NEW PARADIGM IN CONCRETE PRODUCTS PRODUCTION

John T Dean[1] and Nash Dawood[2]

ABSTRACT

The production of Wet Cast concrete paving units with complex decorative edge shapes has traditionally required operators to remove cured products from their moulds (de-moulding) by hand and to stack the finished product onto pallets by hand. A study utilising postural analysis of these operations taking into account the weights of paving units involved some of which exceeded 25kgs. Revealed excessive flexing and twisting of the trunk, uneven loading of the knees and at times excessive exertion according to Borg's rating system. Whilst retraining in correct postural methods has produced positive results and fewer manual-handling accidents, it was concluded that an automated solution had to be developed. An automated solution was needed to remove undesirable body movements but retain all of the agility associated with human activity capabilities of: product inspection, zero size changeover time, rejection of faulty product and a fast cycle time of 6 seconds per paving unit. A new concept of de-moulding was developed utilising three axis linear motion, edge compliance and a Robot working in synchronous action with the linear motion device. A vision camera for inspection purposes with at least pixel level resolution was developed to work in conjunction with a second Robot working within the movement arc of the first Robot. This second Robot rejected any camera inspection failures via a software handshake and stacked the paving on to pallets. The robotic solution provided an agile tool to enable the application of lean concepts by reducing, manpower, material waste, energy waste, from a relatively unsafe environment and provided a platform for further implementation of more advanced production planning methods.

KEY WORDS

SMED, Bar Code Technology, Lean and Agile, Process Map

[1] D (Prof) Student University of Teesside, Site Manager, Aggregate Industries, North End Works, Ashton Keynes, Swindon, Wiltshire, England SN6 6QX, E-mail John.Dean@aggregate.com

[2] Professor of Construction Management and IT, Centre for Construction Innovation Research, University of Teesside, Middlesbrough, TS1 3BA, E-Mail n.n.dawood@tees.ac.uk

INTRODUCTION

Wet Cast concrete paving production has developed in the UK utilising manual handling techniques mainly because of the difficulty associated with removing the finished products from the mould. These products closely match Natural Stone paving slabs used for centuries by the construction industry and they are designated as premium products because of their virtual natural appearance. The polyurethane (p.u.) mould masters are cast from original natural paving. The edges are characterised by rough edges and uneven shape. The moulds are pre-coated with mould release oil (light mineral oil) by a spray gun in an enclosed chamber with an extraction unit to protect the operator prior to a twenty four hour curing cycle. Despite this the paving units are difficult to remove from the moulds because the mould shape has to accommodate the natural edge, which means that the maximum plan area of the paving unit occurs at least 10 mm below the top surface. This undercutting of the mould effectively prevented the use of traditional automatic de-moulding techniques using vacuum central pick up of the paving unit and a fixed size, stripping frame around the edges to trap the p.u. mould in a fixed position whilst the vacuum tool lifted the paving unit out.

Automation attempts and hence the introduction of Lean Techniques, were abandoned because of very low efficiency and manual removal of the mould from the unit was adopted and this has been used for the past thirty years. Manual handling of products often more than 25kgs in weight has major production flow flexibility benefits in that product size change is instantaneous and an operator is capable of stacking any component size or shape on to pallets in any sequence. It is easily possible to cast all of the sizes and shapes associated with a patio project pack on to in sequence for subsequent stacking on to a pallet. Paving circle packs are similarly cast with all the sections of a paving circle cast together to fit on to a pallet after curing and de-moulding. The manual handling strategy proved to be very flexible and agile but not lean because of the high labour costs and the waste costs associated with human error through the whole supply chain.

The UK paving unit market has a highly seasonal demand pattern and it is not unusual for 30% of total annual sales to be concentrated in the selling month prior to Easter. The stocking policy has to accommodate this and it normal to ensure that at least 30 % of annual sales demand is held available before the end of February to ensure that peak demand can be satisfied. The supply chain is also subject "Demand Amplification" or "Bullwhip" which was described by (Lee et al., 1997, p.p. 546-558) as a phenomenon where the variance of replenishment orders is greater than that of actual sales to end customers. This demand amplification especially prevalent from major multiple customers distorts forecasting modeling and injects a requirement for even more agility in manufacturing facilities and amplification levels later found to be five times the real end user demand have been noted.

The Decorative Concrete Products Supply Chain in the UK can be described as a "Tough Case" for the application of Lean Concepts. Demand is influenced by: Weather, Very High Degree of Seasonality, Frequent New Product Introductions, Demand Amplification, Product Popularity Changes, Promotional Activity

With such demand volatility it is clear that Capacity Flexibility or “Agility” has to be considered as being of prime importance and at this juncture it is important not to confuse agility with lean concepts. Christopher’s view was that most companies that adopted lean manufacturing as a business practice were anything but agile in their supply chain (Christopher et al., (1999). The confusion between “Lean” and “Agile” can be understood by relating it to Variety and Predictability (Forecast Error). Figure 1, below adapted from (Christopher M., 1999) illustrates this point. In the concrete products industry in the UK, the market has been heavily influenced by the growth in the number of garden programmes that feature concrete paving, walling, decorative aggregates and other novelty products such as log stepping stones, mill stones and fossil replicas. In the case of one large supplier, this has resulted in a growth from 268 product lines or SKU’s (Stock Keeping Units) in 1999 to over 600 in early 2003. As a result forecast accuracy diminishes as the number of SKU’s increases and it is obvious that cumulative product group forecasting is much more accurate than SKU level forecasting because of the positive and negative effect (sales over forecast Vs sales under forecast). It is easy to forecast overall capacity requirements but very difficult to forecast individual product capacity requirements.

