HOLONIC WORKFORCE ALLOCATION TO REDUCE THE IMPACT OF ABSENTEEISM AND TURNOVER

by

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Thesis submitted in fulfillment of the requirements for the degree of Master of Science

May 2011

ACKNOWLEDGEMENT

First, I would like to acknowledge my research supervisor, Dr. Chin Jeng Feng from School of Mechanical Engineering (Universiti Sains Malaysia) for guiding me through the progress of this study. His invaluable advice and comments have helped me a great deal in accomplishing the research.

I would also like to express my gratitude to my beloved family and my thoughtful employer for their encouragement as well as moral support during the period of this part-time study.

Last but not least, I would like to thank the people who have helped proofread my writing.

Lim Yong Ching

May 2011

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LIST OF ABBREVIATIONS

Abs	Absence
ADACOR	Adaptive Holonic Control Architecture
AlTyp	All Typical
ANOVA	Analysis of Variance
ASL	Average Skill Level
DLL	Dynamic Link Libraries
DSST	Dictionary of Scientific & Technical Terms
EC	European Community
EFTA	European Free Trade Association
Eq.	Equation
EtoPlan	Engineer-to-order Planning
FCFS	First-come-first-served
FISFS	First-in-system-first-served
FNS	Fewest Number of Skills
HiDem	High Demand
HiDis	High Disturbance
HMS	Holonic Manufacturing System
HWM	Holonic Workforce Allocation Model
IMA	Intelligent Machine Architecture
IMS	Intelligent Manufacturing Systems
InterSD	Interpersonal Skill Deviation
IntraSD	Intrapersonal Skill Deviation
LIT	Longest Idle Time
LNQ	Longest Queue

LoWof	Low Workforce
Max	Maximum
Min	Minimum
MEF	Most Efficient
MPS-T	Master Production Scheduling for Temporary Workers
MS	Microsoft®
ODR	Overdue Rate
OH	Operator Holon
OOP	Object Oriented Programming
PL	Proficiency Level
PMLTC	Post-match Labour Turnover Costs
PROSA	Product-Resource-Order-Staff Architecture
RND	Random Allocation
SAA	Skilled & Available Allocation
SD	System Dynamics
SH	Supervisor Holon
SQL	Structured Query Language
SST	Soft Systems Thinking
Std. Dev.	Standard Deviation
STS	Stationed for Total Specialisation
TH	Task Holon
Tnv	Turnover
UML	Unified Modelling Language
US	United States
VB	Visual Basic®

LIST OF SYMBOLS

A	operator availability
C	task urgency
D	task demand
F	F-ratio
F_t	forecast value
f	frequency
h	end sub-holon
L	simulation labour
M	machine
N_{att}	number of attempts
N_M	number of machines
N_{Op}	number of operators
N_S	number of skills
O	operator
P	simulation part
R	random number
S	skill rating
$\overline{S}$	average skill level
T	task
t	t-statistic
t^2	equivalent F-ratio
$\bar{t}$	average duration
t_{idl}	operator idling time
t_{pro}	processing time
t_{res}	resultant time
t_{rev}	review interval
U	machine utilisation rate
w	segment weight
Y_t	actual value
α	smoothing constant
γ	first attempt standard ratio
δ	disturbance rate
κ	learning rate
Π	picking index
σ	standard deviation
σ^2	variance
σ_{inter}	interpersonal skill deviation
σ_{intra}	intrapersonal skill deviation
χ	operator idling rate
Ω	overdue status

PERUNTUKAN TENAGA KERJA HOLONIK BAGI MENGURANGKAN IMPAK KETIDAKHADIRAN DAN PUSINGGANTI

ABSTRAK

Sistem Pembuatan Holonik (HMS) mengambil generalisasi Arthur Koestler mengenai organisma hidup dan organisasi sosial ke dalam suatu paradigma baru yang sesuai untuk industri pembuatan. Autonomi dan kerjasama adalah dua ciri yang utama bagi holon. Konsep-konsep holonik telah digunakan pada banyak bidang tetapi jarang dicubai terhadap peruntukan tenaga kerja. Justeru, kajian saintifik ini membentuk suatu model penasihat dua peringkat bernama *Model Peruntukan Tenaga Kerja Holonik* (HWM) dengan tujuan mengatasi masalah ketidakhadiran dan pusingganti. Peringkat yang pertama, iaitu perancangan pra-aktif menggunakan teknik pemulusan eksponen untuk meramalkan bilangan operator bagi mengendali pelbagai tugasan. Peringkat kedua yang dinamakan peruntukan reaktif mencipta suatu rumusan berunsur rawak supaya dapat memberi peluang latihan bersilang di samping pengkhususan. Dengan adanya data contoh, kajian kes serta simulasi komputer, HWM telah dieksperimenkan dalam beberapa senario dan dibandingkan dengan model-model yang biasa digunakan dalam pembuatan. Keputusan eksperimen menunjukkan bahawa HWM berkeupayaan untuk menentukan jumlah tenaga kerja mengikut keperluan dan lebih berkesan daripada yang lain dalam meminimakan kadar kelewatan tugas, memperbaik taraf kemahiran purata, dan mewujudkan keseimbangan beban kerja serta peluang latihan bersilang yang sewajarnya. Oleh demikian, penyerapan ciri-ciri holonik dalam peruntukan tenaga kerja adalah berharapan, sedangkan aplikasinya boleh dilanjutkan kepada bentuk-bentuk pembuatan padat-buruh yang lain seperti sel pemasangan dan talian pengeluaran.

