Int. J. Engng Ed. Vol. 17, No. 6, pp. 546–557, 2001
Printed in Great Britain.

0949-149X/91 $3.00+0.00

The Federal-Mogul Business Game: The Development and Application of an Educational Aid for Planning and Control

D. J. PETTY
Department of Mechanical Engineering, (Manufacturing Division), University of Manchester Institute of Science and Technology, PO Box 88, Manchester M60 1QD, UK. E-Mail: david.j.petty@umist.ac.uk

S. J. HOOKER
SCT International, Station House, New Stamford Road, Altrincham, Chesire, WA14 1EP

K. D. BARBER
Department of Total Technology, University of Manchester Institute of Science and Technology, PO Box 88, Manchester M60 1QD, UK

Manufacturing Planning and Control (MPC) systems have attracted great interest in recent years. Teaching of this subject however is challenging because of the difficulty of providing appropriate examples in an academic environment. This paper describes a business game developed by a leading automotive components company. The objective of the game is to illustrate the benefits of reducing complexity within manufacturing systems in simplifying planning and control. The paper describes the development process for the game and provides detailed playing instructions. Finally, the paper reviews the use of the game in both an industrial and an academic context.

INTRODUCTION

THERE IS AN INCREASING EMPHASIS in engineering education of the importance of management skills, particularly with the advent of new Standards and Routes to Registration (SARTOR) from the Engineering Council. Teaching management skills to engineering students however, can be challenging. Students accustomed to the logical structure of engineering can find the more descriptive nature of management unfamiliar, particularly since teaching of engineering subjects is usually reinforced by appropriate practical or laboratory work.

This paper describes a business game used to illustrate some of the key principles of Manufacturing Planning and Control (MPC). Initially developed in industry, the game has been used to train engineering students at undergraduate and postgraduate level.

Background

Federal-Mogul is an international manufacturer of automotive components based in Southfield, Michigan, USA with well-known brand names such as Ferodo, Champion, and Goetze. Their turnover in 1999 was over $6bn. In the early 1990's, the company was in the process of implementing computer based MPC systems at a number of sites worldwide. Federal-Mogul have used a variety of packages including Mfg/Pro, Data3 and SAP. The corporate Management Information Systems (MIS) group, (then based in Manchester, UK), was responsible for supporting these implementations. This support was in two forms:

1. Software and systems support to ensure the packages being implemented operated at a technical level.
2. To ensure that the systems supported strategic objectives and yielded benefits in the broader business context.

At this time, group MIS employed the authors as manufacturing consultants supporting the latter activity. The specific task given to the authors was to develop and deliver generic, corporate education MPC programmes while software vendors provided detailed training on any application. The in-house education aimed to explain fundamental MPC principles to personnel working on projects at manufacturing sites.

Group MIS recognised that it is easy to focus on the software implications of the project and lose sight of the more fundamental objectives when implementing large, sophisticated applications. Experience suggested that the business presented the most challenging problems in such projects, rather than the software [1]. An important factor in the design of the education material was to ensure that projects did not lose focus. A number

* Accepted 29 October 2000.

of authors, such as Parkinson and others [2], together with consultancy organisations and manufacturing companies such as Philips and Hewlett-Packard have promoted the use of interactive business games to illustrate manufacturing concepts. Perhaps the best known offering in this area is 'The Beer Game'. Eight to ten people can play the game, which demonstrates the tendency of a supply chain to overcompensate for variations in demand. Played on a table top, the game uses counters and cards to represent real-world business entities, and even academics now use it as a standard case when examining supply chain issues [3, 4].

The authors set out to develop a novel business game for use within Federal-Mogul manufacturing sites. There were four objectives for the proposed game:

- To support the formal lecturing material on MPC.
- To illustrate the benefits of manufacturing improvement and simplification in concert with MPC package implementation.
- To redress the tendency of projects becoming software orientated.
- To provide a mechanism for team building within the manufacturing sites concerned.

This paper describes the development of the game, its operation and reviews its use in industrial and academic environments.

MPC SYSTEMS

MPC systems have received great attention in recent years. As far back as the early 1970s, academics and consultants such as Orlicky and Wight, (see [5] and [6] for a discussion on their contribution), promoted Manufacturing Resource Planning (MRPII) strongly. Indeed, the American Production and Control Society (APICS) described the application of MRPII as a 'crusade' [7]. One of the key success factors cited for MRPII was comprehensive education for company personnel at all levels [8]. By the late 1970's, authors such as Schonberger [9], who argued that MRPII was unresponsive and ignored issues such as material flow, lot-sizes and quality, strongly advocated Just-in-Time (JIT). In the 1980's, authors such as Fox [10] argued that the newly developed Optimised Production Technology (OPT) offered a step improvement over MRPII. OPT also allowed the application of many benefits of JIT in non-repetitive environments. As with MRPII, it is the author's experience that consultants promoting OPT have also emphasised the benefits of education for operating personnel. During the 1980s, several authors [7, 11] argued that the universal application of single approaches such as those described above was unsatisfactory, suggesting that companies need to analyse their requirements and draw on different elements from philosophies such as MRPII, JIT and OPT. More recently, Kochhar and Davies [12] undertook a study of UK manufacturing companies that suggested that there were no MPC panaceas and organisations needed to consider carefully their particular circumstances.