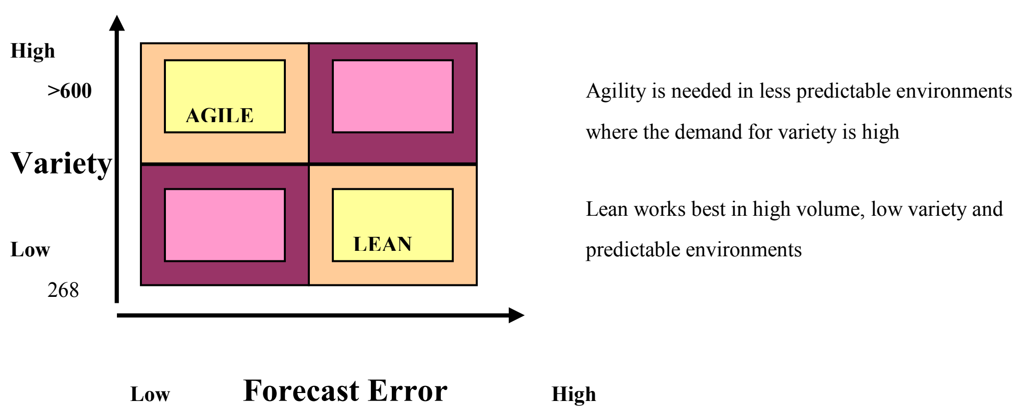

Figure 1: “Lean” versus “Agile”

Lindsay Harding outlines the potential use of relatively old fashioned quick response manufacturing (QRM) as an enabler on the route to agility but tempers his view in relation to capacity redundancy, she compares the cost based view (plant utilization and lot size with efficiency) with the QRM view (Harding L., 2002, p.p. 20-22). A “Holistic Approach” applying flexible, agile methodology where appropriate and lean techniques where they are beneficial is advocated in this paper. This approach is coupled with rapid, near real time modeling and decision making with the aid of integrated and linked IT systems (simulation and finite scheduling), Customer Relationship Management (CRM), Market Intelligence, Visualisation and Transparency of the plant and the abundance of information available from the plant, information accuracy and product tracking to reduce non-value adding waste and to improve service level as a result of fewer stockouts when stock is not available to fulfill an order. The Robot can considered as a prime enabling tool when related to the TFV theory of production outlined by Bertselen and Koskela in their paper (Bertselen, S. and Koskela, L., 2002, p.p. 13-22) because of its’ flexibility (e.g. rapid changeover to new product, ability to directly link to other software, product identification and visual inspection technologies) that can significantly reduce decision making time and improve the accuracy of response to real time demand changes. The paper suggests a route forward to enable "A Concrete Products Company" to thrive in an uncertain supply chain environment.

The technological challenges of the automation were to: (a) match the agile manual operation short lead times; (b) develop an automatic technique to de-mould the premium products with rough uneven edges; (c) devise a capability to stack any shape or size of paving units on to a distribution pallet in any stacking sequence; (d) maintain visual inspection of surface finish in an automated environment inside a Robot Safety cage – eliminating product quality errors; (e) minimise manpower costs: Numbers of People and Associated Health and Safety costs; (f) remove the manual handling safety issues; (g) educe energy and fuel costs in the supply chain; (h) reduce stock levels; and (i) lower material costs by improving concrete mix consistency and eliminating failed batches.

POSTURAL ANALYSIS AND ERGONOMIC STUDY

Consultants were appointed to assist in carrying out the study aimed at understanding the manual handling safety issues. They utilised a survey method developed for the investigation of work related upper limb disorders by Lynn McAtamney and E Nigel Corbett at the Institute for Occupational Ergonomics at the University of Nottingham (England). Three methodologies were used: (a) Rapid Upper Limb Assessment (**RULA**) described in Applied Ergonomics (McAtamney L., Corbett E.N., 1993, p.p. 91-99); (b) Rapid Entire Body Assessment (**REBA**) outlined in Applied Ergonomics (Hignett S., McAtamney L., 2000 , p.p. 201-205); and (c) Borg's Rating of Perceived Exertion (Borg G., 1985). A scoring sheet was used by the consultants and the results are shown in Table 1.

