Process Improvement through Single Minute Exchange of Dies for Reduction of Changeover Time

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Abstract

Businesses around the world strive to operational costs and waste across their supply chains to remain competitive in the growing global market. Initiatives for set-up duration reduction are critical for lean manufacturing implementation despite than many organisations that initiate Single Minute Exchange of Dies (SMED) fail on implementation. The plastic injection moulding machines at an engineering firm are characterised by an ineffective process and the main problem was that the single changeover time ranged from 45 min to over 60 minutes, thereby leading to longer downtime and less production time. The scenario resulted in production capacity constraints, longer lead times and this led to loss of future business with some of the customers due to failure to meet delivery dates. The objective of this study is to identify and separate external and internal elements, establish cycle time and reduce tool changeover time for the plastic injection moulding machines. By implementing the new tailor-made SMED improvement programme of having tools ready before machine stops running, combining steps, bringing tool-holder before commencing the tool change process and establishing the production sequence to take advantage of temperatures, material type and colour, the engineering firm achieved 22% reduction in changeover time.

Keywords
Process improvement, Single minute exchange of dies

1. Introduction
Businesses around the world strive to operational costs and waste across their supply chains to remain competitive in the growing global market. The case study engineering firm manufactures automotive components in metals, leatherette and plastics, with divisions that include automotive trim, plastic injection moulding, automotive accessories, component assemblies, product development, tool and die, quality and logistics. The engineering firm is characterised by four pillars of success, namely manufacturing excellence, cumulative value-added, growth, and people development, and the organisation values are respect, trust, teamwork integrity, responsible manufacturing and professionalism. Many firms invest in the implementation of lean principles to remain competitive. The objectives of lean principles is to satisfy customer demand as much as possible through reduction of waste. Elimination of waste applies throughout the company; that includes human resources, design, production processes and activities, logistics and inventory sectors. Waste is any substance, which is discarded after primary use because it has lost its value. If any activity that a customer is not willing to pay for either with money, time or resources, thus, it is quite crucial to avoid and eliminate it. Waste elimination is the process of getting rid of waste and Single Minute Exchange of Dies (SMED) is one of the pillars of "Lean Manufacturing" that can be deployed to eliminate waste from processes.. It is a technique that makes it simple and possible to conduct equipment or tool set-up and change-over activities within fewer minutes. SMED uses a set of techniques to perform equipment set-up and change-over operations in less than 10 minutes.

The plastic injection moulding machines at the engineering firm are characterised by an ineffective process whereby the plastics granules are added into a hopper, then its passes into the barrel of the injection unit, which is set at a specific temperature, thus the material melts and changes from solid states to liquid states. Inside the barrel, the screw transports the molten material into the mould cavity in which the plastic solidifies in a matter of seconds. The mould would thereafter open, part is ejected and the mould would close again and the process is repeated. However, the main problem is that the single changeover time ranged from 45 min to over 60 minutes, thereby leading to longer downtime and less production time. The scenario resulted in production capacity constraints, longer lead times and this led to loss of future business with some of the customers due to failure to meet delivery dates. The objectives of the study are to identify and separate external and internal elements, establish cycle time and reduce tool changeover time for the plastic injection moulding machines.

2. Literature Review

Changeover operations are those activities that are performed when preparing or adjusting settings for a process before or after a batch is processed (Cakmakci and Karasu 2007; Sabadka et al. 2017). SMED is a critical lean production method for reduction of waste from a manufacturing process by providing a speedy and efficient approach to switch from running the current product to the next product (Ulutas 2011; Tekin et al. 2018). The changeover operations are categorised into internal setup and external setup. External setup operations that can be undertaken while the machine is running. On the other hand, internal setup is described as those setup operations such as attaching or removing the dies, which are undertaken when the machine is shut-down (Faccio 2013; Shingo and Dillon 2019). A comprehensive understanding and analysis of the changeover process and knowledge of the details of all the setup activities, is a prerequisite for a successful SMED implementation (Ferradás and Salonitis 2013; Karekatti and Wickramasinghe 2021). The SMED methodology is characterised by initially identifying internal and external setup followed by separating internal from external setup, and thereafter attempt to convert internal setup into external setup or optimise the internal and external setup (Vieira et al. 2019).

