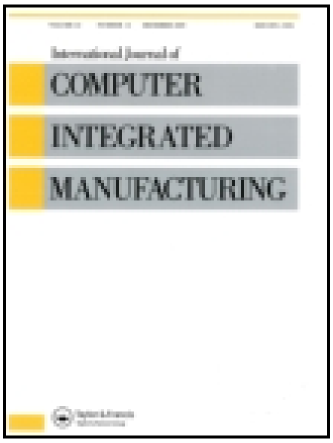
This article was downloaded by: [Loughborough University]
On: 22 August 2014, At: 08:52
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



International Journal of Computer Integrated Manufacturing
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tcim20

Distributed scheduling to support mass customization in the shoe industry

Lee Barnett , Shahin Rahimifard & Stephen Newman
[a] Advanced Manufacturing Systems and Technology Centre, Wolfson School of Mechanical and Manufacturing Engineering , Loughborough University , UK
Published online: 19 Feb 2007.

To cite this article: Lee Barnett , Shahin Rahimifard & Stephen Newman (2004) Distributed scheduling to support mass customization in the shoe industry, International Journal of Computer Integrated Manufacturing, 17:7, 623-632, DOI: 10.1080/09511920412331292628

To link to this article: http://dx.doi.org/10.1080/09511920412331292628

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the “Content”) contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

Distributed scheduling to support mass customization in the shoe industry

LEE BARNETT, SHAHIN RAHIMIFARD and STEPHEN NEWMAN

Downloaded by [Loughborough University] at 08:52 22 August 2014

Abstract. The European shoe industry has experienced significant challenges in the last 20 years, mainly due to the pressures of modern global markets in which the industry has to compete with competitors from low labour cost countries in Asia and the Far East. A new trend is now forecast concerning the mass customization of shoes, where customers choose and order customized shoes from a range of predefined materials and designs. This is to be achieved through the 'shoe shop of the future' with combined capabilities of obtaining 3D models of customer's feet together with the exciting developments offered through the latest advancement in e-commerce. However, such a novel approach for the customization of shoe design and production will have a significant influence on the batch sizes and expected lead times, and will reduce the average batch size of shoe production from 500–1000 pairs to about 10–20 pairs per batch. Consequently, customized shoes will result in an enormous increase in the number of batches, leading to an increase in the complexity of planning, scheduling and tracking of orders both across the supply chain and internally within various production departments of a shoe factory. This research proposes a distributed scheduling approach to provide the required autonomy in decision making and flexibility in job sequencing at departmental level to deal with the complexity of planning a large number of small batch production orders.

1. Introduction

Recently the European shoe industry has seen severe economic problems caused by an increased consumption of lower priced imported footwear. European shoe manufacturers are facing competition from countries with low labour costs, and have responded with a delocalization of production activities outside of Europe and as a consequence 10% of direct jobs have disappeared since 1995. These challenges have necessitated the need for shoe manufacturers to critically analyse and optimize their business and production activities to be responsive to volatile customer demands, and at the same time reduce cost. One approach being considered to regain the lost market share is the provision of mass customization (MC) in shoe manufacture, as a service which currently cannot be provided by mass producers of low cost shoes.

Traditionally the production of shoes involves a large number of operations that can typically be grouped into five major activities of cutting, stitching preparation, stitching, lasting and finishing. These activities are regarded as complex operations that are labour intensive and operator skill dependent. Consequently, a need has been identified to investigate the application of team-based manufacturing adopted in human centred manufacturing systems to provide flexibility and agility required in such complex applications. Furthermore, the application of mass customization in the shoe industry necessitates a novel approach to plan and allocate production to the manufacturing environment which is capable of dealing with a high number of small batches processed by a number of production teams. The research reported in this paper provides an integrated responsive scheduling framework to support the various processes involved in such customized shoe production. This is achieved by the application of distributed scheduling to decompose the decision making tasks involved in planning of the manufacturing activities to empower the local decision maker within production teams providing the flexibility required to support the move towards the implementation of MC principles. The initial parts of the paper outline the issues involved in mass customization of shoes and the later sections describes the development of a novel integrated shoe scheduling system (3S) to support such an MC approach to shoe production.

Authors: Lee Barnett, Shahin Rahimifard, and Stephen Newman, Advanced Manufacturing Systems and Technology Centre, Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, UK.

International Journal of Computer Integrated Manufacturing
ISSN 0951-192X print/ISSN 1362-3052 online © 2004 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/09511920412331292628

Downloaded by [Loughborough University] at 08:52 22 August 2014

2. Mass customization overview

With the increase in the make-to-order market causing a reduction in batch sizes and lead times, manufacturers have been forced to search for a new manufacturing paradigm that allows them to meet customer demand while reducing their cost (Ruddy 2002). Many have turned to implementing mass customization to solve this problem, after consulting with customers (Farish 1997). The term was coined by Stan Davis (1987) and fully expounded by Pine and Victor (1993) as 'the use of flexible processes and organisational structures to produce varied and often individually customised products and services at the price of standardised, mass-produced alternatives'.