The current generation of Enterprise Resource Planning (ERP) systems evolved from MRP/MRPII. Modern ERP packages are highly configurable and invariably use sophisticated Relation Database Management Systems (RDMS) and client-server architectures. The latest ERP packages 'web-enabled'; that is to say, they are capable of being accessed (via appropriate security protocols) via the World Wide Web (WWW). Gupta [13] however, makes the point that there is still a need for fundamental understanding of the underlying business processes present in the organisation, despite the technological sophistication of ERP. Al-Mashari and Zairi [14] undertook a detailed study of a failed ERP implementation. One of the key reasons they cited for the lack of success was that the implementation focused on Information Technology (IT) issues with insufficient emphasis on the business aspects of the project.

THE BUSINESS GAME

The development process

The development process for the game was as follows:

1. To outline the key issues that the game needed to illustrate.
2. To develop a 'first version' of the game.
3. To play the game with group MIS personnel to allow refinements.
4. To disseminate the game throughout the group.

The authors initially established the key issues for illustration and presented them to the MIS team for evaluation and comment. As a result of this process, the following issues were agreed upon:

- To show the importance of simplification in concert with MPC system implementation.
- To show the need to recognise bottlenecks and to illustrate OPT principles.
- To illustrate the benefits of good plant layout.
- To show the necessity of effective planning, control and co-ordination.
- To demonstrate the relationship between manufacturing and financial performance.
- To explain the principles and benefits of 'pull' control systems.
- To show the importance of small lot sizes and in particular, short set-up times.
- To illustrate the importance of appropriate performance measurement systems.

Addition of the following constraints to those listed above allowed its application in practice within group companies:

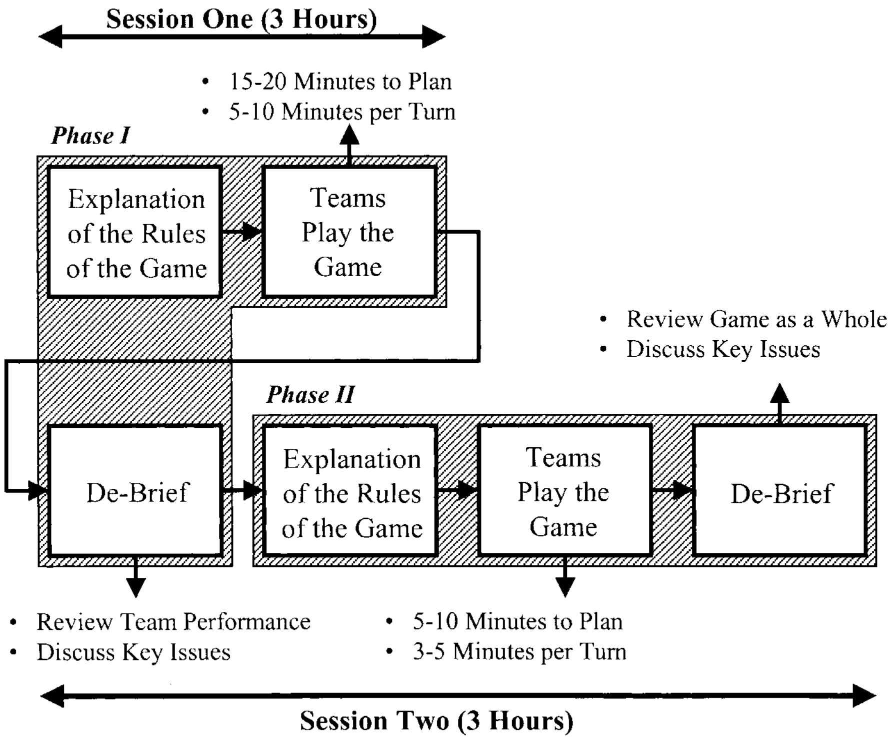

Fig. 1. Overview of the business game

- The game should accommodate six to twenty-five people, as this was the typical number attending courses run by group MIS.
- The game should be capable of being run on the premises of group companies and not require sophisticated infrastructure.
- Basing the game on a physical, rather than a computer, simulation kept it in line with the objective of de-emphasising the software aspects of MPC systems.

Development of the basic outline and rules of the game occurred over several weeks. Agreement that the game should be in two phases, as summarised in Fig. 1, occurred at an early stage. Phase I would set the participants a challenging factory management problem. After an initial explanation of the rules, the participants would play the game. A de-brief session would follow, to allow discussion of the key issues of the game. The second phase would follow the same pattern as the first scenario with some changes being explained to the participants. They would then replay the game, showing the benefits of the key issues described earlier. A final de-brief and discussion session would follow. Experience has shown that the first two elements of Phase I take around three hours, representing approximately half the time for the entire game. It has often proved convenient therefore to split the game into two sessions as shown in Fig. 1.

After the creation of a prototype, selected members from group MIS played the game, and took part in feedback sessions. Dissemination finally occurred after a process of refinement.

BASIC SCENARIO

The basis for the game is a fictitious company called the Ogel Production Corporation, which manufactures two saleable products that differ only in colour (red or white). The game requires teams of six to nine people, with the two phases of the game based on sixteen ‘turns’, each representing a week’s work. The participants start each session with a Sales Schedule, and the production material consists of a number of toy building bricks, each identified by a part number, while the factory plant consists of a number of cards. Each of the two finished products, (one red and one white), are identified by a part number with a different prefix, (R or W); for example, W8 is a basic white brick with eight ‘pips’. Figure 2 contains all the part numbers for the red variety and the basic production sequence.

The manufacturing environment

Raw material is available in three varieties:

1. **Bars**–two sizes and colours (R4BAR, R8BAR, W4BAR and W8BAR).
2. **Castings** (R6CAST and W6CAST)–a basic six-pip brick with a small black brick on top to act as a burr.

