Paper one

The transition of the concrete precast paving industry from a manual labour intensive industry, to a fully automated operation

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Abstract

The paper deals with the cultural and technological changes involved in the conversion of the operational procedures from manual high safety risk operations to full automation, where the risk of accidents is virtually eliminated. The process of change starts with the study of very flexible and agile manual operations, evaluates the wastes involved and describes the processes introduced to eliminate them.

Automated systems that use the latest technology are introduced in an innovative manner to ensure that the automation is capable of changing product type in a lean, flexible and agile way. Radio Frequency Identification (RFID) technology is implemented to initiate changes in robotic operations, equipment changeovers and ASi safety networks (electromechanical interface for data transfer) are used to ensure that the human machine interface activities are safe. Device networks are introduced as an integral part of the system control and data acquisition (SCADA) system which produces key performance indicators direct from the production line. Potentially high levels of downtime associated with the introduction of high technology devices is dealt with by the use of low voltage "plug-in" and "screw-in" sensors to de-skill maintenance operations.

The paper outlines how a major reduction in manpower is achieved by removing virtually all manual processes from concrete paving production. The transition to automation is outlined and consideration is given to the social factors involved as a result of introducing car industry production methodology. Cost reductions from the research enabled a major precast producer in the UK to compete successfully in a global market.

Keywords: Lean, Flexible, Automation, RFID, SCADA

Background

After many years of producing wet cast concrete products using mainly manual production technology with some mechanisation, it was obvious that urgent action was required to reduce an unacceptable accident rate associated with manual processes and to reduce production costs to enable the company to compete in the global economy where sales were being lost to cheap far eastern competition. New and innovative enabling technology was required in order to cope with the variety of product shapes and types involved in the process. Variety was added in the process at five stages of manufacture – Mixing, Filling, De-moulding, Labelling, Packaging.

The pictures shown below in Figure 1 illustrate some elements of the outmoded manual methodology that needed to be replaced in a cost effective manner.

Problem

The challenge was to remove the ergonomic risks from the process and match the agile nature of the manual production techniques (operator changes product instinctively) with new innovative automation in a cost effective and productive manner. The achievement of the required objectives included the management of major societal and cultural changes within the whole of the manufacturing organisation. The key challenge was how to achieve such changes without any major disruption to service levels and maintaining a high level of morale amongst the workforce during the change process. To compete in a global market the company had to reduce its' costs significantly without changing the variety in the extensive product portfolio. Retraining and workforce reduction issues alongside the technological challenge of inventing new methods and bringing them into operation and at the same time mitigating the high risks involved contributed to the problem to be solved.

Lifting Off – Filled Mould

Putting On – Empty Mould

De-moulding product from mould

Filling – Empty Mould

Figure 1 – *Outmoded Manual Methodology*

Learning Objectives:

- How to develop a structured approach in transforming a traditional industry into a modern 'high tech' World Class operation to compete effectively in a global market.
- Selection of the appropriate techniques for the analysis of the issues involved.
- Process mapping and studying the existing process including an ergonomic study as a forerunner to using brainstorming and single minute exchange of die (SMED) techniques to invent new methods and processes to automate virtually all of the processes.
- Dealing with the cultural and societal changes involved.

Approach

The approach used, was to analyse the existing processes in detail including a video study in slow motion, process mapping and SMED in conjunction with an ergonomic study to discover the processes to be automated to overcome major health and safety issues in the workforce. After the study process, a strategy was developed to overcome the expected societal and cultural issues associated with a major transformation project which involved full consultation and communication of the changes involved with the workforce and the trade union representatives. After the study where the prime wastes were identified, brainstorming sessions were organised to invent a new method of de-moulding paving units which was critical to the success of the project. The wastes identified in the existing processes were eliminated by the careful selection of the appropriate automation techniques and the use of RFID as the product changeover enabling technology and the source of information for the production metrics and real time analysis of the metrics for performance management.

Analysis

1. Changeovers and Variety

A process mapping exercise using Microsoft Visio® was carried out map the range of processes of processes involved in detail and the following analysis outlines the outputs from process mapping.

