Modelling and Formulation of Holonic Workforce Allocation to Reduce the Impact of Absenteeism and Turnover

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Abstract

Holonic Manufacturing System (HMS) adopts Arthur Koestler's generalisation on living organisms and social organisations into a novel paradigm suitable for manufacturing industry. While the HMS paradigm has been researched on myriad technical subjects, workforce allocation is rarely attempted. In this research paper, an advisory model called Holonic Workforce Allocation Model (HWM) was developed, with the aim to reduce the impact of absenteeism and turnover in job shop environments. This model is associated with a weighted randomised formulation that can provide cross-training opportunities in parallel with specialisation requirements. For verification purpose, HWM was tested in several computer-simulated scenarios and was compared with some models commonly used in manufacturing. The experimental results showed that HWM is more effective than the others in minimising task overdue rate, improving average skill level, as well as providing moderate workload balance and cross-training chances.

Keywords: Holonic manufacturing, workforce allocation, absenteeism, turnover

1. Introduction

As the current business environment demands a greater product variety and shorter process lead times, manufacturing companies need to be more flexible and productive. One of the manufacturing system paradigms being increasingly researched is holonic manufacturing, whereof the essence is the effective integration of computer intelligence, humans and machines into a functional unit to cope with dynamics in production.

The idea of "holon" was introduced by a Hungarian philosopher Arthur Koestler (1967) in his book "The Ghost in the Machine". 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. Koestler observed that fully self-supporting, non-interacting entities did not exist in living organisms as well as social organisations. Indeed, every identifiable unit of organisation, such as a single cell in an animal or a family unit in a society, is composed of more basic units (e.g. plasma and nucleus, parents and siblings) while at the same time is forming a part of a larger unit of organisation (e.g. a muscle tissue or a community). In 1993, that idea, termed as Holonic Manufacturing System (HMS), was adopted in a reputable collaborative research: Intelligent Manufacturing Systems (IMS). The International HMS Consortium was formed in 1997 to replicate in manufacturing the strengths that holonic systems provide to living organisms and societies, such as efficient use of available resources, stability in the face of disturbances, adaptability and flexibility in the face of change (Bongaerts 1998). Koestler's findings were translated by the consortium into a set of appropriate concepts for manufacturing studies, with the following definitions (Valckenaers *et al.* 1997):

Holon : An autonomous and cooperative building block of a system for transforming, transporting, storing and/or validating information and physical objects. The holon consists of an information processing part and often a physical processing part. A holon can be part of another holon.

Autonomy : The capability of an entity to create and control the execution of its own plans and/or strategies.

Cooperation : A process whereby a set of entities develops mutually acceptable plans and executes these plans.

Holarchy : A system of holons that can cooperate to achieve a goal or objective. The holarchy defines the basic rules for cooperation of the holons and thereby limits their autonomy.

HMS : A holarchy that integrates the entire range of manufacturing activities from order booking through design, production, and marketing to realise the agile manufacturing enterprise.

1.1 Applicability of HMS

Most of the existing manufacturing systems are bound to a strict set of conditions, and hence, the system performance may deteriorate drastically when these conditions are not met. For example, the failure of a machine in an assembly line will halt the entire line and cause the customer orders unfulfilled. Such constraint is ascribed to the rigid hierarchy of the system, wherein the physically structured resources are largely irreplaceable and dependent on each other. In comparison, HMS is designed with a flexible hierarchy based on functional requirements, behaving itself with responsiveness and stability in the face of changes or disturbances. To differentiate the rigid and flexible hierarchies, an analogical example is given by McFarlane (1995): the rigid hierarchy is likened to a "rail system" and the flexible hierarchy is likened to a "city taxi system", because of the fact that the rail timetable is set independently of any periodical variation, whereas the taxi system essentially follows the demand of passengers in town. Despite holonic concepts were first used to analyse biological and social organisations, technological issues related to the substitution for manual requirements (e.g. factory automation and artificial intelligence) have been given much more attention than human elements in the contemporary HMS research (Sun & Venuvinod 2001).

