Set-Up Reduction in Injection Molding Process – A Case Study in Packaging Industry

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Abstract
The competitiveness of manufacturers can be significantly enhanced through implementation of Setup Reduction (SUR) initiatives. This paper presents a simplified SUR approach which was trialed and fully implemented in an injection molding facility. The identification of bottlenecks in production was carried out by using extensive data gathering on machine down-time and/or changeover time records. The detailed analysis of the operations carried out by employees were investigated by using the Single Minute Exchange of Dies (SMED) philosophy. Close collaboration with employees and formation of SUR teams facilitated the development of a system for the organization and storage of molds. The system developed ensures mold readiness conditions, reduces lead times and improves the storage, monitoring and accessibility of machine programs.

Keywords: Manufacturing System, Performance Evaluation, Cost

1 INTRODUCTİON

The injection molding industry in particular is in a position to gain enormous advantages through reducing the time required to change between products as well as lot sizes. Reducing the lot size would inherently increase the number of setups, automatically attracting the stigma of increased downtime and loss of productivity. A number of methodologies to enable operators to reduce this ‘wasted’ setup time have been put forward and covered extensively in Set-Up Reduction (SUR). Shingo [1] has been the basis for most of the work in the field of Setup Reduction (SUR), and it is where many of the techniques that enable changeover times to be reduced below ten minutes were first discussed. The critical concept discussed in his work requires that all possible elements of the setup are completed before the machine finishes the last shot of the previous production run. Thus, all processes that were previously completed during the setup (internally) are now completed beforehand (externally). This methodology is referred to as SMED or Single Minute Exchange of Dies where basic steps are outlined to enable SUR [1]. Shingo also presents very valuable injection molding specific ideas such as the sequencing of dark through to light to improve colour change efficiency and the use of One-Touch clamping solutions. Half-turn tensioning is another important concept explored. Shingo [1] advocates the use of Work Study techniques in determining the time required to complete each phase of the setup process. This enables the SUR team to quantify the time savings when Internal tasks are converted to External tasks, or eliminated altogether. McIntosh et al [2] submit an evaluation of Shingo’s SMED system. İt was suggested that the concept of converting internal tasks to external is not always the most significant factor in a SUR program. Leshke [3] provides five case studies from diferent organisations that implemented SUR at work centre, product and policy levels. Chaneski [4] outlines some simple but valuable ideas to enable SUR at organisational levels. He reviews other techniques including the use of ‘Setup Sheets’ to ensure a process is never re-invented. Gest et al [5] introduces some concepts that are very valuable to the injection molding industry in particular. The first idea is improvements to clamping. This can involve the removal of threaded fasteners vulnerable to damage and reducing the Safety Factor of necessary threaded components down to a reasonable level. One-touch fasteners, half-turn fasteners, T-slots, hydraulic and vacuum clamping and many others are all suggested as viable alternatives to screws. Another initiative is improvement to systems for colour purging. It highlights automatic material/colour change devices and the organisation of production runs. Culley et al [6] explores the issue of the sustainability of a SUR project and suggests that even the most well laid SUR plans can degrade over the following years. Ensuring the program maintains a high profile, making staff accountable for setup times as part of their job description and ensuring that changes to the focus of the business do not contradict the program in the future are highlighted as important success factors. Mileham et al [7] discusses the issue of the correct selection of a team responsible for the implementation of SUR initiatives. The research indicated that many programs are implemented with a lack of structure, and without definitive support from upper management. Also, SUR projects are often left in the hands of team members without the necessary skills to design a more setup-friendly system resulting in changes often only affect the methods used in the setup. While these programs are typically inexpensive, they tend to lack long-term sustainability. Haddad [8] concluded that the most important factors that would support the acceptance of changes that SUR introduce are formal advanced notice, the structure of jobs prior to introduction and good culture and communication in the work place.

This paper covers set of methods trialled and implemented in a packaging firm in order to reduce setup times in injection molding process. It summarises current practices and aims to focus on cost effective mechanical, organisational and procedural changes which will provide a simplified approach that can be implemented in any injection molding facility and enable the operators to experience significantly reduced setup times.