HOLONIC WORKFORCE ALLOCATION TO REDUCE THE IMPACT OF ABSENTEEISM AND TURNOVER

ABSTRACT

Holonic Manufacturing System (HMS) adopts Arthur Koestler's generalisation on living organisms and social organisations into a novel paradigm that suits the manufacturing industry. Autonomy and cooperation are the prime attributes of holons. The holonic concepts have been applied to many areas, and yet, rarely attempted on workforce allocation. Hence, this scientific research is intended to develop a dual-level advisory model called *Holonic Workforce Allocation Model* (HWM) in order to deal with absenteeism and turnover. The first level, termed as pre-active planning, uses the exponential smoothing technique to forecast the number of operators required on a variety of tasks. The second level is called reactive allocation and is associated with a weighted randomised formulation that can provide cross-training opportunities in parallel with specialisation requirements. With the aid of mock-up data, case study and computer simulation, HWM has been experimented in several scenarios and been compared with some models commonly used in manufacturing. The experimental results show that HWM has the capability to determine the workforce size according to demand and 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. With such outcome, incorporating holonic attributes into workforce allocation is promising, while its application can be extended to other forms of labour-intensive manufacturing such as assembly cells and production flow lines.

CHAPTER ONE

INTRODUCTION

1.0 Overview

In the highly competitive as well as transformative business environment, increasing customer requirements for greater product variety and shorter lead time have prompted manufacturing companies to adopt new paradigms that can provide advantages in terms of flexibility and productivity. One of the up-to-date paradigms being researched worldwide is holonic manufacturing, in which computers, humans and machines are integrated into a functional manufacturing unit to primarily cope with dynamics in the appertaining circumstances.

The very first idea of "holon" was written in an Arthur Koestler's book called *The Ghost in the Machine* (Koestler, 1967). In 1993-1994, that idea, termed as Holonic Manufacturing System (HMS), was adopted in one reputable international collaborative research. The research attention was particularly focused on the two hallmark features of HMS: autonomy and cooperation, which derive from biological and social systems. It is important to emphasise that HMS does not represent a new technology; in fact, it is a novel methodology proposed to connect and make use of existing technologies with human interfaces (McFarlane, 1995). Beneficially, the application of HMS may help to continue the production work even when some resources are temporarily out of action (Fletcher & Hughes, 2006).

In the past research related to HMS, technical elements were given much more attention than human elements in spite of the autonomous and cooperative natures inherent in human beings. Even though the holonic concepts were first used to analyse biological and social systems, the technological packages like factory automation and artificial intelligence (i.e. in the substitute of front end operators and/or human decision-makers) were somehow largely promoted in HMS. With a different viewpoint, this research believes that human participation is still paramount in HMS, thereby proposing a relevant holonic framework to deal with changes as well as disturbances concerning the workforce in manufacturing operations.

Evidently, HMS is suitable to improve work organisation with no technology investment. According to a case study conducted on a ship-engine manufacturer (Sun & Gertsen, 1995), the productivity of the company's milling shop had an increase of about 30% owing to a formation of autonomous and cooperative workforce, without further investments in equipment. On that score, a series of organisational changes were carried out and then redefined from the holonic point of view (Sun & Venuvinod, 2001). Despite being applied to a myriad of research fields, the concepts of holons and holonic systems are rarely attempted on workforce allocation, quantitatively (e.g. to plan the size of workforce) or qualitatively (e.g. to select an operator for each task). Such findings greatly motivate this research to investigate the incorporation of HMS paradigm into a workforce allocation model.

