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A Holonic Workforce Sizing Model Based on Demand Trend and Disturbance Rate in Job-shop Production

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Abstract

This paper presents a job-shop workforce sizing method developed in the light of Holonic Manufacturing System (HMS). As one of the management paradigms gaining attention worldwide, HMS represents a novel methodology that integrates computers, machines, and humans into a single function unit capable to cope with dynamics in the business environment. Over the decades, the concepts of holons and holonic systems have been adopted in many research fields, but they are scarcely attempted on labour planning. A literature gap exists, thus motivating the author to come up with a holonic model that uses exponential smoothing to forecast some quantitative variables in labour-intensive production. These varying parameters include the machine utilisation that reflects the demand and the worker absenteeism and turnover that constitute the disturbance. Collective equations are formulated to periodically compute the number of workers required. For model validation purpose, twenty-four-month data analysis is conducted on a mock-up basis.

Keywords: workforce sizing, job-shop production, holonic model

1. Introduction

In the manufacturing sector today, human capital is still essential for most factories to carry out a variety of manual operations, in spite of the rapid advancement of automation technology and robotics. Futuristic vision of “unmanned manufacturing” (Deen 1993) is forbiddingly expensive, because all its hardware components need to be computer controlled so as to freely communicate with each other; and yet, most of the outcomes are not promising (Sun & Venuvinod 2001). By and large, factories equipped with relatively simple machinery controls will require continuous attendance of human operators; for examples, textile mills, leather products, and medical appliances. With limited capital investments in production equipment, the main budget of their fixed costs lies on the workforce size (Techawiboonwong *et al.* 2006).

With regard to cost-effectiveness, labour planning always opts for the minimum amount of workers needed to deal with the daily operations, as well as the probable rate of disturbance (Lim *et al.* 2008). The workforce disturbance is often ascribed to absenteeism and turnover, which may result in considerable loss of productivity for any labour-intensive division (Easton & Goodale 2002). Buffering with redundant skilled workers (Molleman & Slomp 1999) or relief workers (Redding 2004) might be a direct solution to absenteeism; however, the rising labour cost must be justifiable due to the fact that underutilisation of labour during low demand seasons is considered a waste of resources. Absenteeism is the measure of unplanned absences from workplace due to some reasons like personal emergency, accident, illness, etc. Turnover occurs when an active worker resigns from the company of his own accord, thus leaving a vacant post until a replacement is found. If such disturbance has caused a large number of tasks become unattended and overdue, the company is then vulnerable to overtime cost, shrunk capacity and productivity, extra queuing time, lost business income, etc. In order to prevent these deteriorative effects, optimising the number of workers can be helpful. As a fundamental branch of knowledge in manufacturing business, workforce management will never fall behind the times. Therefore, it is worth an attempt to incorporate a novel methodology, such as HMS, into the state of the art of workforce sizing.

2. Holonic Manufacturing System (HMS)

"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. Koestler found that fully self-supporting, non-interacting entities did not exist in living organisms as well as social organisations. Consequentially, 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.

2.1 Establishment of HMS

Towards achieving 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) in 1993. This programme consists of six major projects, wherein the fifth one is entitled "Holonic Manufacturing Systems: system components of autonomous modules and their distributed control". It is important to emphasise that HMS does not represent a new technology, as it is merely a conceptual modelling approach to connect and make use of existing technologies with human interfaces (McFarlane 1995). HMS became one of the first fully endorsed IMS projects in 1997, and so the International HMS Consortium was formed and dedicated to replicate in manufacturing the strengths that holonic systems provide to living organisms and societies. These holonic strengths encompass stability in the face of disturbances, adaptability and flexibility in the face of change, and efficient use of available resources. Succinctly, autonomy and cooperation are known as the prime attributes of HMS (Valckenaers *et al.* 1997; Bongaerts 1998).

