World Review of Business Research
Vol. 3. No. 1. January 2013 Issue. Pp. 174 – 188

Employee Absenteeism and Group Performance – A Markov Chain Model

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This paper presents application and validation of a Markov chain for modelling the relationship between staffing levels and performance of a workgroup while incorporating absenteeism. Three performance indicators examined in the present study are the probability of carrying out work, the availability of workers, and the group utilisation. Experiments were conducted to validate the model. Results from the present study indicate that the proposed Markov chain model can be used to measure quantitatively the staffing levels – performance relationship while including employee absenteeism. The paper also provides a practical tool for managers in modelling and analysing performance of a group. However, the present research is limited to types of work with constant arrival rates and to situations where work is lost if not begun immediately on arrival. Another constraint of the model is that only one staff can become absent at a time.

Keywords: Organisation performance, System reliability, Markov chains, Staffing level – performance relationship, Absenteeism.

Field of Research: Management

1. Introduction

Employee absenteeism is a common problem for a work group. Workers may be absent for a variety of reasons including illness and vacations. If one or more workers are absent then the capacity of the workgroup for carrying out work is reduced. This needs to be considered in the initial sizing of the workgroup or the workgroup will be unable to carry out its allocated work as expected.

The objective of this study is to apply and validate an application of a Markov chain model to measure the effects of different staffing levels on group performance in the presence of absenteeism.

The issue of employee absenteeism has been modelled widely in the literature (Aksin et al. 2007; Easton & Goodale 2002; Fry et al. 2006; Wang & Gupta 2012; Whitt 2006). However, these models do not incorporate absenteeism directly into their queuing or Markov chain models. Instead they modify either the input or output parameters to allow for the absenteeism. The model in the present paper in contrast does incorporate absenteeism directly into the Markov chain model.

The paper is organised as follows. Section 2 reviews the literature on the effects of staffing levels on performance, the quantitative approach in managing human resources, and previous applications of Markov chains and queuing theory to the

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problem of absenteeism in the literature. Section 3 presents the basic concepts of the Markov process and the necessary equations for evaluating system performance. Section 4 shows how to adapt the model to an organisation. Section 5 describes the experiments of the study. Section 6 compares the results of the experiments with the theoretical approach. The last section gives the conclusions of the study.

2. Literature Review

2.1 The Effects of Staffing Levels on Organisation Performance

Choosing the right number of employees to enable an organisation to perform at its best is not an easy task for a manager. Depending on the organisation's strategy, managers have different options for the staffing level for their institution. Some prefer a moderate understaffing, whereas others advocate for a slight overstaffing condition. Regardless of which side they are, managers believe that their decisions on the workforce size would be correct and that this number of employees will help the organisation to perform well.
An understaffing condition is defined as "not having enough people to do all the jobs in the setting" (Scott 2005, p. 308). A moderately understaffed organisation may gain better performance compared with other staffing levels since employees operating in this state are likely to work more efficiently and to experience higher motivation. In a slightly understaffed state, each member is involved in a wider variety of task scopes. Hence they need to use varied skills to complete tasks. Furthermore, workers also need to find ways to combine similar tasks together in order to reduce waste time from repeating redundant activities. As a consequence, their efficiency is improved (Treville & Antonakis 2006; Vecchio & Sussmann 1981). Workers in understaffed conditions are also claimed to have more freedom on deciding the way to organise and complete their tasks, which increases their working motivation (Ganster & Dwyer 1995). These positive experiences lead to improvement in the outputs of individuals and hence the performance of the whole organisation is improved.

However, negative effects on workers have been reported in understaffing organisations. Studies show that workers in understaffed conditions normally suffer from higher burnout and higher emotional exhaustion (Rochefort & Clarke 2010). This leads to demotivation, lower productivity and poor performance among individuals. A high absenteeism rate is another effect of understaffing conditions. Psychologists indicate that high staff burnout, less job satisfaction, high sickness rate, and high conflict in work–life balance are the main reasons for absenteeism by workers (Camdena et al. 2011; Clements et al. 2008; Schalk & Rijckevorsel 2007). Other disadvantages of understaffing claimed by researchers include lower levels of aggregate organisation outputs, lost business opportunities, and an increase in error rates of staff (Ahmed 2007).