Identifying where the need for customization originates may help a company identify where they can customize their product (Duray 2002). Gilmore and Pine (1997) define the element where customers needs differ as 'points of common uniqueness'. It is at these points that the traditional offerings of designing products for average requirements results in customer 'sacrifice gaps' i.e. the difference between what a company offers and what each customer actually wants (Duray and Milligan 1999). To be successful, companies must let the nature of these sacrifice gaps drive their individual approaches to customization. Gilmore and Pine (1997) define a classification that identifies four types of customisation. Each type is distinct and provides a way for categorizing customizers:

- Collaborative: To conduct a dialogue with individual customers to help them articulate their needs.
- Adaptive: The customer customizes the product.
- Cosmetic: A standard product is personalized and presented differently to each customer.
- Transparent: Transparent customizers observe customers' behaviour without direct interaction, then inconspicuously customize their offerings within a standard package.

Each of these MC categories has clear boundaries with 'collaborative' being the most obvious path to customization in which the customer influences the design decisions (Tseng and Du 1998). However, adaptive customization applies to products that are manipulated by the user after the producer has made the functionality available, and where the boundaries of the product are already set and the customer has no influence in the design of the product. Cosmetic customization is a relatively simple way to individualize a product, by altering the outward appearance of the product without affecting its functionality. Although personalizing a product in this way is 'cosmetic', it is still of value to many customers. Transparent customization is appropriate where customization would be of value but customers do not want to spend time explaining their requirements. The concept is an extension of traditional marketing that extends the observation of consumer behaviour to individual customers.

Applying the concept of MC to the footwear industry presents a number of issues. Human feet come in a wide range of sizes, shapes, proportions and different functional characteristics. The foot is actually varies in size and shape under different conditions, thus the question 'What is my shoe size?' probably has no answer, and indicates that shoe size is actually a compromise (Rossi and Tennant 1984). To further complicate the situation the increased market trend of footwear customization, ultimately means an infinite variety of shoe sizes and styles, a prospect that no shoe manufacturer can logically consider with current production and management practices.

Initially the MC of shoes will be achieved through a semi-customized approach with a limited number of lasts being used and 'best fit' being achieved for an individual's foot. An example of the best-fit principle is the CANFIT-PLUS system for footwear customization by VORUM Research Corporation (2001). This Canadian based company has created new libraries of lasts for various types of shoes including golf, casual, dress, hiking and running shoes. Intelligent software matches the scanned data from customer's feet to the last database to determine the best fit. The final aim of MC for shoes should be to produce a pair of individualized shoes for every customer who wants them (i.e. fully customized shoes). Logically the first market area open to complete MC is the specialized footwear segment. An athlete for example, would use their footwear under more consistent conditions allowing a shoe to be customized for the specific purpose of running. For the more general consumer market a benefit of MC for the shoe industry would be the reduced inventory and clearout sales (i.e. loss of profit margin) which is typical of the retail fashion industry. There are footwear companies that have already attempted MC, with their initial results being promising. The Left Foot Company (2001) recently opened a virtual shoe shop in Helsinki, Finland. The customer has their feet measured and has the choice of leather, shoe colour, soling and whether the shoe has a Gore-Tex membrane or not. The completed pair of shoes is then delivered within three weeks.

The implementation of MC in shoe manufacture has far reaching consequences for the way production is planned and controlled in participating organizations (Kellock 1999). The nature of MC requires a company to adopt a 'make-to-order' approach, based on the individual customer orders they receive. Most footwear manufacturers are more comfortable with a 'make-to-stock' policy, replenishing the stock as and when it is supplied to their customers. With the removal of the stock buffer, companies are more vulnerable to fluctuations in consumer demand, and need to be more responsive to ensure they meet individual order deadlines (Radder and Louw 1999, Tinham 2002). The implementation of MC requires the processing of more individual orders and smaller batch sizes, which again adds to the complexity of the planning and control of production (Pancucci 2001). The remaining sections of this paper outline an approach based on the use of distributed scheduling concepts to cope with this increase in complexity of production planning and control in MC applications.

3. Shoe manufacturing overview

The majority of modern day shoe manufacturing companies can have their production operations grouped into five main productive areas of cutting, pre-stitching, stitching, lasting, and finishing, as depicted in figure 1.

The cutting department is where all the materials that form the upper part of the shoe are cut to shape. Most companies either cut the material by hand using guides/knives, or by using press machines and dies that stamp out the components. Where large volumes are required, companies use large presses and dies or water jet cutting machines. Cutting is considered a skilled job, as the 'cutter' uses their skill to determine which areas of the material to cut for which particular component of the shoe. This is especially the case for leather, where the direction and quality of the grain have to be considered. Usually components are cut to order in large batches, and are palletized according to their order number, style and shoe size many weeks before the assembly process in the stitching room. This often leads to large volumes of work in progress in the cutting department.