Although automated production has come into play in the recent decades, workforce is still necessary in most factories. Full adoption of "unmanned manufacturing" (Deen, 1993) is forbiddingly expensive and the results obtained have not been promising (Sun & Venuvinod, 2001). For labour-intensive manufacturing, factories are equipped with relatively simple machinery controls and hence require continuous attendance and handling from human operators (Süer &

Dagli, 2005) — for examples: medical appliances, textile mills, crafts sectors, leather products, soft furnishings, etc. In these factories, the workforce expenditure is proportionally larger (Techawiboonwong et al, 2006). Consequently, workforce management is still a contemporary research issue.

1.1 Problem Statement

Absenteeism and turnover are the two major disturbances in any labour-intensive industry, as they result in production losses (Easton & Goodale, 2002). 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, and lost business opportunities (Herman, 1997; McConnell, 1999; Richardson, 1999).

The occurrence of absenteeism and turnover is sometimes ascribed to poor management rather than bad attitude from workers involved (Khatri et al, 2000; Dionne & Dostie, 2007). To 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).

These methods are highly practical to reduce the impact of absenteeism and turnover on production.

1.2 Objective

The objective of this research work is to develop an advisory workforce allocation model based on the HMS paradigm. The aims of the advisory model are:

- to regulate the number of operators in job shop.
- to allocate a suited operator for each scheduled task.
- to reduce the impact of absenteeism and turnover on production.

1.3 Research Scope

The target group of workforce and the type of tasks to be handled are respectively front end operators and routine production tasks. With this premise, tasks with greater difficulty levels beyond the general qualifications of operators, such as machine setup, maintenance and repair, are excluded. When allocating individual operators to a particular set of tasks, cross-training is incidental to the urgency of these tasks, in order to increase the skill variety of these operators.

The manufacturing disturbances only include absenteeism and turnover. In simulation, only the intensities and frequencies of these disturbances are taken into account.

1.4 Thesis Outline

This thesis is composed of five chapters. Chapter One is an introductory chapter to set out the problem statement, objective, and research scope. Chapter Two is the literature review about the research, encompassing the holonic manufacturing concepts, workforce management, and experimental design. Chapter Three is the research methodology, which identifies the input data, stratifies the allocation model, and specifies the holonic architecture. A dual-level advisory model consisting of pre-active planning and reactive allocation is built and is entitled *Holonic Workforce Allocation Model* (HWM). Through experimentation, the pre-active planning can be verified using a mock-up data and then four allocation models inclusive of HWM will be investigated under several circumstances. All the experimental results are analysed and discussed in Chapter Four to prove that the HWM is capable of fulfilling the research objective, as well as outperforming the other models. Lastly, Chapter Five is written to conclude the research content and to suggest some future works.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter at first reviews Holonic Manufacturing System (HMS) in terms of the background and concepts, the development and applications, as well as the feasibility on workforce management. Then, the matter of workforce management is studied with regard to absenteeism and turnover, cross-training, and the processes of evaluation and selection. Attention is also paid to the experimental design approach, which is inclusive of manufacturing simulation, comparison models, performance measures, and analysis of variance (ANOVA).

2.1 Holonic Manufacturing System (HMS)

The term "holonic" is derived from the word "holon", which was introduced by a Hungarian author and philosopher Arthur Koestler in 1967. The word holon combined 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). The other characteristics of holons include:

- As self-reliant units, holons have a degree of independence and handle circumstances and problems on their particular levels of existence without reaching higher level holons for assistance. The self-reliant characteristic ensures that holons are stable, able to survive disturbances.
- Holons receive instruction from and, to a certain extent, be controlled by higher level holons. The subordination to higher level holons ensures the effective operation of the larger whole.
- Holons cooperate with peers in order to organise and reorganise themselves based on mutually acceptable plans. This is for solving any problem or conflict they might encounter from time to time, and ultimately, serving the goals of the larger whole.

Figure 2.1 shows the interactions between holons in terms of subordination to whole and cooperation with peers.