To overcome the harmful effects that understaffing conditions have on performance, the associated body of literature suggests a slight overstaffing setting for an organisation. Numerous studies have proven that the condition is associated with better outcomes at both staff and organisation levels. Rafferty et al. (2007), for example, reports that employees in overstaffed groups suffer less from burnout, have higher job satisfaction, and produce a higher quality of service. At a strategic level, the existence of extra staff enables creative and innovative behaviours (Nohria & Gulati 1996), and enhances the performance of the organisation (Rust & Katz 2002). Researchers acknowledge that increasing the staffing level leads to higher costs.

Hence they suggest that an organisation should not overstaff greatly (George 2005; Tan 2003). After confirming the existence of an optimal level of additional staff, Tan (2003) concludes that the resource of extra staff can be a source of competitive advantage but too many staff may reduce organisation performance.

2.2 The Quantitative Approach in Setting Staffing Levels

Most of the foregoing research was qualitative in nature. In addition quantitative methods have also been applied to this problem. Che and Henderson (2011), for example, apply queuing models in setting levels of tellers for call centres. In addition, queuing models are also applied in setting the number of nurses or beds for hospitals (see e. g. Yankovic & Green 2011), or in optimising the staffing level based on profit (Tran & Davis 2011; Tran et al. 2011). Other mathematical models are used for monitoring training costs and times, maximising the flexibility of the workforce, and optimising the trade–off between the cost of training and the flexibility of employees (see e.g. Battaa et al. 2007; Palominos et al. 2009; Slomp et al. 2005).

2.3 Applications of Markov Chain Models

Markov chain models have been applied in diverse areas such as wireless communication, financial engineering, internet traffic modelling and so on (Carmichael 2011; Yin & Zhang 2005). In the field of human resource management, Markov models are used in predicting the future needs of employees in a firm (Ke & Cai 2011), or the changes of workforce structure in an organisation (Skulj et al. 2008).

An application of Markov chain models in modelling the organisation performance is presented in Tran and Davis (2012). The research considers workers to be unavailable only because they are currently carrying out a piece of work, and do not consider other reasons why they may be unavailable. This study extends the model to one such case, namely the case where workers are unavailable due to absenteeism. The model provides a practical tool for managers in evaluating the performance of their worker groups. The tool is also useable for those who want to setup an appropriate staffing level for a newly formed team.

2.4 Queuing and Markov Chain Models With Absenteeism

Absenteeism problems have been modelled widely in the literature. Hur et al. (2004) models the real-time work schedule adjustment decision problem (to deal with absenteeism) as an integer programming problem and presents some solution methods. Fry et al. (2006) uses a newsvendor-type analysis to determine the number of firefighters to train each year to allow for attrition and absences. Green et al. (2010) performs a similar analysis for nursing and shows the importance of including workload aversion (where nurses are more likely to be absent if there is less of them to share the work). Wang and Gupta (2012) analysed data on nurse absences and created and tested hueristic models for allocating staff to different units to minimise the effects of absences. Aksin et al. (2007) provide an extensive review of call centre staffing literature, much of which deals with absenteeism.

Specific work focussing on using queuing and Markov chain models to solve the problem of optimising staffing level under the effects of employee absenteeism can be found in Easton and Goodale (2002, 2005) and Whitt (2006). Easton and Goodale (2002) propose a combination of a Markov process and M/M/s queue with reneging model for labour staffing and scheduling decisions under stochastic demand and impatient customers. The model includes the effects of experience levels and random absenteeism of employees in maximising expected profit. Easton and Goodale (2005) then apply this model to real-time schedule recovery policies. Whitt (2006), on the other hand, applies M/GI/s + GI queue with customer abandonments model to maximize the expected net return under uncertain arrival rates and uncertain staffing due to absenteeism.