Humans are inherently autonomous and cooperative — thus, their participation is paramount for a complete HMS. According to a case study on a ship-engine manufacturer (Sun & Gertsen 1995), the productivity of the company's milling shop was increased by 30% by merely revamping the workforce management. This achievement was adequately redefined from the holonic point of view (Sun & Venuvinod 2001). Full adoption of "unmanned manufacturing" (Deen 1993) is forbiddingly expensive, and yet the results obtained do not meet the expectancy (Sun & Venuvinod 2001). Factories equipped with relatively simple machinery controls (e.g. medical appliances, crafts sectors, textile mills, leather products, and soft furnishings) may require continuous attendance and handling from human operators. In these factories, the workforce expenditure is proportionally larger (Süer & Dagli 2005).

1.2 Factors in workforce allocation

Many researchers agree that the operator selection process is a multi-objective decision-making problem, which requires the accomplishment and aggregation of different factors (Lai 1995; Iwamura & Lin 1998). In general, productivity (via specialisation) and flexibility (via cross-training) may be a pair of objectives that contradict each other. To accommodate them under one system, some factors need to be considered so that a best-fit decision can be made. The range of factors may include operator skill and availability, task demand and urgency, cross-training opportunity, etc. Two relevant examples in literature are given — first, a selection fuzzy model (Lazarevic 2001) was used to minimise subjective judgment in distinguishing between an appropriate and inappropriate operator for a task position; second, a "who-rule" model (Bokhorst *et al.* 2004) was proposed to determine which operator should be assigned to a task (if more than one skilled operator is available), as well as to probe the assignment or reassignment possibilities for all idling members in order to minimise the idling time. Although these models were proven successful in their respective aims, they were not designed based on the HMS paradigm and had neglected the impact of absenteeism and turnover, which are the two prominent disturbances in any labour-intensive industry. Absenteeism refers to the unplanned absences from workplace, whereby the reasons are legitimate such as personal emergency, illness, accidence, or familial matters. Turnover occurs when an existing operator resigns from the post not due to company retrenchment but of own accord, leaving a vacant post until a replacement operator is hired. A production plan would be easily derailed when operators are involved in these disturbances and the scheduled tasks are unattended and overdue. As a result, the shop floor is vulnerable to additional overtime costs, shrunk capacity, lowered productivity, lengthened queue times, lost business opportunities, etc. Absenteeism and turnover are sometimes ascribed to poor management rather than bad attitude from the workers involved (Kathri *et al.* 2000; Dionne & Dostie 2007). To help improve the situation, reward schemes and deterrence policies have been widely adopted (Morgan & Herman 1976; Edays 2005; Vikesland 2007; Chiboiwa *et al.* 2010) and been considered preventive measures, but not the solution providers once the disturbances occur. This gives rise to a different category of methods, which include cross-training and assignment rules (Bokhorst & Slomp 2007; Nembhard & Norman 2007; Pastor & Corominas 2007). Since these methods are highly practical to reduce the impact of absenteeism and turnover, they may be applied to the build of HWM.

2. Methodology

The methodology of this research is divided into three parts. How HWM is built with the architecture of HMS is described in 2.1, wherein the holonic terminology and strengths are presented. In 2.2, the operator selection method of HWM is formulated in Equations (1) and (2). To investigate the effectiveness of HWM, some experiments are needed and are set up in 2.3.

2.1 Architecture modelling

The HWM is itself regarded as and is considered as a holarchy. Tasks and operators are heterogeneous holons in the holarchy of HWM. Additionally, a supervisor holon is introduced to resemble the real production. The terminology used in Leitão & Restivo's (2007) Adaptive Holonic Control Architecture (ADACOR) can be adopted:

Task Holon (TH): Production orders launched, carrying all information of tasks.

