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Introducing Fundamental Concepts of Manufacturing Systems to Fresh Engineering Students by Physical Simulation of Automated Factory

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Physical simulation involves the use of scaled-down models of production systems that are fully functional and mimic the operations of the system being modelled. In this paper physical simulation is utilised as a supporting experiment in a first-year course, MECH151 Engineering Instrumentation. The aim of designing such an experiment is to introduce fresh engineering students the fundamental concepts in manufacturing system design and control and to demonstrate some important issues in an automated factory. The automated factory considered here is a flexible processing line consisting of three workstations and an automatic high-level storage warehouse. By developing a computer program to continuously cycle workpieces through different machine layouts and noting down the busy and idle times of production operations, students can have an intuitive understanding about some important issues, such as capacity utilisation, break-even analysis, effect of the layout of workcentres. It has shown in practice that the introduction of this physical simulation system has greatly promoted student's interests in learning.

INTRODUCTION

COMPUTER simulation has been widely used as a powerful analysis tool to model and demonstrate the design and operation of complex manufacturing systems [1]. From the educational point of view, however, physical simulation [2] has the obvious advantage, superior to computer simulation, in improving students' understanding of the underlying problem and promoting their motivation in learning. In a first-year course, i.e. MECH151 Engineering Instrumentation at University of Wollongong, a physical simulation system of an automated factory is designed as one of the supporting experiments, aiming at enhancing student's understanding of fundamental concepts of manufacturing system design and control. This is particularly essential for fresh engineering students, most of whom come from high school directly, as they can obtain some first-hand experience through the active participation in the experiment.

Physical simulation extends beyond the static representation of the system and involves the dynamic manipulation of the system for the purpose of studying operational characteristics. In a typical automated manufacturing system, material handling costs comprise about one third of total manufacturing costs [3]. To reduce this cost, a well-planned layout of various workcentres is essential. In this work, functional layout [4] is adopted in the design of physical simulation, which attempts to arrange workcentres according to function, such as turning, milling/boring and grinding, so that the workpieces flow through the workshop from one end to the other. Through the practice in the designed physical simulation, students will be able to learn the effects of different machine layouts, good or bad, on the capacity utilisation (CU) and hence on the break-even quantity (BEQ) [5].

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EQUIPMENT FOR PHYSICAL SIMULATION

The system used in physical simulation of automated factory is the Fishertechnik Plan and Simulation Modelling [6], as shown in Fig. 1 and described below.

High level storage warehouse model

This model (See Fig. 1a) illustrates the principles of an automated high-level storage warehouse and is controlled by a programmable controller using a microcomputer. Goods enter the warehouse via a conveyor line and are positioned at the required location by a telescopic lifting table which can access any of the storage locations in the warehouse. Goods are retrieved by the same lifting