Although Easton and Goodale (2002)consider the effects of absenteeism, they do it through the use of an effective arrival rate applied to a standard queuing model, rather than including absenteeism inside the structure of the model. Whitt (2006) does not include the effect of absenteeism inside the structure of the model either. Instead the interesting parameters are calculated for each potential amount of absenteeism using the queuing model and then the average taken of these results.

The current research differs from the previous research in that absenteeism is included in the Markov Chain model itself.

3. Modelling

The previous application of Markov chain models in evaluating organisation performance by Tran and Davis (2012) will be presented in this section. Theories presented in this section are found in most texts covering Markov processes (e.g. Stewart 2007; Yin & Zhang 2005) and reliability theory (e.g. Trivedi 2002). Only the selected parts of the theories relevant to the present research are given.

3.1 Markov Chains

Let j = 0, 1, …, m represent the states of the system; p_{ij} is the transition probability of the system from state i to state j; where i, j = 0, 1,…, m. The transition probability matrix of the system is an (m + 1) x (m + 1) matrix and can be given as:

$$P = [p_{ij}] = \begin{bmatrix} p_{00} & p_{01} & \cdots & p_{0m} \\ p_{10} & p_{11} & \cdots & p_{1m} \\ & \ldots\ldots & & \\ p_{m0} & p_{m1} & \cdots & p_{mm} \end{bmatrix} \qquad (1)$$

where:

$0 \le p_{ij} \le 1$ i, j = 0, 1, …, m.

and:

$$\sum_{j=0}^{m} p_{ij} = 1 \qquad i = 0, 1, \ldots, m. \qquad (2)$$

Assume that the system is such that the probability of being in any particular state is constant over time. Denote a row vector $\pi = (\pi_0, \pi_1, \ldots, \pi_m)$ with each $0 \le \pi_j \le 1$ being the probability of the system being in state j. Then

$$\sum_{j=0}^{m} \pi_j = 1 \qquad (3)$$

Also if the system is in equilibrium then:

$$\pi = \pi P \tag{4}$$

Equations (3) and (4) have (m + 2) equations with (m + 1) unknowns. However, the row vectors comprising P are linearly dependent (due to (2)) and so one of the equations in (4) will be eliminated. This gives (m + 1) equations in (m + 1) unknowns. Solving these gives π_j, the probability of being in each state j.

3.2 Reliability Theory

The availability of a system is calculated as:

$$\text{Availability} = \text{MTTF} / (\text{MTTF} + \text{MTTR}) \tag{5}$$

Where:

MTTF is the mean time to failure and MTTR is the mean time to repair of the system.
It is assumed that the time taken to carry out each piece of work can be described using an exponential distribution, and the time between the arrivals of any two consecutive pieces of work is constant. The time between arrivals is used as the time step in the Markov chain.

A worker is available to accept incoming work for a time step if he or she was not working during the previous time step, or if he or she finished his or her work during the previous time step. The probability that a worker finishes during a time step is given by:

$$p = \exp(-\mu/\lambda) \tag{6}$$

where λ is the arrival rate and μ is the processing rate of the group, hence 1/λ is the inter–arrival time of work and 1/μ is the average time for doing one piece of work.

3.3 Binomial Distribution

If the workers work independently of each other and all have the same probability of finishing in any given time interval then the number of workers who finish working in a given time step will follow a binomial distribution given by:

$$p_{ij} = \binom{j}{i} p^i (1-p)^{j-i} \tag{7}$$

3.4 Organisation Utilisation

The utilisation of an organisation is the ratio between the average number of occupied staff and the total employees of the organisation. It is given by

$$H = N_{\text{occupied staff}} / N_{\text{total employees}} \tag{8}$$

Where

$$N_{\text{occupied staff}} = \sum_{j=0}^{m} \pi_j j \tag{9}$$

And π_j is the probability that j workers are occupied when work arrives.

The approach described heretofore is the basic approach used in developing queuing theory solutions for this type of problem. Therefore taking this approach and extending it to cover absenteeism is an appropriate methodology.

4. Adaption to Work Groups with Absenteeism

The previous approach requires adaptions when being applied to the extended case. The adaptions are described as follows.