Operator Holon (OH): Operators or physical resources, possessing a set of skills.

Supervisor Holon (SH): Supervisors, who coordinate and optimise the production.

In Figure 1, the HWM is a supra-holon composed of the sub-holons TH, OH and SH, also known as the first level holons. These holons group the second level or end sub-holons under their respective shells, namely tasks (h_T), operators (h_O) and supervisors (h_S). Both TH and OH are integrated with a database containing the information of each h_T and h_O, in order to continually inform the SH as well as the whole HWM about the current situation.

In a bidding fashion, OH provides information to TH of each operator's availability and skill rating. Based on the information received in TH, each task is matched with an individual operator to form a "contract", whereby the selected operator has to finish the incoming task. In terms of auction-based approach (Haque *et al.* 2008), OH is effectively the "seller agent", liaising with TH the "buyer agent", which determines the way to allocate the operators. The decision made by TH is not absolute and is later opened for the affected operators of OH to accept or reject the offer. This stage is considered as the negotiation stage allowing these operators to express their preferences. Essentially, the negotiation power of a relevant holon can be regulated by limiting its autonomy through the agency of cooperation.

Under normal circumstances, SH is passive and provides little interruption to the other holons. The intervention of SH is triggered only when severe degradation or abnormality is detected (e.g. the productivity falls below the baseline or the overdue rate exceeds its predetermined limit). To remediate the situation, SH is given the authority to take over the decision-making processes aforementioned. Therefore, a supervisor (under SH) may request for additional workforce or adjust the task orders (under TH). He may also instruct the operators (under OH) on alternative plans such as working overtime hours, resetting production orders, delaying certain deliveries, etc. Negotiation between SH and OH is permitted, while the extent of negotiation is governed by SH. The intervention of SH may continue until the production is back to normal.

2.2 Allocation formulation

The HWM determines which operator to handle which task, with an intention to promote the workforce flexibility by giving cross-training chances (on a case-by-case basis) while exerting minimum pressure on the overall productivity. The task urgency and the operator skill rating are taken into account. The urgency of task *i*, C_i, is defined as the ratio of processing time to allowable time. Based on the Learning Curve theory, the skill *i* held by operator *j*, $S_{i,j}$, can be rated according to his cumulative number of attempts on skill *i*, $N_{att(i,j)}$, and the learning rate, κ:

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

To pick operator *j* for task *i*, the "picking index", $\Pi_{i,j}$ is formulated and is inclusive of the corresponding skill, $S_{i,j}$ and the mean of the other skills held by operator *j*, $\bar{S}_{i:oth,j}$; the skill gap between the minimum, $S_{i,min}$, and maximum, $S_{i,max}$, of the operators; 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 operator is calculated. At the end, the one with the highest picking index will be selected:

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

The above equation is composed of three segments, namely the directive segment (i.e. the product of C_i and $S_{i,j}$), followed by the randomised segment and the relative segment. The rationale of Equation (2) is given: higher task urgency will amplify the corresponding skill rating on the directive segment and result in a smaller random value on the randomised segment. Consequentially, high-skilled operators will have higher tendencies to be allocated for the tasks with high urgency, so that the productivity can be secured. On the other hand, the tasks with low urgency will show a higher value on the randomised segment, which plays a more dominant role in the allocation. This dominant role provides a greater cross-training opportunity, as low-skilled operators will have a fairer chance to be selected. To eschew the potential inordinateness, the randomised segment is designed such that it is influenced by the range of the required skill (i.e. the gap between $S_{i,min}$ and $S_{i,max}$) and also the urgency of the task. Further, the third segment of the equation considers the task urgency in relation to the mean urgency, as well as the operator skill rating in relation to the mean of other skills. This segment holds a positive value if both the relative differences are positive or negative (i.e. multiplying two negatives makes a positive). The positive segment can uplift the picking index and vice versa. As a result, the matching is more probable between a relatively high-skilled operator and a task of high urgency (i.e. positive and positive) or between a relatively low-skilled operator and a task of low urgency (i.e. negative and negative). An operator possessing relatively low $S_{i,j}$ and high $\bar{S}_{i:oth,j}$ is unfit for tasks with high C_i, but he may be reserved for a task with low C_i (for cross-training purpose) or the other types of tasks (where he possesses a higher rating on average).