Following cutting, components are usually taken to the pre-stitching department where a range of operations need to be performed before stitching is undertaken. Often this department is merged with the stitching department, as many of the operations can occur between stitching and assembly processes. Two of the main pre-stitching operations are skiving and folding, both generally used with leather. Skiving is a process to reduce the thickness of leather, so that thin leather-to-leather joints can be made. Folding often follows skiving as an operation, and creates folds in the leather, to ensure neater component and assembly edges. The most complex and labour intensive operations are seen in the stitching department, where the majority of the assembly work is carried out. All the individual components are assembled to form the 'upper' of the shoe using different stitching operations, ranging from chain stitching to reinforcement stitching. The overall operation quality, and therefore product quality, relies heavily on the skill of the operator. Like the cutting department, large volumes of work in progress are often seen, as the individual operations frequently have relatively long cycle times.

The final set of assembly operations occur in the lasting department, where the shoe upper is assembled onto the sole. The 'upper' part of the shoe is stretched around a wooden or plastic former called a last, which gives the shoe its shape and final size. With the last providing rigidity and shape, the upper is then joined with the sole using processes such as stitching, nailing or bonding depending upon the type of shoe construc-

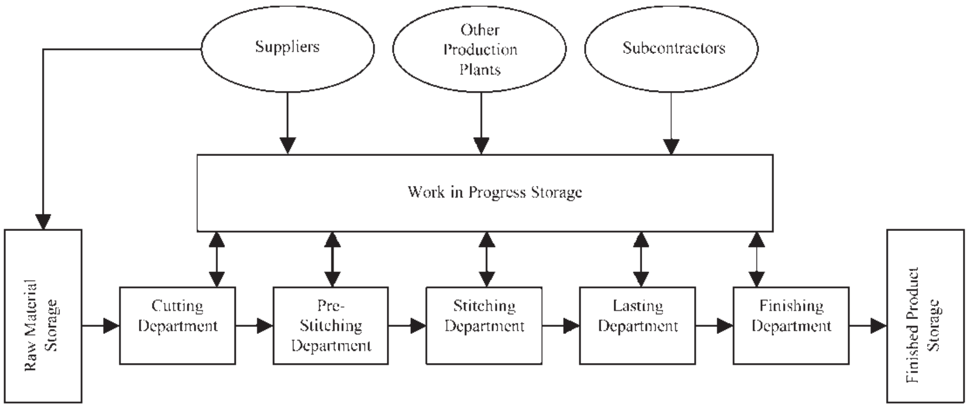


Figure 1. Shoe manufacturing departments.

Downloaded by [Loughborough University] at 08:52 22 August 2014

tion and style. Once lasting has been completed, the shoes are taken to the finishing department, where they are cleaned, trimmed and polished ready for placement into their packaging. The finishing processes are crucial as they are the final operations prior to shipment to the customer and dictate how the customer perceives the product when they open the packaging.

The material flow between departments is usually handled manually and is traditionally organized in the following manner: Production orders are split into lots where each lot often contains only one size of only one model to allow correct and easy identification. These production lots are then placed in plastic containers which are circulated between the work stations, either manually or using conveyor systems. The reduction of lot size and the increase of model variety occurring in the last few years in the fashion shoe industry have had a negative impact on the resource efficiency. The implementation of MC in shoe manufacturing companies may result in small lots of one to five pairs, which also means an increase variety of shoe style required to be produced on the same production line (in some cases up to 30 different models at the same time). This highlights the inability of traditional manual planning approaches to deal with increased complexity introduced as a result of MC shoes. A survey of European footwear industry undertaken as part of the EUROShoe Programme (2004) has highlighted the lack of utilization of production planning and control systems within this manufacturing sector. The absence of formal production planning and control systems has major consequences on the manufacturing performance, including:

- Long customer order lead times.
- Large amounts of work-in-progress.
- The inability to track production orders through factory.
- Low resource utilization.
- The inability to deal with manufacturing disturbances (machine breakdown, operator shortage, etc.)

Of all the departments described in Section 3, the stitching department presents the greatest challenge in terms of optimization, not only for manufacturing processes but also for production planning, scheduling and control. In most cases, the stitching processes are linear with different successive manual operations. The operators generally remain at one machine and carry out one repetitive task. This configuration only allows limited operator flexibility, and can cause problems, especially when an operator is absent or when a processing station breaks down. A typical shoe style contains anything from 20 to 30 individual stitching operations, lasting anything from 10 s to 1.5 min. The range of different types of stitching operation also varies widely. Although standard chain stitching on a single needle machine remains the most common operation, other stitching processes include decorative chain stitching, reinforcement stitching, two-needle chain stitching, CNC decorative stitching, etc. Such operations are further complicated by the range and thickness of materials used in the production of shoe uppers. Often between batches of different shoe styles, needles will have to be changed to deal with different materials, and threads will have to be changed to suit different shoe style colours. These set-ups although not significant in duration, can amount to substantial delays in production if the changeovers are frequent, so the correct sequencing of work is essential to ensure these are minimized.