The first stage is made-up of three parallel operations:

1. **Sawing 1 and 2**–separate the bars into individual bricks (R8, R4, W8 and W4).
2. **De-Burr**–removes the black brick from the casting to produce individual bricks (R6 and W6).

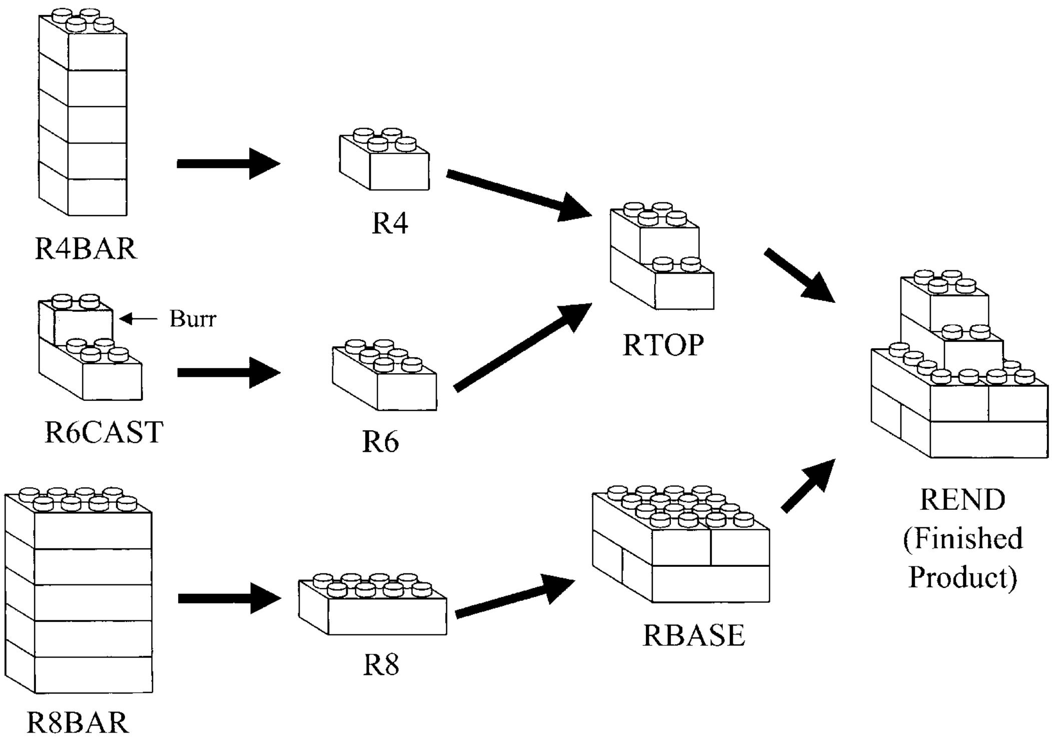

Fig. 2. The Manufacturing sequence for the simulated red product.

The next stage is made-up of two parallel sub-assembly operations:

1. **Welding 1**–involves placing a four brick onto a six to form an upper sub-assembly (RTOP and WTOP).
2. **Welding 2**–involves constructing a lower sub-assembly from four individual eight bricks (RBASE and WBASE).

Finally the participants place the top sub-assembly onto the base (final assembly).

There is one workcentre for each of the six operations described above, with one team member responsible for each. In addition to the actual manufacturing processes, there are three other roles that can be fulfilled by team members:

- *Customer Services Manager*: Responsible for recording deliveries and advising the rest of the team of requirements.
- *Purchasing Manager*: Responsible for deciding what materials the company purchases on any particular turn.
- *Finance Manager*: Responsible for managing cash and ensuring that the company receives payment for items purchased.

A participant in one of the roles described above can also be in control of a workcentre, to give some flexibility in the number of participants.

Sales schedule and financial details

The teams start each of the two phases of the game with identical customer schedules, (see Table 1). Note that the levels of WIP provided will enable completion of the schedules in both phases.. Each schedule can be considered as being comprised of individual, discrete orders, (for example, the three red products required in week 16 is a single order), and there are 26 orders in total. The object of the game is to minimise the number of orders supplied late. Shipping of orders must occur in date sequence to prevent teams from choosing not to ship one of the earlier orders, thereby allowing the supply of a larger number of later orders on time.

As stated earlier, an objective of the game was to illustrate the impact of operational decisions on financial performance. To achieve this, teams start each phase with 60p, (with team using local currency abroad). Raw materials cost 1p per brick, giving a purchase price of 5p per bar and 1p per casting. Teams receive 25p if shipping of a finished product occurs on time, (early delivery is not allowed). After each turn, teams pay 30p to cover overheads, and a penalty of 4p charged for every week that any order is late. For example, if an order were one week late, only 21p per product would be paid. If an order were two weeks late, 17p per product would be paid. If two or more

Table 1. Sales schedule for the red and white end products.