2 METHODOLOGY

The implementation of Setup Reduction (SUR) initiatives were carried out in a packaging firm which experienced difficulties in dealing with inefficiencies caused by extended delays between production runs leading to increased lead times, extended production runs and high levels of inventory. It designs and manufactures a range of specialty closures, mainly for the food and beverage industry, and is a market leader in the development of innovative solutions for the Australasian market. It comprises of three main manufacturing areas, one of which is climate controlled, and two large warehouses. There are twenty-two injection molding machines ranging in age from just a few weeks right up to more than fifteen years. Raw materials are delivered to the machines through either a vacuum delivery system from bulk storage, or from large containers located next to the machine. The vacuum delivery system feeds from three large silos at the front of the plant, and is the primary material supply system. It operates approximately fifty molds with thirty being used on a regular basis. Some molds can accommodate various 'Inserts' allowing that mold to produce a number of products with similar specifications. This brings the total number of products currently in regular production to approximately forty. Aside from molding the closures, the firm also utilises a range of assembly machines to complete the finished product. These machines are highly automated, and are either custom built assembly lines, or in a number of cases completely robotic. While these machines have their own problems associated with lengthy setup procedures, they were not considered in this paper.

The following steps are covered to identify the mechanical, organisational and procedural bottlenecks followed by suggestions for SUR initiatives :

1. Formation of a SUR team
2. Data collection and analysis

2.1 Formation of a SUR team

It was vital to form a SUR team that staff from all levels of the organisation are recruited. This approach enabled fast and effective communication of ideas and feedback, and sent the message that everyone (even those not within the actual SUR team) was welcome to contribute. The differences in opinion between managerial and shop-floor levels as to what can be achieved by SUR are another crucial consideration especially at the beginning of the program. It was also very beneficial to define the language used by the SUR Team to ensure that all staff are completely aware what is happening and how it will affect their day-to-day work.

2.2 Data Collection and Analysis

Downtime and changeover time records

The concept of identifying 'Bottlenecks' in production has been well covered in the literature [1]. A thorough analysis of downtime or changeover-time records of machineries were carried out covering a full data set around twelve hundred records spanning around eighteen months. Every machine was sorted by the type of change (for example: C:Colour, I: Insert, M: Mold) and the average variation for each type of change was calculated (Figure 1). Due to the possible inaccuracies that may be present in the data analysed, information from staff were also gathered to select target machines from a variety of sources. The technicians who work with the machines on a daily basis formed a large part of this knowledge base. The information provided revealed issues that otherwise would not have been considered and supported a more thorough assessment to be carried out. Regular discussions took place with staff on every phase of the study. Analysis also showed that machine programs used were consistently causing production delays in excess of one hour and a better system had to be devised.

The results of this analysis for one of the molding machine is presented in Figure 1. The X-axis represents the amount of time allocated for the completion of a given setup. Positive values denote that the setup was completed in less than the allocated time whereas negative values mean that this time is not achieved.

Workstudy analysis

One of the most important steps towards reduced setup times is the analysis of the steps employees complete to physically change the mold towards maintaining a Single Minute Exchange of Dies (SMED) philosophy and it is vital to any SUR program. A form was produced with columns for Type of Process and Target Time. The tasks which could have taken place before the setup began were labelled 'External', and were given a Target Time Value of zero. Internal processes were analysed and revised to reflect the amount of time the task would be expected to take once SUR measures had taken place. Table 2 is an