2.3 Experimental setup

A case study was conducted on a local carton manufacturer and a computer simulation model was thereby built to verify the feasibility of HWM. Each carton produced by the case company is made of recycled paper with corrugated pallet design, requiring five major parts or tasks: laminate the structure, make the lid, make the legs, make the box, and assemble the final product. When visiting the case company, the processing time data of the five tasks were collected. The simulation model contains three types of manufacturing elements: part, machine, and labour. These elements and the element flow have been created on Witness®, as shown in Figure 2. There are seven parts in total, representing the five tasks: T1 to T5, plus two disturbances: absence and turnover. The information carried by each simulation part includes its lot size and inter-arrival time. Seven machines are provided to process the respective parts and their information. The timely intervention of supervisors proposed in 2.1 is exempted from simulation due to its very complex nature. When a part arrives, the corresponding machine will select one operator from the group of labour to process the part and thereby change the operator's status to be "busy" (i.e. engaged in a task) or "unavailable" (i.e. involved in a disturbance), based on the machine's labour rule and cycle time. Once the processing is finished, the part is shipped out of the machine and the selected operator returns to be "idle" (i.e. available).

The programming, data input and output works were aided with Visual Basic® and Microsoft® Access. Three experiments will be conducted, namely All Typical (Exp. 1: AlTyp), High Demand (Exp. 2: HiDem) and High Disturbance (Exp. 3: HiDis). The performance measures include the tasks' overdue rate (ODR), the operators' average skill level (ASL), the interpersonal and intrapersonal skill deviations (InterSD and IntraSD). Since the duration for each experiment is two years and the performance is measured half-yearly, there are four intervals to trace the progress of simulated production: 1Y1H, 1Y2H, 2Y1H, and 2Y2H.

Four allocation models including HWM are chosen to be simulated one by one, and then be put into comparison. The three other models are termed as Random Allocation (RND), Skilled & Available Allocation (SAA), and Stationed for Total Specialisation (STS):

RND: The selection process among the available operators is totally random in spite of the evaluation of skill rating and task urgency. If no one is idling, the selection is open to everyone at work.

SAA: Always select the most skilled or specialised operator from the available ones despite the task urgency. If no one is idling, the selection is pointed to the most skilled operator among all who are at work.

STS: Permanently station each operator at a particular machine, disregarding any cross-training opportunity. As each operator is trained for only one skill and is rated high on the respective skill, total specialisation can be attained.

HWM: A relatively complex model based on the interactions between OH and TH, as the selection method formulated in Equation (2) is carried out. It will at first consider the idling operators, and then the busy ones if nobody is idling.

3. Results and Discussions

The four performance measures (i.e. ODR, ASL, InterSD and IntraSD) on comparing the HWM with other allocation models are acquired from simulation. These measures are required for statistical analysis, including analysis of variance (ANOVA). The analysis may provide sufficient support on the validity of the evidences produced, hence allowing comparison to be made between the allocation models.

3.1 Analysis of variance

All the performance measures in the three experiments may be analysed using ANOVA to help determine whether the difference found in each array of results is significant. F-test is conducted on the whole empirical data resulting from four independent allocation models (i.e. HWM, RND, SAA and STS) to investigate if significant difference exists among them. And then, Student's t-test is applied between HWM and each other model (i.e. HWM–RND, HWM–SAA and HWM–STS). Both the tests are subjected to 5% significance level, while a null hypothesis is given as "there is no difference between the models".