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Red Req.	1	0	1	0	1	0	1	0	1	1	1	1	1	1	1	3
White Req.	1	1	1	1	0	2	2	2	1	1	1	0	2	2	1	1

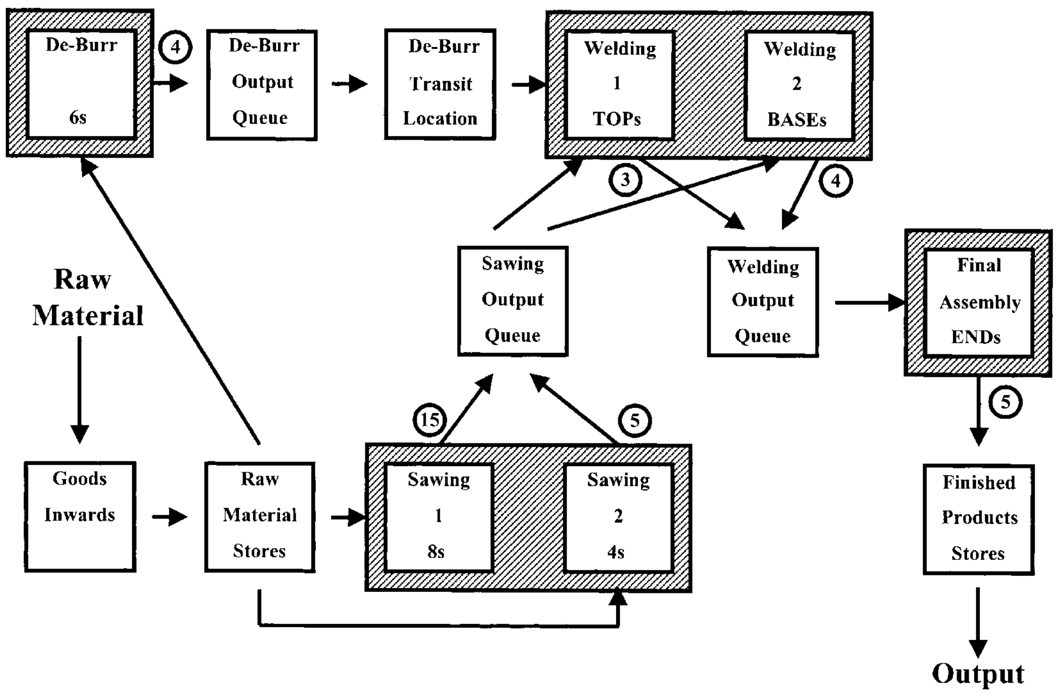

Fig. 3. The simulated factory for phase.

teams compete in the game and each team has the same number of overdue orders at the end, the team that has the most cash left at the end wins the game. The winning team gets a small prize.

THE GAME: PHASE I

Typically, one instructor runs the game. An assistant is usually necessary if more that one team plays in any given session. (The requirements for the game are at the end of the paper.) The instructor begins the first phase by giving an overview of the game, then outlines the manufacturing sequence described earlier. Next, the factory layout is described (see Fig. 3).

The factory is simulated using cards and the instructor is advised to arrange these prior to the session, (there is an example of a card in Fig. 4). To enable production to start immediately, the various stock locations have Work in Process (WIP) pre-located.

Table 2 summarises the opening inventory position. In the instructor's explanation, the following points need emphasis: the participants play in discrete turns for the sixteen weeks of the game. The instructor begins each turn by asking the purchasing manager what raw materials the team

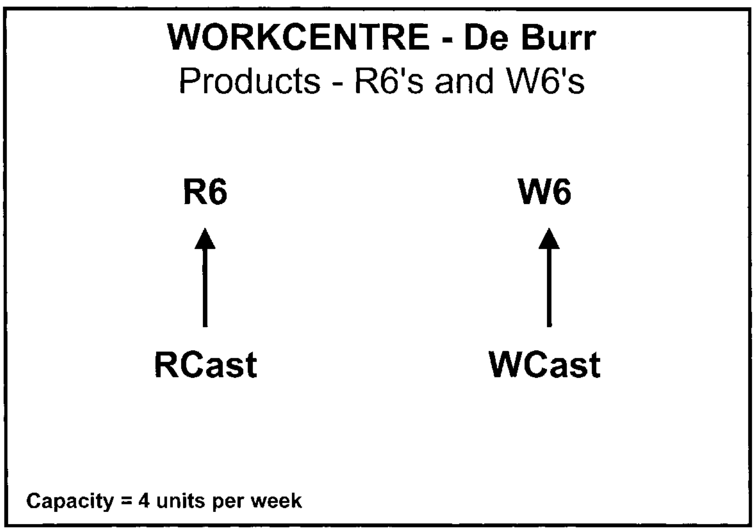

Fig. 4. Example of a workcentre card.

Table 2. Initial work in process for Phase I.

Stock location	Red product WIP	White product WIP
Goods inwards		
Raw material stores	3 × R8BAR	3 × W8BAR
	3 × R4BAR	3 × W4BAR
	4 × R6CAST	4 × W6CAST
De-burr output queue	3 × R6	
De-burr transit locations		2 × W6
Sawing output queue	8 × R8	4 × W8
	2 × R4	3 × W4
Welding output queue	2 × RBASE	2 × WBASE
	2 × RTOP	2 × WTOP
Finished products stores		

require. Each of the participants operating a work centre then carries out their week's production in three stages:

- **Get** the material from the input queue of the workcentre.
- **Carry out** any operations on the bricks.
- **Place** the completed items in the output queue of the workcentre.

Note that it is essential for the participants to undertake these stages synchronously. When the game was first played, the authors noticed that there was a strong tendency for participants to carry out their production out of sequence. The authors therefore recommend that the participants play the first few turns of the game slowly until they achieve some familiarity with the situation. Note the style of production described represents a 'push' manufacturing system. The diagram in Fig. 3 illustrates the material flow through the factory. The following key points are explained:

- Raw material enters the factory at Goods Inwards. This material however, is not available for processing. At the end of the turn, the material is moved to the Raw Material Stores where it can be used during the next turn. This introduces a one week delay to availability of raw material to represent inspection, and means that the purchasing manager has to plan ahead when determining what material to buy.
- There is also a one-week delay between De-Burr and the Welding 1 workcentres due to the presence of a transit location. This simulates the fact that De-Burr is physically remote from the rest of the factory. Again, this complicates planning.
- Each workcentre has a limited capacity as indicated by the circled numbers in Fig. 3. Thus Final Assembly has a maximum capacity of five end products per week. Workcentres do not have to utilise their full capacity.