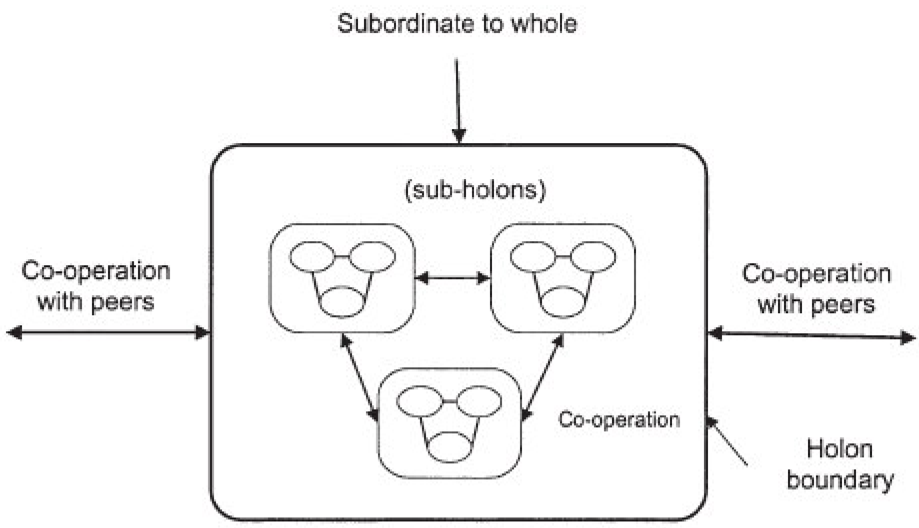

Figure 2.1: Holons and their interactions
(adapted from Van Brussel et al, 1998)

2.1.1 Background and Concepts

To achieve a higher level of efficiency and competitiveness in manufacturing operations, the European Community (EC), European Free Trade Association (EFTA), Australia, Canada, Japan and the United States (US) founded an international collaborative research programme called Intelligent Manufacturing Systems (IMS) around 1993. At that time, it was probably the largest research programme ever launched on manufacturing. This programme consists of six major projects, in which one of them is ‘Holonic Manufacturing Systems: system components of autonomous modules and their distributed control’, known by the acronym HMS.

Over the four years of the IMS feasibility study, HMS became one of the first fully endorsed IMS projects in 1997. The International HMS Consortium was then formed and dedicated to replicate in manufacturing the strengths that holonic systems provide to living organisms and societies, such as stability in the face of disturbances, adaptability and flexibility in the face of change, and efficient use of available resources (Bongaerts, 1998). Under the consortium, Koestler’s findings were first translated into a set of appropriate concepts for manufacturing purpose. The ultimate goal was to derive a novel integration methodology for a number of existing technologies, thereby integrating computers, humans and machines into a single function holonic manufacturing unit capable of adjusting itself to varying production demands (McFarlane, 1995). A list of definitions (Table 2.1) was given to help understand and guide the standardisation of holonic concepts during the HMS feasibility study.

Table 2.1: Definitions by HMS consortium
(adapted from 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.
Holonic Attributes	Attributes of an entity that make it a holon. The minimum set is autonomy and cooperativeness.
Holonomy	The extent to which an entity exhibits holonic attributes.

According to Subramanian et al (2001), the complex and dynamic nature of HMS arises from four basic control attributes: real-time control, event-driven control, intelligent control, and distributed control. The real-time control is required for holons to process the relevant information because 'the correctness of the system depends not only on the logical result of the computation but also on the time at which the results are produced' (Stankovic, 1988). The event-driven control can be used to describe the dynamic behaviour of holons, to the extent that their action plans are developed and executed through the occurrence or non-occurrence of certain events.

The intelligent and distributed control is important to make a holonic system reconfigurable and adaptive to changes. A system component that uses intelligent control is expected to be able to accomplish its specific task in the presence of uncertainty and variability in its environment (DSST, 2003). In practical terms, intelligent control can help resolve problems, identify objects, or plan a strategy for a complicated function of a system (Cai, 1997). A significant example of intelligent control in our daily life is the *anti-skid brake system* for motor vehicles. With respect to distributed control (also known as decentralisation), the system components, each with its own functions, are flexibly interconnected (instead of relying on a centralised regulator) to carry out integrated data acquisition, dynamic behavioural control, as well as decision-making application (Hardy-Vallée, 2007).

The control attributes explained above have also been well correlated with autonomy and cooperativeness, namely the two main attributes possessed by holons. Marik et al (2002) defined a holon as ‘an autonomous cooperative unit which can be considered as an elementary building block of manufacturing systems with decentralised control.’ The definition given by Wooldridge (2002) is even more specific, that is ‘a holon, aware of its situated environment, uses its intelligence, autonomy, cooperation and self-similarity to meet the design and organisational challenges associated with responsive and flexible manufacturing by performing rational reasoning task and balancing goal-directed with reactive behaviour.’

2.1.2 Development and Applications

Most of the existing manufacturing systems are engaged in a strict set of conditions, and hence, the system performance may drop abruptly and drastically when these conditions are not fulfilled. For example, the failure of a machine in a manufacturing assembly line can halt the entire line until the machine is repaired. According to McFarlane (1995), such drawback 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, making it responsive and stable in the face of changes or disturbances. To vividly explain the difference between rigid and flexible hierarchies, McFarlane likened the rigid hierarchy to "rail system" and the flexible hierarchy to "city taxi system" — the rail timetable is set independently of any periodical variation, whereas the taxi system essentially follows the demand for its use in town.

