Can support systems adversely affect cell performance?

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Abstract

This paper aims to determine the effect that support systems have upon the productivity of manufacturing systems. Two case studies were undertaken in two separate factories. The method encompassed: determining the support system configuration, identifying significant production problems, problem-solving to identify root cause and the tracking of process routes. Links between configuration, production problems and process routes are emphasised. The results show that the design of the support system adversely affects the manufacturing system by causing quality problems and an inability to meet production deadlines. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

In order to remain competitive, many companies seek to implement more efficient and flexible manufacturing systems. Previous research has centred upon the development of these systems, that is, followed a technocentric approach, while very little work has been undertaken concerning the effect of holistic organisational design upon the success of a factory. This paper attempts to address this issue by heeding Small's \cite{1} recommendations that knowing what the whole plant and its support functions will eventually look like is vital in the generation of a master plan for manufacturing. The following paragraph discusses the systems that constitute a manufacturing organisation. It is proposed that a manufacturing organisation consists of two distinct, but interacting systems: (1) the manufacturing system; and (2) the support system \cite{2}. This research focuses upon the support system and its effect upon the manufacturing system. A support system is defined as the ‘indirect’ element of the manufacturing organisation, and is an essential contributor to the success of the overall process \cite{3}. This means that, although support systems are not directly involved in manufacturing products, they have an essential supportive role within the factory \cite{4}. A support system is composed of up to 11 support functions: (1) information technology; (2) maintenance; (3) engineering; (4) quality; (5) design and development; (6) human resource management; (7) procurement; (8) sales; (9) marketing; (10) production planning; and (11) finance \cite{5}. A company may operate using either all or some of the support functions. The following section describes how information pertaining to the support system is used in this research.
2. Aims

The aim of this research is to discover whether the way in which support functions work affects the performance of the manufacturing system either positively or negatively. Examining the way in which support functions work entails determining their structure, their location within the factory, whether they are team based or functionally divided, and finally, the processes they use to achieve their goals. This information is gathered in two case study companies, a method which allows the investigation of support functions in situ. The research is standardised by selecting two companies which use manufacturing cells. The following section summarises the literature pertaining to this research.

3. Background

This section is structured around three questions: (1) do manufacturing cells attain the projected benefits?; (2) if they do not, in which areas are they failing to achieve their projected benefits?; and (3) are these areas linked to the support system?

The literature indicates a high level of performance in terms of cell engineering, with many companies professing to attain benefits in terms of reducing fixtures, equipment used, space and unit cost, throughput time, quality rejects, WIP, complex product flow and material handling [6–11]. However, the more removed the research focus is from the immediate manufacturing cell, the greater the identified problems, indicating a technocentric approach within factories. This is supported by the fact that many companies are failing to achieve benefits in terms of the people operating the system. Bratton [10], Wemmerlov and Hyer [7], Kumar and Hadjinicola [12], Delbridge et al. [13], Nichols and Beynon [14], Waterson et al. [6] and Loo [8] find that in terms of people, many companies suffer low levels of operator training other (with the exception of companies described as world-class), very little operator accountability beyond quality and a negligible degree of cell self-management.

Again, as the focus moves even further from the manufacturing cell and more towards the support system, goal attainment becomes worse. Appleby and Prabhu [15] found that even world class companies perform poorly in terms of production innovation and design cycle time, one reason for this being that 60% of companies do not use any form of concurrent engineering, which is inherently support-orientated [6]. Similarly, many companies experience delays with customer orders within the support system, unresponsive supply chains, assembly drawings arriving after the product has been manufactured and incorrect components at the point of assembly, all of which are the responsibility of support functions [16,17]. Due to the lack of published research in the area, it is not clear why this is the case, but one possibility is that companies might be retaining inflexible, Tayloristic structures beyond the manufacturing cell. There is some evidence to support this. Firstly, it appears that many companies still have support workers divided by function rather than multifunctionally [18–20]. Muhlemann et al. [21], Adair and Murray [22] and Schubert and Couchman [23] all claim that the functional division of labour leads to complex, sequential product flow, inflexibility and a lack of traceability. Considering this, it is not surprising that systems such as MRP/II are still used by between 82 and 90% of companies [7,8] respectively, even though they are acknowledged to be inflexible [18]. Similarly, although many authors advocate the use of cell-based rather than centralised support functions [8,24,25], in reality there is scant evidence that this is happening in industry.