2.2 Applications of HMS

In literature, the concepts of HMS were associated with a myriad of technical measures. McFarlane (1995) stated that a holon is able to detect and diagnose problems internally or by cooperating with neighbouring holons of the same manufacturing unit. Types of holons given include processing holon, negotiation holon, scheduling holon, database holon, input/output holon, tracking holon, etc.; and in his steel mill cooling control problem, five cooling holons were used. Gou *et al.* (1998) created a holonic scheduling model using Lagrangian relaxation for a factory equipped with multiple cells. 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 for the purpose of meeting unexpected assembly requests. Huang *et al.* (2002) framed a holonic virtual enterprise control consisting of global coordinator and member enterprises to enhance the cost-effectiveness on production planning, resource sharing, and change management. Fletcher & Hughes (2006) discussed the technology and policy challenges to be encountered for introducing holons into factory automation. Leitão & Restivo (2007) presented the Adaptive Holonic Control Architecture (ADACOR) that is able to execute fast rescheduling in line with global optimisation during the intervals of resource breakdown. Lim & Chin (2011) devised the Holonic Workforce Allocation Model (HWM) which makes collective operator-task matching decisions based on the operator skill and task urgency parameters, in consideration of specialisation requirements as well as cross-training opportunities.

In the realm of academic management, Karapetrovic & Willborn (1999) constructed a holonic model for quality systems in higher education as to implementing ISO 9000 international standards. Their model contains a set of seven holons to carry out parallel series of tasks on documenting a service organisation. Bell *et al.* (2000) proposed a "holon planning and costing framework" based on system dynamics (SD) and soft systems thinking (SST) to assist in improving the teaching and research qualities given the cost constraints. Montilva *et al.* (2010) used the combination of holonic networks and business models to design an academic organisation devoted to professional training programmes (PTP) on software engineering.

Despite the flourishing research works listed above, the extension of HMS on the subject of labour planning is barely seen. As the gap in the literature is addressed, this paper intends to formulate a holonic model called Workforce Sizing Plan (WOZIP), which is particularly suitable for job-shop production.

3. Workforce Sizing Plan (WOZIP)

Job-shop production refers to a manufacturing environment that produces goods in small batches according to customer specifications. Usually, one or several types of products are deliverable, while the incoming orders may differ in the design, quantity, process flow, or urgency (Henrich 2005). Flexibility is allowed in terms of switching between machines, methods, and resolving problems in production. Depending on the nature of business, each of the workers hired may need to possess a certain range of skills to handle different tasks or machines, whereas the total number of workers may be adjusted in response to the varying demand. In practice, transferability of permanent workers and recruitment of temporary or contract workers will help make such adjustment feasible, thus admitting of the idea of WOZIP.

3.1 Required Data Input

The utilisation rate of machines in a period of time, U_t, can be calculated as the total processing time, t_{pro}, over the duration of periodical review, t_{rev}, and the number of machines, N_M, on the shop floor:

$$U_t = \frac{\sum_i t_{pro,i}}{t_{rev} N_M}{}_t \qquad (1)$$

As mentioned earlier, absenteeism and turnover are identified as the two major problems leading to workforce disturbance. Each type of disturbance can be quantified by its frequency and intensity of occurrence. The frequency, f , ascribes to how often it occurs over a period of time (e.g. one turnover in a month), whereas the intensity, $\bar{t}$, refers to the average duration it has occupied (e.g. absent for two days). With the subscript *Abs* for absence and *Tnv* for turnover, the collective disturbance rate for a period of time, δ_t, is hence computed as:

$$\delta_t = \frac{f_{Abs}\bar{t}_{Abs} + f_{Tnv}\bar{t}_{Tnv}}{N_W}{}_t \qquad (2)$$

Where, N_W represents the number of workers in total.

The other piece of information concerned is the idling time spent by worker j, $t_{Idl,j}$, which indicates the degree of underutilisation of human resources. The idling rate for a period of time, χ_t, is shown below:

$$\chi_t = {\frac{\sum_j t_{Idl,\,j}}{t_{rev}\, N_W}}_t \tag{3}$$

3.2 Forecasting and Sizing

This section relates to the data output stage. In order to labour redundancy besides negating the adverse effects of turnover and absenteeism, WOZIP is meant to estimate the number of workers for a production period based on the utilisation, disturbance, and idling rates acquired from the past period *t-1* by the Equations (1) to (3). Exponential smoothing, a common forecasting technique in operations management, is used to find the U_t, δ_t, and χ_t rates for the coming period. The general formula for exponential smoothing:

$$F_t = F_{t-1} + \alpha\,(Y_{t-1} - F_{t-1}) \tag{4}$$

Where, F and Y respectively denote the forecast value and the actual value of each variable considered, and the symbol α is the user-defined smoothing constant.