By introducing a variation through the application of lean methods, Sousa et al. (2018) used SMED for the improvement of an equipment in the cork industry. Value stream mapping technique was used to establish the activities that added value to the product and SMED was deployed to reduce the downtime that was caused by tool changes thereby leading to a 43% reduction in total changeover time. On the other hand, Antosz and Pacana (2018) conducted a comparative analysis of the deployment of the SMED methodology on selected production stands that differed in type. The results demonstrated in increase the efficiency of machines for the production work stands.

Karam et al. (2018) conducted an SMED project to establish the contribution of lean manufacturing tools to decrease changeover time and within 12 months, major changeover time at the bottleneck process decreased by 30%. Process quality, teamwork and standardisation improved along with the economic benefits from the SMED implementation. Gökler and Boran (2021) developed an integrated novel SMED-fuzzy FMEA model for reduction of setup time to prevent problems that cause extended setup time on setup activities. By using a developed Setup observation and analysis form, the new approach was deployed to set up a plastic injection mould and a 48% improvement in reduction of setup time was achieved.

Haddad et al. (2021) used SMED as a lean manufacturing approach to improve overall equipment effectiveness of an extrusion machine. Real experimental procedures were applied for SMED implementation on the extrusion line to explore the effect of SMED on improving overall equipment effectiveness and decreasing the setups time of the extrusion machine. The results demonstrated successful implementation of SMED leading to an increase of overall equipment effectiveness by 3.26% and machine availability by 4.86%. On the other hand, Suryaprakash et al. (2018) conducted a study on the improvement of overall equipment effectiveness of a machining centre using total productive maintenance. The first step in SMED implementation was to segregate the internal elements from external elements In order to achieve SMED and reduce the fastening time, the sizes of the bolts were reduced. In order to avoid the wrong positioning, or use of Pokayokes, the guide pins, fixtures, stop heels and standardized tools were used. The results of implementation of SMED demonstrated a reduction in changeover time by 30 min, improvement in machine availability of 3% and improvement of overall equipment effectiveness by 6.06%.

3. Methods

The tools or materials that were used for the study include a video camera, stopwatch, and a change-over operations analysis chart. The changeover process was observed with the aim of gaining insight of the steps need to perform a successful change – over. Six changeovers were filmed and analysed; the filming process involved mounting a camera on the tripod to capture the duration of the changeover. It was desirable to capture the entire changeover, that is, the time between one part A and another part B. The changeover process did not interfere with the setters in anyway throughout the duration of changeover. Once the film was gathered it was analysed and the advantage of using the video to analyse work element activities in establishing the cycle times was that it is possible to review activities in slow motion if necessary, and it also provides the detail overview of all activities. The following key steps were adopted for the process improvement to reduce the changeover time:

- Step 1 – Separation of external and internal work elements. External work elements are those activities that can be performed before the machine/production stops, such as bringing the next tool close, material preparation for next run; while the internal work element are those activities that need the machine/production to stops in order to perform them, for example, unclamping the tool, loosening of nuts and bolts.
- Step 2 – Changing internal setup elements into external setup elements. This stage involves, firstly, the observation of the exact roles and purposes of all activities in the current internal setup. The second step is to explore different ways to converts internal elements to external elements.
- Step 3 – Aligning internal and external elements. In this final stage, the main aim is to continuously improve each and every remaining internal and external setup element.

Table 1 shows the documented changeover standard sheet that was currently used by the engineering firm, which is characterised by 24 elements. It was worth investigating whether the operators or machine setters were working according to the documented changeover standard.

Table 1. Changeover standard sheet

Number	Activity	Duration (s)
1	Loosen front clamps	120
2	Hooke chain	26
3	Walk to the back	13
4	Loosen back clamps	74
5	Walk to the front	15
6	Open platten	47
7	Remove tool from machine and leave the tool hanging	14
8	Remove the ejector bar	26
9	Remove locating ring	25
10	Use hyster to remove the hanging tool	69
11	Use hyster to take next tool and hang it	107
12	Put ejector bar and locating pin	44
13	Use hoist to locate the tool into the machine	20
14	Locate the tool	92
15	Tighten front clamps	147
16	Remove hoist	20
17	Walk to the back	12
18	Tighten back clamps	183
19	Walk to the front	15
20	Put water pipes on	120
21	Set the machine to “on” status	104
22	Wait	141
23	Purging	600

