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Algorithm and Simulation of Holonic Worker Selection Guide with Case Study on Task Urgency and Skill Rating

Yongching Lim
Physics Unit, School of General & Foundation Studies, AIMST University
Jalan Bedong-Semeling, 08100 Bedong, Kedah, Malaysia
E-mail: lim_yongching@aimst.edu.my

Jengfeng Chin
School of Mechanical Engineering, Universiti Sains Malaysia, Engineering Campus
14300 Nibong Tebal, Penang, Malaysia
E-mail: chinjengfeng@eng.usm.my

Abstract

This paper explicates the Worker Selection Guide (WOSEG), that is, a functional branch of Holonic Workforce Allocation Model (HWM). A case study is conducted on reckoning the task urgency and skill rating parameters in a job-shop setting, from which the workforce performance data are acquired. The destined performance measures encompass overdue rate, average skill level, interpersonal and intrapersonal skill deviations, which can be generated via computer simulation. The corresponding simulation model is built with the software of Witness®, Visual Basic®, and Microsoft Access® for the input instruction coding and output analysis purposes.

Keywords: Holonic manufacturing, worker selection, algorithm, simulation

1. Introduction

“Holonic” is derived from the word “holon” introduced by a Hungarian philosopher Arthur Koestler (1967). The word holon combines the Greek *holos* meaning *whole*, with the suffix *–on* meaning a *particle* or *part*, is used to describe a basic unit of organisation in biological and social systems. In 1993-1994, that idea was adopted in an international research programme: Intelligent Manufacturing Systems (IMS), due to the collaboration of the United States (US), European Community (EC), European Free Trade Association (EFTA), Australia, Canada, and Japan. The IMS programme consists of six major projects, whereof the fifth one is entitled “Holonic Manufacturing Systems: system components of autonomous modules and their distributed control”, with its acronym HMS. In 1997, over the four years of feasibility study, HMS became a fully endorsed project under the IMS programme.

As one of the HMS applications, the Holonic Workforce Allocation Model (HWM) is composed of a pre-active level: Workforce Sizing Plan (WOZIP) and a reactive level: Worker Selection Guide (WOSEG), as delineated in Figure 1 (Lim *et al.* 2008; Lim & Chin 2008; Lim & Chin 2011; Lim 2011a; Lim 2011b). In particular, the WOSEG attempts to make qualitative worker-task matching decisions based on worker skills and task urgencies, in view of both specialisation requirements and cross-training opportunities.

2. Computational Algorithm

Every scheduled task in the job-shop production can be distinguished by the type of skill required. Each type of skill is considered unique as it pertains to only one type of machine. A number of manufacturing variables are defined as follows.

2.1 Processing Time, $t_{pro,i}$

For a certain type of task *i*, the processing time can be estimated via time study. It is normally distributed and prorated based on the customer order quantity and the inherent production variability.

2.2 Resultant Time, $t_{res,i}$

The resultant time for task *i* depends on the relevant skill rating of the worker handling the task. For this, the Learning Curve theory is adopted and the equation is:

$$t_{res,i} = \gamma \cdot t_{pro,i} \cdot N_{att(i,j)}^{\frac{\log \kappa}{\log 2}} \quad | \quad \gamma \geq 1 \tag{1}$$

Where, $N_{att(i,j)}$ is the number of attempts owned by worker *j* on task *i*; κ is a fractional number indicating the learning rate (e.g. 0.8 or 0.9); γ is a multiplying constant called “first attempt standard ratio” to compute the longest processing time for any worker when he first takes up the task.