To compute the workforce size required in the coming period, the formula is composed of the number of working machines, the three parameters stated above, and the user-defined maximum utilisation, U_{mac}:

$$N_{W,\,t} = N_M \left(\frac{U_t + \delta_t}{U_{max}} - \chi_t \right) \tag{5}$$

On a monthly basis, a numerical example is given. Let the smoothing constant be 0.30, the forecast utilisation in January be 0.80, and its actual rate be 0.75. As a result, the forecast utilisation rate for February is $U_{Feb} = 0.80+0.30(0.75-0.80) = 0.79$. The same calculation applies to the disturbance as well as the idling rate. In the case of $U_{mac} = 0.80$, $N_M = 10$, and the other variables showing $\delta_t = 0.05$ and $\chi_t = 0.17$, the Equation (5) will give $N_{W,Feb} = 8.84$, approximate to integer 9. This means, the month of February requires nine operators, by estimate, to run the ten machines on the production floor.

3.3 Holonic Architecture

“Architecture” means the art and science of building. A system or functional structure built up with holons is known as “holarchy”, wherein the basic rules for the cooperation and limited autonomy of holons are expressed. Van Brussel *et al.* (1998) made a reference architecture called Product-Resource-Order-Staff Architecture (PROSA), whereby the HMS building blocks were categorised into three basic types of holons, namely product holon, resource holon, and order holon. In their respective functions, an order holon represents the customer order or demand information; a resource holon offers the handling as well as production capacity to fulfil the order received; a product holon holds the process and knowledge to assure the correct making of the product or decision. With this end in view, a holon can be a machine tool, a robot, a human worker, or a planning unit. Every holon must consist of an information processing part in association with the physical processing part of its own or its counterparts under the same holarchy. According to Rodriguez (2005), every holarchy is a moderated group, in which the supra-holon is the representative or moderator of the group as well as a part of the vivid interface in coordination with the local environment; meanwhile, each of the sub-holons has to play at least one role to secure its status in the supra-holon composition.

For the architecture of WOZIP, a holarchy consisting of machinery holon (MH), operational holon (OH), forecasting holon (FH), and sizing holon (ZH) is delineated in Figure 1. The WOZIP is itself regarded as the supra-holon, which allows and coordinates the information transfer as well as the interactive computing between the four sub-holons. In the normal process flow, MH (i.e. the order holon) will supply the work information based on customer specifications for OH (i.e. the resource holon) to prepare the workforce that will handle the machines. At the threshold of workforce sizing, both the MH and OH, which compose the input holon, will generate their respective data items via Equations (1) to (3), for the use of FH (i.e. the intermediate product holon) to conduct the exponential smoothing. The forecast outcomes of Equation (4) of FH will be channelled into ZH (i.e. the final product holon), which completes the procedure using Equation (5) — adjust the workforce size of OH. Essentially, the FH and ZH belong to the output holon. Some negotiation might take place around the beginning and the end of the process flow, between the MH and the customer side (i.e. the external environment) as well as between the ZH and the human resources division (i.e. the internal environment). As the whole process will repeat for every production period, a database has to be integrated into each of the holons for efficient information storage and retrieval.

4. Model Validation

To enable the validation procedure, some periodical variable data are needed from the production floor, namely machine utilisation, U_t, disturbance rate, δ_t, and worker idling rate, χ_t. Owing to the lack of these data input for a duration of two years, a mock-up data is provided in order to study the effectiveness of WOZIP. Based on the two-year observation, it can be concluded whether such a method is able to respond to the trend of the varying parameters concerned.

4.1 Mock-up Test

Assuming there is a workplace equipped with ten machines, for which the required number of workers is forecasted on a monthly basis. For the two-year duration, the smoothing constant and maximum utilisation are given as $\alpha = 0.30$ and $U_{max} = 0.80$, to be put in Equations (4) and (5).

In the first year of mock-up, a lower range of δ_t is given (between 0.04 and 0.12); the U_t is in the downtrend (from 0.75 to 0.23) and the χ_t is in the uptrend (from 0.20 to 0.30). The forecasting model is continued for the second year, in which a higher range of δ_t is given (between 0.12 and 0.20); the U_t is gradually raised till exceeding the U_{max} and going up to 0.90, while the χ_t is in the downtrend (from 0.26 to 0.03).

The complete datasheet for this mock-up test is shown in Table 1.

4.2 Results and Discussion

A graph indicating the actual rates of utilisation, disturbance, and idling versus the forecast number of workers upon twenty four monthly intervals is plotted in Figure 2.