The concepts of holons and holonic systems, in conjunction with technical measures, have been applied to many areas of interest. Gou et al (1998) developed a holonic scheduling model using *Lagrangian Relaxation* for a factory equipped with multiple cells. Shu et al (2000) emphasised the HMS reusability, configurability and extensibility with the aid of *Unified Modelling Language* (UML) and *Intelligent Machine Architecture* (IMA). Giebels et al (2001) built the multiple and temporary holarchies for concurrent manufacturing planning and control named "EtoPlan", after the concept of *engineer-to-order planning*, in a prototype software system that resolves production randomness and information incompleteness. Arai et al (2001) proposed a new concept "Plug & Produce" on their holonic assembly system to handle three manipulators, one belt-conveyor, and two warehouses with the purpose of meeting unexpected assembly requests. Ulieru et al (2001) described holonic enterprise as a "collaborative information ecosystem" where the workflow can be managed through communications between the inter-enterprise, intra-enterprise, and machine levels. Huang et al (2002) framed a holonic virtual enterprise control consisting of global coordinator and member enterprises to enhance the cost-effectiveness on planning, resource sharing, and dealing with changes. Fletcher & Hughes (2006) discussed the technology and policy challenges to be encountered for introducing holons into factory automation. In the realm of higher education management, Bell et al (2000) set forth a "holon planning and costing framework" based on *System Dynamics* (SD) and *Soft Systems Thinking* (SST) to assist in improving the teaching and research quality given the cost constraints.

To gain a better insight of the holonic approach used in manufacturing, Leitão & Restivo (2007)'s *Adaptive Holonic Control Architecture* (ADACOR) is worthwhile to explore. ADACOR intends to achieve fast rescheduling combined with global optimisation. The system consists of three types of holons, namely supervisor holon (SH), operator holon (OH) and task holon (TH). Such arrangement can be viewed as an extension from McFarlane & Bussmann (2000)'s *Holonic Component Based Architecture*, in which there are two classes of holons: resources and orders. Order holons are spawned upon a purchase request with a "recipe" describing how that product will be made. The order holons negotiate with the resource holons (who offer manufacturing services) to achieve the goals within the recipe. When these components are extended into ADACOR, the order holons and resource holons are respectively represented by a parallel series of tasks under TH and a group of operators under OH, while the recipe is composed of the optimised scheduling plans generated by SH.

In normal operations, i.e. without the occurrence of unexpected disturbances, SH can always coordinate the resources in OH and optimise the scheduling plans to meet the TH production orders. Though the OH members have the capability to accept or reject the plans, they normally follow the advice given by SH as they have a lower level of autonomy. But once an unexpected disturbance is noticed, the coordination of SH is temporarily void and substituted with a distributed scheduling mechanism; wherein, each holon is given the autonomy to resolve the disturbance within the estimated recovery time. Based on the direct interactions between OH and TH, any operation belonged to a broken resource is reallocated to another similar resource. The key to the success of such holonic architecture is the cooperativeness between the interacting holons.

2.1.3 HMS for Workforce Management

The holonic mechanism is rarely attempted on workforce management. Sun & Venuvinod (2001) raised the fact that most research works related to HMS are focused on technical aspects. They brought up the need for investigating the system in a proper balance of both technical and human elements. Although there is no direct indication of conflict to incorporate human capital into HMS, two schools of thought on the eventuality of HMS have come into notice. Tonshoff et al (1994) stated that a human participant is often a part of a holon involved in the information processing and sometimes the physical processing, contradicting the largely automated "unmanned environment" concept claimed by Deen (1993). Fletcher & Hughes (2006) suggested that it is most cost-effective to implement HMS in countries with high labour costs, as the effective automation will reduce the need for human employees. Van Brussel et al (1998) presented a reference architecture called *Product-Resource-Order-Staff Architecture* (PROSA) consisting of three basic holons (i.e. product holons, order holons and resource holons) as building blocks, while staff holons can be added to assist the basic holons with expert knowledge.

According to Bongaerts (1998), HMS is intended to preserve a place for humans, since they are the most flexible and intelligent components in the system.

On the other hand, the integration of HMS into workforce management may be timely re-examined due to the interesting characteristics possessed by holons. Workforce management in the manufacturing sector has become more challenging as the current business environment demands shorter processing lead time and maximum utilisation of capacity including labour, with the purpose of handling fluctuated customer orders while maintaining daily productivity. Manufacturing systems are vulnerable to disturbances (e.g. absenteeism and turnover) unless they are able to cope with the degree of environmental influences or changes. Any policy devised to negate disturbances can itself be a complex and interwoven combination of problems that involve management, design, maintenance, as well as operator functions (Harlin, 2002).