The literature in this section does hint at a link between the support system and problems in the manufacturing cells, although published research is not comprehensive enough to draw solid conclusions [26]. If there is a link however, it is likely to be magnified in the future. Wemmerlov and Hyer [7] and Wemmerlov and Johnson [27] claim that currently support workers constitute 49.5 and 44.34% of the workforce, respectively, even though they are acknowledged to be inflexible [18]. Similarly, although many authors advocate the use of cell-based rather than centralised support functions [8,24,25], in reality there is scant evidence that this is happening in industry.

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research needs to be undertaken. The following sections present the methodology used to obtain data from two case study companies.

4. The case study companies

To standardise the data obtained, it is proposed that the case study companies need to have 2 years operational experience of manufacturing cells, centrally based and functionally divided support. The two companies selected are described below.

4.1. Company A

Company A is a manufacturer of gas- and oil-fired heating products, employing 800 workers, with a turnover of £60 million. The company has five process and six product cells, producing sub-assemblies and finished products, respectively. The products are all manufactured on site, except for heat exchanger castings which are supplied by a sister company.

4.2. Company B

Company B employs 450 people, has a turnover of £40 million and is a manufacturer of diesel engines and steam turbines varying from 50 to 80 tons in size. Although based on one site, the factory is divided into three autonomous financial units, of which two are relevant to this research: (1) ‘Company B Steam Turbines’ who procure customer orders and design steam turbines to specification; and (2) ‘Company B Manufacturing’, who are paid by Company B Steam Turbines to build engines for their customers. The company has five process cells and six product cells.

The methodology used to collect data from the case study companies is described below.

5. Case study methodology

There are three steps in obtaining data from the case study companies which are described below.

5.1. Determining the support system configuration

The first stage in data collection involves outlining the support system configuration for the 11 support functions. This involves examining: (1) the degree of association between support functions; and (2) the division of support functions. In terms of the degree of association between support functions and the manufacturing cells, previous research [5] has shown four possible categories into which the 11 support functions can be placed. These degrees of association are (1) cell based and responsible for supporting one cell, i.e. the support function is based within the one cell it supports; (2) centrally based but dedicated to a few specific cells, i.e. the support function is based in central offices, with responsibility for supporting only a few cells; (3) centrally based and directly supporting all cells, i.e. the support function is based in central offices with responsibility for supporting all factory cells; (4) centrally based with little direct cell contact, i.e. the support function is centrally based, but perform their tasks in isolation. In terms of the division of support functions, they can be either functionally divided or based in multifunctional teams.

5.2. Identification of significant production problems

After determining the support system configuration, a representative manufacturing cell within the factory is selected for stage 2 of the analysis. The next stage is the identification of a significant production problem related to that cell. Common significant problems are line stoppages, late delivery of products and recurring poor quality.

Once the significant production problem has been identified, it is verified and quantified through data collection. For example, if a product is often delivered late, the type of product and the frequency of its late delivery is recorded in addition to other pertinent data. The next stage involves identifying the root cause of the production problem, and a problem solving technique called ‘5 whys’ [28] is applied. This enables the identification of any links between the production problem and the support system. If a link is identified, stage 3 (described below) can commence. If a link is not identified, the methodology is discontinued.
5.3. Tracking process routes

Problem solving identifies the cause of a production problem, but does not determine why that cause exists. A flow process chart [29] is used in order to elaborate upon the role of the support function in causing production problems. The flow process chart has a fixed start (either the forecast of demand or customer places order, depending upon the logistics system within the factory) and end (components delivered to cell) in order to standardise inter-company data. The level of detail in flow process charts give a good indication of support system efficiency.

In terms interpreting the chart, each box represents a single stage in the process and each arrow indicates the direction in which the sequence proceeds. Unmarked arrows show that the process stage moves ahead unhindered while arrows labelled ‘not OK’ show the path of the process if a problem occurs. In addition, the flow process chart is adapted slightly for the benefit of this research. The adaptations are: (1) a box with a grey background indicates a link to another system, for example an MRPII system; and (2) bold type in the boxes represents departments where the tasks are carried out.

6. Company A results

6.1. Configuration

The configuration shows that virtually no support functions are based in the cell. Indeed the skew is very much towards centrally based workers, with four functions rarely contacting the cell (Table 1).

In terms of the division of support functions, all are functionally divided.