4. Data Collection

The data collection process revealed a different picture from what was stipulated in the documented changeover standard sheet. Table 2 shows the preparatory work element sheets describing all the activities that a setter performs to conduct the tool changeover; with the work element categorized as external or internal, respectively. The setter selects a spanner from toolbox and search for torque, walks to the injection moulding machine and removes operator’s table room walk-way. The setter thereafter loosens the front clamps, walks to the back of the machine and thereafter loosens the back clamps. The setter then walks to the tool location, removes some boxes that are stored on top of the tools, takes the tool and walks to the hoist, swings the hoist to the machine and then walks to the injection moulding machine.

Table 2. Preparatory steps

Step	Changeover element	Duration (seconds)	Changeover category		
			Internal	External	Waste
1	Select spanner from toolbox and search for torque	251.2		X	
2	Walks 7 steps to machine	5		X	
3	Remove operator’s table room walk-way	0.64		X	
4	Loosen the front clamps	167	X		
5	Walk 11 steps to the back	10		X	
6	Loosen the back clamps	72	X		
7	Walk 15 steps to the tool location	15		X	
8	Remove boxes on tool	94		X	
9	Walk 4 steps to hoist	2		X	
10	Swing the hoist to the machine	3.27		X	
11	Walk 8 steps to the machine	5		X	

Table 3 shows the first tool removal steps, characterised by 3 internal activities and seven external elements. The setter hooks the hoist to the tool, removes the tool from the injection moulding machine. The setter then removes the locating from the hanging tool, walks to the hyster, drive hyster to collect tool holder and returns to the machine. The setter then loads the tool to the tool holder, walks to the front of the hyster, unhooks the tool from the hoist, walks to the hyster and move the tool with forklift to the tool storage area.

Table 3. First tool removal steps

Step	Changeover element	Duration (seconds)	Changeover category		
			Internal	External	Waste
11	Hook hoist to the tool	5	X		
12	Remove the tool from machine	107	X		
13	Remove the locating from the hanging tool	25	X		
14	Walk 5 steps to the hyster	3		X	
15	Drive hyster to collect tool holder and return	62		X	
16	Load the tool to the tool holder	6		X	
17	Walk 5 steps to the front of the hyster	5		X	
18	Unhook the tool from the hoist	3.28		X	
19	Walk 5 steps to the hyster	5		X	
20	Move tool with forklift to the tool storage area	12		X	

Table 4 shows the second tool steps for setting, characterised by 5 internal activities and 10 external elements. The setter brings the next tool with forklift, walks to the front of the hyster and hooks the tool to the hoist. The setter thereafter walks to the hyster, removes the hyster, walks to the hanging tool and loads the tool to machine using hoist. The setter then tightens the front clamps, selects machine settings, and walks to the back of the machine. The next step is to tighten the back clamps, moving to the front of the injection moulding machine and removing the hoist from the tool. The setter then sets the machine, adjusts the machine temperature and material purging is thereafter undertaken.

Table 4. Second tool setting

Step	Changeover element	Duration (seconds)	Changeover category		
			Internal	External	Waste
21	Bring next tool with forklift	105		X	
22	Walk 5 steps to the front of the hyster	5		X	
23	Hook the tool to the hoist	83		X	
24	Walk 5 steps to the hyster	4		X	
25	Remove hyster	64		X	
26	Walk 8 steps to the hanging tool	5		X	
27	Load tool to machine using hoist	125	X		
28	Tighten front clamps and select machine settings	72	X		
29	Walk 11 steps to the back	4		X	
30	Tighten back clamps	192	X		
31	Walk 11 steps to the front	5.7		X	
32	Remove hoist from the tool	3.21		X	
33	Set the machine	21.05	X		
34	Machine temperature adjustment	600	X		
35	Material purging	1380	X		
36	Waiting for first off to come out right	48		X	

5. Results and Discussion
5.1 Work element categorization
Figure 1 shows the separation of changeover work elements. In total, there are 36 work elements and it was found out that 11 work elements were internal work elements, and 25 were external work elements.