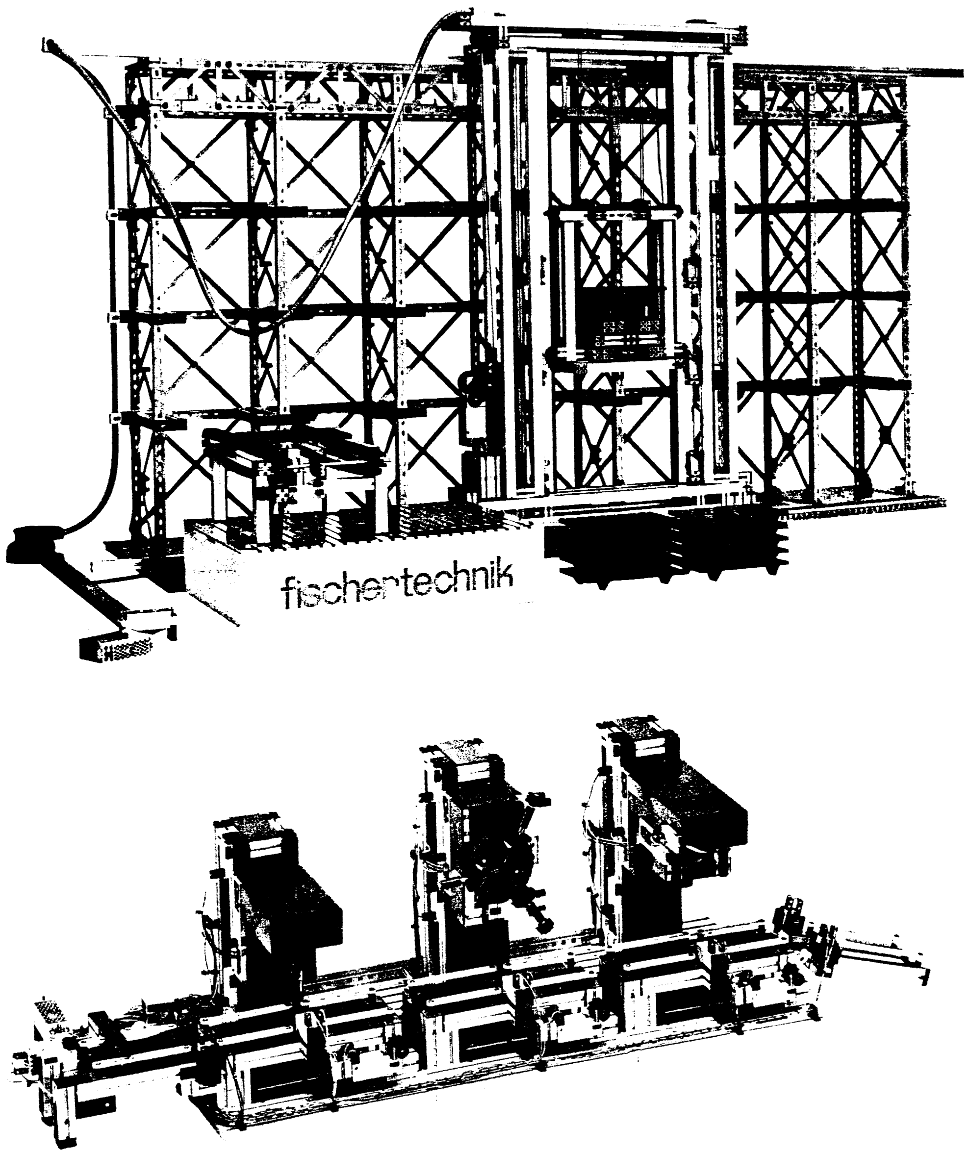

Fig. 1. Fischertechnik model of automated factory [6].

table, and despatched from the warehouse on the conveyor line. The model has 21 storage locations, arranged on three levels, and has 20 storage pallets.

Goods enter and leave the warehouse via a conveyor line. Incoming goods operate a proximity switch which starts the conveyor to position the pallet on the telescopic lifting table. Outgoing goods are transferred from the lifting table to the conveyor and when they reach the end, a contact switch is operated to stop the conveyor, leaving the pallet in position. The lifting table runs on tracks from side to side of the warehouse model. Positional feedback is provided by microswitches on the lower track, which are operated by the moving carriage. Vertical position is detected by microswitches, one above and one below each level to give input and output positions. The carriage is operated by cords connected to the lifting motor. Pallets are inserted and removed from the warehouse by the backwards or forwards movement of the pallet carrier. The forward position inserts or removes the pallet from the storage space and the backward position deposits it on a conveyor line.

Flexible processing line model

This model (See Fig. 1b) contains three work stations—drill unit with tool drive, vertical boring machine with a turret head containing three cutting tools and a milling machine with horizontal tool. Conveyor belts are used to move the workpiece along the line to each workstation where the required machining operations are performed. When all the operations are complete the workpiece is transferred to the end of the processing line. The model is mounted on a base plate equipped with wiring and a board mounted plug and is suitable for operation by industrial controller or microcomputer.