2.3 Inter-arrival Time, $t_{int,i}$

The time interval between two successive tasks is called inter-arrival time. The demand for task *i*, D_i is determined by the ratio of its mean processing time to its mean inter-arrival time:

$$D_i = \frac{\bar{t}_{pro,i}}{\bar{t}_{int,i}} \tag{2}$$

2.4 Allowable Time, $t_{all,i}$

The difference between the arrival time and the due time of a task defines its allowable time. Any task that spends more than the allowable time is considered overdue. The urgency of task *i*, C_i is computed as the ratio of the processing time to the allowable time:

$$C_i = \frac{t_{pro,i}}{t_{all,i}} \tag{3}$$

2.5 Skill Rating, $S_{i,j}$

The skill *i* held by worker *j* can be rated in regard to his cumulative number of attempts requiring skill *i*, $N_{att(i,j)}$, and the learning rate, κ:

$$S_{i,j} = 1 - N_{att(i,j)}^{\frac{\log \kappa}{\log 2}} \tag{4}$$

2.6 Picking Index, $\Pi_{i,j}$

To pick worker *j* for task *i*, the “picking index”, $\Pi_{i,j}$ is formulated from Equations (3) and (4), inclusive of the corresponding skill, $S_{i,j}$ and the mean of the other skills held by worker *j*, $\bar{S}_{i:oth,j}$; the skill gap between the minimum, $S_{i,min}$, and maximum, $S_{i,max}$, of all the workers; the task urgency, C_i, and the user-defined mean urgency, C_{mean}; a fractional random number, R ($0 \leq R \leq 1$). For an incoming task *i*, the picking index associated with each available worker is calculated. Eventually, the matching with the highest picking index will be accepted:

$$\Pi_{i,j} = C_i S_{i,j} + \frac{R(S_{i,max} - S_{i,min})}{2C_i} + (C_i - C_{mean})(S_{i,j} - \bar{S}_{i:oth,j}) \tag{5}$$

3. Performance Data

This section delineates four performance data items: overdue rate, average skill level, interpersonal and intrapersonal skill deviations. Each of these performance measures is defined and formulated as below.

3.1 Overdue Rate (ODR)

As the primary concern among others, the overdue rate reflects the capability of the production floor to meet delivery times with no additional aid or cost. As mentioned in *2.4*, any task that is unfinished at the due time (i.e. the task's resultant time, $t_{res,i}$ exceeds the allowable time, $t_{all,i}$) is an overdue task. The overdue rate can be calculated through dividing the number of overdue tasks by the total number of finished tasks:

$$Let \;\; \Omega_i = \begin{cases} 1 \; ; \; t_{res,i} > t_{all,i} \\ 0 \; ; \; otherwise \end{cases} \tag{6.1}$$

$$Overdue \;\; Rate = \frac{\sum_i \Omega_i}{\sum_i T_i} \tag{6.2}$$

3.2. Average Skill Level (ASL)

Every skill i held by worker j is given a rating, $S_{i,j}$, as accounted in *2.5*. The personal skill mean, $\overline{S_j}$ is given by the sum of all his skill ratings over the total number of skills, N_S. Upon that, the average skill level, $\overline{S}$ can be calculated per the total number of workers, N_W:

$$\overline{S_j} = \frac{\sum_i S_{i,j}}{N_S} \tag{7.1}$$

$$\overline{S} = \frac{\sum_j \overline{S_j}}{N_W} \tag{7.2}$$

3.3 Interpersonal Skill Deviation (InterSD)

The interpersonal skill deviation, σ_{inter} is the indicator of workload balance among the entire workforce. This measure is computed with the standard deviation of each and every personal skill mean from the average skill level:

$$\sigma_{inter} = \sqrt{\frac{\sum_j (\overline{S}_j - \overline{S})^2}{N_W}} \tag{8}$$

3.4 Intrapersonal Skill Deviation (IntraSD)

The intrapersonal skill deviation, σ_{intra} is a measure reflecting the inherent cross-training chances. In practice, a great intrapersonal skill deviation would be expected from a selection method with limited cross-training chances, and vice versa. At first, the standard deviation of every skill i held by worker j, $\sigma_{intra,j}$ is computed; and then, the collective standard deviations are averaged out as σ_{intra}:

$$\sigma_{intra,j} = \sqrt{\frac{\sum_{i}(S_{i,j} - \overline{S}_j)^2}{N_S - 1}} \tag{9.1}$$

$$\sigma_{intra} = \frac{\sum_{j}\sigma_{intra,j}}{N_W} \tag{9.2}$$

The rationales of the above equations have already been provided in Lim (2011a).