6.2. Identification of significant production problems

The representative cell selected for analysis is a product cell containing 15 full-time direct operatives and a cell manager. It manufactures four main products which have 29 variations. The output goal is 35 boilers/day. An interview with the cell manager pinpointed that main problem suffered in the cell is downtime which averages 395/labour hours per week. The manager claimed that the downtime is caused by one supplier either not delivering control boxes on time or delivering non-conforming control boxes. The fact that outsourced control boxes are non-conforming and delivered late is verified through data obtained from the company COPICS system, shown in Table 2.

The data in Table 2 relate to the eight months preceding the case study (03/95 to 01/96). Once the problems have been verified, they are subjected to the ‘5 whys’ problem-solving exercise. In this instance the information was obtained from the supplier of the control boxes, referred to as Company A supplier. It can be seen from Table 3 that the root cause of the production problems is fluctuating orders from Company A.

The above table shows that there is a direct link between the Company A supplier not being able to deliver on time and the purchasing function of Company A. A flow chart is now produced in order to determine whether Company A’s support system affects this process.

<table>
<thead>
<tr>
<th>Degree of association between support functions and cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell based and responsible for supporting one cell</td>
</tr>
<tr>
<td>Centrally based but dedicated to a few specific cells</td>
</tr>
<tr>
<td>Production planning</td>
</tr>
<tr>
<td>Production engineers</td>
</tr>
<tr>
<td>Purchasing material control</td>
</tr>
<tr>
<td>Centrally based and directly supporting all cells</td>
</tr>
<tr>
<td>Quality</td>
</tr>
<tr>
<td>Maintenance</td>
</tr>
<tr>
<td>Information</td>
</tr>
<tr>
<td>Technology</td>
</tr>
<tr>
<td>Personnel</td>
</tr>
<tr>
<td>Stores</td>
</tr>
<tr>
<td>Centrally based with little direct cell contact</td>
</tr>
<tr>
<td>Finance</td>
</tr>
<tr>
<td>Marketing</td>
</tr>
<tr>
<td>Sales (&amp; forecast)</td>
</tr>
<tr>
<td>Design</td>
</tr>
</tbody>
</table>
6.3. *Company A* flow process chart

Fig. 1 shows the process used from forecast of demand to delivery of parts in the cell.

A flow chart analysis of the non-value adding stages is shown in Table 4. An additional category of rework is added in this instance because it represents non-value adding work but this is not clear using the existing categories.

Table 4 makes the system appear efficient, with 11 operations out of a total of 15 which are generally classified as value-adding. However, upon closer examination, most of the operations in the flow chart are simply not needed. The only essential operations are forecast parts, order parts and receive delivery of the parts to the cell. Instead, six departments are involved and the total lead time of the process is over a month. In addition, the table does not take into account the rework loops, of which there are three, each meaning that a segment of the process must be repeated.

The following section shows the data obtained from Company B.

7. *Company B* results

7.1. Configuration

Table 5 depicts the degree of association between support functions and manufacturing cells within the organisation.

Company B again shows skew towards being centrally based with very little cell contact. Similarly, the support workers are all functionally divided.

7.2. Identification of significant production problems

The representative cell is a steam turbine assembly cell which has been operational for over 2 years. All steam turbines manufactured by Company B must pass through the cell, making the cell part of
the critical path. An interview with the manager of the steam turbine assembly cell, highlighted that the most consequential problem is the inability to meet build-plan dates. This claim was verified by an analysis of process lead times for critical components involved in the production of one steam turbine (see Table 6).

The above table confirms that build plan dates are not being met due to component shortages. Analysis continues with the problem-solving exercise which seeks to determine the cause of the components shortages detailed above. Table 7 shows the results of the problem solving exercise.

Table 7 shows that the root cause of production problems is specification changes in steam turbines which are issued to the manufacturing cells by the design department. In addition, the cell manager claimed that steam turbine engines were delivered to the customer up to 1 year late. Due to the fact that the problem-solving exercise and late delivery claims were made by one person, a further verification exercise was undertaken, in which the number of engineering changes made by the design department were monitored. The results are shown in Table 8. The total number of drawings produced as part of the manufacturing process was 2896, and the period covers 1 year.