Table 1: Key Ergonomic Survey Results

Task Assessed	**REBA score**	**RULA Score**	**Borg RPE (High Only)**
Putting On – Lift Mould Box off stack and Feed to conveyor, push to oiler.	11	N/A	N/A
Filling – Pull Box below chute and fill mould with concrete mix.	N/A	7	N/A
Floating – Leveling mix in mould.	N/A	6	N/A
Lifting Off – Lift filled Mould from conveyor and stack 5 high.	13	N/A	20
Stripping – Lift box with cured slab, separate box and mould, palletise.	11	N/A	N/A
Shrinkwrapping – Place bag on pallet, walk round with blow torch	9	N/A	N/A

Three conclusions were drawn from the survey: (a) RULA scores greater than 7 to be automated; (b) REBA scores greater than 8 to be automated; and (c) Ergonomic coaches to be established to ensure that correct - Manual Handling techniques are used until the processes are automated.

Redback (Harmful) and Greenback™ (Safe) coaching courses were organised to manage musculoskeltal risks. Ergonomic coaches were trained and the training courses were rolled out to the whole workforce. Coaching courses now take place for: (a) people returning to work following long periods of absence; (b) new starters; and (c) operators experiencing physical difficulties in the workplace.

The automation process was considered using the matrix presented in Table 2

Table 2: Matrix representing the platform to create a new paradigm in concrete products manufacture

Process Element	**Equipment Available**	**Prototype development required**	**REBA**
Putting On	Yes –Mould Boxes to be mounted on carriers, which in turn to be stacked by auto stacker.	No	11
Lifting Off	Yes – Carriers to be auto de-stacked.	No	13
Stripping/De-moulding	No	Yes	11
Palletising	Yes – Automated		11
Shrink-wrapping	Yes- Automated	No	9

PROTOTYPE DEVELOPMENT TO FINAL INSTALLATION

The whole process was considered at top level using process mapping, described by Hunt as being capable of properly linking both things and activities (Hunt V.D.,1996, p.p. 14-17). The diagram below illustrates a "top level" process map.

PROCESS CHANGES ADOPTED

- **Existing Resource allocation** – No SCADA (System Control and Data Acquisition), Inadequate stock control, Very High Direct Labour costs.
- **Efficient Resource allocation –** Stock control from SCADA package, Deliveries direct to line via KANBAN (Movement of Raw Material from Quarry to manufacturing site-using pull concept)..
- **Change Management Leadership-**Increase workforce skills and develop multi-skilling, change from single shift to 24 hour multi-shift operation.
- **Performance Management Tools –** Develop plant Metrics and conduct regular workforce performance reviews.

- **Benchmarking** – Benchmark new labour cost and throughput rate to manual production line.
- **Process Improvement** – Adopt continuous improvement techniques**.**
- **Technology** – Use Robotics, Bar Code Technology, SCADA, Linear Motion, Dual circuit safety systems.
- **Corporate Objectives** – Reduce accident rate, claim costs and production resource costs.

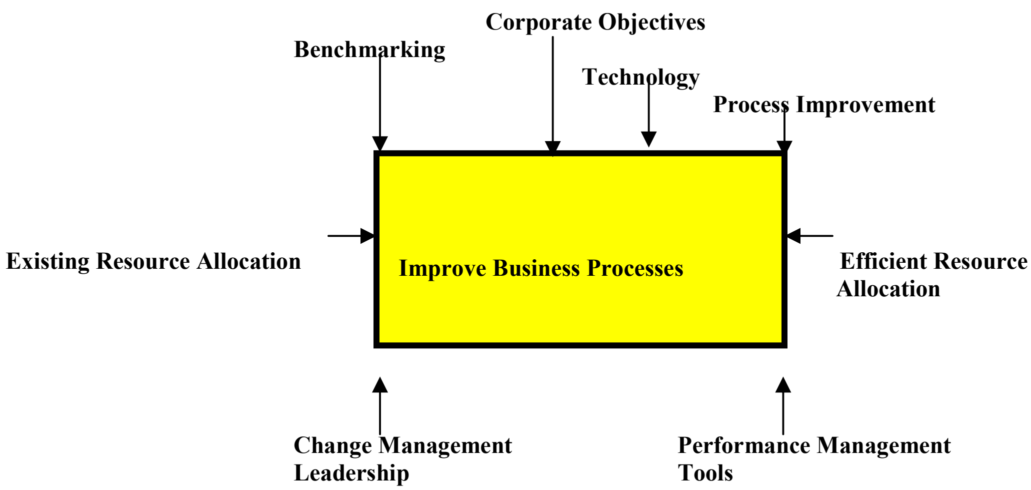

Figure 3: Top Level Process map (adapted from Hunt V.D., 1996, p. 16)

In order to start the process of automating the manual tasks described earlier it was decided to form a project team with the correct range of skills and knowledge. This project was assigned to work with a technical partner. Appropriate lean methodology was chosen to complete the task as detailed below:

- Video-Manual Method – Analyse video in slow motion to assist in determining the method of automation.
- Single Minute Exchange of Dies (SMED) – Developed by Shingo in the Toyota car plant (Shingo S., 1981) the elements of the process operations were broken down and studied in structured manner.