4.1 Modelling the Whole System

The following conventions are used when modelling the whole system:

- The system state, k, is defined as the number of unavailable workers, including the number of occupied workers, j, and the number of away workers, j’. k = 0, 1, …, m; k = j + j’.
- The transition matrix has m(n+1) x m(n+1) dimensions. The transition probability $p_{ii'\,jj'}$ is the probability that the group changes from the state in which i workers are occupied and i’ workers are on leave to the state in which j workers are occupied and j’ workers are on leave. The transition probability, $p_{ii'\,jj'}$, is given as follows:
    - For i ≥ (m-i’-j’) and i’ < j’ (i.e. when the number of workers on leave increases by the same amount as the number of workers working decreases and all workers are busy or on leave at the beginning of the state), then

      $$p_{ii'\,jj'} = p_{(m-i'-1)i'\,jj'} \qquad (10)$$

    - For i = (m – i’) and i’ = j’ (i.e. all workers are busy or on leave at the beginning of the state and the number of workers on leave does not change), then

      $$p_{ii'\,jj'} = p_{(i-1)i'\,jj'} \qquad (11)$$

    - For all other cases:

      $$p_{ii'\,jj'} = p_{ij} \times p_{i'j'} \qquad (12)$$

- The probability of being in state k, π_k, is the probability of the group having exactly k workers unavailable; π_k is given by:

  $$\pi_k = \sum_{j=0,\; j'=k-j}^{m} \pi_{jj'} \qquad (13)$$

- The group is “not available” when all workers are unavailable. If work arrives at this time then no workers are available to immediately commence the arriving work. The probability of being in this state is π_m. In this study, a success is defined as a piece of work being done on arrival. Otherwise work leaves the system immediately and the group loses that piece of work. Thus the probability of accepting a piece of work is the probability that any worker is available, 1- π_m.

The transition matrix of the system is given by:

$$P = [p_{ii\ jj'}] = \begin{bmatrix}
p_{00\ 00} & p_{00\ 10} & \cdots & p_{00\ m0} & p_{00\ 01} & p_{00\ 11} & \cdots & p_{00\ (m-1)1} & \cdots & p_{00\ 0n} & p_{00\ 1n} & \cdots & p_{00\ (m-n)n} \\
p_{10\ 00} & p_{10\ 10} & \cdots & p_{10\ m0} & p_{10\ 01} & p_{10\ 11} & \cdots & p_{10\ (m-1)1} & \cdots & p_{10\ 0n} & p_{10\ 1n} & \cdots & p_{10\ (m-n)n} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
p_{m0\ 00} & p_{m0\ 10} & \cdots & p_{m0\ m0} & p_{m0\ 01} & p_{m0\ 11} & \cdots & p_{m0\ (m-1)1} & \cdots & p_{m0\ 0n} & p_{m0\ 1n} & \cdots & p_{m0\ (m-n)n} \\
p_{01\ 00} & p_{01\ 10} & \cdots & p_{01\ m0} & p_{01\ 01} & p_{01\ 11} & \cdots & p_{01\ (m-1)1} & \cdots & p_{01\ 0n} & p_{01\ 1n} & \cdots & p_{01\ (m-n)n} \\
p_{11\ 00} & p_{11\ 10} & \cdots & p_{11\ m0} & p_{11\ 01} & p_{11\ 11} & \cdots & p_{11\ (m-1)1} & \cdots & p_{11\ 0n} & p_{11\ 1n} & \cdots & p_{11\ (m-n)n} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
p_{(m-1)1\ 00} & p_{(m-1)1\ 10} & \cdots & p_{(m-1)1\ m0} & p_{(m-1)1\ 01} & p_{(m-1)1\ 11} & \cdots & p_{(m-1)1\ (m-1)1} & \cdots & p_{(m-1)1\ 0n} & p_{(m-1)1\ 1n} & \cdots & p_{(m-1)1\ (m-n)n} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
p_{0n\ 00} & p_{0n\ 10} & \cdots & p_{0n\ m0} & p_{0n\ 01} & p_{0n\ 11} & \cdots & p_{0n\ (m-1)1} & \cdots & p_{0n\ 0n} & p_{0n\ 1n} & \cdots & p_{0n\ (m-n)n} \\
p_{1n\ 00} & p_{1n\ 10} & \cdots & p_{1n\ m0} & p_{1n\ 01} & p_{1n\ 11} & \cdots & p_{1n\ (m-1)1} & \cdots & p_{1n\ 0n} & p_{1n\ 1n} & \cdots & p_{1n\ (m-n)n} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
p_{(m-n)n\ 00} & p_{(m-n)n\ 10} & \cdots & p_{(m-n)n\ m0} & p_{(m-n)n\ 01} & p_{(m-n)n\ 11} & \cdots & p_{(m-n)n\ (m-1)1} & \cdots & p_{(m-n)n\ 0n} & p_{(m-n)n\ 1n} & \cdots & p_{(m-n)n\ (m-n)n}
\end{bmatrix} \quad (14)$$