2.2 Workforce Management

To narrow the focus of this research, only the effects of absenteeism, turnover, and cross-training are taken into consideration.

2.2.1 Absenteeism and Turnover

Absenteeism and turnover are recognised as the two major disturbances in labour-intensive manufacturing (Easton & Goodale, 2002), because of the fact that they may lead to resource shortage and production losses. The issue is not new, as independent reports by Syrett (1994), Barnett (1995), Chang (1996), and Leonard (1998) have pinpointed the voluntary turnover as a major problem for companies in Asian countries like Hong Kong, Malaysia, Singapore, South Korea, and Taiwan.

According to The Business Roundtable (1989), excessive rework, poor supervision, and unsafe working conditions are the frequent reasons for absenteeism than personal illness, whereas unproductive relationship and poor management are the prime reasons cited by the workers for turnover. Dionne & Dostie (2007) used a linked employer-employee data to present the evidence on the determinants of absenteeism. Their evidence showed that work arrangement issues are the important determinants of absenteeism. A similar study was conducted by Khatri et al (2000) to find the major source of turnover with respect to demographic, controllable and uncontrollable factors. They concluded that turnover is due to poor management practices rather than bad attitudes.

Absenteeism and turnover often result in overtime and additional expenses. According to Herman (1997), McConnell (1999), and Richardson (1999), until a vacant task is attended, the employer may have born overtime costs, reduced productivity and lengthened customer queue times, lost sales and business opportunities, along with the likelihood of additional absenteeism and turnover due to the extra work shouldered by coworkers of the departing employees. With regard to overtime, Brunies & Emir (2001) calculated the loss of productivity due to overtime using published charts and Yap (2006) investigated the effect of extended overtime to labour productivity in construction. For additional expenses, Silva & Toledo (2006) extended a current model by introducing the *Post-match Labour Turnover Costs* (PMLTC) to compute the total cost associated not only with hiring but also with training of new recruits and separation of employees.

Buffering with redundant skilled workers (Molleman & Slomp, 1999) or relief workers (Redding, 2004) might be a direct solution to absenteeism, but the rising labour cost must be justifiable as any resultant underutilisation of labour during low demand seasons is a form of production wastes. Easton & Goodale (2002) developed a labour scheduling model to mitigate the day-to-day operational impact of absenteeism and turnover through short-term staffing and scheduling decisions. The *Bradford Factor* is used by many organisations to measure and identify areas of absenteeism, serving as a deterrent to tackle persistent absenteeism (Edays, 2005). In the face of high absenteeism, Vikesland (2007) suggested four actions: change management style, change working condition, provide incentive, and develop attendance policy.

The general causes and effects of absenteeism and turnover, along with some techniques used to measure or counteract these disturbances, have been exhibited in the above context. Nevertheless, the literature to date has only paid limited attention towards reducing their aggregate impact by means of planning the workforce size, setting the training and assignment rules, as well as using the holonic concepts.

2.2.2 Cross-training

Cross-training is a conduct in which a group of workers are trained on different tasks to broaden their capabilities (i.e. spectra of skills), thereby providing better ways to meet customer needs (Hopp & VanOyen, 2004). The most prevalent objective of cross-training is to improve workforce flexibility. Molleman & Slomp (1999) defined this type of flexibility based on three concepts: functional flexibility as the total number of skills in a group, multi-functionality as the number of different machines a worker is able to cope with, and machine coverage as the number of operators that can operate a specific machine. They also stated that demand variation and absenteeism are the two important conditions affecting the required level of workforce flexibility. This built the case for the development of a cross-training policy that can help reduce the impact of absenteeism, as well as turnover, in the face of variable demand or resources.

On the other hand, Kher & Malhotra (1994) observed that higher levels of flexibility may lead to more labour transfers and considerable losses in productivity, while most of the benefits can be attained without going to the extreme of flexibility. Molleman & Slomp (1999) also found that too much multifunctionality and machine coverage can make worker skills remain unused and workers begin to feel that their contributions are less unique. Since they are no longer specialised, each worker's capacity on a specific task is lowered (Qin & Nembhard, 2007).

With reference to the mentioned advantages and disadvantages associated with cross-training, it can be concluded that having a cross-trained workforce may support an organisation's strategy only if it is carefully designed and operated. Since full workforce flexibility is practically not needed, a question about what is the appropriate level of cross-training to achieve optimal performance is frequently raised (Nembhard & Norman, 2007). Hence, determining the proper extent of cross-training is always an important aspect to consider when forming a relevant policy.