As seen in the datasheet and the graph, the forecast number of workers required on the production floor has decreased from 9 to 2 in the first year due to the lower disturbance rate, decreasing utilisation rate, and increasing idling rate. Nonetheless, this number has bounced back from 2 up to 11 in the second year, in which the condition is reversed (i.e. at the higher disturbance rate, increasing utilisation rate, and decreasing idling rate). Towards the end of the mock-up, the greater utilisation and disturbance rates are accountable to a situation where more workers are required than the number of machines.

In short, the mock-up data analysis has proven that the WOZIP method is able to follow the trend of the varying machine utilisation and worker idling rates, upon the different levels of disturbance.

5. Conclusion

A functional structure made up of holons is called holarchy. 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 setting up the WOZIP, holonic attributes such as autonomy and cooperation must have been integrated into its relevant components. The computational scheme for WOZIP is novel as it makes use of several manufacturing parameters: utilisation, disturbance, and idleness. These variables were at first separately forecasted by means of exponential smoothing, and then conjointly formulated with two constant parameters, namely the number of machines and their maximum utilisation. As validated through mock-up data analysis, the practicability of WOZIP is encouraging and promising.

Suggested future works include developing a software package to facilitate the WOZIP data input and conversion processes, exploring the use of WOZIP in the other forms of labour-intensive manufacturing (e.g. flow-line production and work-cell assembly), and attaching a costing framework to determine the specific cost of each resource or to help minimise the aggregate cost of production.

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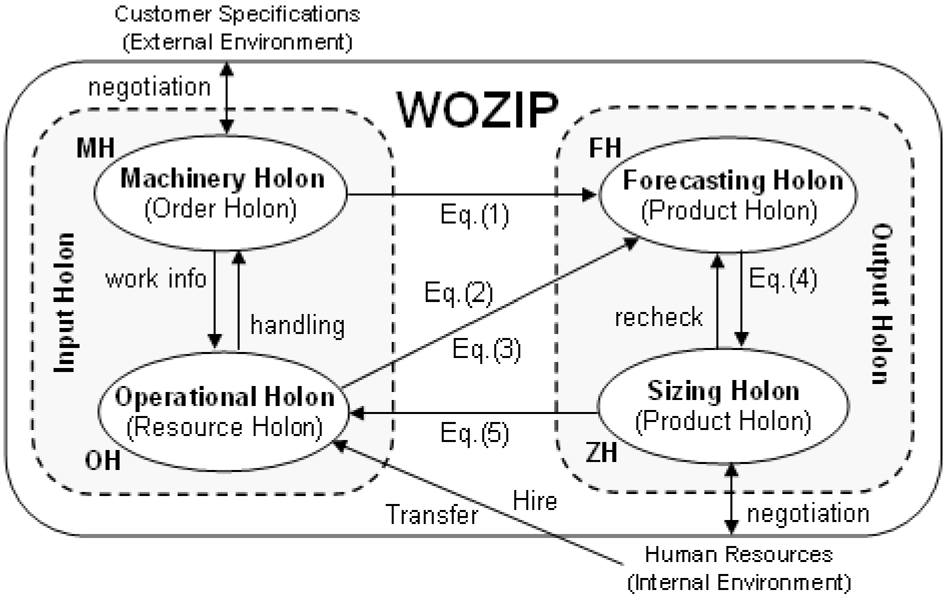
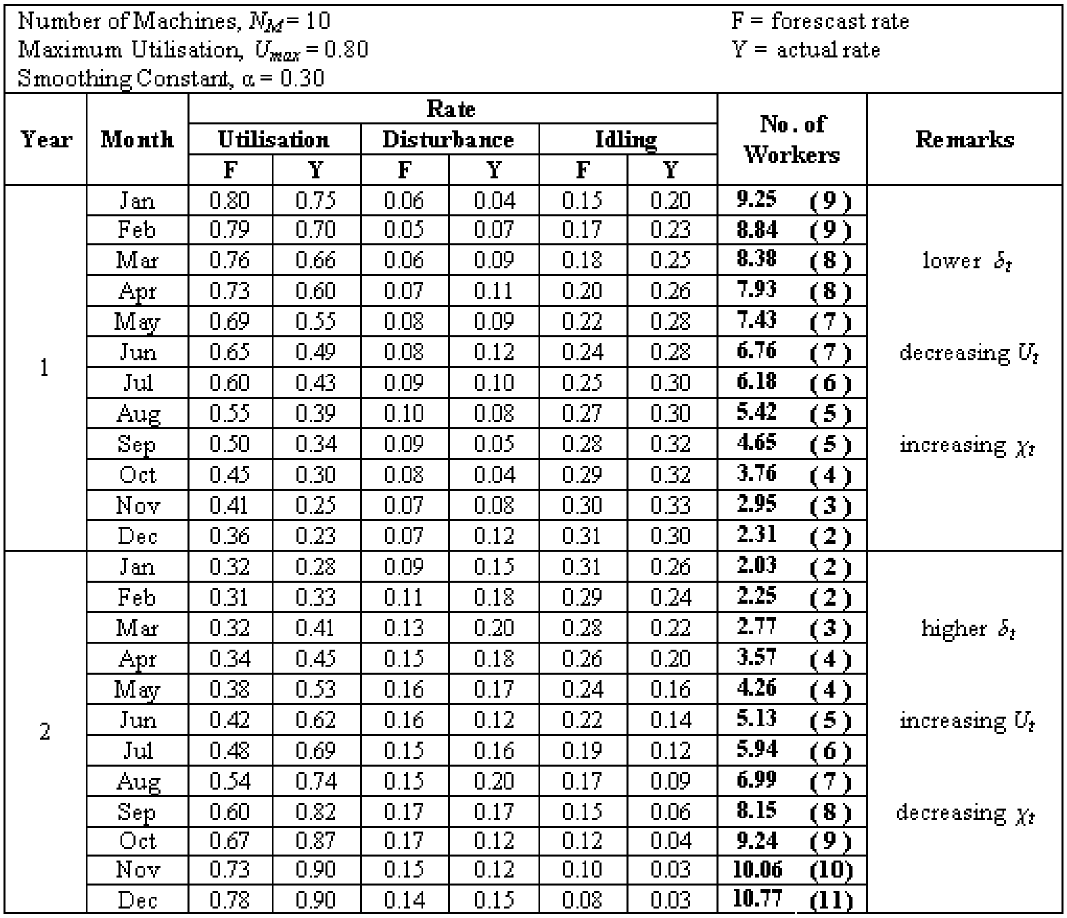