Including terms related to both customer service and employee absence in the transition matrix is a novel contribution of this paper.

The row vector indicating the probability of being in a state of the system is:

$$\pi = (\pi_{00} \ \ \pi_{10} \ \dots \ \pi_{jj'} \ \dots \ \pi_{(m-n)n}) \qquad (15)$$

Where

$$0 \le \pi_{jj'} \le 1 \qquad (16)$$

And

$$\sum_{j'=0, j+j' \le m}^{n} \pi_{jj'} = 1 \qquad (j = 0, \dots, m) \qquad (17)$$

The equilibrium condition of the whole system is given by Equation (4).

Equations (14) and (4) give [m(n+1)+1] equations with m(n+1) unknowns. However, the row vectors comprising P are linearly dependent and so one of the equations in (4) will be eliminated. This gives m(n+1) equations in m(n+1) unknowns. Solving this gives π_{jj} and using Equation (13) to get π_k the probability of being in each state k.

4.2 Modelling the Number of Occupied Workers in Groups

The arrival rate of work, λ, and the processing rate, μ, are known, so Equation (6) is used for calculating the probability of finishing work of a worker during a given time step. Equation (7) is used to calculate all transition probabilities p_{ij} for the transition matrix of the system.

4.3 Modelling Workers on Leave

Denote j' as the state of leaving workers, n (n ≤ m) is the maximum number of away workers of all times. A period for being away is chosen as an interval time. It may be a half day, or a day, etc. The average away time of workers is denoted as μ' and is known.

Equation (6) is used for calculating the probability of coming back during the following interval if a worker is on leave during the current interval. It is noted that λ in this case is 1. Hence the transition matrix of the system in this case is given as:

$$P' = [p_{i'j'}] = \begin{bmatrix} p_{00} & p_{01} & \cdots & p_{0n} \\ p_{10} & p_{11} & \cdots & p_{1n} \\ & \dots\dots & & \\ p_{n0} & p_{n1} & \cdots & p_{nn} \end{bmatrix} \qquad (18)$$

Where $p_{i'j'}$ is the probability that the system transits from state i' to state j' and given by Equation (7).

5. Experiments

5.1 Experimental Design

Experiments were conducted on work groups where workers independently disassembled electronic components from circuit boards. The number of workers in the experimental groups ranged from 8 to 12.

Work arrived at a constant rate and one piece at a time. Each piece of incoming work was allocated to a single randomly selected worker. In the case that no workers are available at the time that a piece of work arrived, then the piece of work left the system and was unable to be executed by the group.

Workers were asked to leave the workplace randomly during the experiments. The maximum time that a worker was absent was five intervals. A maximum of one worker was allowed to begin leave at any particular time.

Workers worked independently of each other. Four sets of experiments were designed. The following table summarises the conditions of the experiments.