Table 8 confirms the results of the problem-solving exercise; the design function do cause delays through engineering changes, with 431 recalls
Table 5
Support system configuration for Company B

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Tool services</th>
<th>Maintenance</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell based and responsible for supporting one cell</td>
<td>Production planning</td>
<td>Purchasing</td>
<td>Finance</td>
</tr>
<tr>
<td></td>
<td>Stores control</td>
<td>Tool design</td>
<td>Marketing</td>
</tr>
<tr>
<td>Centrally based but dedicated to a few specific cells</td>
<td></td>
<td></td>
<td>Sales</td>
</tr>
<tr>
<td>Centrally based and directly supporting all cells</td>
<td></td>
<td></td>
<td>Scheduling</td>
</tr>
<tr>
<td>Centrally based with little direct cell contact</td>
<td></td>
<td></td>
<td>Personnel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IT</td>
</tr>
</tbody>
</table>

Table 6
Data relating to turbine component shortages

<table>
<thead>
<tr>
<th>Number of components or sub-assemblies required before steam turbine can be completed</th>
<th>Average number of operations the components require before they are ready for assembly</th>
<th>Average length of time each component is overdue (days), in terms of meeting product delivery date</th>
<th>Average length of time since the last operation on that component (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>72</td>
<td>5</td>
<td>54.01</td>
<td>110.479</td>
</tr>
</tbody>
</table>

Table 7
‘Five whys’ problem-solving exercise for inability to meet build plan dates

<table>
<thead>
<tr>
<th>Problem</th>
<th>Unable to meet build-plan deadlines</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Why</td>
<td>Product priority is changed and another product is more urgent</td>
</tr>
<tr>
<td>Second Why</td>
<td>The new priority product is more urgent because the deadline is more overdue</td>
</tr>
<tr>
<td>Third Why</td>
<td>The new priority product is overdue because it did not have all components needed in the original schedule</td>
</tr>
<tr>
<td>Fourth Why</td>
<td>The components were not available because they were awaiting design drawings</td>
</tr>
<tr>
<td>Fifth Why</td>
<td>Changes to the steam turbine specification meant that the design drawings had to be re-drafted and were therefore late</td>
</tr>
</tbody>
</table>

Table 8
Engineering change analysis 1997

<table>
<thead>
<tr>
<th>Reason for change</th>
<th>Number of changes</th>
<th>Percentage of changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional information</td>
<td>149</td>
<td>5.14</td>
</tr>
<tr>
<td>Change of standard</td>
<td>80</td>
<td>2.76</td>
</tr>
<tr>
<td>Customer change</td>
<td>22</td>
<td>0.76</td>
</tr>
<tr>
<td>Error within operations</td>
<td>73</td>
<td>2.52</td>
</tr>
<tr>
<td>Design standard change</td>
<td>35</td>
<td>1.21</td>
</tr>
<tr>
<td>Change for cost saving</td>
<td>66</td>
<td>2.28</td>
</tr>
<tr>
<td>Workshop error</td>
<td>6</td>
<td>0.21</td>
</tr>
<tr>
<td>Total changes</td>
<td>431</td>
<td>14.88</td>
</tr>
</tbody>
</table>

The results encompass two financial units: Company B Steam Turbines and Company B Manufacturing. Each unit has a separate chart for clarity and the two charts are sequential, that is, Fig. 3 continues from Fig. 2.

Two observations should be noted about the above figure. The first is that in 35% of cases, the customer changes the product specification following approval. The second observation is that in 14% of instances, Company B rejects the drawings. Both observations show percentages which are considerably higher than the figures quoted in the engineering change analysis (see Table 8). This could be due either to inaccuracies in the data
supplied by the Senior Design Engineer, or to incorrect data being presented in the official report of engineering changes which is supplied to senior management.

Fig. 3 is a continuation of Fig. 2, and encompasses Company B Manufacturing. It should be noted that neither Company B manufacturing, nor Company B Steam Turbines have any knowledge of the others process routes.

An flow chart analysis of the storage, operation, transport and inspection is shown in Table 9. Table 9 shows 26 stages in the combined process routes. Of the 26, 15 (storage + transport + inspection) are non-value added. Similarly, the operations exist within a non-optimised system and may therefore, be unnecessary. The results of the flow process charts show that Company B’s support system is extremely complex with a high number of non-value-adding stages.

8. Discussion

The results show that there is a relationship between the support system and poor production performance. The discussion addresses both case studies individually.

8.1. Company A discussion

Initially, downtime problems within the cell seem to be caused by the supplier of control boxes, although the problem-solving exercise and flow process chart disproved this. The results show that the sales’ forecast of demand to delivery of parts to the cell process has become part of the critical path in terms of manufacturing lead time. This means that the overall time taken to complete a product can be either lengthened or shortened by the sales’ forecast of demand to delivery of parts to the cell process,
and the manufacturing cell has no control over this. The reason that the process is part of the critical path is the long lead time, which frequently exceeds a month. Even worse, if the sales' forecast fluctuates, which it often does, the whole process has to be repeated. Repeating the whole process does not leave enough time for suppliers to deliver the correct quantity of control boxes on time, and thus the manufacturing cell suffers component shortages and downtime. The following paragraphs try to explain these process problems in Company A.