This phase of shoe manufacturing has been among the first to be outsourced to alleviate the burden of labour costs. Often stitching operations are outsourced to subcontractors, small or micro enterprises who are specialized in the stitching of just one style of upper. This can frequently introduce production delays and additional cost. In addition, this significantly affects the complexity of the work organization, introducing uncontrolled variables with consequences for the logistics, management of human resources and quality. This delocalization often involves high costs for the shoe companies and requires the involvement of company resources.

4. Application of distributed scheduling in shoe manufacture

In general the manufacture of shoes is a highly skilled manual process, consisting of many individual process operations. Traditionally, the production planning and control activities for such human-centred manufacturing systems have been viewed in a hierarchy of three levels namely aggregate planning, production scheduling and production activity control. Furthermore the majority of R&D projects have adopted a centralized modelling approach in which the planning and control decisions are often made in a planning office, away from production environment. The effects of these planning and control decisions are vital in the efficient operation of the production systems, and consequently in the ability to meet delivery dates of products (customized production).

Many attempts have been made to improve these decision-making processes through the utilization of appropriate integration models, information systems

Downloaded by [Loughborough University] at 08:52 22 August 2014

Downloaded by [Loughborough University] at 08:52 22 August 2014

and networks to provide access to the most up-to-date shop floor status and localized knowledge, based on concepts defined by computer integrated manufacturing (CIM). However, there is an increasing belief among researchers in this area that the implementation of CIM results in manufacturing systems which are in general too rigid and that the attributes of such highly integrated systems with totally predictable patterns of operation, will not meet the needs of a customized manufacturing industry which has to be highly reactive (Sousa and Ramos 1999). In pursuit of this greater reactivity, there is a growing opinion that current CIM based organizations should be replaced by more innovative distributed systems consisting of a conglomerate of autonomous units which operate as a set of co-operating entities. In this respect, new concepts have been proposed which include holonic manufacturing (Van Brussel *et al.* 1996), bionic cells (Okino 1989) and fractal factories (Warnecke 1993). Readers are referred to Tharumarajah *et al.* (1996) for a critical comparison of these concepts. A similar innovative approach has been adopted within human-centred manufacturing systems through implementation of team-based manufacturing to provide the flexibility and agility required to deal with fluctuation in customer demands and to take better advantage of localised knowledge throughout a production system (Croxall 1995). There are other reported potential advantages in adoption of team philosophies within manufacturing systems which include the elimination of non-value added activities and reduction of lead times (Elmuti 1996).

The approach adopted for the development of a bespoke scheduling system for customized shoe manufacturing is based on a team-based distributed production planning and control structure, as shown in figure 2. Such approaches are often characterised by planning on two levels, namely at a global (factory) level and a local (team based) level (Rahimifard *et al.* 1999). On the factory level, the overall production requirements are divided onto a number of intermediate tasks that have to be carried out by various cells, departments and teams within the production system. On the local (team based) level, the intermediate production processes are scheduled onto the local production resources. Clearly in this approach one of the main planning tasks at factory level is the co-ordination of various local production activities.

To accommodate the planning requirements of the shoe industry and overcome some of the issues described in Section 3, a new scheduling system called 3S has been developed using the PREACTOR Scheduling software supplied by PREACTOR International Ltd (2004).

PREACTOR is a highly configurable finite capacity planning system, and utilizes graphical user interfaces for ease of use and rapid access to information. It has a modular structure of functionality, named PREACTOR 100, 200, 300 and APS. It starts at its lowest level of functionality with PREACTOR 100, which supports a limited number of the most common scheduling algorithms, and fixed data tables fields. In PREACTOR 200 the list of scheduling rules are expanded, and elements like the data table fields can be customized by the user. PREACTOR 300 allows multiple constraints for each operation, meaning more than one resource can be specified as necessary to perform a task, and users are able to implement rules that they create. All of these PREACTOR versions are for finite capacity scheduling (FCS). The latest member of PREACTOR's family of scheduling tools is PREACTOR APS, for advanced planning and scheduling. PREACTOR APS adds additional features and functionality over the

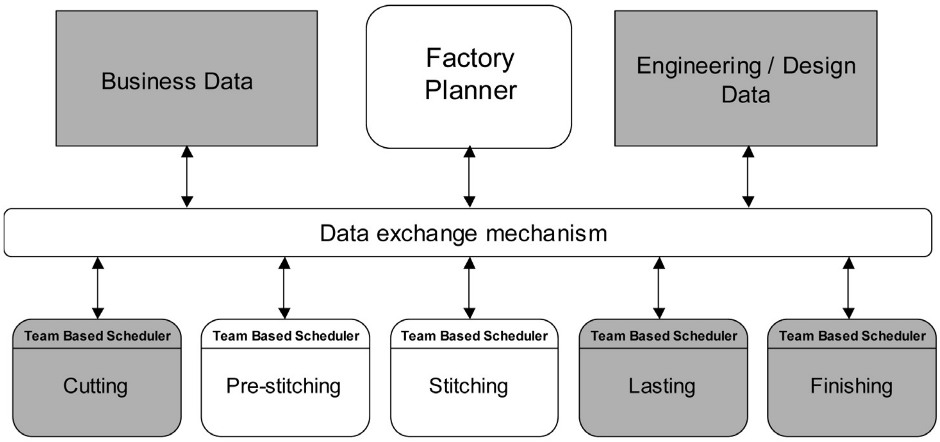


Figure 2. Distributed production planning and control structure.