The study of the Video produced a major “Breakthrough”. It was noted that the operator broke the vacuum at the corners of the mould whilst simultaneously stripping the p.u. mould from the unit. The automation task was very clear from then and following a “Brainstorming Session” it was decided to build a prototype de-moulding rig first to test the theory. H Kent Bowen et al stressed the importance of a building a prototype in the Harvard Business review, in an article “Development Projects: The engine of renewal”. They outlined the benefit of a prototype assisting project teams in solving problems faster at strategic junctures

(Bowen H. K., et al, 1994, p.p.110 –119). The prototype tool which uses compliant, air-operated push rods to replicate the action of a persons' finger, is shown in the Figure 3.

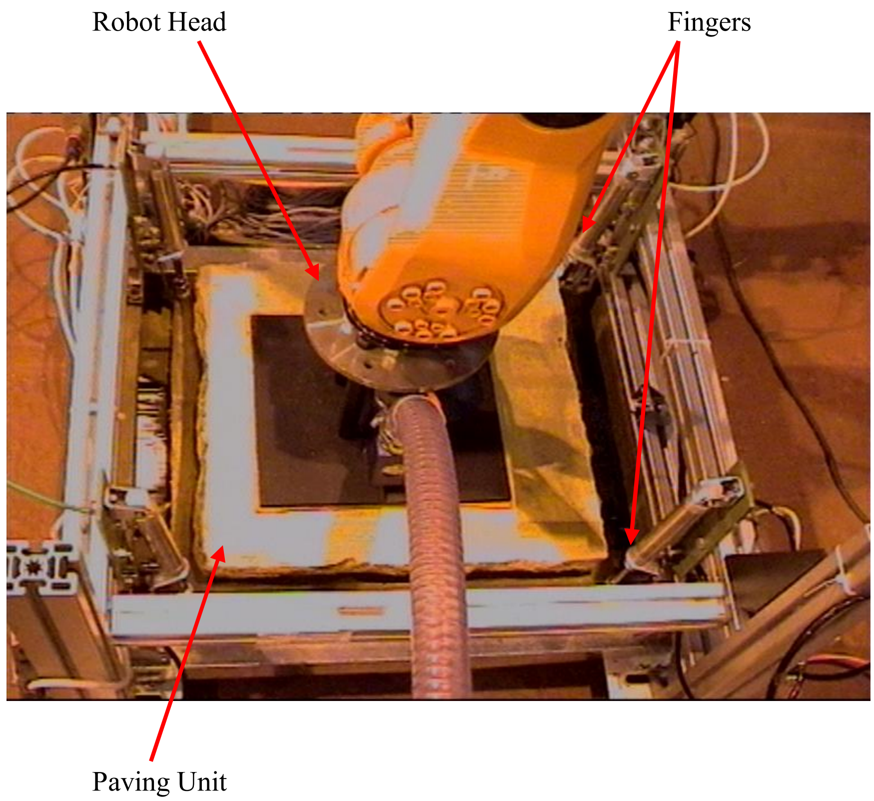

Figure 3: The prototype tool

The prototyping work was carried out at the "KUKA" robot assembly plant located at Halesowen near Birmingham, England. Observation of the action of the robot test rig introduced the need for the air push rods to be compliant with the edge shape of the "premium paving" unit. The synchronous action of the robot vacuum tooling in lifting the mould and paving unit from the mould box as the push rods operated in compliance with the edge shape enabled the mould box to return to its' mould box as the robot continued in its' action to stack the released paving unit. Previous attempts to automate the de-moulding of premium products had failed because a fixed stripping frame had been used to trap the outer edges of the mould in the mould box whilst a Gantry robot vacuum head picked the paving unit out of the mould box. This methodology could not work because of the undercut nature of the mould the end result is a de-moulding device that is virtually 100% efficient for all types of paving unit. This compares with a 95% efficiency level with "straight sided" products and zero with premium products achieved by alternative automation.

SMED studies resulted in the requirement to develop a de-moulding rig that was capable of changing its' geometry with product size in less than a minute. To achieve this, it was decided to purchase a linear motion device capable of changing geometry to match all paving unit sizes and shapes produced. Six air push rods were mounted on the servo driven, linear motion device (three axis motion plus edge compliance). This device achieved a size change in less than 10 seconds. This compared with an average of ten minutes and up to 15 minutes to the traditional stripping frame approach and virtually zero associated with manual methods. Software communication “handshakes” were developed between the robot software and the linear motion device software to ensure synchronous action was achieved. With products size changes occurring up to 15 times per shift this capability represented another significant “Breakthrough” it also introduced the potential, if required, to produce paving circle packs and full patio project packs.

Further study introduced the need for error proofing. It was soon realized that if an operator introduced the wrong size of product on to the automatic de-stacker upstream from the variable geometry de-moulding unit. The incorrect use of the Human Machine Interface (HMI) and shift register system could have resulted in the robot picking up a 600X600 mm paving unit when the variable geometry was set at 450X450 mm. To avoid machinery damage due to human error it was decided to use bar code technology to overcome the problem. Three downstream bar code readers check the product prior to entry into the variable geometry de-moulding unit. The “non-destructible” bar codes were mounted in a precise manner in a clean position beneath the mould box carriers. The bar code identification represented the product code (size identified) and a Microsoft® Access database was set up for all products to be run through the system. The access database figure 5, which follows, produced the added benefit of being able to measure product age and it was possible to bar products that were not fully cured from entering the de-moulding unit. Subsequent human error experience during process commissioning, demonstrated the validity of the Bowen et al strategic juncture approach.