4. Manufacturing Simulation

Simulation is a technique that models a real-life or hypothetical environment, in particular one with dynamic and stochastic aspects, to enable the user to preview how a model works. A series of alternatives can thereby be tested and assessed offline to help identify the best solution for a specified problem (Hlupic *et al.* 2006). According to a survey made on selected publications between 1992 and 1997, simulation has already become a primary research methodology in operational management (Pannirselvam *et al.* 1999). With regard to the workforce planning and reassignment, Zülch *et al.* (2004) stressed the effectiveness of simulation to consider the plurality of possibilities and to exploit the flexibility of human resources.

4.1 Strengths and Limitations

Although simulation does not assure optimal solution, it is the only proper analysis technique when formal mathematical methods fail to reflect some characteristics of a system (Lanner 2000). The strengths of simulation (Yücesan & Fowler 2000) include *time compression* (potential to simulate years of real system operation in a much shorter time), *component integration* (ability to integrate complex system components to study their interactions), *risk avoidance* (hypothetical systems can be studied on “what if” analysis, without financial or physical risks of a real system), *physical scaling* (ability to study much larger or smaller versions of a system), *repeatability* (ability to study different systems in identical environments or the same system in different environments), and *control* (everything in a simulated environment can be precisely monitored and exactly controlled).

On the other hand, Hlupic *et al.* (2006) stated that simulation can generate output in quantitative rather than qualitative format to offer objective grounds for discussion and support informed decision-making. For instance, a simulation model may help the user anticipate the productivity (i.e. quantitative output) and then it is up to the user to accept, reject or modify the tentative strategy (i.e. decision-making). According to Grewal *et al.* (1999) and Siow (2008), simulation is ideal for the cycle time study in semiconductor manufacturing, whereby it allows the user to model the complex system behaviour, identify the minimum resource requirements, analyse the loading capacity, predict the throughput, and gather the tool performance statistics.

Aside from the inherent strengths mentioned, several issues or difficulties might be encountered when modelling and simulating a manufacturing system. Even if incorporation of detail can increase the credibility of the model, excessive levels of detail may render a model hard to build, debug, understand, deploy, and maintain (Chance *et al.* 1996). The whole process to collect data, build, execute, and analyse the model can be very time consuming (Fowler & Rose 2004). By and large, knowing the proper amount of detail is paramount in designing a simulation model. The experimentation time can be reduced by exploring simpler models that still hold realistic results, as well as using distributed and parallel simulation. A simulation of relatively low complexity can be performed without a computer, using pencil and paper instead (Symankiewicz *et al.* 1988). There is no need to include all the salient features in the beginning of simulation, wherein the progressive model building rule is recommended — start with a simplified version to introduce detail step-by-step until the model is completely built (Brooks & Tobias 2000).

4.2 Witness Modelling

Witness®, as one of the simulation software packages flourishing in this computer era, provides a range of drag-and-drop manufacturing elements with animate display. Calinescu *et al.* (1999) observed that Witness® is a leading software tool that holds variability-related capabilities, hence admitting of low-cost rapid development of flexible and generic simulation models.

For this research, a case study has been conducted on a local carton manufacturer. Each carton requires five major tasks: laminate the structure, make the lid, make the legs, make the box, and assemble the final product. To simulate the job-shop situation, our Witness® model contains three types of manufacturing elements: part, machine and labour. There are seven parts in total, representing the five tasks (T1 to T5) and two disturbances (absence and turnover), while each of the parts has a specific machine to process its material or information. The Witness® elements and their flows are shown in Figure 2.

4.3 Visual Basic and Microsoft Access

Further information about the tasks and workers (e.g. processing time and skill rating) are stored in as well as retrieved from a database via *Dynamic Link Libraries* (DLL) and *Structured Query Language* (SQL) made with the Visual Basic® (VB). For the selection process, the *object oriented programming* (OOP) code is written in VB. According to Wang (1998), an OOP divides a programme into isolated parts called “objects”. There are two types of contents in each object: the data (called *properties* in VB) and the commands to manipulate that data (called *methods* in VB). When the programme needs to get some data (e.g. worker availability), it merely gives a command to the object that contains the targeted data, and so the main programme itself never accesses the data in a direct manner. Such facility helps make computer codes easier to write, modify, and reuse. Figure 3 indicates how VB is used to communicate Witness® to Microsoft Access®. In more detail, the programming codes and the statistical distribution patterns inputted into these computer tools are displayed in Lim’s (2011a) Appendices A1–A3.