The null hypothesis of the F-test has been rejected in all cases, whereby the F-ratio computed in each array of results is greater than its corresponding critical value derived from the F-distribution at 5% significance level. It can be concluded that, in every experiment, the four allocation models are altogether significantly different in their performance measures. This leads to further investigation with Student's t-test, on which model has contributed the most differences or has shown any similarity to HWM.

For the Student's t-test, the only degree of freedom is calculated using the *Welch-Satterthwaite* equation on the populations with unequal variances. Since the degree of freedom is not always an integer, the interpolation technique is used to find the critical value on the same F-distribution. The critical value from F-distribution is required to check on the t^2 value computed in each case. This procedure is to determine the rejection status of the null hypothesis, as summarised in Table 1.

As of Experiment 1, when the simulated scenario is all typical, the null hypotheses in regard to overdue rate and intrapersonal skill deviation are all rejected. In the HWM–RND comparison, no significant difference is found in average skill level for the first and the last period of time, and the difference noted in the third period is marginal. This shows that RND can outperform HWM in the intermediate periods, but the difference between them will diminish in the long run. With regard to interpersonal skill deviation, most of the cases under HWM–RND and HWM–SAA present no significant difference. In this experiment, only the HWM–STS comparison rejects all the null hypotheses, showing that the difference between these two allocation models is always significant, upon every piece of result.

For Experiment 2 in the high demand scenario, the measure of overdue rate rejects all the null hypotheses in the first year, but not those under HWM–SAA and HWM–STS in the second year. This shows that a length of about one year is required for SAA and STS to catch up with HWM in meeting delivery times. About the average skill level, the HWM–RND comparison is similar to that of Experiment 1 — accept only the null hypotheses for the first and the last period. The comparison of HWM–STS rejects all of them, while HWM–SAA rejects three out of four. On the subject of interpersonal skill deviation, there is lack of evidence showing that HWM and RND are producing different effects. From the second period onwards, HWM–SAA rejects all the null hypotheses for interpersonal skill deviation but accepts all of them for intrapersonal skill deviation. This means that eventually HWM and SAA may differ in workload balance despite sharing similar cross-training chances.

For Experiment 3 in the high disturbance scenario, the measure of overdue rate rejects all the null hypotheses. In the matter of average skill level, HWM–RND accepts all the null hypotheses while the other two comparisons reject all of them. This shows that the average skill level of HWM is always close to that of RND and is far better than SAA and STS. HWM–RND and HWM–SAA accept most of the null hypotheses for interpersonal skill deviation but reject most of them for intrapersonal skill deviation, as these three models are making similar workload balance in spite of their different chances of cross-training. Again, the HWM–STS comparison rejects all the null hypotheses in this experiment.

3.2 Results of simulation

Each of the performance measures stated above may be obtained by averaging the percentage (%) values from five trials. There are a total of twelve graphs plotted in Figure 3 to display the four performance measures in three experiments.

With reference to overdue rate, HWM performs consistently to be the best model except in Experiment 2 (i.e. high demand) where it is outperformed by STS. Nonetheless, their gaps on average are considered marginal, as well as presenting a trend of gradual reduction and an eventuality in which HWM can perform better than STS. For longer term production, the trend indicates that HWM is preferable in lowering the overdue rate in that experiment. The difference is insignificant when comparing HWM with SAA and STS in the second year. In the aggregate of three experiments, the overdue severity in HWM is the least and remains low over time — make it the most favourable model among others.