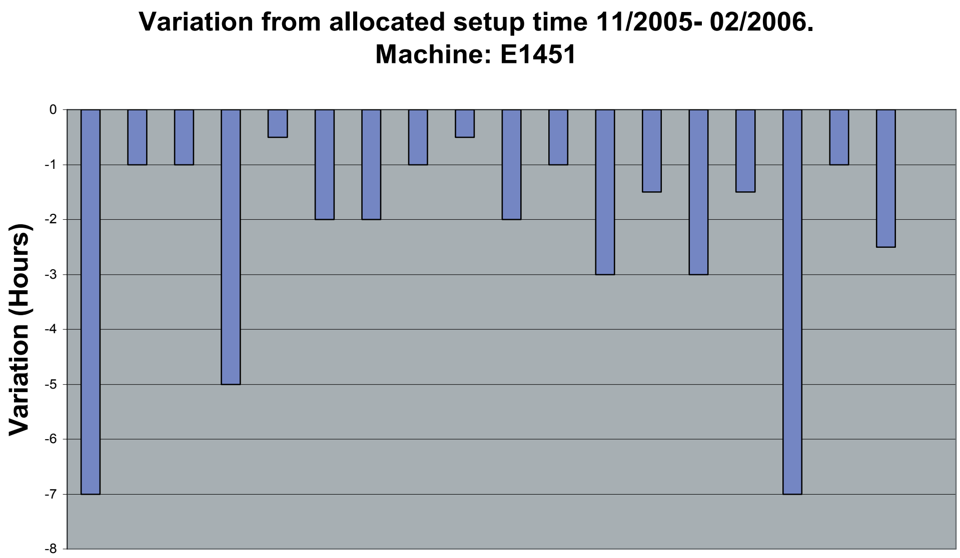

Figure 1: Variation results for machine E1451

Date	Shift	Machine	Product	Type	Hours	Time Allowed	Variation
04-May-06	AS	E502	CR3 38 OUT	I	4	4.00	0
04-May-06	DS	KM420	NEW PROD	M	8	6.00	-2
03-May-06	AS	E1253	ZELL RIB	M	3	4.50	1.5
03-May-06	DS	E802	GAT BASE	M	8	3.00	-5
02-May-06	AS	TOSH2	CR3 28 OUT	I	4	4.50	0.5
02-May-06	DS	E1502	CHUNK	M	1.75	2.00	0.25
02-May-06	AS	E502	CR3 38 OUT	C	4	2.00	-2
02-May-06	AS	TOSH2	CR3 28 OUT	C	4	2.00	-2
02-May-06	DS	E1451	ZELL SM	I	5.75	2.50	-3.25
02-May-06	NS	TOSH2	CR3 28 OUT	C	8	2.00	-6
01-May-06	DS	E1101	TWIST SPOU	C	2	1.00	-1
01-May-06	NS	E1451	ZELL SM	I	3.5	2.50	-1
01-May-06	DS	E802	GAT BASE	M	8	3.00	-5

Table 1: An example of data gathered for downtime due to Setups during the beginning of May 2006. The 'Time Allowed' and 'Variation' fields were created using pre-SUR values.

E1451 Mould Change (Jan '06) SUR Evaluation				
Task	Approx Time Taken	Type of Process (ideally)	Action/Which Technician	Target Time (Min)
Remove Mould	30	Internal	1 + 2	15
Clean Machine	10	External	1	5
Mould To Shop Mould from Shop Find Pallet Truck	10	External	Convert to External	0
Install Mould	45	Internal	1 + 2	15
Install Closing device	20	Internal	1 + 2	10
Hydraulic Connector Problem	25	Internal	N/A	0
Connect Sensors and Plugs (Front)	15	Internal	1	15
Adjust the Ejector	5	Internal	2 Standardise Ejectors	0
Connect Water	15	Internal	1 New Manifold and Connector System	1
Connect Heats	5	Internal	1 New ID System (Colour Coding)	1
Set and Repair Chute	20	External	Convert to External	0
Change Nozzle	20	N/A	N/A	0
Calibrate Colour Doser	10	External	Convert to External	0
Setup Granulator	5	External	Convert to External	0
Load Program	10	Internal	1	1
Set Chute Program + Sensor	15	Internal	2	5
Purge and Adjust Settings	30	Internal	2	5
Fill out Sheet (checklist)	25	External	Convert to External	0
Inform QA & Operator	25	External	Convert to External	0
Adjust Parameters	25	External	Convert to External	0
Total	365		Total	73

Table 2: Work Study Analysis showing the original and improved setup times of machine E1451.

example of the analysis carried out in machine E1451 which reduced the time required to complete the setup from 365 minutes to just 73 minutes. It also highlights many of the steps that could be completed “Externally”. Similar analysis was carried out for all production molds.