4.4 Experimental Setup

Through adjusting the demand, disturbance and workforce factors, four scenarios or experiments would be simulated:

Experiment 1: All Typical (AlTyp)

All the experimental factors are placed on a typical or medium level

Experiment 2: High Demand (HiDem)

Only the demand factor is elevated to high level while the rest remain typical

Experiment 3: High Disturbance (HiDis)

Only the disturbance factor is elevated to high level while the rest remain typical

Experiment 4: Low Workforce (LoWof)

Fewer workers are recruited while the other factors remain typical

Statistics of these experimental factors are derived from the case company’s production history, as tabulated in Lim (2011a). Moreover, several assumptions have to be made on the working time: 8 working hours per day, overtime hours out of use; 22 working days per month on average, including public holidays. As the duration for each experiment is two years and the performance is measured half-yearly, there are four intervals to trace the progress: 1Y1H, 1Y2H, 2Y1H and 2Y2H.

5. Results and Discussion

The performance data output (i.e. ODR, ASL, InterSD and IntraSD) of four distinct experiments (i.e. AlTyp, HiDem, HiDis and LoWof) with five trials each is recorded in Table 1.

For each experiment, the WOSEG exhibits much reduction in the overdue rate from 1Y1H to 1Y2H; and then, the rate remains low till the end of 2Y2H. Even though the initial overdue rate in the HiDem scenario is as high as 20.59%, it goes down to 8.62% in the second period, and below 6.25% in the subsequent periods. Such reduction is attributed to the improved worker skills and the shortened resultant times that better meet the task urgencies.

There is a gradual increment in the average skill level in the four experiments, from a minimum 45.28% in 1Y1H to a maximum 58.30% in 2Y2H, despite the labour turnover issue. This is because, the Equation (5) of WOSEG can duly increase the randomness in the worker selection process when task urgency is low and vice versa, making the cross-training chances appropriate (i.e. inversely proportional to task urgency). Such a strategy can gradually upgrade the average skill level and promote the workforce flexibility (a.k.a. “immunity” against disturbances) while exerting minimum pressure on the overall productivity.

On the other hand, the WOSEG has a narrow interpersonal skill deviation range between 9.19% and 13.99%, along with the range of intrapersonal skill deviation between 6.34% and 12.72%. These two data items are considered secondary as they merely reflect the workload balance and the cross-training tendency in tandem, which make no direct influence to the overall performance. In fact, it is very rare to have only one performance measure, like workload balance or cross-training chances, to be optimised.

6. Conclusion

The development of HWM is suitable for the subject of workforce allocation, which is rarely studied using the HMS paradigm. In a pre-active and quantitative form, the WOZIP component was devised to estimate the number of workers required in a certain production period; while in a reactive and qualitative manner, the WOSEG component is intended to choose a best-suited worker for every incoming task. It takes both the worker skill and the task urgency into account to secure a good performance in terms of overdue rate and average skill level. Computer simulation is carried out to verify the effectiveness of WOSEG, for which the experimental results obtained are satisfactory. For comparison with other selection models commonly used in manufacturing industry, refer to Lim (2011a).

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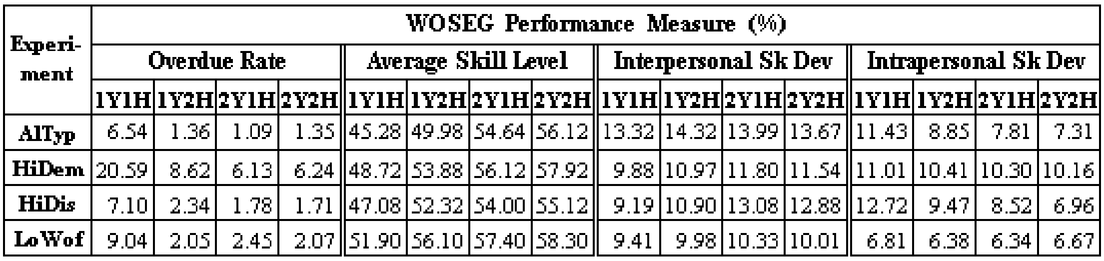
Table 1. Simulation Results