Figure 1. Architecture of WOZIP

Table 1. Datasheet of Mock-up Test



Number of Machines, N_M = 10
Maximum Utilisation, U_{max} = 0.80
Smoothing Constant, α = 0.30

F = forescast rate
Y = actual rate

Year	**Month**	**Rate**						**No. of Workers**	**Remarks**
		Utilisation		**Disturbance**		**Idling**			
		F	**Y**	**F**	**Y**	**F**	**Y**		
1	Jan	0.80	0.75	0.06	0.04	0.15	0.20	**9.25 (9)**	
	Feb	0.79	0.70	0.05	0.07	0.17	0.23	**8.84 (9)**	
	Mar	0.76	0.66	0.06	0.09	0.18	0.25	**8.38 (8)**	lower δ_t
	Apr	0.73	0.60	0.07	0.11	0.20	0.26	**7.93 (8)**	
	May	0.69	0.55	0.08	0.09	0.22	0.28	**7.43 (7)**	
	Jun	0.65	0.49	0.08	0.12	0.24	0.28	**6.76 (7)**	decreasing U_t
	Jul	0.60	0.43	0.09	0.10	0.25	0.30	**6.18 (6)**	
	Aug	0.55	0.39	0.10	0.08	0.27	0.30	**5.42 (5)**	
	Sep	0.50	0.34	0.09	0.05	0.28	0.32	**4.65 (5)**	increasing χ_t
	Oct	0.45	0.30	0.08	0.04	0.29	0.32	**3.76 (4)**	
	Nov	0.41	0.25	0.07	0.08	0.30	0.33	**2.95 (3)**	
	Dec	0.36	0.23	0.07	0.12	0.31	0.30	**2.31 (2)**	
2	Jan	0.32	0.28	0.09	0.15	0.31	0.26	**2.03 (2)**	
	Feb	0.31	0.33	0.11	0.18	0.29	0.24	**2.25 (2)**	
	Mar	0.32	0.41	0.13	0.20	0.28	0.22	**2.77 (3)**	higher δ_t
	Apr	0.34	0.45	0.15	0.18	0.26	0.20	**3.57 (4)**	
	May	0.38	0.53	0.16	0.17	0.24	0.16	**4.26 (4)**	
	Jun	0.42	0.62	0.16	0.12	0.22	0.14	**5.13 (5)**	increasing U_t
	Jul	0.48	0.69	0.15	0.16	0.19	0.12	**5.94 (6)**	
	Aug	0.54	0.74	0.15	0.20	0.17	0.09	**6.99 (7)**	
	Sep	0.60	0.82	0.17	0.17	0.15	0.06	**8.15 (8)**	decreasing χ_t
	Oct	0.67	0.87	0.17	0.12	0.12	0.04	**9.24 (9)**	
	Nov	0.73	0.90	0.15	0.12	0.10	0.03	**10.06 (10)**	
	Dec	0.78	0.90	0.14	0.15	0.08	0.03	**10.77 (11)**	