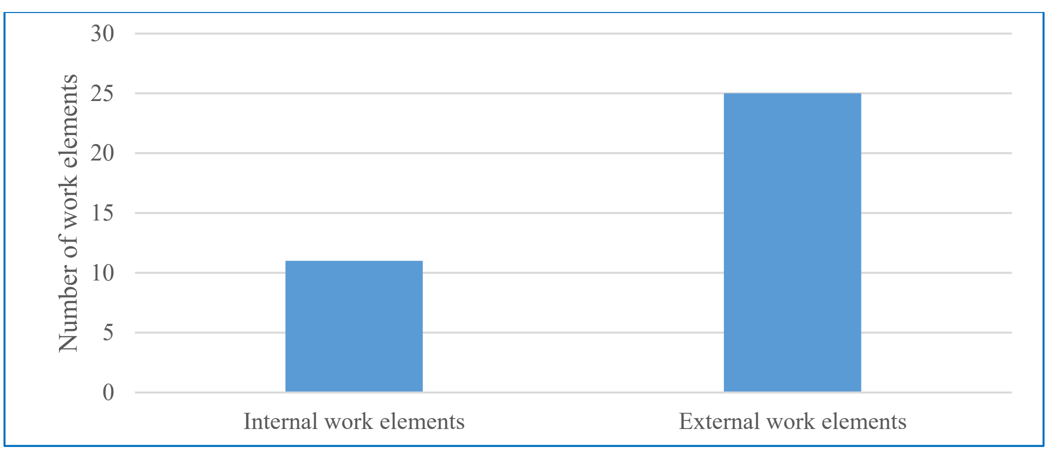

Figure 1. Work element categorization

5.2 Material colour and purging standardised changeover

For many press operators of injection molding, packaging, extrusion, blown film, and extrusion blow molding machines, the traditional cleaning methods used between colour and material changeovers lead to a predictable and frustrating cycle that is characterised by residue that remain after cleaning, and even the smallest remnants can create create buildup over time. Production problems occur and parts can come out streaked, spotted, and discoloured, which results in unusable pieces, higher scrap rate, more downtime, lower-quality finished products, and machine damage that's compounded by daily use. Time is also a critical factor for an efficient and profitable production process when it comes to changing plastic resins or colours. Colour residues, additives or deposits are the key element for both increased scrap and increased costs. Purging compounds for quick material and colour changeovers are the solution of choice to reduce material and changeover costs, unproductive machine downtime and to optimally exploit machine capacities. Better performing technical compounds significantly reduce both cleaning expenses and cleaning-related downtime if compared to conventional methods while it is easily and conveniently applied during ongoing operation. Table 5 shows the established material colour standardised changeover elements sheet. The elements are placed in a sequential manner and when the video film was analysed, the changeover time was found to range from 45 min to + 60 min as highlighted in red in Table 5. A further investigation was conducted to find out what are the contributors to over-scheduled changeover.

Table 5. Established material colour standardised changeover elements sheet

Material Colour (From-To)	Duration (min)	Scheduled time (min)	Purging	Time (min)	Temp.	Time(min)
Black-white	96	45	Yes	15	Yes	10
White-grey	51	45	No	0	Yes	10
White-grey	34	45	Yes	15	Yes	10
Grey-white	15	45	Yes	15	Yes	10
White-black	30	45	Yes	15	Yes	10
Black - black	149	45	No	0	Yes	10
Black-black	52	45	No	0	No	10
Black-white	45	45	Yes	15	Yes	10
White-black	45	45	Yes	15	Yes	10
Black-white	30	45	Yes	15	Yes	10
White-white	56	45	No	0	No	10
White-black	45	45	Yes	15	Yes	10
Black-black	13	45	No	0	Yes	10
Black-black	30	45	No	0	Yes	10
Black-black	45	45	No	0	Yes	10
Black-black	45	45	No	0	Yes	10
Black-black	30	45	No	0	Yes	10
Black-white	60	45	Yes	15	Yes	10
Black-black	60	45	No	0	Yes	10
Black - grey	37	45	Yes	15	Yes	10
Grey - black	34	45	Yes	15	Yes	10
Black - grey	45	45	Yes	15	Yes	10
Grey-white	37	45	Yes	15	Yes	10
White-white	35	45	No	0	Yes	10
White-black	41	45	Yes	15	Yes	10
Black-black	31	45	No	0	No	0
Black-black	40	45	No	0	Yes	10

Figure 2 shows the changeover times for purging from one material colour to the next. Material purging was found to be the major contributor of out of scheduled changeover. Therefore, to resolve the above problem, certain parts sequencing was established based on material colour as well as temperature pick-up.