PREACTOR FCS versions like additional scheduling techniques (event and resource focused), which allow you to select and create your own scheduling rules using Visual Basic programming. In addition material constraints can be considered through PREACTOR's own bill of materials module or via integration with an ERP/MRP system.

5. Shoe scheduling system

The 3S scheduling system is based on a two-level planning approach described in Section 4 and includes a factory planner (FP), and a number of team-based schedulers (TBS). The architecture of the scheduling system allows for communication between the two levels, so the FP can communicate new production orders to the TBS, and the TBS can send resultant due dates back to the FP following allocation across team resources, as shown in figure 3. This enables 'what if' scenarios to be tested between the two planning levels to find the most appropriate scheduling compromises to achieve the necessary order due dates.

The FP provides the initial scheduling interface for the incoming customer orders and generates a rough-cut schedule for the whole factory. The FP has been developed to be modular to provide a communication platform to allow departmental schedulers to be integrated.

Once customer orders are scheduled across departments, the resulting schedule information for each department which can be considered as a list of jobs to be processed by each department before a given due date, is sent directly to the relevant departmental scheduler for more detailed scheduling using the departmental resources. Once the production orders are scheduled at the departmental level, the results are returned to the FP to allow comparisons to be made with the original schedules.

Figures 4–11 illustrates the major steps in creating a production schedule generated for a shoe manufacturer, and highlights the information exchange between the FP and a TBS, in this case the stitching department, as detailed below:

- The shoe scheduling system is started and the FP awaits new customer orders (figure 4).
- FP imports customer order data from MRP/ERP system (figure 5).
- These customer orders are scheduled across all manufacturing departments (figure 6).
- FP generates stitching production orders based on factory schedule and sends them to stitching scheduler (figure 7).

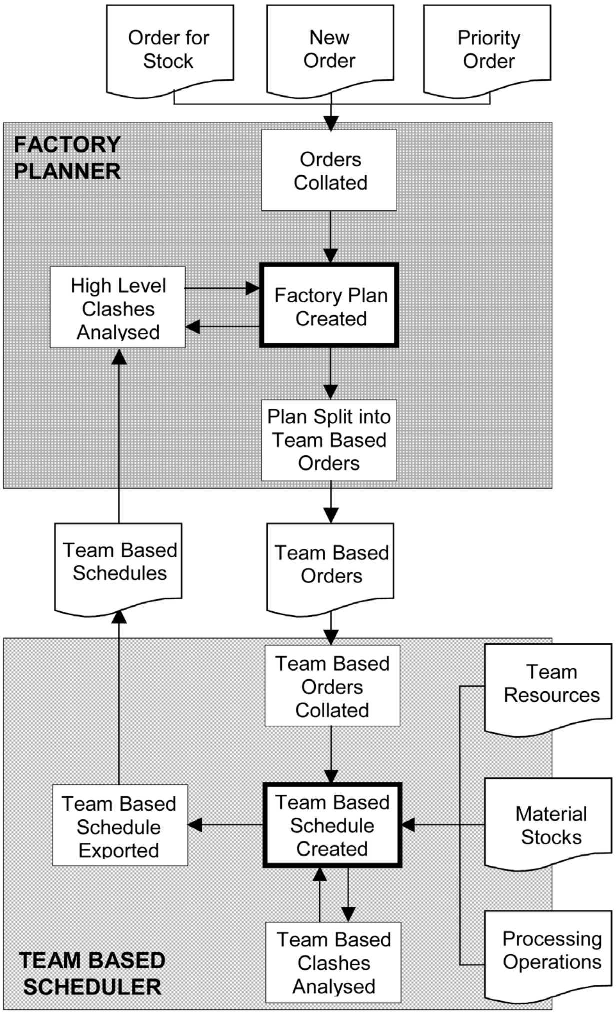


Figure 3. Shoe scheduling system architecture.

Figure 4. Factory planner awaits customer orders.

Downloaded by [Loughborough University] at 08:52 22 August 2014

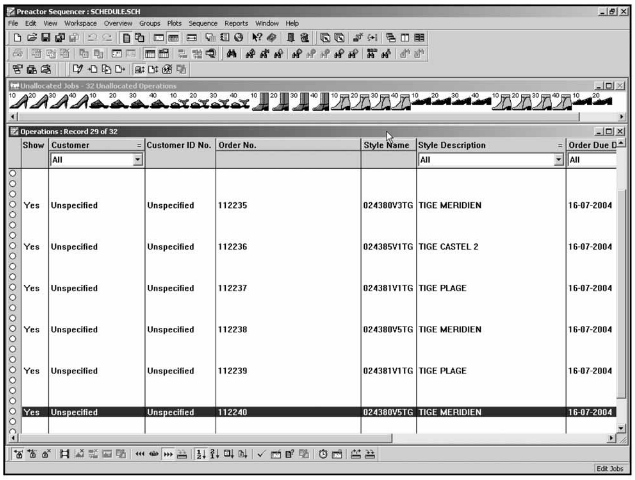


Figure 5. Factory planner imports customer order data.