The rules require each workcentre to produce a mixture of red and white products to support the sales schedule. A set-up time of one week associated with changing between the two colours means, in effect, that if a workcentre changes over, it has to miss a turn. The only exception to this rule is the Final Assembly workcentre that can manufacture a mixture of red and white products in each turn. If this were not the case, it would not be possible to achieve the initial requirement of one red and one white product.

The instructor explains that an incentive scheme is in place. The team as a whole has the objective of maximising delivery performance and cash flow. The individual workcentre with the highest utilisation also receives a small prize. Utilisation is calculated as follows:

$$\text{Utilisation} = \frac{\text{Actual Production Over 16 Weeks}}{\text{Maximum Theoretical Production Over 16 Weeks}}$$

Therefore, if the Welding 2 workcentre (capacity 4 units per week) produced 32 units during the game, this would represent a utilisation of 32/64 or 50%. Note that the rules do not allow credit for set-ups. To track the production levels at each workcentre, time sheets are handed-out (see Fig. 5).

Phase I: game playing guidelines

The authors will show later that the scenario for Phase I is extremely challenging, with the result that it is very common for there to be considerable confusion among the participants. To some extent, this is desirable as it graphically illustrates the importance of simplification. It is essential however for the instructor to maintain control. The best way that the instructor can achieve this is by prohibiting participants from touching the bricks except when actually engaged in a turn.

The teams' participants will require around fifteen to twenty minutes to organise themselves and develop a plan. Experience has shown that a longer period is counterproductive. The instructor can answer questions of fact, but it is important not to give advice or guidance. The participants should play the first three or four turns fairly slowly under close supervision. Thereafter, each turn should require no more than 5–10 minutes. Most teams generally complete the last two turns very quickly, because they are attempting to flush out their WIP. During the course of the game, the customer services manager maintains an on-going record of schedule adherence. At the end of Phase

Time Sheet

Workcentre Name ________________

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Planned Output	R																	
	W																	
Actual Output	R																	
	W																	
Set Up																		
Customer Orders	R	1	0	1	0	1	0	1	0	1	1	1	1	1	1	1	3	
	W	1	1	1	1	0	2	2	2	1	1	1	0	2	2	1	1	

Total Output ______

Total Capacity ______

Workcentre Utilisation ______

Fig. 5. Example of a time sheet.

I, the customer service percentage is calculated by dividing the number of orders on time by the total (twenty-six) and the finance managers are asked to report on the teams' cash total.

It is common for teams to run out of cash, (and there is an explanation of the reasons for this in the next section). Under these circumstances, the instructor should make a loan in 10p multiples at a negotiable interest rate of between 1–3p per week per 10p borrowed.

Review of Phase I

A de-brief session occurs after completion of Phase I. The participants should now be convinced that the task is extremely difficult, despite the apparent simplicity of the game. Indeed, no team has ever achieved a customer service of 100% in over sixty games, the best result being one late order. Typically, between seven and ten late orders is the outcome. Five or fewer late orders is an excellent score. Because of the participatative nature of the exercise, the outcome at the end of Phase I will be different each time. Based on the large number of occasions the game has been played however, a number of common themes have emerged:–

1. **Non-recognition of the bottleneck.** Figure 3 shows that the workcentre 'Welding 1' has the lowest capacity in the factory. While this may appear obvious, many teams do not recognise this because of the general complexity of the game and because of confusion between the participants. Because the factory operates on a 'push' basis, there are no built-in limits to WIP levels. If non-bottlenecks manufacture at their maximum capacity, high levels of WIP will result, inevitably leading to poor cashflow and potentially the requirement for a loan. Another factor that often causes problems is that De-Burr does not deliver the correct mix of parts to the Welding 1 workcentre. This can result in the bottleneck being starved of parts. The so-called 'nine rules of OPT' [15] suggest that time lost at the bottleneck affects the entire manufacturing system.
2. **Poor coordination.** The layout of the factory is not conducive to effective planning and coordination. It is extremely common, for example, to have large numbers of unmatched RTOPS and WBASES (or vice-versa) in the Welding Output Queue.
3. **Too many set-ups**. Many companies have recognised that large lot-sizes are undesirable. Large lot-sizes, however, are only a symptom of a more fundamental problem: that of long set-up times [16]. A simple analysis demonstrates that this effect is very significant in the game. There is a production target of 33 end products during the 16-week period. The bottleneck would be capable of producing sufficient parts in only eleven weeks in a single colour, (at the rate of three per week). This leaves five 'spare' weeks available for set-ups. Exceeding this number will reduce availability and there will be insufficient parts available to meet customer requirements. Because of this, it is necessary to time the set-ups very precisely to achieve the schedule. It is noteworthy that if large amounts

Table 3. The supply/demand pattern required to achieve 100% service.

	REND	WEND	RTOP			WTOP		
Wk	Demand	Demand	Demand	Stock	Supply	Demand	Stock	Supply
				2			2	
0			1	1	0	1	1	0
1	1	1	0	1	0	1	2	2
2	0	1	1	0	0	1	1	0
3	1	1	0	3	3	1	0	0
4	0	1	1	2	0	0	0	0
5	1	0	0	2	0	2	1	3
6	0	2	1	1	0	2	2	3
7	1	2	0	1	0	2	3	3
8	0	2	1	0	0	1	2	0
9	1	1	1	2	3	1	1	0
10	1	1	1	4	3	1	0	0
11	1	1	1	3	0	0	0	0
12	1	0	1	2	0	2	1	3
13	1	2	1	1	0	2	2	3
14	1	2	1	0	0	1	1	0
15	1	1	3	0	3	1	0	0
16	3	1	0	0	0	0	0	0
Total	14	19	13	1.375 Average	12	18	1 Average	17

of WIP were available at the outset of the game, recognition of the problem of long set-up times would not occur. Within the de-brief session, it is useful for the instructor to refer to the so-called 'rivers and rocks' [17] analogy to emphasise this point.