Table 1: Conditions of the experiments

The experiment set	Probability of workers on leave	Time for starting leave	Duration for on leave
1^{st}	40%	Just before the beginning of an interval	A multiple time of an interval
2^{nd}	20%	Just before the beginning of an interval	A multiple time of an interval
3^{rd}	20%	Just before the beginning of a half interval	A multiple time of an interval
4^{th}	20%	Just before the beginning of a half interval	A multiple time of a half interval

5.2 Data Collection

Data collected from the experiments included arrival times, service times, and finishing times of each piece of work. For each period of leave the starting time and the finishing time were recorded. Each experiment lasted for 48 intervals, equivalent to 1440 pieces of work arrived. After being stopped the experiments were repeated a second time from the beginning.

6. Comparison of Experimental Results with the Theoretical Results

After the experiments, the three aspects of performance mentioned in Section 1 were calculated and then compared with the model. Results from the comparisons are as follows.

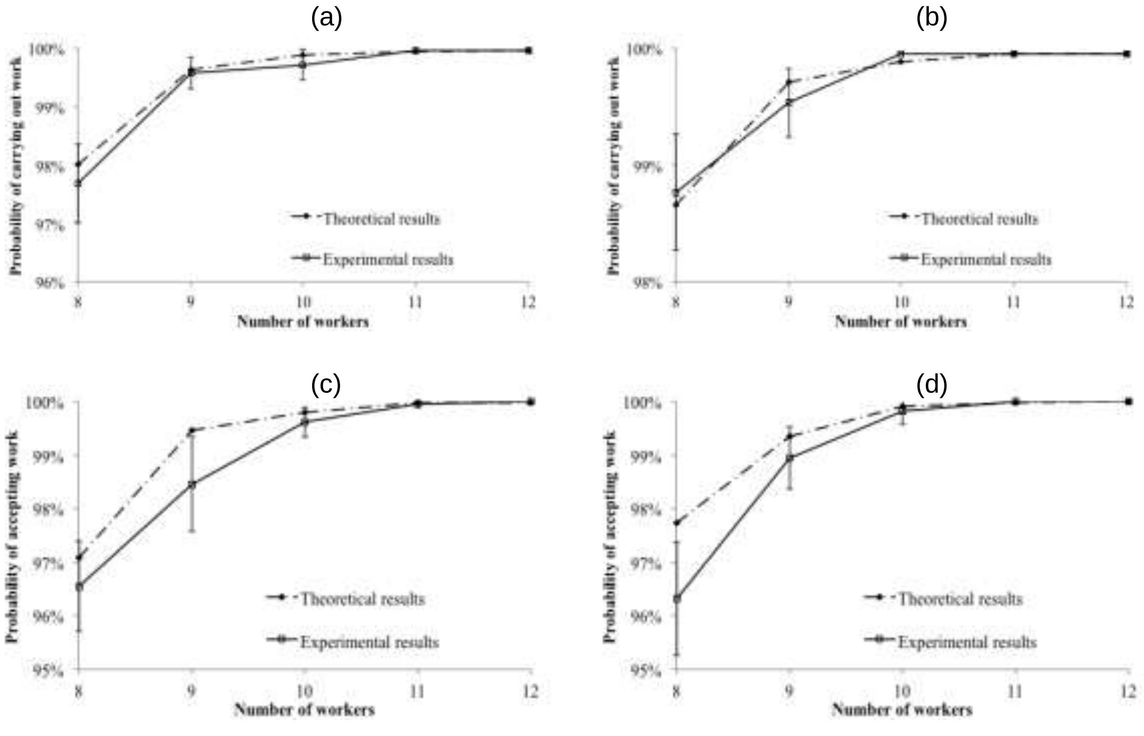
6.1 Probability of Carrying out Work

The study assumes that all work being accepted by groups will be processed successfully. So the probability of carrying out work here is the probability of accepting work. As mentioned in previous sections, the probability of a group accepting a piece of work is the probability that at least one worker is available when a piece of work arrives. The model gives this as $1 - \pi_m$. For the experiments this is taken to be the ratio between the amount of work carried out to the amount of work arriving.

It is proven that increasing the number of workers in a group leads to increased probability of accepting work, and adding an additional worker to a small group has a bigger effect than adding to an already large group (Tran & Davis 2011, 2012). Results from this research agree with previous studies.