To reduce response time to a production requirements change, the product variety funnel principle of adding variety as late as possible in the supply chain was utilised. The usefulness of this process is outlined in the book "The Lean Toolbox" (Bicheno., 2000). The variety adding process in the Concrete Products Industry is described in table 1 which follows. The analysis showed that an average day produced a total of 32 changes. However, when patio circle packs (multiple shapes) or full patio project packs were produced with a range of plan shapes the sequence of changeover meant that 36 or more plan size changes occurred over a period of 3-5 minutes, very demanding for automation, requiring a new invention and a novel approach.

Table 1: Variety in the process

Process Stage	Variable	Variants
Mixing	Colour	20
Filling	Thickness	3
De-Moulding	Product Plan Area	8
Frequency of change	Product Plan Area	36 in 3 minutes
Labelling	Product Type	100
Pallet Labelling	Product Type	100
Packaging	Pallet Size	6
Packaging	Shrink Wrap Bag	2

Variety induces changeover time and waste since it involves non-value adding activity in changing over from a one size to another or from one colour to another. Koskela defined Non Value-adding Activity as "activity that takes time, resources or space but does not add value". This definition was further refined to a more process relevant definition of waste by Formosa et al, where they defined Waste as "any losses produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the client"(Formosa et al.1999). The challenge for the industry was how to embrace variety, whilst at the same time minimising or eliminating waste where possible. Figure 2 shows the wastes in terms of productive time lost in the production process due to changeovers. It identifies the wastes resulting from the variety in the process prior to automation. These wastes were obtained from the analysis of a partially mechanised process and were virtually eliminated by the introduction of automation involving the innovative use of RFID (Radio Frequency Identification), vision enabled Robots plus automated: package strapping machinery, shrink wrapping machinery and Labelling machines. The use of SCADA incorporating Asi Safe network systems and device network systems alongside extensive messaging and component level fault identification systems combined to reduce downtime waste.

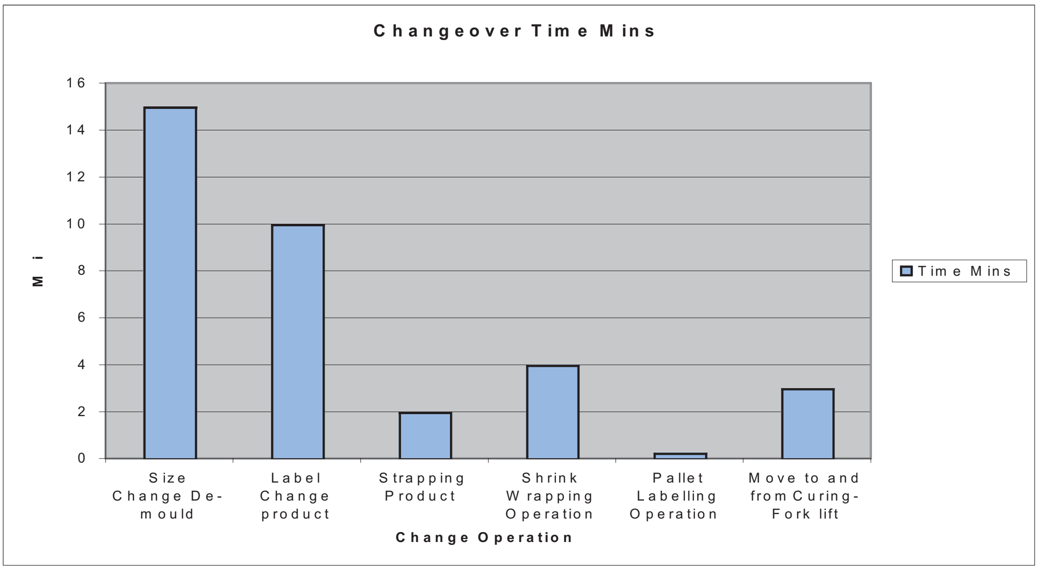

Figure 2: *Changeover waste in the process*

Major savings could be achieved by the automatic changeover of the de-mould frame, the label reel change plus motion savings achieved by removing operators from: putting-on, lifting off, de-moulding, manual shrink wrapping with a gas gun and manual pallet strapping (figure 1). A process of transformational change, utilising emerging innovative technology alongside a cultural/societal change strategy was required to achieve the desired outcome. The sections that follow illustrate the change process involved, including the resolution of the major issue (de-moulding rough edge natural type paving units with undercut moulds).