4. **Use of unsophisticated planning techniques.** Table 1 shows a requirement for a mixture of red and white end products. Planning backwards from customer requirements will lead to a production plan requiring red and white products during the same week, violating the rules. This reveals a need for a more sophisticated approach; demand needs to de-coupled from supply and a feasible top-level schedule derived. This will enable the development of lower level schedules for all work-centres. Effectively, this is the application of Master Production Scheduling (MPS) to de-couple manufacturing from sales demand. An overview of MPS is given by Berry and others [18]. Even in the simple situation offered by the game, deriving the appropriate MPS is very difficult without access to a spreadsheet programme. Table 3 shows one of the schedules for the bottleneck that leads to 100% customer service. It is of course necessary for the other non-bottleneck workcentres to support this schedule. Table 3 indicates five occasions between the significant period of weeks 1–15 when set-ups occur during those weeks where the supply schedule for red and white TOPS is zero. This is in keeping with the logic described in point three above.

The de-brief session should describe the benefits of formal planning systems for manufacturing effectiveness. It should also indicate that planning systems alone cannot guarantee excellence. Further illustration occurs in the second phase where there is emphasis on importance of improvements within the manufacturing system itself.

THE GAME: PHASE II

Introduction to Phase II

At the start of Phase II, the instructor will invite the participants to comment on the game. Participants sometimes observe that the simulated company has some advantages over those they have encountered in real-life. For example, the simulated company has no breakdowns, absenteeism or quality problems and suppliers of raw material are reliable. Furthermore, a firm sixteen-week demand schedule is available. There are a number of problems however:

- **Poor layout**. The layout of the factory is very poor. Because material flow paths cross, visualisation of the production situation is very difficult. Participants have to walk around the table to understand what is happening.
- **Delays**. The delay built-in at Goods Inwards and the De-Burr Transit Location complicates planning.
- **Raw material sizes.** Raw material is in inconvenient sizes.
- **Incentive scheme.** The individual incentive scheme is unhelpful. If participants at non-bottleneck workcentres attempted to maximise utilisation, this would inevitably lead to high WIP and poor cashflow. Indeed, in the context of this game, incentives at team and individual level are mutually contradictory.
- **Long set-up.** The long set-up times are the main cause of serious problems, complicating planning and control enormously.

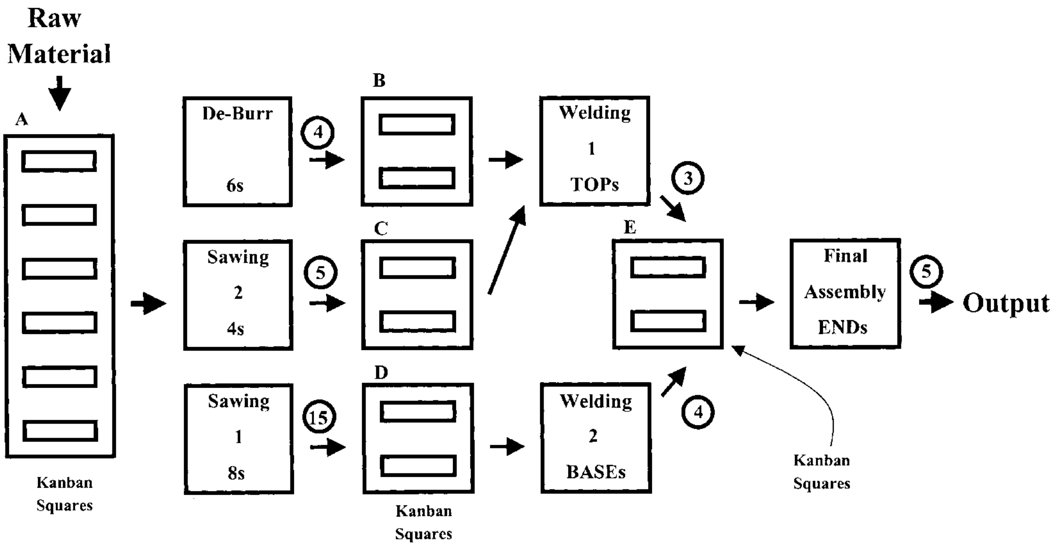

Fig. 6. Factory Layout for Phase II.

The next stage is for the instructor to outline the second phase. In this case, the products, sales requirements, initial cash and the workcentre capacity are identical to Phase I but there are significant changes to the plant layout. Figure 6 illustrates this aspect.