3 RESULTS

The analysis of data and information gathered led to significant improvements to be carried out in three categories, namely; Mechanical, Procedural and Organisational in order to implement Setup Reductions. Mechanical improvements covered several engineering changes that will streamline the physical processes involved in completing a setup. Procedural improvements aimed to investigate the efficiency of the procedures used to carry out a setup whereas Organisational improvements were towards how resources have to be organised and allocated to the setup process.

3.1 Mechanical Improvements

These are the engineering changes that will streamline the physical processes involved in completing a setup.

Water Manifolds

Connecting the equipment associated with the mold was identified in the Work Study analysis as one of the major causes of delays during the setup process. Some of the more complicated molds had up to thirty water lines, and therefore sixty separate hoses which have to be connected to complete the mold change. Since each line has both an ‘In’ and ‘Out’ to connect, great care needs to be taken when attaching each hose to ensure every loop is complete.The most cost effective design solution was determined to involve the following steps:

1. Manufacture new manifolds for machines.
2. Move existing manifolds to inside the machine molding bay.
3. Reduce the length of hoses to eliminate confusion.
4. Change connector types on the Inlet lines to distinguish them from Outlet lines.
5. Install existing (spare) Staubli® system on problem mold.
6. Replace all return loops with permanent attachments where possible.

Connections

Pneumatic connections such as those manufactured by Festo® are already designed with easy connection and removal in mind, so they lend themselves very well to SUR programs. Push-in connectors allow one-touch connection of air lines and mean the overall time to connect up the system is greatly reduced.

Safety

Significant crushing hazards can be present during the setup process due to the pneumatic system used to drive the plates of the mold. Cutting the pressure by restricting the inlet tube by folding it and securing with a cable tie is not only a dangerous solution, but can also increase setup time. For this reason dedicated safety valves need to be fitted to the system.

Mold Skips

The efficient transport and storage of moulding equipment is very important when it comes to Setup Reduction. An important part of implementing the Mold Kit system was creating a safer and more effective means of storing and transporting moulds. A prototype Skip was produced to store the mold and provided a dedicated place for the storage of all the related equipment. The Zeller type mold for which the prototype was designed requires a mechanism to first close, and then unscrew a cap from the core of the cavity. The system was able to calculate the required dimensions of the Skip, so that future models could be designed safely with minimal engineering input. This ensured that all future moulds can be stored securely and that the skip would be sufficiently robust for any size mold, without being prohibitively expensive. With this information, a design for the prototype could be created using a CAD package, and the accuracy of the calculations could be tested using an analysis program.

The results from the CAD analysis were identical to the Factor of Safety predicted by the Mold Skip Worksheet. This fulfilled the goal of allowing a relatively inexperienced user to design a Mold Skip quickly and safely. The prototype was fabricated and then galvanised to protect it from contamination and ensure it remained food-safe.

Mold Clamping

Another time consuming aspect of the setup that was highlighted by the Work Study analysis was the process of clamping the mold into place on the machine. Injection molding machines have a fixed and a mobile platen which attach to each side of the mould. The dimensions of the clamping face on molds in use ranged from around 0.3 x 0.5m through to 1.0 x 0.7m, requiring between four and eight clamps for each of the two platens. In general, securing a mould requires four of the eight clamps are first used to attach the mould to the fixed platen, ensuring proper alignment. At this point the crane can be removed. The mobile platen is then moved into position under negligible pressure to avoid damage to the mould completing alignment of the mould. The remaining four clamps can then be attached (Figure 2).

Fasteners

If the bolt is not of correct length, time is wasted by having unnecessary turns to tighten the bolt. When this wasted time is multiplied by eight clamps a significant amount of time is wasted.The correct length for the bolts for each mold was calculated, and this data was added to the setup sheet for that mould.