2. Ergonomic Study

Three major methodologies were used for the postural analysis and ergonomic study: a survey method developed for the investigation of work related upper limb disorders by Lynn McAtamney and E Nigel Corbett at the Institute of for Occupational Ergonomics at the University of Nottingham (England) known as Rapid Upper Limb Assessment (**RULA)** described in Applied Ergonomics (McAtamney, L., Corbett, E.N., 1993), Rapid Entire Body Assessment (**REBA)** also outlined in Applied Ergonomics (Hignett, S., McAtamney, 2000) and Borg's Rating of Perceived Exertion (Borg, G., 1985). The survey carried out by Lynn McAtamney and her team found that virtually all of the manual operations involved carried a high risk of causing muscular/skeletal disorders. The challenge became much clearer and it was how to find a means of automating the whole process. Only one operation, filling, was assessed as being of relatively low risk. Filling included a hand mixing process which produced a degree of randomness to the final colour appearance of the premium "natural" paving units being manufactured. This natural appearance was a key unique selling point (USP) for the product. To remove the risk from the filling process a job rotation regime was introduced alongside stricter control of the mixing process. Until automation could be installed a high cost safety strategy was introduced in 2001. This included warm up exercise periods, more frequent breaks, return to work programmes and the introduction of ergonomic coaches.

3 Societal Changes

The core of operators had long service and until the late nineties the absence levels were relatively low at 3% or less. Analysis indicated that the workforce was ageing with more than 50% over the age of 45. As could be expected there was evidence of muscular/skeletal disorders. Until 2000 most of the workforce did not work beyond the time range of 06.00 to 18.00 until high product demand and seasonality factors required the introduction of a fixed night shift in 2000. The introduction of a night shift with new personnel resulted in a very high rate of accidents being recorded (110 accidents in year) and absence levels exceeded 8%. The employment level varied depending on season and peaked at 140 in spring 2000 by the employment of a large number of temporary workers. This compared with a core level of 80 brought about by a peak month demand more than five times the average month demand. The accident rate continued to increase until the ergonomic strategy started to be effective. The Management team spent an excessive amount of time investigating accidents and a reducing trend was established. However, more effective action in the form of automation was urgently required. Despite the health and safety issues the core workforce remained highly motivated and the pay rates for the physically demanding work were 20% higher than the best offered by other local employers. The vast majority of the workforce had only ever worked dayshift and had only been involved in manual operations. A small maintenance team of 6 engineers were only familiar with maintaining mechanised plant. It was clear that considerable re-training would be required for those remaining to operate a fully automated plant.

4 Strategy for dealing with the cultural and societal changes

As a result of introducing the ergonomic improvement strategy in 2001 productivity dropped significantly and labour costs increased. Competing with imports from low wage cost countries where the workforce was not regulated to the same extent as in the UK was difficult. Automation was urgently required but it needed to be accomplished without any major disruption to customer service or the morale of the workforce as far as was possible. A societal/cultural change strategy was adopted and the major elements are shown in table 3 which follows. Maximum emphasis was placed on communication and everyone in the workforce was aware of the automation programme which started in 2001. The likely effect on their jobs was understood and the policy approach was agreed with the trade union representatives at all stages. The strategy covered three areas: working hour changes, Re-training, and the manpower plan or recruitment plan. Training requirements were split into groups: management, engineers and plant operators.