The SMED approach was utilised to further develop the production process and the conversion of a series operation to a parallel operation as outlined by Norman Gaither was achieved by changing the mixer cleaning operation (Gaither N., 1996, p.547). The process time saving amounted to 20 minutes per mixer clean that took place up to three times per shift. A microwave moisture controller and a more accurate colour addition system were introduced into the automated mixing process, this enabled a more consistent mix to be produced with water control capabilities of ±0.5%. Raw material waste was reduced as a result since batch rejection levels are now virtually zero.

Rockwell™ Control Logix and Devicenet was used alongside an RS view SCADA package to enable the introduction of the linked, near real time planning processes utilising Arena™ and Finite Scheduling to compress lead time and remove the wasteful infinite capacity scheduling system in use. The diagram below is a top level system overview. Finite Scheduling is scheduling with due consideration being given to limitations e.g. Labour Resources, Downtime, Bottlenecks, Changeover Times, Set-Up and Set-Down times.

The by directionality involved in the advanced planning processes is provided in real time by the transparency of the plant metrics illustrated in figure 5 provided by the use of Bar Code Technology and the capability of the automation to change product Rapidly and Automatically to accommodate plan changes.

The SMED study identified the opportunity to move the wet mix hopper whist filling of the moulds continued as a result of the 20 minutes of mix contained in the filling chute. The wet mix hopper was mounted on wheels and the hopper was moved with the aid of an air-operated cylinder motion. This enabled the mix cleaning water and concrete mix residue, to be collected off-line. After cleaning a new colour mix was prepared in readiness whilst the filling chute was emptied. The mixer was also cleaned at the end of the shift in this manner.