Other features of the model are:

- loading station which senses if workpieces are available;

Table 1. Busy and idle times in seconds

	Workcentre 1				Workcentre 2				Workcentre 3			
	WP1	WP2	WP3	WP4	WP1	WP2	WP3	WP4	WP1	WP2	WP3	WP4
Busy time	TB11	TB12	TB13	TB14	TB21	TB22	TB23	TB24	TB31	TB32	TB33	TB34
Idle time	TI11	TI12	TI13	TI14	TI21	TI22	TI23	TI24	TI31	TI32	TI33	TI34
Total time	TT11	TT12	TT13	TT14	TT21	TT22	TT23	TT24	TT31	TT32	TT33	TT34

- electromechanical slide unit for conveyor loading;
- light beam control of conveyor belt system;
- proximity device for positioning of the workpieces at each work station;
- movement and tool drive.

DESIGN OF PHYSICAL SIMULATION

A program is developed in Pascal to simulate the operations of the automated factory. This program cycles workpieces through three workcentres. The time during which machining takes place on individual workcentres may be programmed as desired. At the beginning of the cycle, the first workpiece is positioned on the conveyor belt and is moved to the first workcentre (milling machine). Machining of the first work\-piece is commenced and when it is completed the workpiece moves to the second workcentre (drilling machine). Meanwhile the second workpiece is positioned on the conveyor and as soon as the first machine is free this workpiece is moved on to it. This cycle is continued and the workpieces are moved sequentially to the three workcentres. When the final machining of boring is completed on any workpiece it is moved to the end of the processing line from where the telescopic lifting table transfers the workpiece to pallet carrier and then to the automated storage and retrieval system (AS/RS).

The physical simulation is started by running the program and students note down the busy and idle times of each workcentre for a set of, say, four workpieces and record them in Table 1.

WP1, WP2, WP3 and WP4 denote the four workpieces respectively. Idle time here also includes the blocked time that is the time during which the workcentres are waiting for workpieces being machined on other workcentres. Work centre capacity utilisation (CU) is computed by using the following formula:

$$\mathrm{CU}_{(\text{workcentre } j)} = \frac{\text{busy time}}{\text{Total time}} \times 100 = \frac{\sum_{i=1}^{4} T_{Bij}}{\sum_{i=1}^{4} T_{Tij}} \times 100 \qquad (1)$$

where $j = 1$, 2 or 3 in this work. Total time for one cycle can be obtained by adding all the total times, i.e.

$$\text{Total cycle time} = \sum_{j=1}^{3} \sum_{i=1}^{4} T_{Tij} \qquad (2)$$

Break-even quantity is then computed by utilising the formula:

$$\mathrm{BEQ} = \frac{\mathrm{FC}}{(\mathrm{P} - \mathrm{VC})} \qquad (3)$$

where FC is the fixed cost (such as production equipment), P is the selling price per set (consisting of four workpieces in this case) and VC is the variable cost (such as labour and material). Variable cost is the one that increases as the level of production increases and can be calculated as follows,

$$\mathrm{VC} = (\text{Total cycle time})(\text{Machine hour rate}) + \text{Material cost} \qquad (4)$$

The significance of arrangement of the workcentres in a proper sequence could be demonstrated by interchanging the positions of the workcentres. Thus, students will be able to study the effects of different layouts of workcentres on capacity utilisation and break-even quantity, through the comparative analysis of busy and idle times of production operations.

CASE STUDY

The concepts described above could be well demonstrated by considering an example of a product mix having four workpieces. Machining operations required to produce the four workpieces include milling, drilling and finally boring in that order. Physical simulation is commenced by running the simulation program for the arrangement of workcentres shown in Fig. 2.

The busy and idle times of workcentres for completing the machining of one set of workpieces are noted down as shown in Table 2. Based on the values of busy and total times the capacity utilisation for the three workcentres could be computed by using equation (1) and are shown in Table 2.