Experi-ment	WOSEG Performance Measure (%)															
	Overdue Rate				Average Skill Level				Interpersonal Sk Dev				Intrapersonal Sk Dev			
	1Y1H	1Y2H	2Y1H	2Y2H	1Y1H	1Y2H	2Y1H	2Y2H	1Y1H	1Y2H	2Y1H	2Y2H	1Y1H	1Y2H	2Y1H	2Y2H
AlTyp	6.54	1.36	1.09	1.35	45.28	49.98	54.64	56.12	13.32	14.32	13.99	13.67	11.43	8.85	7.81	7.31
HiDem	20.59	8.62	6.13	6.24	48.72	53.88	56.12	57.92	9.88	10.97	11.80	11.54	11.01	10.41	10.30	10.16
HiDis	7.10	2.34	1.78	1.71	47.08	52.32	54.00	55.12	9.19	10.90	13.08	12.88	12.72	9.47	8.52	6.96
LoWof	9.04	2.05	2.45	2.07	51.90	56.10	57.40	58.30	9.41	9.98	10.33	10.01	6.81	6.38	6.34	6.67

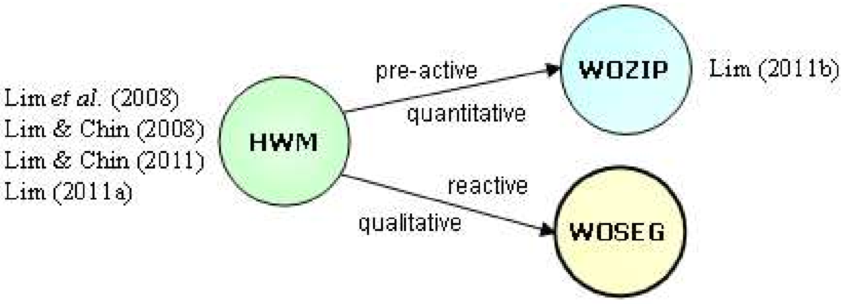


Figure 1. WOSEG as a branch of HWM

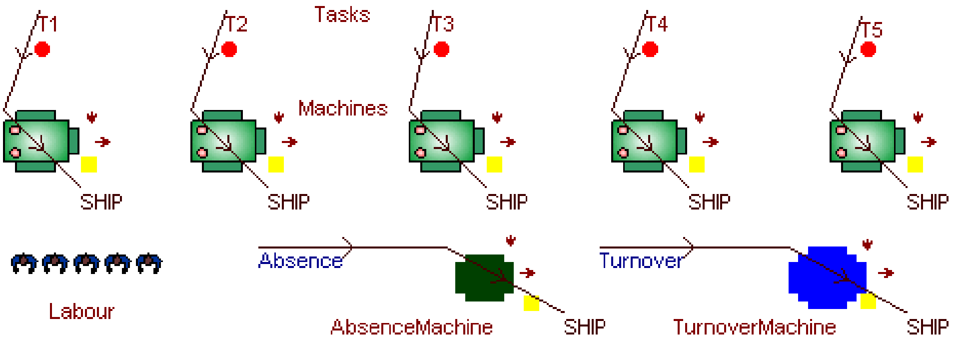


Figure 2. Witness® elements and flows

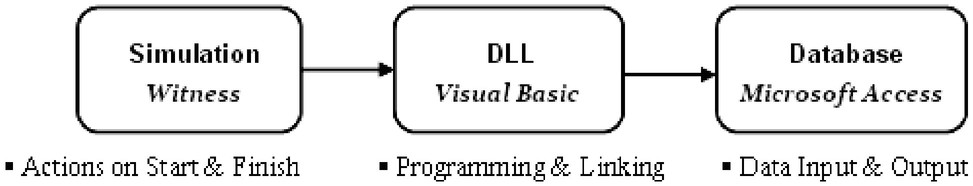


Figure 3. Linkage of computer tools

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