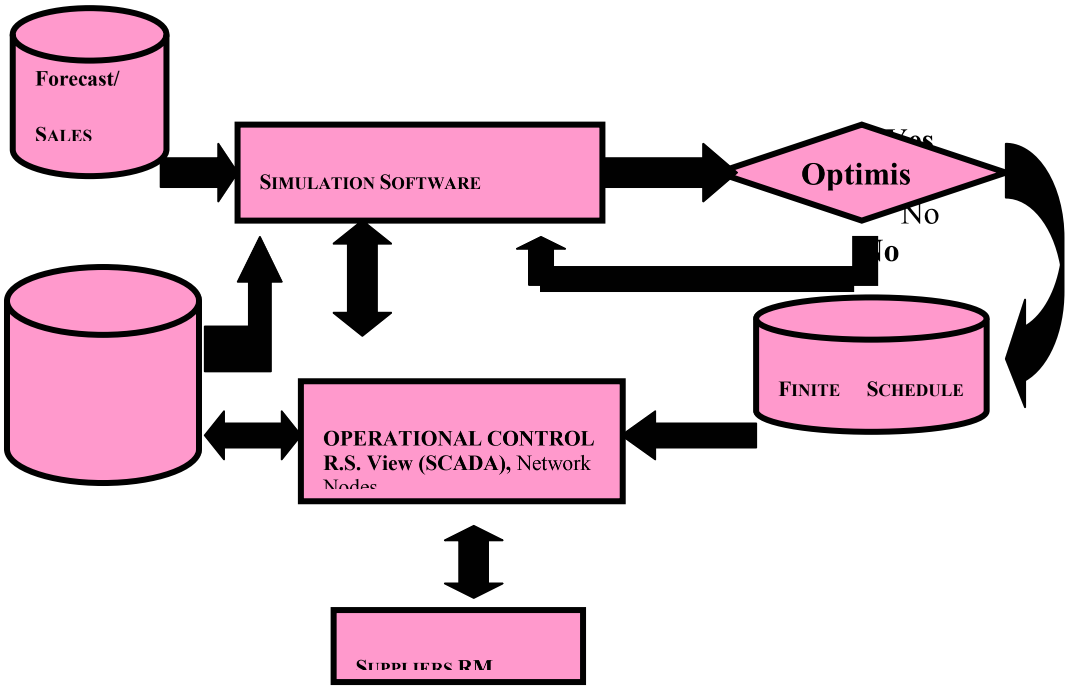

Figure 4: High Level System Diagram

Carriers : Table

CarrierID	Product	TimeStamp	BCQuality	Full	FillStamp	Code	WOnumber	Valid
1276	17	13/02/2003 09:47:19	2	☑	13/02/2003 09:51:04	06343	22	☑
1284	17	13/02/2003 10:38:17	20	☑	13/02/2003 10:43:07	06343	22	☑
1291	17	13/02/2003 10:58:27	28	☑	13/02/2003 11:03:10	06343	22	☑
1296	17	13/02/2003 10:59:20	11	☑	13/02/2003 11:03:31	06343	22	☑
1509	17	13/02/2003 10:46:14	23	☑	13/02/2003 10:51:58	06343	22	☑
1510	17	13/02/2003 10:07:29	10	☑	13/02/2003 10:14:24	06343	22	☑
1511	18	13/02/2003 13:27:34	1	☑	13/02/2003 13:32:26	06343	22	☑
1512	18	13/02/2003 14:01:26	8	☑	13/02/2003 14:05:25	06343	22	☑
1513	18	13/02/2003 14:01:47	1	☑	13/02/2003 14:05:44	06343	22	☑
1514	18	13/02/2003 13:35:05	24	☑	13/02/2003 13:39:51	06343	22	☑
1515	18	13/02/2003 13:34:41	29	☑	13/02/2003 13:39:24	06343	22	☑
1516	18	13/02/2003 13:34:21	28	☑	13/02/2003 13:38:42	06343	22	☑
1517	18	13/02/2003 13:33:54	28	☑	13/02/2003 13:38:10	06343	22	☑
1518	18	13/02/2003 13:51:40	23	☑	13/02/2003 13:56:02	06343	22	☑
1519	18	13/02/2003 13:51:20	13	☑	13/02/2003 13:55:39	06343	22	☑
1520	18	13/02/2003 13:32:44	23	☑	13/02/2003 13:37:01	06343	22	☑
1521	18	13/02/2003 13:29:28	23	☑	13/02/2003 13:33:56	06343	22	☑
1522	18	13/02/2003 13:28:53	23	☑	13/02/2003 13:33:34	06343	22	☑
1523	18	13/02/2003 13:28:29	1	☑	13/02/2003 13:33:09	06343	22	☑
1524	18	13/02/2003 13:27:59	24	☑	13/02/2003 13:32:47	06343	22	☑
1525	18	13/02/2003 13:33:07	1	☑	13/02/2003 13:37:24	06343	22	☑
1526	18	13/02/2003 14:12:39	1	☑	13/02/2003 15:03:44	06343	22	☑
1527	18	13/02/2003 14:12:58	1	☑	13/02/2003 15:04:11	06343	22	☑
1528	18	13/02/2003 13:41:38	1	☑	13/02/2003 13:46:00	06343	22	☑

Figure 5: Access™ Database – Product Codes related to bar codes

Palletisation was achieved by the use of a second robot and knowledge of robot head position within the system was maintained by the utilisation of ultrasonic distance transducers capable of position accuracy of less than 1mm over the robot arc of operation. Two robots effectively operated interactively. Opportunities for visual inspection in a robot cage are clearly impossible without the introduction of a vision system. The camera chosen was capable of sub pixel detection and was able to detect air void holes, cracks, paving unit shape, size and major base colour differences. The vacuum tooling used by the robots proved to be very effective in crack detection alongside the camera.

Lean product supply principles were introduced by the use of a stock control system integrated with the aggregate weighing conveyor and the cement weigh hopper. By the monitoring the usage rate (feedback from weigh hoppers and weigh belt) from a known stock position enabled just in time deliveries to be obtained with less than 12 hours of stock maintained. The aggregate bay system below includes four bays for two aggregates when 1 bay is emptied the shuttle supply vehicle fills it up from the quarry stock. Daily timed deliveries of cement ensure that stocks of this expensive material are minimized.

Bulk liquid colourant supplies are accomplished by the use of a novel tank storage system with the disadvantages of running Ethernet cabling over long distances between several factories on a large site being overcome by the use of radio data terminals (RDT). To enable a LAN and subsequent modem linkage to the colourant supplier based over 70 miles from the site. Ultrasonic level detectors accurate to 1 mm of level in the site colourant tanks were cross-calibrated with the tanker flowmeter and site weighbridge. The supplier is able to access the tank stock levels and replenish stocks Just in Time. Distribution costs are minimised and stocks in the supply chain are reduced as a result of this real time remote access capability. Figure 6 illustrates the system. This is another example of a push system being converted to a pull system by the enabling automation process