Extensive research papers have also been produced recently in regard to the design and examination of cross-training policies. Slomp et al (2005) built an integer programming model that can be used to select workers to be cross-trained in a cellular production. Nembhard & Prichanont (2007) described the factors affecting the cross-training performance in serial production systems, inclusive of staffing level, bottleneck position, task similarity, rotation interval, and multifunctionality. Stagl et al (2007) suggested nineteen best practices of cross-training to aim for a better array of results comprising financial performance, adaptation, efficiency, productivity, safety, service quality, satisfaction, and commitment. Tai (2009) investigated the respective influences of four cross-training strategies in assembly lines, namely scheduled rotation, floating operators, zoned work-sharing, and craft. From their collective research outcomes, a conclusive statement can be made, that is, different objectives or environments may require different cross-training strategies to achieve optimum performance. This is because, the way of making a cross-training policy is greatly affected by the environmental factors, such as production layout and workload demand.

2.2.3 Evaluation and Selection

Workforce evaluation is a method that provides rating for a group of operators who are ready to be assigned a given list of tasks. An evaluation function may take one or more criteria into account, making a certain problem solving mode more precise and less difficult (Pastor & Corominas, 2007). Workforce selection is a complex decision-making procedure, aiming to place the right operators on the right tasks at the right time, based on an integrated set of qualitative and/or quantitative data acquired from the evaluation process. In the context of holonic control requirements (Subramanian et al, 2001), the evaluation data needs to be real-time updated (i.e. information processing) to support the event-driven selection process (i.e. action planning), as mentioned in Sections 2.1.1 and 3.2.2.

Two non-holonic examples of workforce evaluation are discussed as below. Techawiboonwong et al (2006) created a mixed integer programme called MPS-T, which stands for *Master Production Scheduling for Temporary Workers* and divides the workers into “skilled” and “unskilled” categories to be allocated to several flow lines of workstations under the same dichotomy. Another current evaluation model is referred to Golec & Kahya (2007), who offered a relatively comprehensive hierarchical structure using a competency-based fuzzy model with a wider scope of evaluative criteria: self-motivation, communication, interpersonal skills, decision-making, knowledge, career development, and management. Each criterion would split into yet another set of subpoints, individually gradable in the fuzzy linguistic values such as *P (poor), F (fair), A (average), G (good),* and *S (superior)*. By and large, the MPS-T model is found to have deficient numeric details about worker qualifications, while the fuzzy model of Golec & Kahya is subjected to tendency of overlapping in its large set of criteria. As their primary source of input is from human expert or supervisor, bias is inevitable in these two evaluation models.

Lai (1995) described the operator selection process as a multi-objective decision-making problem. In general, productivity (via specialisation) and flexibility (via cross-training) may be a pair of objectives that are contradictory to each other. To accommodate such objectives under one system, a range of factors need to be considered so that a best-fit decision can be made on each case. The range of factors may include operator skill and availability, task demand and urgency, cross-training opportunity, etc. This corresponds with Iwamura & Lin (1998), who explained that the selection process requires the accomplishment and aggregation of different factors.

For more recent and relevant examples, Lazarevic (2001) presented a selection fuzzy model to minimise subjective judgment in distinguishing between an appropriate and inappropriate operator for a task position. Bokhorst et al (2004) introduced the “who-rule” model to determine which operator should be assigned to a task if more than one skilled operator is available. They also studied the assignment or reassignment possibilities for all idling members in order to minimise unprofitable 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.

2.3 Experimental Design

Experimentation is often required to investigate how well a particular model can perform, in comparison with different models holding the same function or objective. The investigation also requires the definition of performance measures. In operational research, running experiments via computer simulation is a common approach. The experimental results obtained later will be analysed using a suitable statistical tool: analysis of variance (ANOVA). Hence, some past findings about manufacturing simulation, comparison models, performance measures, and ANOVA are highlighted in the following context.

2.3.1 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 Pannirselvam et al (1999)'s survey on selected journals published between 1992 and 1997, simulation has emerged as a primary research methodology in operations management. 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.

Although simulation does not assure optimal solution, it is the only proper analysis technique when formal mathematical methods fail to reflect some behaviour of a system (Lanner, 2000). The strengths of simulation (Yücesan & Fowler, 2000) may 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.

Though 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 a primary goal 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, whereby 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).

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. More details of this application will be discussed in Section 3.5.1. Calinescu et al (1999) defined the strength of Witness® as a leading software tool that holds variability-related capabilities, allowing for low-cost rapid development of flexible and generic simulation models.