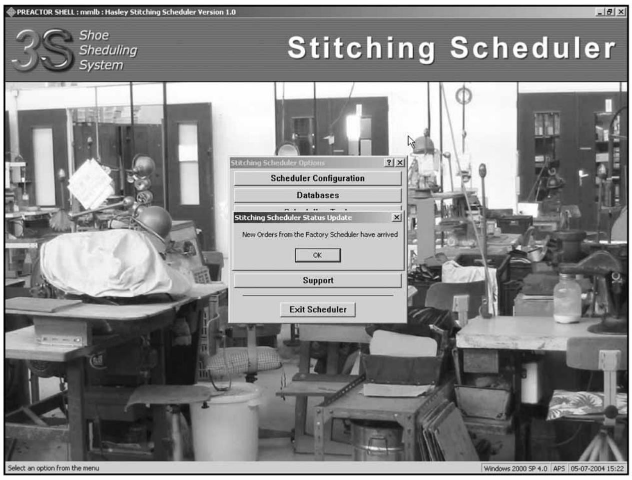


Figure 7. Factory planner produces stitching production orders and sends to Stitching Scheduler.

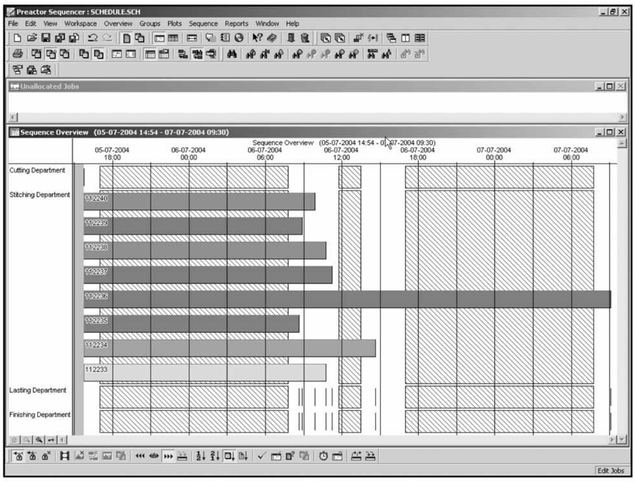


Figure 6. Customer orders are scheduled across all departments.

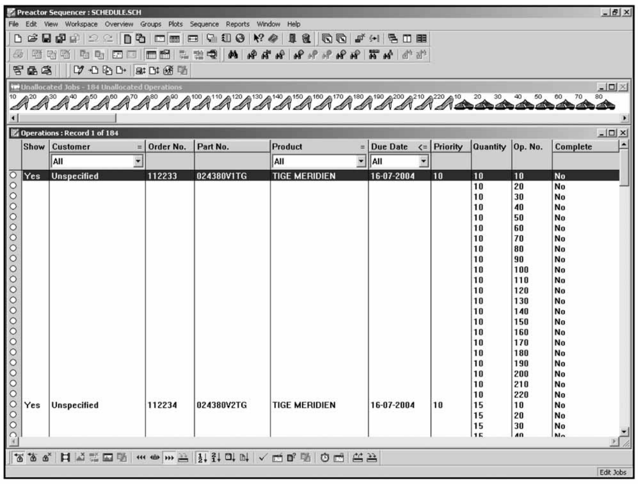


Figure 8. Stitching Scheduler imports stitching production orders from factory.

Downloaded by [Loughborough University] at 08:52 22 August 2014

- Stitching scheduler imports production orders from FP (figure 8).
- Stitching scheduler schedules production orders across stitching departmental resources and releases the stitching schedule to the shop floor and to the FP (figure 9).
- FP compares the production order completion dates from the TBS with desired customer due dates, and if required changes are made (figure 10).
- FP confirms and reports expected delivery dates (figure 11).