Table 3: *Working hours, Retraining & Recruitment strategy*

Working Hours	**Retraining**	**Recruitment**
Negotiation of a new shift pattern	**Operatives Training**	No permanent operatives to be recruited from 2001
Work annualised hours pattern with more hours worked in spring /early summer and fewer in winter	Carryout psychometric testing and select for new role based on results	One highly skilled network system and robotics engineer recruited
New shifts linked to automation requirements	Train operatives in safe systems of working with automation	No managers recruited
Machinery operation over 24 hours	Carry out robotics operation training	No operatives recruited except on short term contracts
Shift working pattern of 4 days on and three off	**Engineers Training**	Early retirement to voluntary requests
Length of shift to vary seasonally. Extended weekends to reduced hours	Robot programming PLC programming	
Minimise cycle change effect	ASi Safe systems	
Shift cycle 6 weeks	SCADA	
Communicate all agreed changes from 2001	Device networks	
Involve whole team	**Management**	
	SCADA	
	Automation Safety	
	KPI extraction	

5 Innovation introduced

The likely effects on their jobs and all changes introduced were discussed and agreed with the trade union representatives. The automation was planned in two phases: Phase 1 (2003)-prototype technology introduced costing £500K, Phase 2 (2005)-full automation introduced costing £1.25M following a learning process from the first phase. Before the automation could be considered it was necessary to achieve a major breakthrough to automate the de-moulding process illustrated in figure 1. A slow motion video study of the process and a detailed process mapping exercise was required prior to brainstorming sessions that were organised for a development team including engineers, process operators and managers. Before the actual sessions took place the team was trained in the principles of single minute exchange of dies or SMED methodology as utilised by Shigeo Shingo (Shingo, S., 1989) to improve the Toyota car plant. This structured approach was invaluable in the process of developing the tooling, however, the actual breakthrough came from close observation of the manual process in slow motion. The outcome of the final brainstorming session is shown in figure 3. A flowchart was developed for the automation and a prototype was developed as the engine for renewal as observed by Kent Bowen in the Harvard Business review. (Bowen, H.K., 1984)

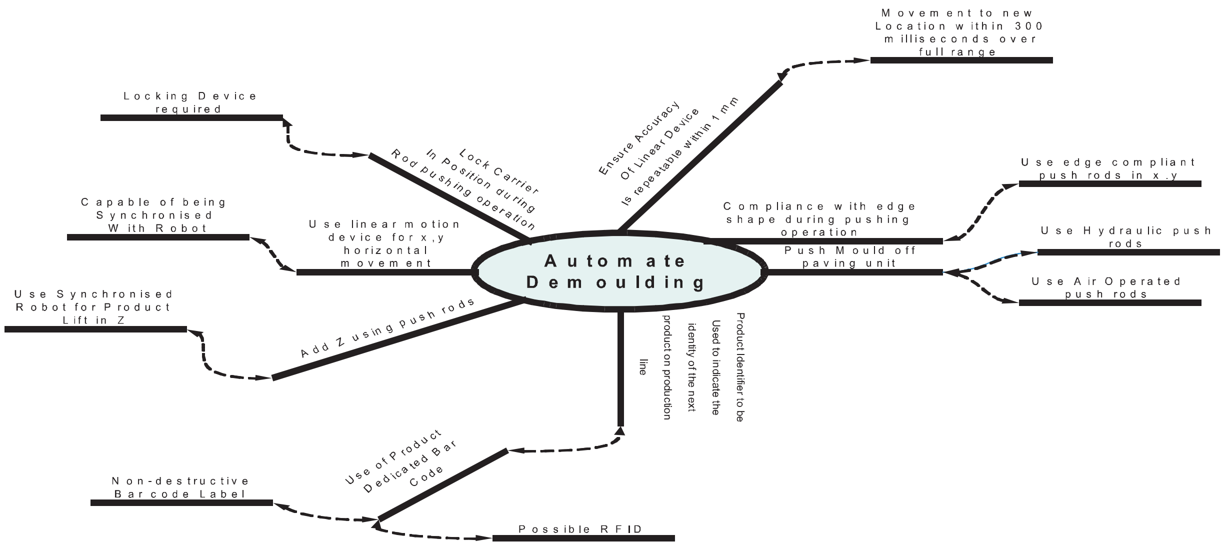

Figure 3: *Outcome of final brainstorming sessions*

The prototype was tested under rigorous conditions – paving units with rough edges and undercut moulds that had matured for six weeks in the mould, were successfully de-moulded in less than five seconds. This would have represented a major challenge for manual de-moulding. When units that were 24 hours old (the normal maturity period) and when all air operated push rods were operated together (see figure 4), the de-mould process took less than a second. A breakthrough was achieved and the requirement for the development team was to convert the prototype into a practical operating system.