2.3.2 Operator Selection Models

In literature, a number of operator selection models have been commonly used for experimentation or comparison purpose. The selection models based on task status (e.g. arrival time or sequencing) include *first-come-first-served* (FCFS), *first-in-system-first-served* (FISFS), and *longest queue* (LNQ). Besides, there are some models related to operator status (e.g. availability or skill rating), such as *longest idle time* (LIT), *most efficient* (MEF), *proficiency level* (PL), and *fewest number of skills* (FNS). The simplest and non-technical model among others is *random* (RND). All these selection models were shown in Rochette & Sadowski (1976), Hogg et al, (1977), Kher & Malhotra (1994), Bokhorst et al (2004), and Bokhorst & Slomp (2007).

Special attention is given to three of the selection models listed above — first, the RND that chooses an operator randomly when a choice between operators has to be made (Bokhorst et al, 2004); second, the MEF derived from Hogg et al (1977) to select the operator who is the most efficient at performing the task (e.g. to have the available operator with the highest skill rating); third, the FNS created in Bokhorst & Slomp (2007) that assigns the operator possessing the fewest skills to the machine (e.g. the number of skills can be 1 for the maximum level of specialisation). These three selection models will be readopted in Section 3.5.3, whereby the second and third models (i.e. MEF and FNS) are respectively redefined as *Skilled & Available* (SAA) and *Stationed for Total Specialisation* (STS).

2.3.3 Performance Measures

Manufacturing system performance is often measured in terms of production time and productivity. Bokhorst et al (2004) studied the flow time effects of applying different labour assignment rules in several pre-defined systems. In an attempt to improve the average flow time of all parts through a system, Ekren & Ornek (2008) analysed some process parameters affecting the system performance. By definition, flow time is the time that a part spends in the system from raw materials area to finished-goods stage. In an experiment conducted by Nembhard & Prichanont (2007) to evaluate the performance in serial production, batch time and productivity were used. Batch time was defined as the average time taken to reach a certain number of output units based on customer demand, while productivity was defined as the total amount of finished tasks during the production period.

To estimate the individual production time on a repetitive task, the Learning Curve theory founded by Ebbinghaus (1885) and quantified by Wright (1936) might be used. These two classic resources were cited from Nembhard & Norman (2007) and Rai (2004). Learning Curve has mostly been adopted in defence industries (e.g. aircraft and electronics) by a suggestion: the longer a person studies, the longer the retention — that is to say, in Rai's plain English: the more often you work at a task, the better the skill you gain, the shorter the time you need. The corresponding formulation with the resultant time curve is generally recognised as a negative exponential graph, which will be presented in Section 3.1.2(ii).

With reference to the production time and productivity information, some researchers were more interested in solving the issue of task lateness, which is determined by how far a task's finish time goes beyond the due time (Stankovic et al, 1995; Abdelzaher & Shin, 2000; Marmier et al, 2009). Manufacturing disturbances such as machine breakdown and absenteeism may lead to task lateness. Despite the above findings, the literature thus far has shown limited concern about the number of overdue tasks, as well as the ratio of overdue tasks to finished tasks.

On the other hand, the workforce skill rating and their workload balance may be part of the system performance. Zhang (2005), Dai et al (2007), and Tai (2009), in their respective studies, computed the average skill level of workforce. Tai also investigated the effects of skill deviation within operator and between operators. Both the effects were simply based on statistical range instead of standard deviation;

meanwhile, the author did not relate the latter effect to workload balance. These two skill deviation effects will be redefined in Section 3.5.4 as *intrapersonal* (i.e. within operator) and *interpersonal* (i.e. between operators) and be recomputed via standard deviation, following the technique suggested in Bokhorst & Slomp (2007) — use standard deviation to find workload distribution.

2.3.4 Analysis of Variance (ANOVA)

ANOVA is a powerful statistical tool, commonly used for testing hypotheses related to the mean values of several independent groups of observations. The F-test is used when a null hypothesis, H_0 is investigated for three or more means drawn from the same population. If only two means are available, the Student's t-test is used as a special case, whereby the F-ratio is equal to the square of t-statistic ($F = t^2$). Both F-ratio and t-statistic are dependent on degrees of freedom to account for probabilities and critical values. There is a difference between *F* and *t* in terms of the degrees of freedom: *F* has two different degrees of freedom to analyse the situation, whereas *t* has a specific formula to calculate only one degree of freedom (Malloy, 2000). The outcome will be compared with the F-distribution under a certain significance level (e.g. 0.05 or 0.10) to determine the rejection of null hypothesis. Such a procedure is called *test of significance*, in which the null hypothesis can be rejected if the F-ratio exceeds the corresponding critical value in the F-distribution (Hill & Lewicki, 2007). The relevant and detailed test procedure of ANOVA is given in Appendix B.