BEQ is now computed by utilising the total cycle time from Table 2 and by multiplying this total cycle time by a scale factor of 60 for the

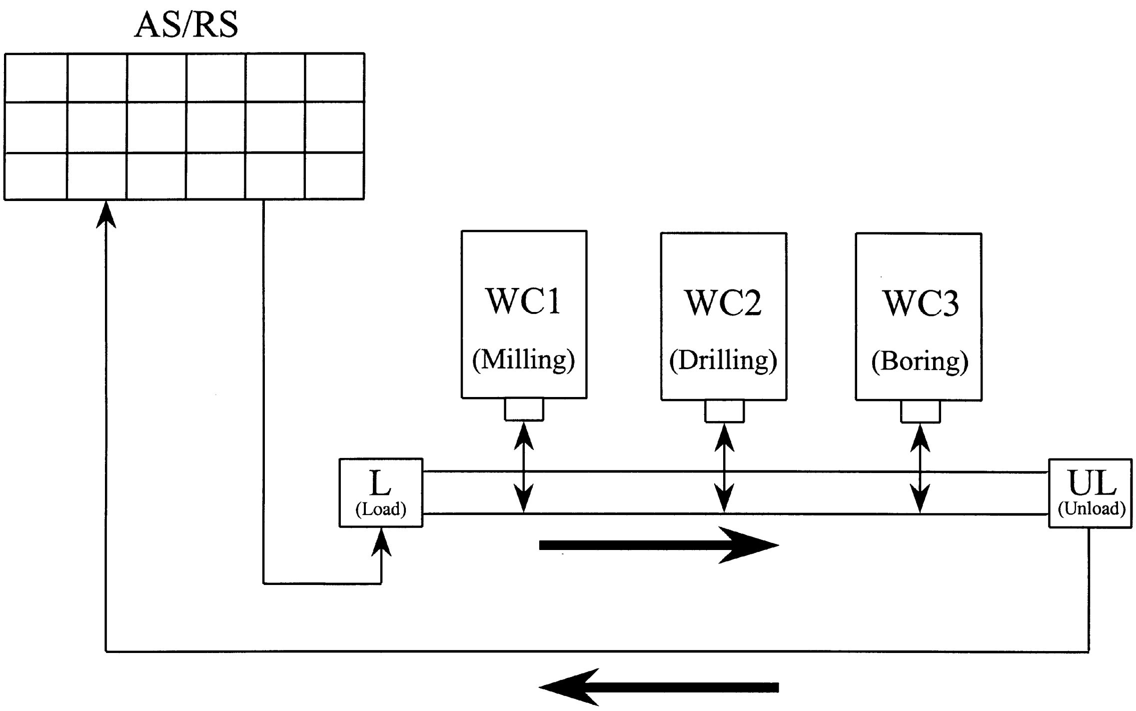

Fig. 2. Machine layout 1.

Table 2. Busy and idle times in seconds

	Workcentre 1				Workcentre 2				Workcentre 3			
	WP1	WP2	WP3	WP4	WP1	WP2	WP3	WP4	WP1	WP2	WP3	WP4
Busy time	15	20	25	15	20	15	25	28	20	25	30	25
Idle time	5	10	12	8	5	10	8	9	10	15	8	7
Total time	20	30	37	23	25	25	33	37	30	40	38	32
Capacity utilisation		68.2%				73.35%				71.4%		