Phase II: Game Playing Guidelines

The key differences in phase II are as follows:

1. Delivery of raw material is in more convenient units. Delivery of R8BAR and W8BAR is in units of four bricks (cost 4p). Delivery of R4BAR and W4BAR is in units of three bricks (cost 3p).
2. This phase employs a system of Kanban squares. The practical implication of this new style of manufacture is that the first stage of each turn involves the production of customer requirements. Components are then 'pulled' through the system to Purchasing, (which Kanban also controls). Table 4 shows the sizes of the Kanban squares. Figure 7 shows an example of one of the cards used to represent Kanban squares. When any of the Kanban squares is empty, this is a signal for an upstream workcentre to initiate production. There is a slight complication in the case of the Sawing 2 Kanban in that delivery of the raw material is in bars of three bricks. It is therefore necessary to make provision for two spare bricks. Note that if the overflow area is empty, this is not a signal to manufacture. There is a description of the use of Kanban squares in [19].
3. Reduction of the set-up time occurs. Under the new scenario, workcentres do not need to miss a turn to change between colours, although production of red and white products, however, cannot occur during the same turn. This means the teams still need to take some decisions as it is likely both red and white Kanbans for a given part will on occasion, simultaneously yield conflicting signals. The exception to this is Final Assembly that (as in Phase I) can manufacture a mixture of RENDs and WENDs in the same week.
4. Payment for purchased materials takes place at the end of the week, and payment of overheads takes place at the start of the week to compensate for this.
5. There is no longer an individual incentive scheme. Consequently there is no requirement for the time sheets since these represent a non-value adding activity.

Table 4. Initial WIP and Kanban sizes for Phase II

Kanban	RED WIP	WHITE WIP	Kanban Size
Raw material (A)	3 × R8BAR	3 × W8BAR	3 × W8BAR + 3 × R8BAR
	3 × R4BAR	3 × W4BAR	3 × W4BAR + 3 × R8BAR
	3 × R6CAST	3 × W6CAST	3 × W6CAST + 3 × R6CAST
De-burr (B)	3 × R6	2 × W6	3 × W6 + 3 × R6
Sawing 2 × (C)	2 × R4	3 × W4	3 × R4 + 3 × R4
Sawing 1 (D)	8 × R8	4 × W8	12 × W8 + 12 × R8
Welding (E)	2 × RBASE	2 × WBASE	3 × WBASE + 3 × RBASE
	2 × x RTOP	2 × WTOP	3 × RTOP + 3 × WTOP

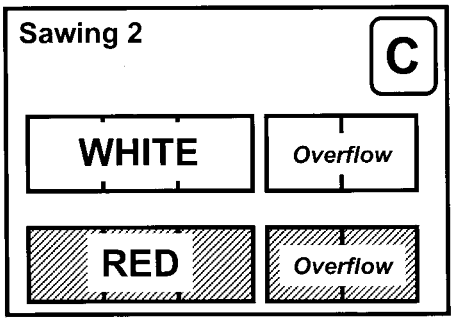

Fig. 7. Example of a Kanban squares card.

6. The Kanban squares do not allow replication of the initial WIP of Phase I. Table 4 shows the opening WIP position for Phase II.
7. Elimination of the delays at Goods Inwards and De-Burr Transit Location occurs.

It is possible to play Phase II far faster than Phase I as planning complexity is significantly reduced.

Review of Phase II

The main conclusion from Phase II is that the simplifications made have the effect of reducing planning complexity enormously. It is very common however, for teams to fail to supply the final week's requirement of one WEND and three RENDs. The relative simplicity of Phase II can lead to over-confidence from participants and teams often fail to plan correctly for the final week's requirement. The reason for this is that the bottleneck workcentre cannot produce red and white components in the same week. The message from this result is that there is still a requirement for further set-up improvements.

REVIEW OF THE BUSINESS GAME

The game has been played over fifty times throughout the Federal-Mogul Group in the UK, USA, Southern Africa and in Germany, (where participants use German translations of the material). Because of its popularity, group companies have on several occasions requested wider repetition of the game, following an initial session. Discussion with participants suggested that there is a preference for interactive games over formal lecturing. While it is very difficult to assess the value of this form of education, feedback from participating companies suggests it has been valuable in communicating the key concepts and in team building.

Because of differing circumstances in the various group companies, participants addressed a variety of issues during sessions:

- Importance of simplification and the consequences of complexity
- Importance of bottlenecks
- Utilisation/WIP/cashflow
- Importance of team working
- Need for coordination and planning
- Problems of incentives schemes
- The concealing effect of high stocks (river and rocks analogy)
- Need for MPS
- Effect of lot-size and the importance of set-up reduction
- Importance of good layout
- Mechanics and benefits of Kanban

There have also been a number of opportunities to trial the game with undergraduate and postgraduate students in a university environment to support lecture programmes on MPC and manufacturing systems. Following the first of two three-hour sessions, the students write a critical report on the simulated company and make suggestions for improvement. These reports reveal a number of creative suggestions, including:

- 'The casting supplier should remove the burrs at their plant. This would minimise material handling.'
- 'Only white products should be manufactured. A paint spraying process should be introduced to create red products in response to customer orders.'

Just how seriously participants at all levels from undergraduates to board members take the game has been a source of consistent surprise for the authors. Indeed, on several occasions, instructors have needed to carefully manage the level of competitiveness between teams.

Instructor guidelines

A number of guidelines have emerged to facilitate the game's successful operation during its use in both academic and industrial situations. It is important to recognise that the objective of the game is to illustrate a number of key concepts. To this end, there is deliberate exaggeration of some elements of the game to graphically illustrate these ideas. However, it is dangerous to press the analogy of the game to real-life to the personnel of participating companies.

Next, it is important that the game has a clear objective. It is possible to use the game as a vehicle to discuss a number of issues, but to attempt to discuss all of these areas would be extremely difficult in the time normally available. It is important, therefore, to establish which areas to cover at the outset. It is also important that the instructor does not give advice and guidance to the teams. Although it is tempting to give hints to teams that are making obvious mistakes, the authors believe that errors represent an important part of the learning process. Finally, although it is important for the instructor to encourage the participant's enthusiasm, it is also important to ensure the maintenance of good order to allow the game to progress smoothly.