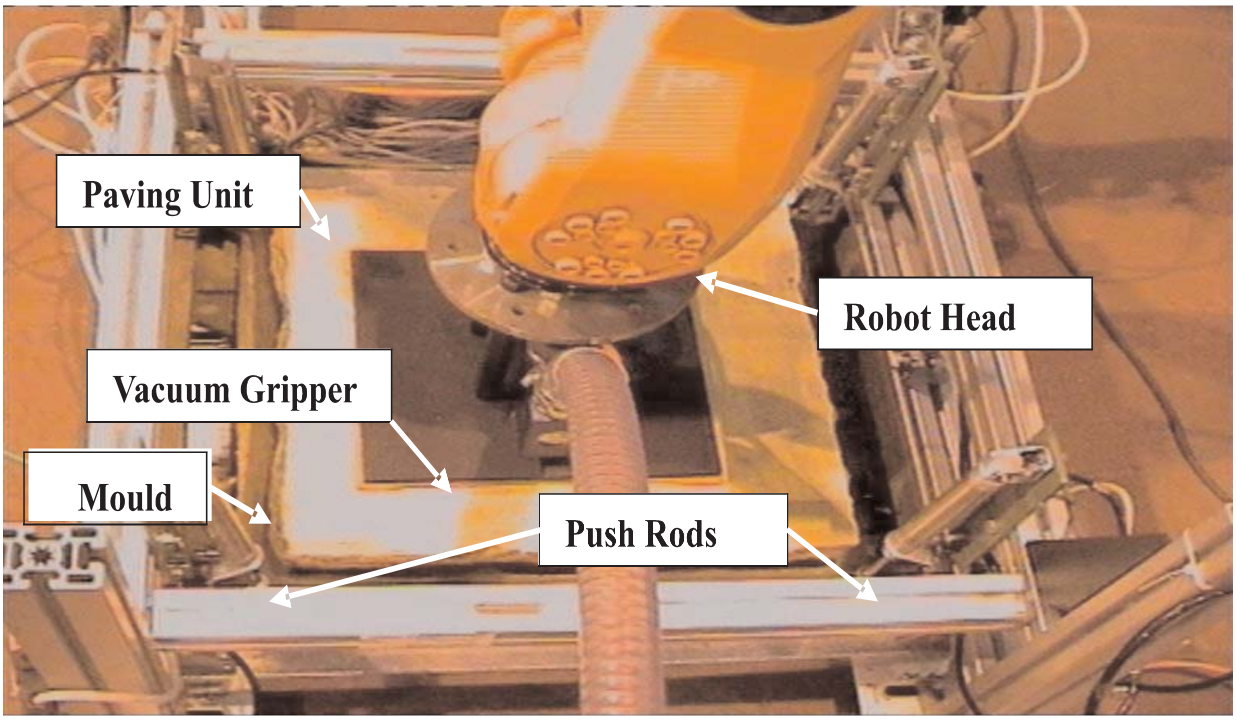

Figure 4: *Prototype de-moulder*

The prototype in Figure 4 utilises a fixed stripping frame (no variation in geometry) for testing purposes only, in the finished version a linear motion device was used to produce a variable geometry stripping frame with the geometry changes initiated by product unique bar codes in phase 1 of the automation and by RFID tags in phase 2.

The variable geometry stripping frame required the use of a linear motion device working synchronously with a Robot vacuum gripper. Figure 5 shows the de-moulding process capable of a size change in a second in the final form alongside the automation of pallet building using a vision enabled robot to correctly orientate the paving units prior to stacking them on to a pallet.