3.2 Procedural Improvements

Standardisation of Procedures is another powerful Setup Reduction tool. Standardised procedures were designed for conducting the three types of setup usually encountered in injection molding. It should be noted that these procedures must be constantly updated through consultation with the technicians and revised to incorporate faster methods from time to time. The standardised procedures can then be followed by a skilled technician to determine the Normal Time.The three main types of setups that take place during normal injection moulding manufacturing operations are

1. Mold Change –- physically swapping one mould for another.
2. Insert Change – changing the cores and cavities to enable the same mould to produce a different product.
3. Colour Change – changing the colour of the resin.

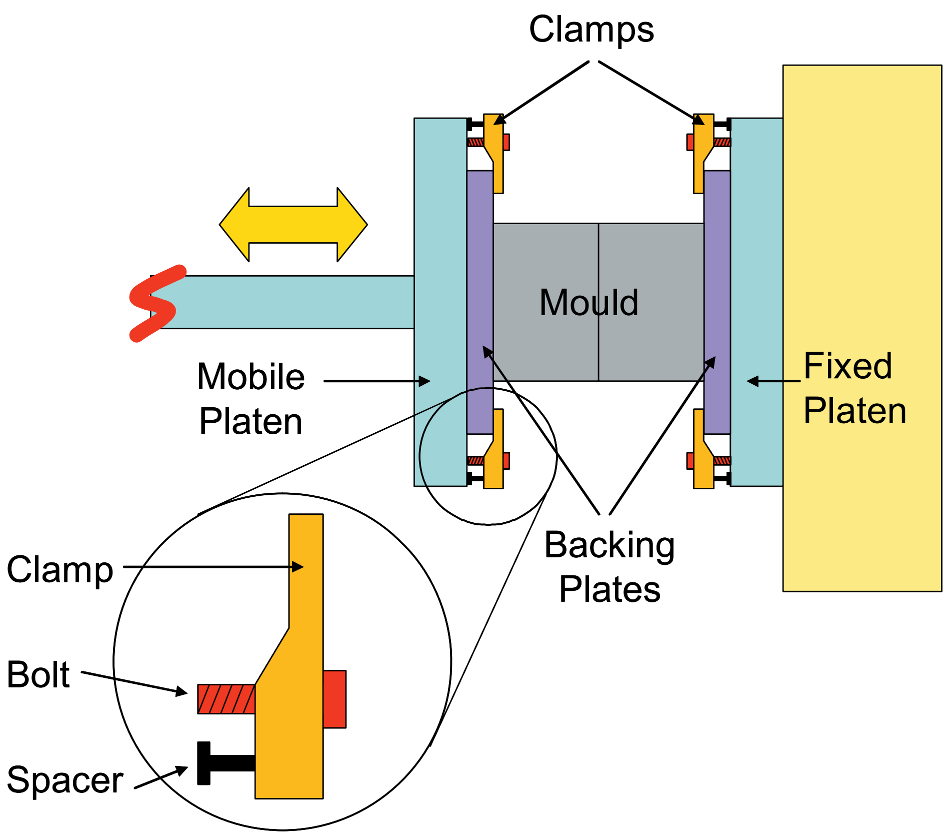

Figure 2: Diagram of a typical mold clamping setup (above view).

Mold Change

Since the mold change process is fairly simple in comparison to the other types of change it is vital that the steps involved are as streamlined as possible. The use of the Mold Kit and Setup Sheet systems developed can effectively eliminate a lengthy preparation process and should have been implemented by this stage of the SUR program. In general, all possible External operations should be performed at this stage. Some examples are preheating the hot runner system while removing the mould from the previous production run, and ensuring all return loops on the coolant system are connected.

Insert Change

Injection molding is a very flexible manufacturing technique, and often one mold can be used to produce a number of different products with similar specifications. This is achieved by producing a set of Inserts for each individual product that can be exchanged into a generic mold.