To ensure the ease of use of the planners both of at factory and team levels, the schedulers have been designed with similar functionality and screen layout. This enables the factory level planner to be able to use and understand the operation of individual department schedulers, and vice versa. In order to develop the 3S scheduling system, the functionality of the standard PREACTOR software has been extensively enhanced to include custom scheduling routines, custom import and export scripts, and specially designed user interfaces to support the management of shoe production. For example in the case of the stitching scheduler the data related to operators and their efficiencies have been utilised to achieve more realistic processing times for stitching operations. This ensures a more accurate stitching schedule is generated based on localised knowledge of operator skill levels, stitching equipment,

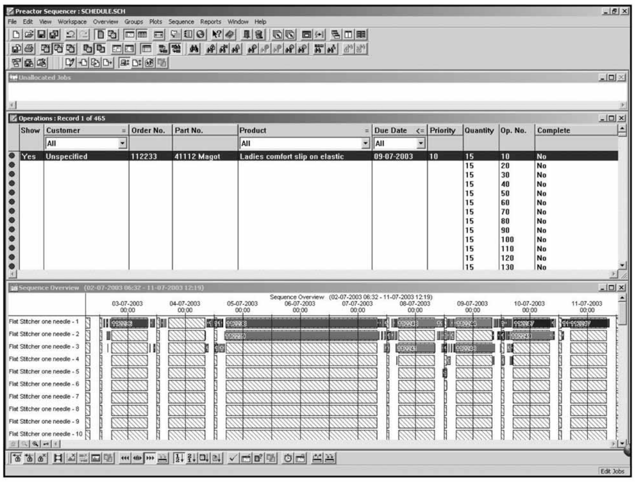


Figure 9. Stitching Scheduler schedules production orders across stitching room resources.

Figure 11. Factory planner exports amended delivery dates.

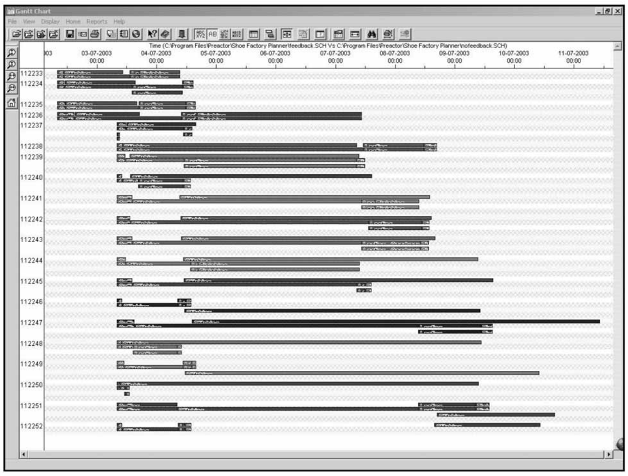


Figure 10. Factory planner compares production order completion dates in Stitching Scheduler with customer due dates, and changes are made.

Downloaded by [Loughborough University] at 08:52 22 August 2014

shoe styles and operation times. PREACTOR does not usually support the use of operators as resources, but in the shoe manufacturing industry it is the skill and speed of the operators that determines the actual processing time. To overcome this, a custom scheduling routine has been developed in the 3S scheduling system using Visual Basic programming to allow operator efficiencies (as a percentage) to be defined for each manufacturing operation. This directly modifies the set-up and process time for an operation based on the assigned operator.

PREACTOR natively uses a series of standard databases to store information required to perform scheduling operations. The 3S scheduling system uses new customized databases tailored to the bespoke requirements of shoe manufacture. The specifically developed operator's database allows information about employees to be recorded. The new operations database contains a list of standardized shoe manufacturing operations that have generic process times and set-up times that can be modified for an individual shoe style. Another innovation in the 3S scheduling system are 'Process Groups', a database format that logically groups together operations that are common for a range of similar shoe styles. When a shoe style is defined, it can be assigned to a process group that limits the number of feasible operations for that shoe style.

The 3S communication mechanism, allows the FP and TBS to directly communicate with each other. This mechanism utilizes the PREACTOR communications object (PCO), and custom built event, import and export scripts to transfer data between schedulers. This communication mechanism can either be implemented across a local area network (LAN), a wide area network (WAN) or the World Wide Web. Therefore it should be noted that such team based distributed scheduling approach can include a subcontractor (as another team) or in fact any other agent in a shoe supply chain. This communication mechanism supports a distributed decision making structure, which enables frequent interactions with production planners across the factory. At the same time, such an interactive planning structure should be supported by suitable security measures, to provide different levels of responsibility to the various planners. Therefore, three types of access privilege, namely operator, scheduler and administrator have been defined. The 'administrator' has access to all the functionalities allowing them to change communication mechanisms, databases, etc. The 'scheduler' only has access to databases and the scheduling tools, while the 'operator' can only access the scheduling tools.

6. Conclusion

The predicted increase in the application of MC over the next 10–15 years will have a major impact on the way companies process customer orders and manage their operations. The adoption of MC requires companies to be highly reactive with a make-to-order policy to production. The authors argue that the current centralized production planning and control systems will not be able to provide the flexibility and agility required in MC manufacture. The research reported in this paper has presented a novel solution based on a team based distributed planning approach to provide reactive scheduling not only internal to companies, but through the entire MC supply chain.

The 3S scheduling system has been designed and developed based on bespoke requirements of shoe manufacturers and provides the capabilities to plan a large number of small batch production orders. This system through its customised functionality (e.g. operator efficiencies) could be used not only to increase performance and productivity of current shoe production systems, but also could be used to support the adoption of a mass customization approach in shoe manufacture. The two level planning approach used in this system allows organizations to take a high level view of their production requirements based on their customer demands and to track production orders through individual departments. This division of customer demands into departmental production orders, provides each department the autonomy to schedule their own activities, while still maintaining their responsibility to the rest of the organization in terms of achieving through-put and expected delivery dates.