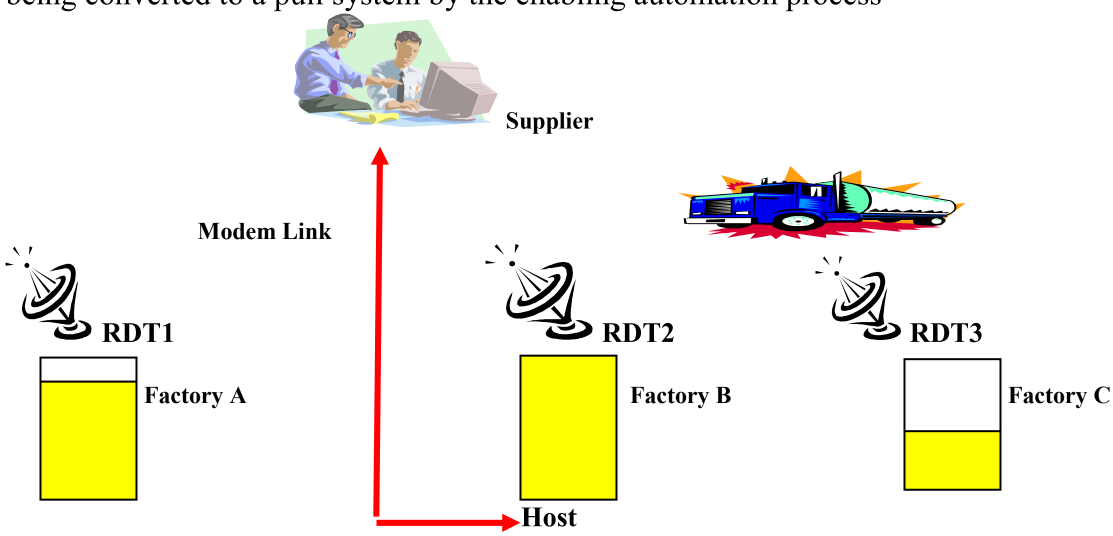

Figure 6: RDT – LAN

The use of a Robot produces many advantages in the specified application since they are capable of a maximum speed of 2.5 metres per second using brushless AC servo motors for very high acceleration and velocity without wear. They have a mean time before failure (MTBF) of 70000 hours and the KUKA Robot chosen has a control capability that enables it to work with up to eight axes if a new production requirement is introduced. They are flexible and suitable for agile manufacturing environments. The massive range of synchronous action capability allows them to easily interface with vision systems for quality inspection, and other high-tech devices such as linear motion and Radio Frequency Identification.

Table 3 presents the lean and agile concepts enabled by automation.

Table 3 - Lean and agile concepts enabled by the automation

Lean	**Agile**	**Value View**
Compression of lead time by quicker color changes.	Much quicker response.	Labor cost per unit reduced.
Colorant stock reduction. Fuel cost saving by fewer tanker deliveries.	Supplier observes real-time stock movement and responds just in time.	Stock value reduced by £20K. Delivery costs reduced by £12K p.a.
SCADA enabled cement. Stock reduction.		Cement stocks reduced by £3K
Ability to utilise automated guided vehicles.	System capable of responding to plan change in real time.	Elimination of direct labor cost allocated to fork-lift trucks saves £132Kp.a.
	Variable Geometry. De-moulding automation enabling product changes of ≤ 10 seconds.	Large stock reduction compared with previous attempts to produce lean automation.
Overall Equipment effectiveness increased by long MBTF of robots and automation		Labor resource costs reduced.
Consistent mixing. Automated reject. System using vision.		Non Value adding material waste reduced.

DEFECT CONTROL FEATURES EMBEDDED IN THE PLANT

The approach taken is similar to the simple XYZ defect control outlined by Philippa Collins and Tom Richardson in their case study from NSK Europe (Collins P., Richardson T., 2002, p.p.15-18). The simple basis for their system related to a paving unit was to:

Classify the defect — Void holes, Surface Finish, Cracks, Broken Edges, Colour, Correct Dimensions (Set by Mould).

Communication of Problem — Defect displayed on a Colour Screen with the software of the vision system tuned to reject the most critical defects (Z defects). Direct communication links between the vision software and the plant control software ensured that a problem is highlighted. The system tuning is done with the aid of Failure Mode Effect Analysis (FMEA).

Action on the Problem Robot picks up the defective paving unit and drops it in to the waste bin.

In addition to the most critical identified above as Z two other rating levels were used:

X – Defined as a Low risk quality problem detected upstream of the final detection by the Robot.

Y – Defined as Medium Risk where a problem is noted and recorded but not considered as being likely to cause a defect in the surface finish.

The final reject settings of the Robot/Vision system were FMEA based using a simple Risk Evaluation: (SEVERITY x WHERE FOUND x FREQUENCY)

Once set it is relatively easy to maintain the standards at the unacceptable Z level since they are locked in the vision system software. The vision inspection cabinet is shown in the picture that follows. The camera is protected and mounted within the cabinet alongside lighting to illuminate the surface of the paving unit.

The "de-moulding robot" places the paving unit on the cabinet for the camera system to compare the image with an acceptable standard. Any failure is rejected on to a reject conveyor by the second "palletising" robot. The mimic diagram is a screen copy of the actual SCADA mimic screen in use and it shows the components of the automated line.