Colour Change

Often multiple colour variations of the same product are to be run successively. This means that the tool itself need not be removed from the machine and the technician only needs to remove the material from the previous product that is still inside the barrel. This process is called Purging. Depending on the colours involved this can either be a simple process or quite a time consuming one. If it is not possible, the purging process can be made considerably faster by the use of commercially available purging agents. One of these agents, Culapurge®, was obtained and trialled as part of this study. By testing different add-rates and timings the most efficient settings were determined and this information was added to the Setup Sheet or Work Order.

3.3 Organisational Improvements

Setup Sheets

The most important innovation implemented during the Organisational improvement phase was the concept of the Setup Sheet. It enabled the business to begin streamlining several aspects of operations relating to the setup. Two such examples are organising material handlers ahead of time to have the right colour prepared, or ensuring the right raw material is organised in advance. Also, the operations that were causing delay were improved through the further analysis used in the creation of the Setup Sheet system. For instance, components like bolts can be much longer than is needed causing excessive time spent on tensioning. Measuring a more acceptable length is an automatic step in the creation of that mould's Setup Sheet. Another area where excellent time savings was achieved was through the provisioning of a section on the sheet to detail what spare parts might be needed during the setup. Often O-rings or fasteners need to be replaced, and rather than having to measure and locate a suitable replacement, significant time can be saved by listing the specifications of spare parts on the Setup Sheet and having them present at the machine during the setup.

Job Cards

One of the main problems encountered during implementation was the lack of proper records regarding the reasons behind the setup delays. Technicians had nowhere to record this information, and also had no specific hierarchy of the tasks they were asked to perform during a shift. This problem was solved with the introduction of a new system of ‘Job Cards’. This system allowed technicians to record specifically where, how and why delays occur as well as generating a feedback mechanism from employees. Analysis of the ‘Description of Lost Time’ enabled the SUR Team to quickly identify areas that the greatest improvement can be achieved.

Machine Programs

Each product in the diverse range required its own unique machine program. Each mold may run in a number of machines and produce a number of different colour variations and specifications. Added to this is the need to account for environmental variations and the limitations of some of the older machines. A program that functions perfectly in June may require a completely different set of machine parameters in December. In summary, there were literally hundreds of programs required for production, so an efficient system for their organisation was crucial. Incorrect or missing programs were identified as leading causes of increased setup times.

Mold Kits

The safe and secure storage of molds are costly as well as a paramount for protecting the financial security of the business and the safety of employees. A system for allowing for the storage of all components and related paraphernalia with the mold itself was decided upon to eliminate technicians having to search for components and allow much faster transport of molds to and from the workshop. The system was labelled a Mold Kit, and consisted of a Setup Sheet for the mold, as well as a Mold Skip. The Mold Kit system was designed to facilitate the storage all of the items listed on the setup Sheet with the mold itself, rather than in separate areas as was the practice in the past. Ensuring everything is in one place meant that when the time came to complete a setup, the technician need only go to the tool room and retrieve a complete kit, confident everything would be present when he/she arrived at the machine. Aside from ensuring everything is with the mold and ready to be taken out to the machine, a completed Mold Kit also has all possible External operations completed before it is considered ‘Ready’. This includes ensuring any maintenance has been completed satisfactorily, inserts are cleaned and installed, and water and hydraulic fittings are in place. This applies right down to the lifting mechanism for attachment to the crane being fitted and ready. Only then would the Mould Kit be deemed ready for production.

Another benefit of the Mold Kit was enabling any external involvement such as the input of a material handler, to be triggered well in advance.

4 DESİGN FOR SETUP REDUCTİON

At the completion of the SUR program a new approach was suggested to be implemented for the acquisition of new tooling. New molds for instance should be designed with the following features to ensure that the time taken for a setup is low from the first time they enter production.

1. Standardised die dimensions. Where possible molds should have similar dimensions to ensure minimal machine adjustment is necessary when switching molds. Die height/closure is one area where standardisation can have considerable affect on setup times (Shingo 1985). Setup time reduction savings will more than outweigh the expense of the extra stainless steel in the short term.
2. Standardised backing plates. Introducing this feature enables faster clamping of moulds during a setup by allowing the clamps from the previous production run to remain fixed to the machine.
3. Streamlined connections. When designing new tooling the Engineer should consider the placement of water and pneumatic connections to allow for simplified setups and eliminate unnecessary confusion. The perfect time to implement a “One-touch” connection system is when the mold is being trialled.