Figure 5: *Pallet Building Robot – Vision enabled* *De-moulding Robot RFID enabled*

The whole process device network was monitored using SCADA and entry to guards and the conveyor / robot cells was controlled using ASi safe to ensure safety at human machine interface points. The main overview SCADA screen is shown in Figure 6 below alongside the RFID tag mounted on the mould carrier where care was taken to use a plastic mounting bracket to ensure there was no interference with the radio frequency signal. The RFID tag was used both as a unique product identifier and for obtaining information for performance metrics and other control purposes.

Figure 6: *SCADA Overview Screen* *RFID tag mounted on mould carrier*

To reduce the extensive skill levels required for operating sophisticated automated equipment, automatic component level fault identification/diagnostic technology was introduced to locate faults. Low voltage plug in and screw in photocells, switches and other monitoring components were used where possible to enable trained process operators to replace components when a fault was identified via the SCADA diagnostics system. The key performance indicators were obtained in real time from remote access computers to avoid any need for manual computation and the associated time lags. Any undesirable trends were identified early to enable rectification action required to be taken at an early stage. Being able to monitor performance in real time offered a major improvement.

Results and Business Impacts

Key Findings

The key findings are summarised as follows: accident rate was reduced to zero for automated processes, productivity improvements valued at £750K per annum in the form of a reduction in the wage bill were achieved for phase 2 for an investment in new equipment of £1.25M producing a simple payback of less than two years, world class performance was achieved after one year of operation when all personnel had been fully trained, redundancy levels were minimised and variable annual hours in the form of a 24 hour shift system were introduced to counteract seasonality in sales demand, the global threat was minimised and profitability was returned to acceptable levels. The whole process involved in manufacturing 'wetcast' paving units was transformed from outmoded manual methodology to a 'high tech' process environment.

The use of 3D drawings and virtual reality images linked to Microsoft Project® of the processes and automation to be installed during the planning and rehearsal stages of the project would have avoided the majority of the resource and space clashes that occurred during the project execution. The use of 4D technology (3D + time) is advocated for future projects of this nature. The project was completed within the cost budget allocated following the negotiation of a fixed price contract with the principal supplier but was three months late in completion (12 months duration expected). Further benefits would have been obtained from the use of simulation technology to model the cycle times associated with the processes, prior to implementation, to ensure that the overall cycle time specification was achievable. Some modification and improvement was required to the equipment components during commissioning, which took longer than was expected to achieve the specified cycle time.

Business Impacts

The key business impact was the mitigation of a major business risk from the onset of global competition. Whilst the business benefited from the a reduction of the wage bill of £750K, other significant value stream impacts included lower stocks and holding costs, lower transportation costs following the avoidance of re-deliveries as a result of stock availability issues. Safety costs were reduced because the accident rate was reduced to virtually zero where automated processes were used. Employment was maintained for a smaller workforce in a much changed market environment subject to global competition.

Conclusions

The transformation took place over a period of four years following a strategy developed in 2001. Extensive risk analysis took place and risk mitigation strategies were used which included prototype development and a lower cost first phase project to test the innovation involved. Issues expected from societal changes were overcome by a high emphasis on involvement, communication and consultation. Further emerging issues have been identified in other precasting operations where little automation is applied e.g. walling, building sections, drainage systems, and bridge sections. Detailed process mapping and simulation of the processes may provide a route forward to improve and transform these processes.

Key Lessons Learned:

- Importance of developing an agreed strategy for automation.
- Use of a slow motion video study, process mapping of existing processes and SMED techniques can promote innovation.
- RFID can be used as a key enabling technology for automation.
- Rigorous prototype testing can mitigate innovation risks.

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Authors' Biographies

J T Dean an Electrical Engineer with over thirty years experience including ten at Board level in operations management associated with process industries. Specialising in change management and business process reengineering over eight years prior to 2006 and currently engaged in developing IT projects and supervising research students at the University of Teesside. Member-Institute of Operations Management. Member-Chartered Management Institute. With an MSc in Operations Management

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