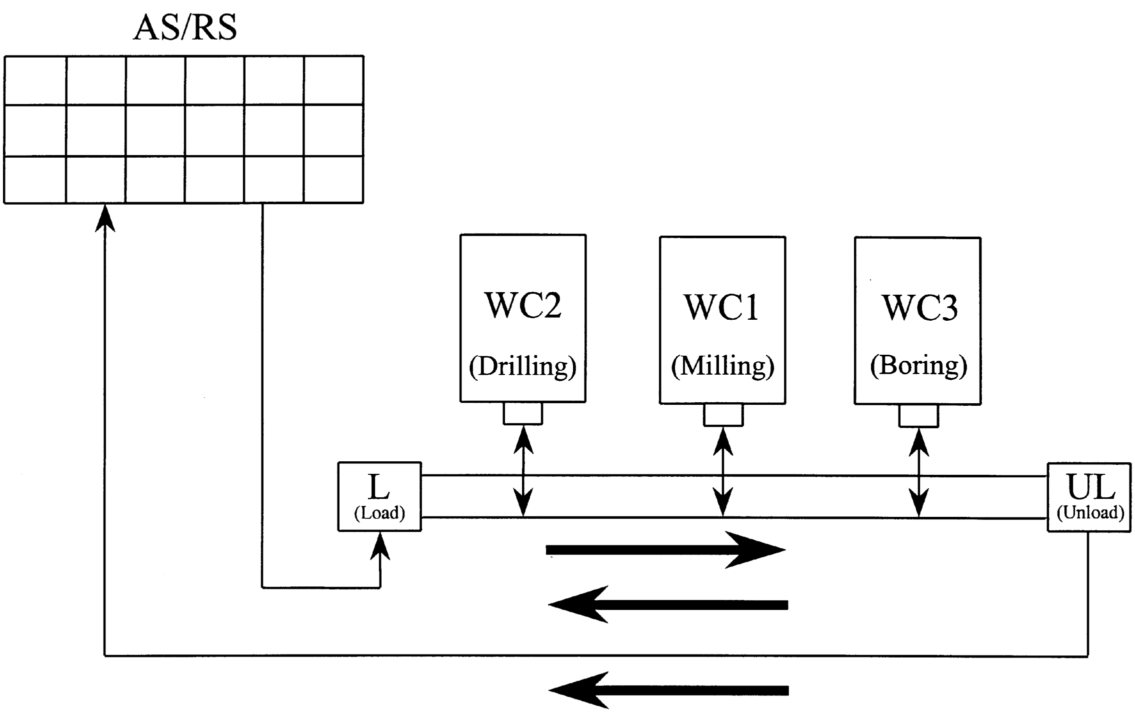

Fig. 3. Machine layout 2.

Table 3. Comparison of the two machine layouts

	Workcentre 1		Workcentre 2		Workcentre 3	
	Layout 1	Layout 2	Layout 1	Layout 2	Layout 1	Layout 2
Busy time	75	75	88	88	100	100
Idle time	35	90	32	120	40	130
Total time	110	165	120	208	140	230
Capacity utilisation (%)	68.2	45.5	73.3	42.3	71.4	43.5

experimental purpose to obtain the actual total cycle time. The following values are used in the computation of BEQ:

FC = \$500,000
P = \$2000
Machine hour rate = \$60
Material cost = \$100
Total cycle time = (110 + 120 + 140) 60 s.
Substituting in equation (3), BEQ = 327 sets.

A comparative study is conducted to demonstrate the effects of different machine layouts by interchanging the positions of the first workcentre (milling machine) and the second workcentre (drilling machine), as shown in Fig. 3.

The procedure of noting down the various time components as explained earlier is repeated and comparative results are given in Table 3. This interchange of the first two workcentres results in increased material handling time as the workpieces now have to be moved first to the milling machine (for first operation) then back to the drilling machine (for second operation) and finally to the boring machine for the third and final operation. This new arrangement also results in an increase of BEQ value (i.e. 386 sets) and correspondingly a decrease in the capacity utilisation for all the workcentres. With such a design, students would understand more that a proper arrangement of workcentres in a sequence is very important to reduce the total cycle time and also to simplify the operation scheduling.

CONCLUSION

In order to promote fresh students' interests in studying engineering courses, physical simulation of an automated factory is introduced as one of the supporting experiments within a first-year course, MECH151 Engineering Instrumentation, at University of Wollongong. Through the practice in operating the physical simulation system, students could have a better and more intuitive understanding about some fundamental concepts in manufacturing system design and control such as various machining operations, break-even analysis, capacity utilisation and effect of different machine layouts. And also we believe that the introduction of such a physical simulation system is essential for fresh engineering students to solidify their conceptual knowledge because most of them come from high school directly and have no practical experience.

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