Requirements for the game

Listed below are the items required to play the game. Quantities are quoted per team. When calculating numbers of bricks required, allowance has been made for WIP build-up during the game.

Workcentre Cards	6 (one per workentre)
Stock Location Cards	7 (one per location)
Kanban Cards	5
Time Sheets	10 (one per team member)
Large Schedule Requirements Sheet	1
R8 Bricks	100
R6 Bricks	30
R4 Bricks	30
W8 Bricks	130
W6 Bricks	40
W4 Bricks	40
Black '2' Bricks (Burrs)	70

CONCLUSIONS

The game has proved successful and its use continues within the company. It has also proved useful in an academic environment, providing a stimulating and enjoyable supplement to formal lectures. Development on the game is continuing. There appears to be particular potential to use the game to highlight weakness in standard costing systems.

Acknowledgements—The authors would like to thank Federal-Mogul for their support. They would also like to thank the various members of group MIS for their valuable suggestions for improvement of the game.

REFERENCES

1. D. J. Petty and D. K. Harrison, Implementation of a business control system in a divisionalised manufacturing company—a case study. Advances in Manufacturing Technology IX; *Proc. Eleventh National Conference on Manufacturing Research,* pp. 331–335, Professional Engineering Publishing Ltd, Bury St Edmunds, UK (1995).
2. B. Parkinson, R. Senior and P. Hudson, Teaching strategic management through simulation. Advances in Manufacturing Technology XII; *Proc. Fourteenth National Conference on Manufacturing Research,* pp. 517–522, Professional Engineering Publishing Ltd., Bury St Edmunds, UK (1998).
3. D. H. Taylor, Demand amplification: has it got us beat? *Int. J. Physical Distribution and Logistics*, **30**(6), pp. 515–533 (2000).
4. R. de Souza, S. Zice and L. Chaoyang, Supply chain dynamics and optimisation, Integrated Manufacturing Systems, **11**(5), pp. 348–364 (2000).
5. K. Ishii, K. Takahashi. and R. Muramatsu, Integrated production, inventory and distribution systems, *Int. J. Production Research*, **26**(3), pp. 473–482 (1988).
6. M. C. Meal, M. H. Wachter and D. C. Whybark, Material Requirement Planning in hierarchical planning systems. International Journal of Production Research, 25(7), 947-956 (1987).
7. J. Browne, J. Harhan and J. Shivnan, *Production Management Systems: A CIM Perspective*, p. 66, 267–273, Addison-Wesley, Wokingham, UK (1988).
8. G. W. Plossl, *Production and Inventory Control: Principles and Techniques*, pp. 343–344, 2nd Edition, Prentice-Hall, Englewood Hills, NJ, USA (1985).
9. R. J. Schonberger, *Japanese Manufacturing Techniques—Nine Hidden Lessons in Simplicity*, pp. 12–13, The Free Press, New York, USA (1982).
10. R. A. Fox, OPT vs MRP: thoughtware Vs software part II. *Inventories and Production Magazine*, **4**(1), pp. 13–18 (1984).
11. S. C. Aggarwal, MRP, JIT, OPT, FMS: making sense of production operations systems. *Harvard Business Review,* **63**(5), pp. 8–16 (1985).
12. J. Davies and A. K. Kochhar, A framework for the selection of best practices, *Int. J. Operations and Production Management,* **20**(10), pp. 1203–1217 (2000).
13. R. Lundigran, What is this thing called OPT? *Production and Inventory Management*, **6**(2), pp. 2–11, (1986).
14. A. Gubta, Enterprise Resource Planning: the emerging organizational value systems, *Industrial Management and Data Systems,* **100**(3), pp. 114–118 (2000).
15. M. Al-Mashari and M. Zairi, Supply-chain re-engineering using enterprise resource planning (ERP) systems: an analysis of a SAP R/3 implementation case, *Int. J. Physical Distribution* **30**(3/4), pp. 296–313 (2000).
16. R. Lundigran, What is this thing called OPT? *Production and Inventory Management*, **6**(2), pp. 2–11, (1986).
17. S. Shingo, *A Revolution in Manufacturing: The SMED System*, The Productivity Press, New York, USA, (1985).
18. P. J. O'Grady, *Putting the Just-in-Time Philosophy into Practice.* Kogan Page Ltd., London, UK, pp 36–38 (1988).
19. W. L. Berry, T. E. Vollman, and D. C, Wybark, *Master Production Scheduling: Principles and Practice*, pp. 3–16. APICS, Falls Church, VA, USA (1987).
20. R. Russell and B. W. Taylor, *Production and Operations Management: Focusing on Quality and Competitiveness,* p. 758. Prentice-Hall, New Jersey, USA, (1995).

David Petty is a lecturer in the Department of Mechanical Engineering, UMIST. He is a fellow of the Institution of Electrical Engineers and the Institute of Operations Management. Prior to his appointment at UMIST, he undertook manufacturing systems consultancy for the Federal-Mogul automotive components group for eleven years. His main interest are planning and control and the application of systems within industry.

Simon Hooker is a physics graduate and is a supply chain consultant for STC International. He has fifteen years experience in the manufacturing software sector. He started his career with Federal-Mogul group where he was responsible for a number of successful implementations of Manufacturing Control Systems.

Kevin Barber CEng is head of Total Technology at UMIST. He is a fellow of the Institution of Electrical Engineers. He has wide industrial, academic and research experience. He has supervised twenty PhDs to date and has worked closely with manufacturing industry on a variety of collaborative projects. His principle research interests are manufacturing systems, production management and business process modelling.