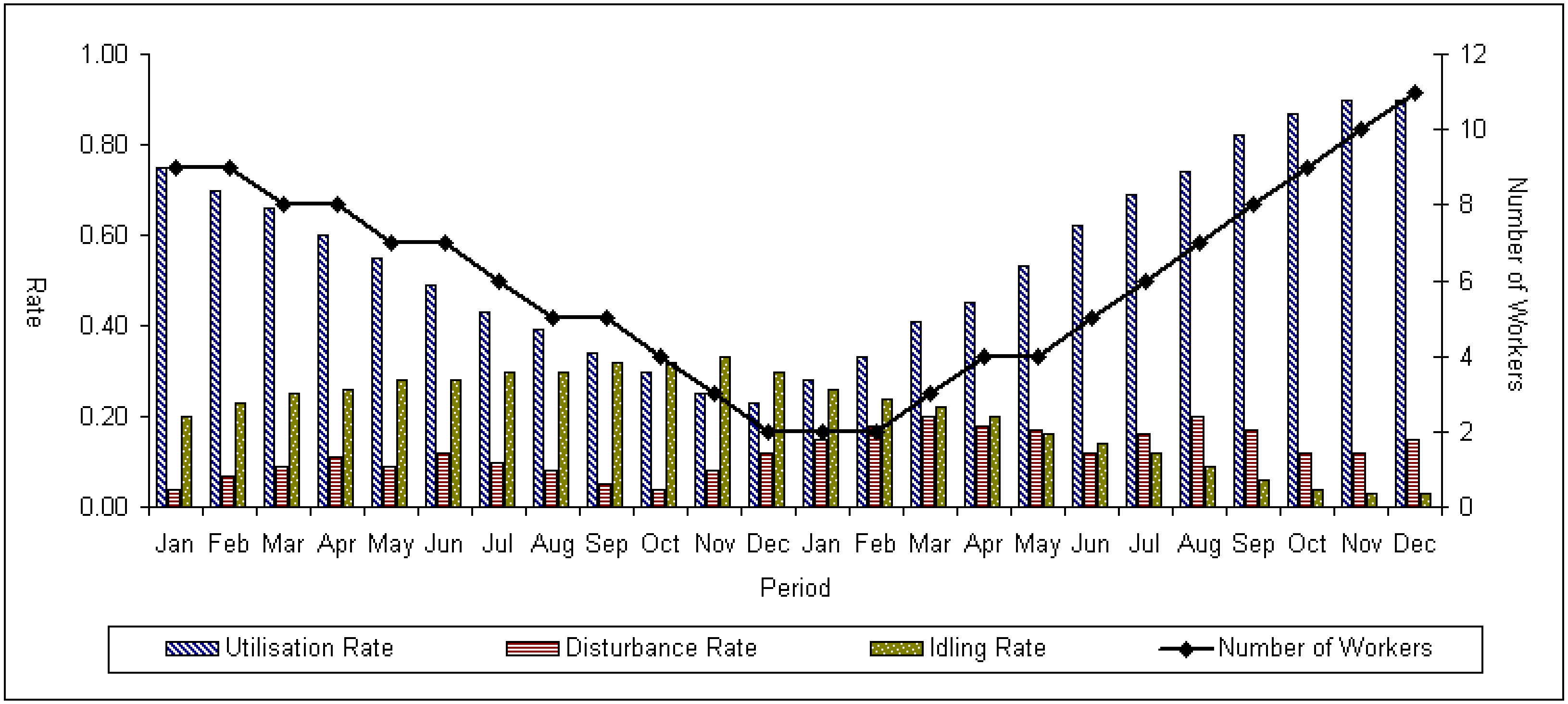


Figure 2. Graph of Test Results

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