Figure 1 illustrates the probabilities of accepting arriving work in the experiments and compares them with the results from the theoretical model presented in Section 4. Error bars give the standard error for the mean of the experimental results. In order to determine these error bars, each experiment was divided into intervals of 150 seconds. Work arrived at a rate of one piece of work every five seconds so 30 pieces of work would arrive during each 150 seconds interval. The number of pieces of lost work for each interval was counted. The figure indicates that the theoretical results are consistently within the standard error for all experimental groups. A conclusion from this comparison is that the proposed model is useful for modelling the relationship between the group sizes and the probability of carrying out work. However, the model does tend to overestimate the probability of carrying out work and the reasons for this are being investigated.

Figure 1: Probabilities of carrying out work of groups in the 1st (a), 2nd (b), 3rd (c), and 4th (d) experiments



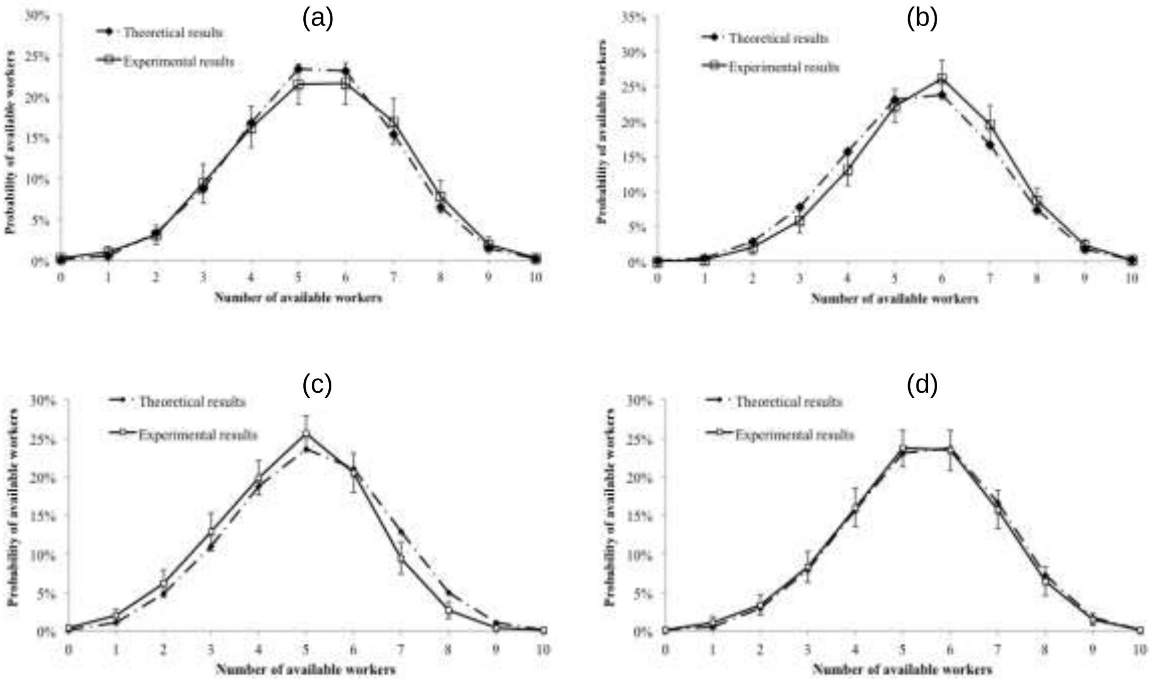
6.2 Availability of Workers

The availability of workers in a group is the number of available workers in the group who are neither not working nor absent when a piece of work arrives. The number of available workers indicates the efficiency of staff usage in a group. The more workers available in a group the less efficient a group is in using its human resources. Studying the availability of workers would help a manager to reduce the waste of its organisation by reducing the number of redundant workers.

Figure 2 presents the probability distribution of available workers of the 10–worker group in the experiments. The experiment's curve comes with error bars to show the standard error of the experimental results. **Figure 2** shows that both theoretical curves fall in between error bars. The same results are also given in other groups.

Kolmogorov – Smirnov goodness of fit tests were carried out for each different sized group of workers and the results show that all the models fit the experimental results well for each experimental group.