Although the 3S scheduling system has initially been developed for the shoe production industry, it is envisaged that the system could be implemented in other manufacturing industry sectors where MC principles are being adopted. Furthermore, the concept of including operator efficiency in production scheduling is equally applicable to any other industry with labour intensive processes.

The consideration of MC in the shoe industry has highlighted the significant changes required in both the manufacturing capabilities and the management of production. Therefore the authors believe that to ensure a successful application of MC in any industrial sector a step-wise approach is required to replace the traditional mass production practices with contemporary mass customization approaches.

Downloaded by [Loughborough University] at 08:52 22 August 2014

Acknowledgements

The work reported in this paper has been carried out within a European-based research programme, namely CICLOP: Computer Integrated Closing Operations (EU Framework 5 – CRAF-1999-71422). The authors would like to acknowledge the collaboration of PREACTOR International Ltd and the supporting work of other participants in the CICLOP project.

References

Croxall, S., 1995, Business process reengineering: teams in business. *Manufacturing Engineer*, **74**(1), 35–37.

Davis, S., 1987, *Future Perfect* (Reading, MA: Addison-Wesley).

Duray, R., 2002, Mass customisation origins: mass or custom manufacturing? *International Journal of Operations & Production Management*, **22**(3), 314–328.

Duray, R. and Milligan, G. W., 1999, Improving customer satisfaction through mass customisation. *Quality Progress*, **32**(8), 60–66.

Elmuti, D., 1996, Sustaining high performance through self-managed work teams. *Industrial management*, **38**(2), 4–9.

EUROShoe Programme, 2004, Development of the process and implementation of management tools for the Extended User Oriented Shoe Enterprise, EU Framework 5 Integrated Project, GRD1-2000-25761. http://www.itia.cnr.it/Euroshoe/home.htm

Farish, M., 1997, Mass customisation. *Engineering*, **238**(6), 14–16.

Gilmore, J. H. and Pine, B. J., 1997, The four faces of mass customisation. *Harvard Business Review*, **75**(1), 90–101.

Kellock, B., 1999, Mass customisation in action. *Machinery & Production Engineering*, **157**(3984), 76–78.

Left Foot Company, 2001, Shoe shop with no shoes. *World Footwear*, **15**(5), 9.

Pancucci, D., 2001, Mass customisation: manufacturing for an audience of one. *Manufacturing Computer Solutions*, **7**(11), 30–32.

Pine, B. J., Victor, B. and Boynton, A.C., 1993, Making mass customisation work. *Harvard Business Review*, **71**(5), 108–119.

PREACTOR International Ltd, 2004, *PREACTOR User Manuals* (Chippenham, Wiltshire, UK).

Okino, N., 1989, Bionic manufacturing systems – bio-model on based system design. *Proceedings of CAM-I Annual International Conference*, New Orleans, Louisanna, pp. 485–492.

Radder, L. and Louw, L., 1999, Mass customisation and mass production. *TQM Magazine*, **11**(1), 35–40.

Rahimifard, S., Newman, S. T. and Bell, R., 1999, Distributed autonomous real-time planning and control of small to medium enterprises. *Proceedings of the Institution of Mechanical Engineers Part B: Manufacturing Engineering*, **213**(B5), 475–489.

Rossi, W. A. and Tennant, R., 1984, *Professional Shoe Fitting* (New York: Pedorthic Footwear Association).

Ruddy, M., 2002, Mass customisation now closer than ever. *Machine Design*, **74**(12), 59–61.

Sousa, P. and Ramos, C., 1999, A distributed architecture and negotiation protocol for scheduling in manufacturing systems. *Computers in Industry*, **38**(2), 103–113.

Tharumarajah, A., Wells, A. J. and Nemes, L., 1996, Comparison of the bionic, fractal and holonic manufacturing systems concepts. *International Journal of Computer Integrated Manufacturing*, **9**(3), 217–222.

Tinham, B., 2002, Mass customisation: wouldn't you like to just churn them out? *Manufacturing Computer Solutions*, **8**(9), 22–25.

Tseng, M. M. and Du, X., 1998, Design by customers for mass customisation products. *Annals CIRP*, **47**(1), 103–106.

Van Brussel, H., Valckenaers, P., Wyns, J., Bongaerts, L. and Detand, J., 1996, Holonic manufacturing systems and LiM. In J. Browne, R. Haendler Mas and E. Holdversson (Eds), *IT and Manufacturing Partnerships* (Amsterdam: IOS Press), pp. 185–196.

VORUM Research Corporation, 2001, All go for mass customisation of footwear. *World Footwear*, **15**(5), 51–52.

Warnecke, H. J., 1993, *The Fractal Company: a Revolution in Corporate Culture* (London: Springer-Verlag).

Downloaded by [Loughborough University] at 08:52 22 August 2014