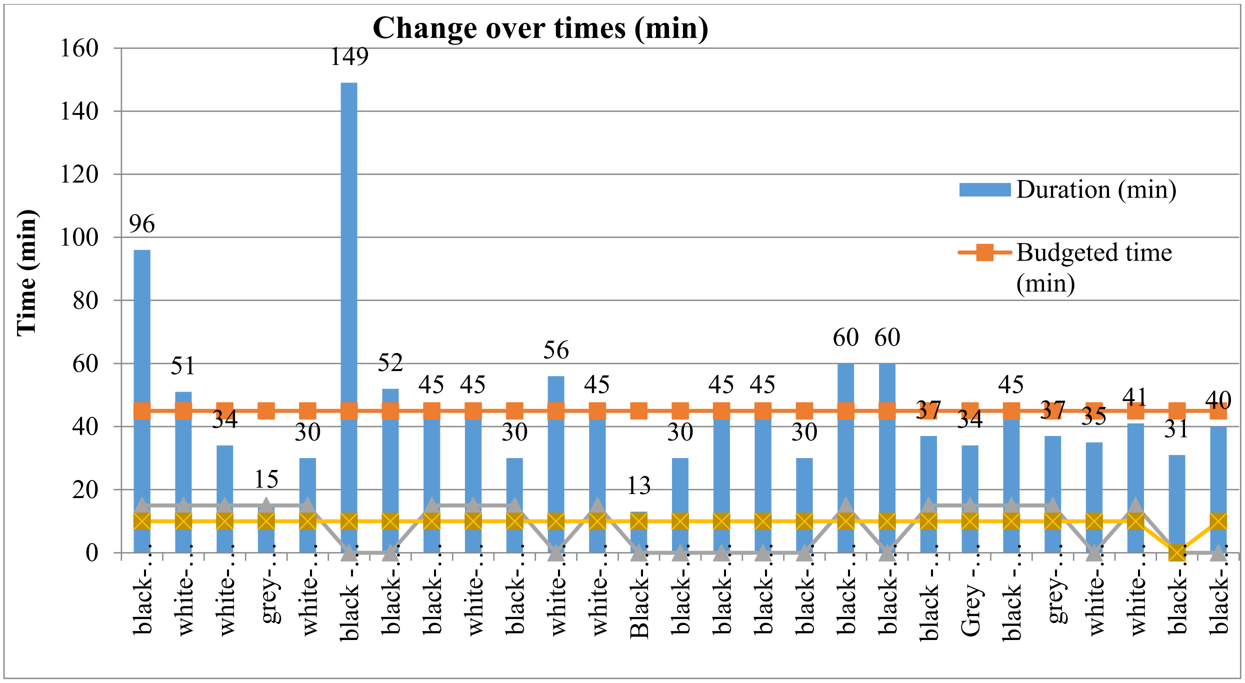

Figure 2. Changeover times for purging from one material colour to the next

5.3 Proposed Improvements

Table 6 shows the improvement initiatives that span from having tools ready before machine stops running, operator having to remove table from walk-way after using it, non-storage of boxes on tools, combining steps, to bringing tool-holder before commencing the tool change process and establishing the production sequence to take advantage of temperatures, material type and colour.

Table 6. Improvement initiatives

Step	Changeover element	Improvement initiative	Goal of improvement initiative		
			Eliminate	**Internal to external**	**Reduce**
1	Select spanner from toolbox and search for torque	Have tools ready before machine stops running	X		
3	Remove operator's table room walk-way	Operator to remove table from walk-way after using it	X		
8	Remove boxes on tool	No storage on tools	X		
9	Walk 4 steps to hoist	Combine with step 6			X
14	Walk 5 steps to the hyster	Bring tool-holder before commencing the tool change process		X	
15	Drive hyster to collect tool holder and return	Bring tool-holder before commencing the tool change process		X	
21	Bring next tool with forklift	Arranging the tools in the tool-holder according to production sequence			X
22	Walk 5 steps to the front of the hyster	Arranging the tools in the tool-holder according to production sequence			X
34	Machine temperature adjustment	Establish production sequence to take advantage of temperatures			X

35	Material purging	Establish production sequence to take advantage of material type and colour			X

Table 7 shows a summary of changeover time, material purging and new scheduled changeover time after establishing the production sequence that resulted in less time lost due to purging and temperature pick-up.