Figure 2: Probability distributions of available workers in the 1st (a), 2nd (b), 3rd (c), and 4th (d) experiments

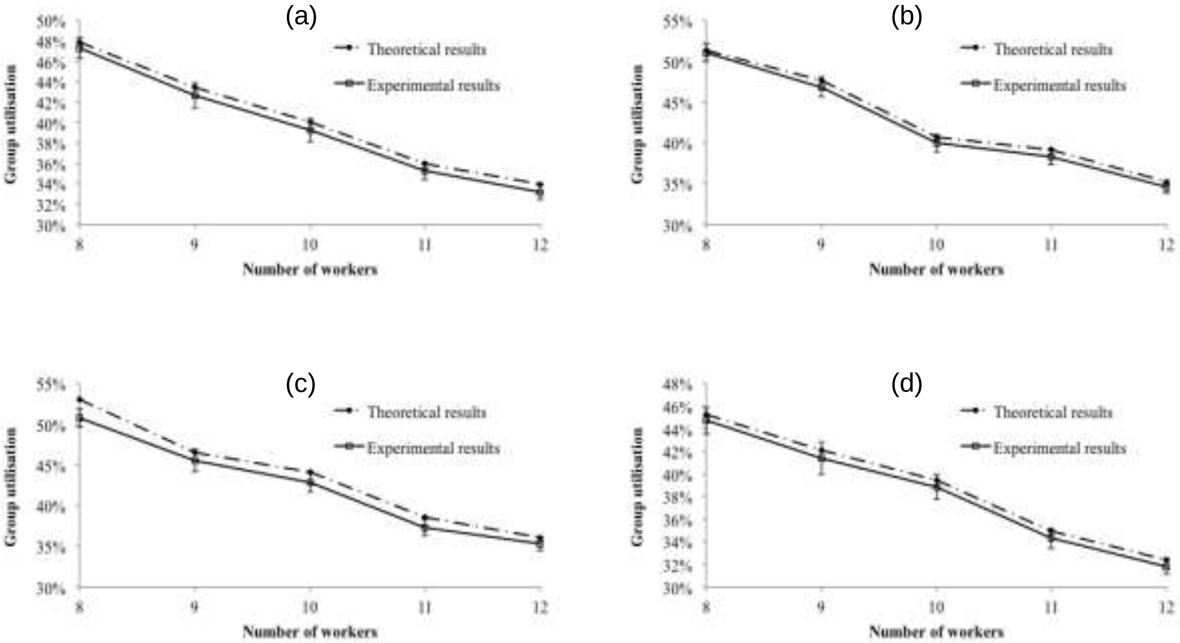


6.3 Group Utilisation

Utilisation is also examined in this study. Values of the indicator are in the range of 0 and 1. When its value is close to 1 it means that the group is at high efficiency in using staff resource as most of the employees are busy because of working at most of the time and vice versa. When the utilisation is known, the output production can be estimated when the probability of accepting work and the arrival rate of work are known. See Tran and Davis (2011) for details on calculating output production rate.

The group utilisation can be calculated by using Equations (8) and (9). Results from the theoretical approach and the experiments on the utilisations of groups are presented in **Figure 3**. The figure shows that the theoretical curve is consistently within the standard error bars for all groups in the experiment. However, the model does tend to overestimate the error and reasons for this are being investigated.

Figure 3: Utilisations of groups in the 1st (a), 2nd (b), 3rd (c), and 4th (d) experiments



7. Conclusions

Results from the study confirms that the Markov chain model gives a reasonable approximation in modelling the relationship between staffing level and organisation performance in the case where workers may be leave from the work place. The model does seem to overestimate the probability of accepting work and the utilisation. Reasons for this are being investigated. However, the error is quite small. Thus the proposed model provides a useful tool for managers in measuring the relationship between staffing level and performance of workers in a group for three aspects: the probability of a group in carrying out work, the availability of workers, and the group utilisation. The model can be used in setting up the workforce size of a newly formed group when the arrival rate of work, the processing rate of workers, and the average time of on leave by workers are estimated.

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