The RND model records the greatest average skill level along with the smallest intrapersonal skill deviation in most of the cases. This shows that randomness may result in the best rating and balance of skills, but at the expense of overdue rate. As observed, RND always entails the highest number of overdue tasks and ranks the second-worst over STS in Experiment 3 (i.e. high disturbance). In an extreme case, the overdue rate of RND surpasses 44% during the first period of Experiment 2. The advantage of RND in average skill level over HWM is insignificant as their gaps are only 1.40~4.62%, 3.32~5.04%, and 0.04~2.76% in the three experiments. This is because, the (2) of HWM can duly increase the randomness in the operator 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 average skill level and promote workforce flexibility (a.k.a. "immunity" against disturbances) while exerting minimum pressure on the overall productivity. In terms of interpersonal and intrapersonal skill deviations, SAA is found to have growing interpersonal skill deviation over time while its intrapersonal skill deviation is decreasing. Contrary to this, the STS model always maintains the lowest interpersonal skill deviation below 5.00% despite holding the highest intrapersonal skill deviation in a narrow range of 23.38~26.86%. This model denies any cross-training opportunity as it allows each operator to be trained for one particular skill only. As specialisation is put to extreme, the highest intrapersonal skill deviation is observed. Meanwhile, the lowest interpersonal skill deviation implies that the workload distribution among operators is balanced at best. The performance of HWM in both the skill deviations is ordinary, as STS and RND hold better interpersonal skill deviation and HWM always makes the second lowest intrapersonal skill deviation after RND. Such a condition shows that HWM is not the best option if based solely on either workload balance or cross-training chances. However, it is very rare to take place in real production whereby only one performance measure, specifically workload balance or cross-training tendency, is optimised.

Based on the aggregate results, HWM has turned out to be the most advantaged model among others due to its high ranking in the first two important measures: overdue rate and average skill level. Even though HWM is outperformed by others in the interpersonal and intrapersonal skill deviations, these criteria have been considered secondary as they merely reflect the workload balance and the cross-training chances, without giving direct influence to the overall performance of the shop floor.

4. Conclusion

A holonic system, or holarchy, is commonly known as a flexible hierarchy consisting of holons. The holons, in coordination with the local environment, function as autonomous wholes in supra-ordination to their parts, while as dependent parts in subordination to their higher level controllers. When developing the HWM, notable holonic attributes such as autonomy and cooperation must have been integrated into the manufacturing components of the model. The HWM, on a case-by-case basis, performs labour assignment via checking the task urgency and the cross-training opportunity for the operators to expand their skills. Quantitative data items processed by the task holon (e.g. task urgency) and the operator holon (e.g. skill rating) are taken into a complex, duly randomised formulation. With the purpose of selecting a best-suited operator for each task given, the formula is composed of specific segments called directive segment, randomised segment, and relative segment. These three segments, each with its own computational scheme, are intended to make a collective decision apportioning the chances between specialisation and cross-training upon every task’s arrival.

Verification is often required on a newly developed model to prove its feasibility or credibility. With this premise, a computer simulation model is built on varied scenarios, thereby comparing the HWM with three other allocation models in terms of their overdue rate, average skill level, interpersonal and intrapersonal skill deviations. The F-test and the t-test of ANOVA are carried out to investigate the differences between these allocation models. As proved by the results obtained from simulation, the performance of HWM is superior to the other models as it consistently achieves the lowest overdue rate and higher average skill level, with moderate interpersonal and intrapersonal skill deviations. This series of results sufficiently conclude that HWM is over time able to balance the requirements to meet delivery time via specialisation and to improve workforce flexibility via cross-training. Most importantly, the minimal overdue rate reflects that the aggregate impact of absenteeism and turnover is significantly reduced in HWM, thus achieving the main objective of this research.

The current HWM is devised to manage a homogeneous group of operators, presumably local and hired on a permanent basis. In future, the application may be extended to a heterogeneous workforce such as a mix of local and foreign operators (from different backgrounds), a mix of permanent and contract or temporary operators (from different employments), or a mix of operational and supervisory workers (from different positions). Under these circumstances, additional considerations and relatively complex training policies are needed. The contract or temporary operators may be assigned to a different set of tasks as they are usually less cross-trained than permanent operators. If supervisors and operators are being managed together, the supervisors’ absenteeism and turnover may result in a different impact. Hence, a different scheme needs to be applied for the evaluation and selection of the supervisors. The use of HWM can also be explored in other forms of labour-intensive manufacturing such as production flow lines and assembly cells. Further attention needs to be paid to the efficiency in handling the information and interactions between holonic components. In this computer era, a range of software packages under the flag of HWM may be developed to suit various manufacturing divisions, as well as to facilitate the holons' data input and conversion for the decision-making processes.

