1	88.5	31.8	89.8	126

Appendix B (... *continuation*)

105	17	14	13	8.2	56.8	51.0	70.1	76.6	30.5	88.6	26.1	89.3	126
106	18	12	12	13.5	48.8	45.0	67.6	84.6	44.6	88.7	16.9	90.4	128
107	18	13	12	14.4	50.9	46.3	71.3	78.5	45.0	88.5	29.4	90.1	127
108	18	13	12	6.7	52.9	48.1	68.2	83.3	29.4	88.4	16.7	90.7	124
109	18	14	12	7.5	50.5	40.5	70.3	75.2	27.8	88.3	27.3	90.4	123
110	18	13	11	6.7	52.9	48.1	68.2	83.3	29.4	88.4	20.8	90.7	124
111	18	12	11	13.5	48.8	45.0	67.6	84.6	44.6	88.7	21.1	90.4	128
112	18	13	11	14.0	53.5	49.3	71.3	77.8	43.8	87.8	34.9	90.5	126
113	18	14	11	6.8	46.6	39.4	70.2	72.5	28.8	88.0	32.0	90.8	124
114	18	12	12	14.2	53.0	46.9	68.0	88.3	48.3	86.7	22.1	89.4	128
115	18	13	12	6.6	54.3	48.3	68.4	85.3	32.9	90.0	21.3	89.8	129
116	18	12	13	14.2	53.0	46.9	68.0	88.3	48.3	86.7	17.7	89.4	128
117	18	13	13	7.0	54.3	48.3	68.4	85.3	49.4	90.0	17.1	90.0	129
118	18	13	12	13.2	49.2	47.1	70.6	78.5	47.5	88.4	33.2	89.4	128
119	18	14	12	7.0	47.4	50.3	70.5	73.3	32.1	88.3	31.1	89.8	127
120	18	14	13	7.0	45.1	49.3	70.6	76.1	31.6	88.7	26.9	89.3	128
121	19	12	12	12.7	48.8	50.3	68.2	86.3	43.6	88.6	17.3	90.4	125
122	19	13	12	16.2	57.2	55.7	71.1	77.8	44.2	88.6	28.3	90.1	125
123	19	13	12	7.4	52.9	53.7	68.2	86.1	29.8	86.6	17.2	90.7	121
124	19	14	12	7.4	51.8	52.4	70.2	77.2	30.2	87.0	27.7	90.4	123
125	19	13	11	7.4	52.9	53.7	63.7	86.1	29.8	86.6	21.5	90.7	121
126	19	12	11	12.7	48.8	50.3	68.2	86.3	43.6	88.6	21.6	90.4	125
127	19	13	11	14.9	58.5	56.3	71.4	77.5	44.0	88.1	34.5	90.5	124
128	19	14	11	7.3	53.5	52.0	70.3	75.1	30.2	86.7	32.8	90.8	122
129	19	12	12	16.4	64.7	66.5	68.3	86.4	48.7	87.2	21.6	89.4	124
130	19	13	12	6.3	51.6	42.3	68.2	86.1	32.6	90.4	21.5	89.8	131
131	19	12	13	16.4	64.7	66.5	68.3	86.4	48.7	87.2	17.3	89.4	124
132	19	13	13	6.3	51.6	42.3	68.2	86.1	32.6	90.4	17.2	89.8	131
133	19	13	12	16.9	46.3	50.0	70.3	77.9	48.6	88.2	33.0	89.4	129
134	19	14	12	7.6	49.5	41.7	71.3	78.8	32.1	89.1	33.7	89.8	127
135	19	14	13	7.6	49.5	40.4	71.4	81.2	31.7	89.0	29.2	89.3	127
136	17	13	13	13.0	116.8	123.5	68.5	78.9	47.2	98.3	26.0	88.7	128
137	17	12	13	9.0	67.8	70.1	68.1	74.7	46.3	95.0	24.1	88.4	129
138	17	13	13	13.5	49.9	46.5	70.1	77.2	47.5	88.6	27.4	88.9	132
139	18	13	13	12.0	113.3	115.7	67.8	72.6	47.0	97.8	23.4	88.7	128
140	18	12	13	10.0	62.0	60.3	68.0	73.8	45.6	92.6	23.8	88.2	123

Appendix B (… *continuation*)

141	18	13	13	14.0	48.8	44.5	70.7	78.7	47.2	88.2	28.5	88.9	128
142	19	13	13	12.3	133.3	141.0	68.3	80.8	48.8	98.3	26.4	88.7	126
143	19	12	13	11.4	75.3	80.0	68.0	74.8	47.8	93.8	24.0	88.2	125
144	19	13	13	17.0	49.2	51.2	70.5	79.7	49.0	88.0	28.3	88.9	129

% utilisation of