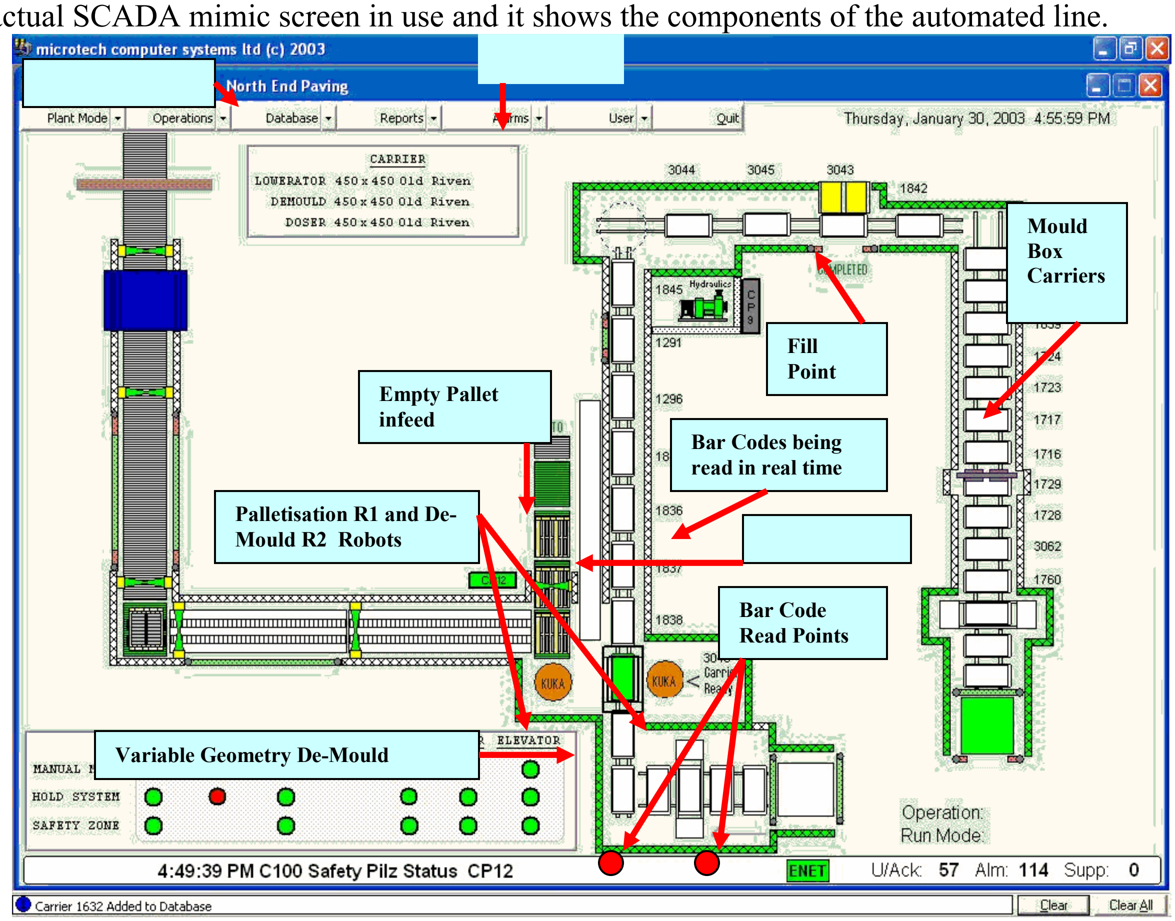

Figure 7: Actual SCADA mimic screen showing the Components of the Automation

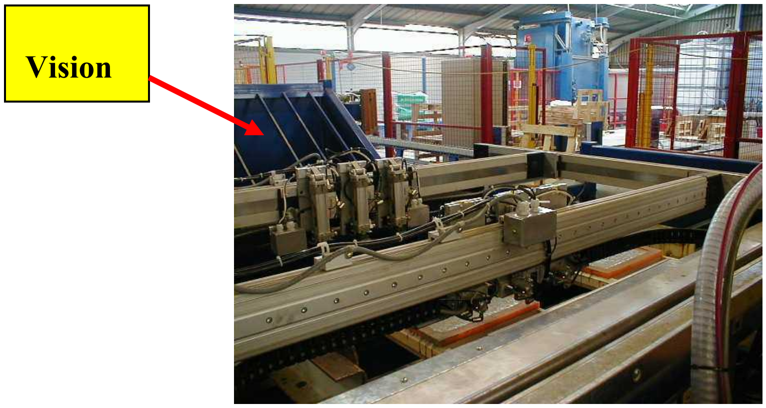

Figure 8: Vision Cabinet used in Conjunction with two Robots

CONCLUSIONS

The key technology challenge to match the agility and responsiveness of the manual line was achieved by adopting a "High-Tech" solution.

- Matching the agility of a manual line was achieved with the aid of two 6-axis robots with a maximum payload capability of 150kgs and a positional repeatability of <0.2 mm. working in synchronous communication with a linear motion device. Bar code technology was used for product verification and for the automation of the changeovers.
- A new technique for the automatic de-moulding of premium products with rough edges was introduced as a result of a "Breakthrough" following the use of a video camera and SMED techniques and "Braining Storming" by the project team. The cycle time target of de-moulding two units in 14 seconds was achieved. The only doubt being the utilisation of manual filling techniques which restricts the overall machine cycle time, with varying levels of skill and speed noted in the range 12.7 –16.5 seconds.
- Combining "Bar Code Technology" and using an Access® data base in "Real Time" enabled the requirement to be able to palletise any product in the paving unit portfolio in any stacking configuration to be met.
- Postural analysis techniques utilised to reduce accidents rates associated with manual handling lines were developed to aid decision-making. A matrix was used to decide on the extent of automation to be applied in the final solution.
- Non- value adding colourant stocks were reduced as a result of the use of an RDT-LAN system with remote direct indication of tank contents displayed in the suppliers location to enable "lean –purchasing" objectives to be achieved, alongside optimised deliveries to site.

The business case objectives are still being evaluated by post project analysis of real savings. However, the payback period will be between 14 to 18 months depending on the level of efficiency finally achieved following further improvement team activity. There is no doubt that a new paradigm in "Wet Cast Concrete Products Production" has been established.

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