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Table 1: Rejection status of null hypothesis in Student's t-test

t–test		Rejection of Null Hypothesis (Yes / No)											
Meas.	Exp.	1Y1H			1Y2H			2Y1H			2Y2H		
		RND	SAA	STS	RND	SAA	STS	RND	SAA	STS	RND	SAA	STS
ODR	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No
	3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ASL	1	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	2	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes
	3	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Inter SD	1	No	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes
	2	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	3	No	No	Yes	No	Yes	Yes	No	No	Yes	No	No	Yes
Intra SD	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	2	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes
	3	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes

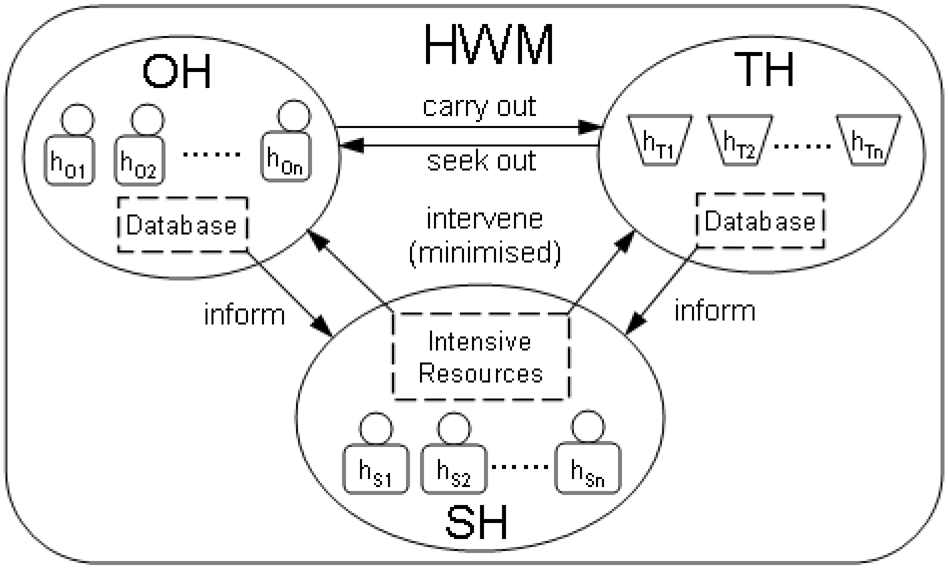

Figure 1: Holarchy of HWM

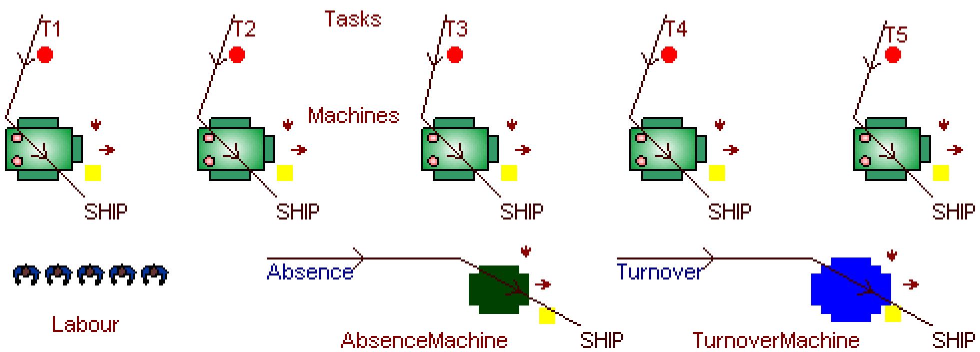

Figure 2: Witness® simulation layout

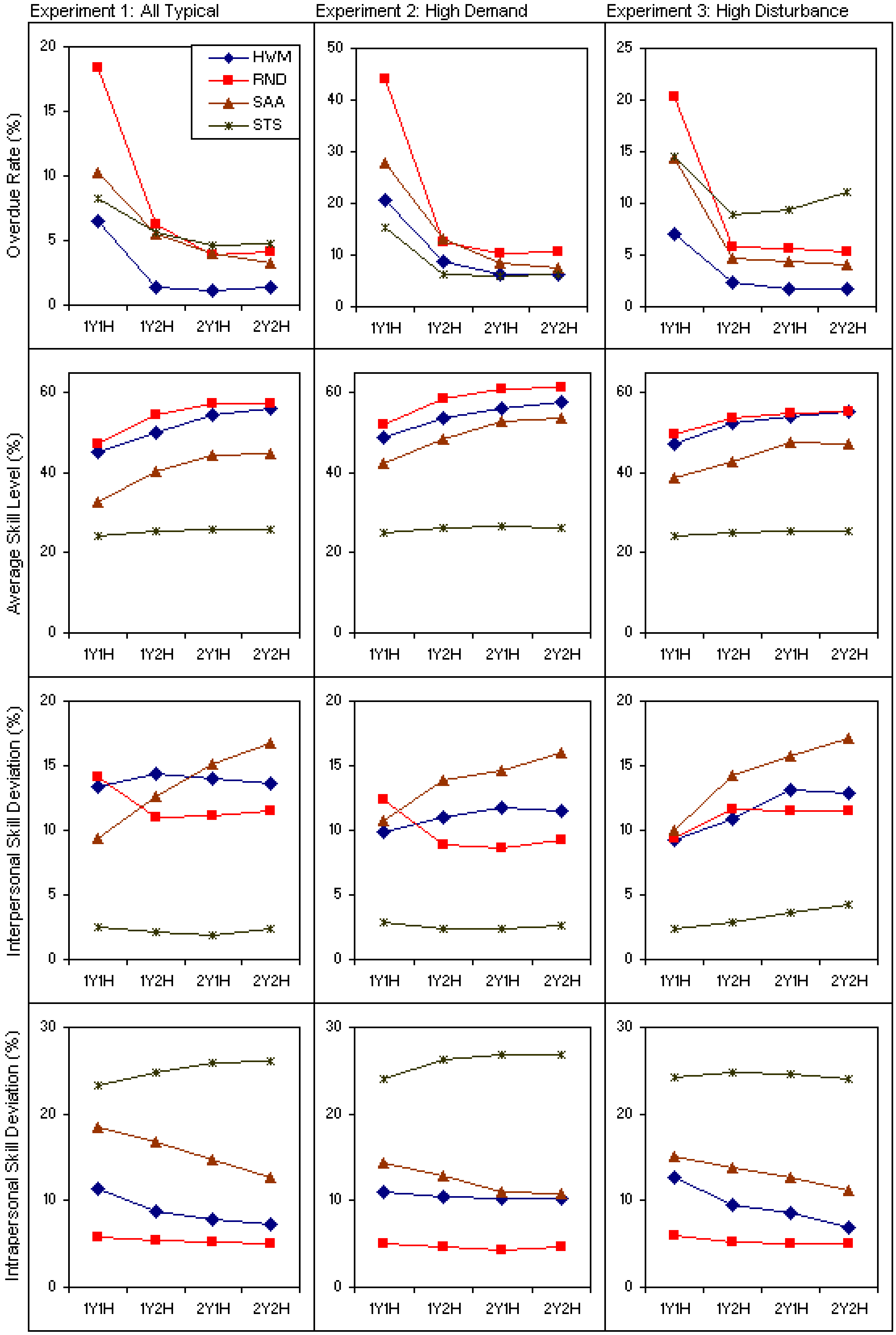

Figure 3: Results of simulation