If the design process incorporates these concepts, and involves consultation with the SUR team a more efficient solution can be generated from the commissioning of the new tool.

5 CONCLUSİONS

A methodology for implementation of Setup Reduction in industry was created and the new systems were trialled and implemented.The Mold Skip prototype was a successful innovation, but due to labour restraints further skips have not been produced at this stage. The CAD plans have been generated, and a procedure for the effective design of further skips has been formulated. Materials for the manufacture of further skips have been fully costed, and this project will be pursued in due course.At this stage the absence of the Mold Skips has limited the ability of the Mold Kit program to organise the tool room. Technicians viewed the Skip as a fundamental part of this improvement and although Setup Sheets were generated for all production molds, the system will be ineffective until the skips are produced. The colour purging agent trials found the product to be completely ineffective in reducing the amount of time required to complete a difficult colour change. The installation of water manifolds on the target machines simplified the connection of the coolant systems significantly. This will allow for much faster setups to be carried out. New tooling will be implemented with One-Touch connection solutions such as the Staubli system from the outset. A comprehensive set of machine programs was gathered on the central server, which allowed technicians to request a program rather than searching for it as per the old system. However, the number of programs will continue to grow, and the process of cataloguing them will need to continue indefinitely.

While the methodology created for the implementation of Setup Reduction was sound, there may be some limitations to its effectiveness if the involvement and support from all levels of the organisation can be achieved as the program moves forward. Another limiting factor was a shortage of mold technicians from the beginning of the program. The labour shortage meant that the number of setups being performed dropped dramatically, and also that technicians were less likely to adapt to the new procedures. Technicians had less time to complete the SUR projects they were assigned, and as a result did not have a sense of involvement in the program. It was not possible to allocate time specifically to SUR initiatives due to the labour shortage, meaning that the improvements proposed could only be implemented on the target machines rather than throughout the entire facility. New staff members joining the team as this study concludes will eliminate these issues, and should the SUR program be allocated sufficient resources the implementation will progress.

SUR is an extremely valuable approach in modern manufacturing. To ensure its success it must begin at a grass-roots level of the organisation, and a constant drive towards improvement must come from all levels of the company. The circumstances that have limited the success of this implementation thus far can occur in any organisation, but perseverance is essential to continue the drive towards greater flexibility and more efficient manufacturing.

6 ACKNOWLEDGEMENT

The Authors would like to acknowledge the contributions of Mr Tim Jones to the contents of this paper.

7 REFERENCES

[1] Shingo, S., 1985, A Revolution in Manufacturing : The SMED System. Stamford, Conn., Productivity Press.

[2] McIntosh, R.I., Culley, S.J., 2000, A Critical Evaluation of Shingo's 'SMED' (Single Minute Exchange Of Die) Methodology. International Journal of Production Research, 38/11: 2377-2395.

[3] Leschke, J.P., 1997, Setup-Reduction Process: Part 1. Production and Inventory Management Journal 38/1: 32-37.

[4] Chaneski, W.S., 2004, Success in Setup Reduction Efforts. Modern Machine Shop, June 2004: 40-42.

[5] Gest, G., Culley, S.J.,1995, Review of Fast Tool Change Systems. Computer Integrated Manufacturing Systems 8/3: 205-210.

[6] Culley, S.J., Owen G.W., 2003, Sustaining Changeover İmprovement. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 217/10: 1455-1470.

[7] Mileham, A.R., Culley, S.J., 1998, Rapid Changeover – A Prerequisite for Responsive Manufacture. London, UK, IEE, Stevenage, England.

[8] Haddad, C.J., 1996, Employee Attitudes Toward New Technology İn A Unionized Manufacturing Plant. Journal of Engineering and Technology Management, Vol 44, 39-45.