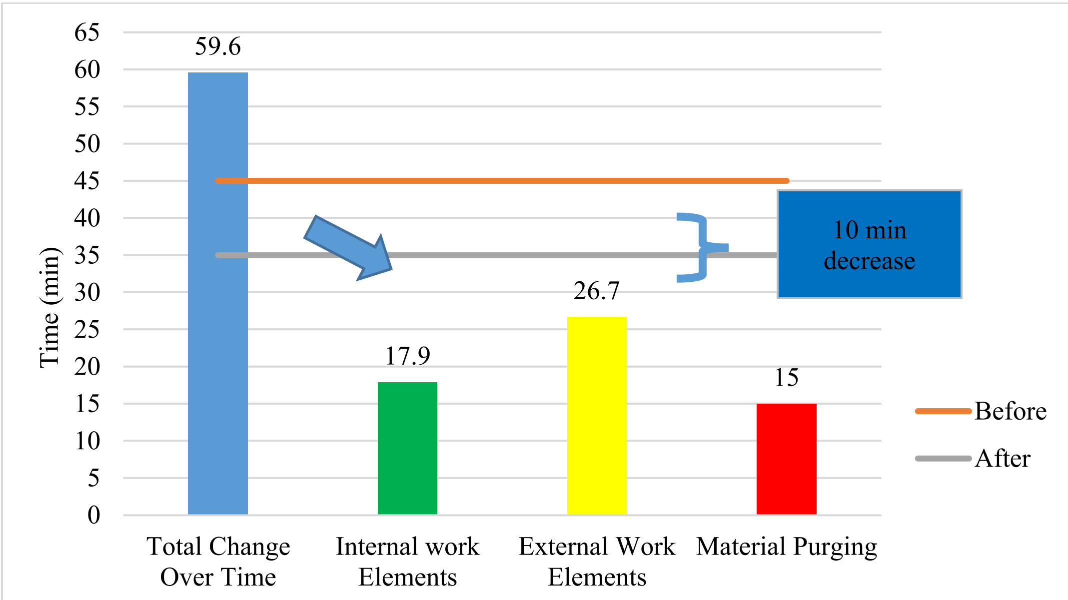

Figure 3. Proportion of changeover work element

Figure 3 shows the proportion of changeover work element to each other. It was found that about 70% of the activities taking place are non-value adding and can be converted to external work element. As results, the changeover time decrease from 45 min/changeover to 35 min/changeover. This 35 min is made up of internal work elements combined with material purging and is 22% reduction in changeover time.

Table 7. Summary of changeover time, material purging and new scheduled changeover time

Activity	Time (min)
Total Changeover Time	59,59
Internal Work Elements	17,9
External Work Elements	26.7
Material Purging	15
New Scheduled changeover Time	35

6. Conclusion

The data collection and analysis provided the work element sheets that were categorised as external and internal elements. The total cycle time for changeover was established as 59.59 minutes. The implementation of the proposed improvement initiatives by the engineering firm reduced the tool changeover time from 45 min/changeover to 35 min/changeover or 22% reduction. It is recommended that to sustain the minimum tool changeover time, the established production sequence to be followed, that would minimise the time lost due to material purging, since the production sequence takes advantage of material colour, type as well as material temperatures. Companies must pay attention to SMED activities carried out during separation phase, since proper identification of internal and external activities has direct and positive effects on activities performed at the transformation phase as well as improvement phase. Future studies regarding the optimisation of SMED should focus on developing a scheduling algorithms for parts sequencing based on material colour as well as temperature pick-up.

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Biography

Mendon Dewa is a senior lecturer in the Department of Industrial Engineering at the Durban University of Technology in South Africa. Dr Mendon Dewa holds a Bachelor of Engineering degree in Industrial Engineering from National University of Science and Technology, a Masters in Manufacturing Systems and Operations Management from the University of Zimbabwe and a Doctorate of Engineering from Durban University of Technology. He has presented at local and international conferences and has written several journal articles. He has also supervised postgraduate students and has a strong passion for optimisation of manufacturing systems and operations management.