The first problem is that support functions are remotely based in relation to the cell and have very little contact. This means that fluctuations in forecast for demand are not communicated to the cell, who schedule a build plan not realising that: (1) demand has changed; and (2) it is unlikely that they will receive the necessary components from the suppliers.

The second problem is functionally based support workers. This leads to: (1) the evolution of a sequential approach to work where each function performs their own task before passing it on to another function. This means that the process takes longer, hence contributing to long lead times; (2) individual support functions having little understanding about the tasks performed by other functions. This manifests itself negatively in that
individual functions become self-focused rather team-focused. Self-focus is exacerbated by the reaction of management to poor support system performance. Interviewed support workers believe that the sequential nature of the system means they are trapped in a rigid process. However, they are blamed when parts are late, even though it is the process rather than the individual causing the delay. For example, when the manufacturing cells do not receive their parts on time, energy is spent apportioning blame rather than solving the fundamental problem of a poor support system structure. In addition, staff also feel that their suggestions to improve the process are ignored by management.

The complexity of the sales' forecast of demand to delivery of parts in the cell process is demonstrated by the number of stages involved. When examining the process there are 15 stages and six departments in total. Interviews with managers confirmed that the process evolved as the company expanded and this lack of formal design is borne out by the complex, rigid network of links and loops. System re-design could eliminate up to 70% of these stages as non-value-adding. The following section discusses the results of the case study in Company B.

8.2. Company B discussion

This inability to meet production deadlines seems to be inextricably linked to the design support function in particular. Indeed, analysis showed that this was the case, with 14.88% of products being subject to design changes after they have entered Company B Manufacturing, leading to large fluctuations in build-plan schedules. But is this a support system or a support function problem? The results tend to suggest that the problem lies with the latter. If the design support function was more stringent in its cut-off deadlines regarding engineering changes, then the build-plans would not require alteration. This problem is due to poor management and planning rather than an inherent support system problem. This does not support the hypothesis (stated in Section 1 of this paper); it is the support function rather than the support system which causes manufacturing delays. If however, the support system did operate in an efficient manner, the inefficiencies of the design department may not form part of the critical path, that is, the poor design of the support system serves only to highlight problems within the design department. So why isn’t the support system efficient? The answer is that the support system suffers a lack of flexibility.

The lack of support system flexibility is caused by three factors. The first is the division of the factory into three autonomous business units. This means that there are three separate support systems, when, for efficient production, they should be intertwined. The second factor is the functional division of support (people performing the same or similar jobs are based in the same office). Functional division leads to a sequential approach to work; when one function completes their task, it is passed to a subsequent function for completion of another task, and so on. The time taken in a sequential approach to work is high in comparison to that taken by multi-skilled teams. The third and final factor contributing toward a lack of flexibility is remotely based support. This means that the support functions are based in offices away from the shopfloor. The three factors combined lead to the complex process routes shown in Figs. 2 and 3 and long process lead times (approximately one month from start to finish). Long process lead times mean that changes in product design are obviously problematic. For each of the 431 design changes in 1997 (see Table 8), the support process route had to be repeated, taking on average 2 months for each change to reach the shopfloor (many of these changes pass through the system concurrently). Whilst the product design is being changed, production has to stop, resulting in the rescheduling of the build-plan, and subsequently an inability to meet deadlines. The problems highlighted in the paragraph above show that the support system is fundamental in causing productivity problems, thus supporting the hypothesis.

As a final note for those who think that factory improvement comes about by optimising the manufacturing system; many of the 52 steam turbines on order for 1998 have contractual penalty clauses for late delivery equating to £10,000 per week (each). Despite having excess capacity in the manufacturing cells, each turbine is delivered on
average, a year late due to the delays in processing design changes.

9. Conclusions

Data show that both companies are suffering from the same fundamental problems: (1) remotely based support functions; and (2) functional division of support workers. This leads to a sequential support system process, a high number of non-value adding stages, long lead times and inflexibility. These inherent problems mean that the manufacturing cells suffer in terms of not receiving parts or drawings on time. More seriously, the customer ultimately suffers because they do not receive their order on time. In conclusion, the flow chart results show that the flow of information and components is overly complex and not conducive to a typical cellular manufacturing pull system, resulting in the need for re-design.

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