- 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.

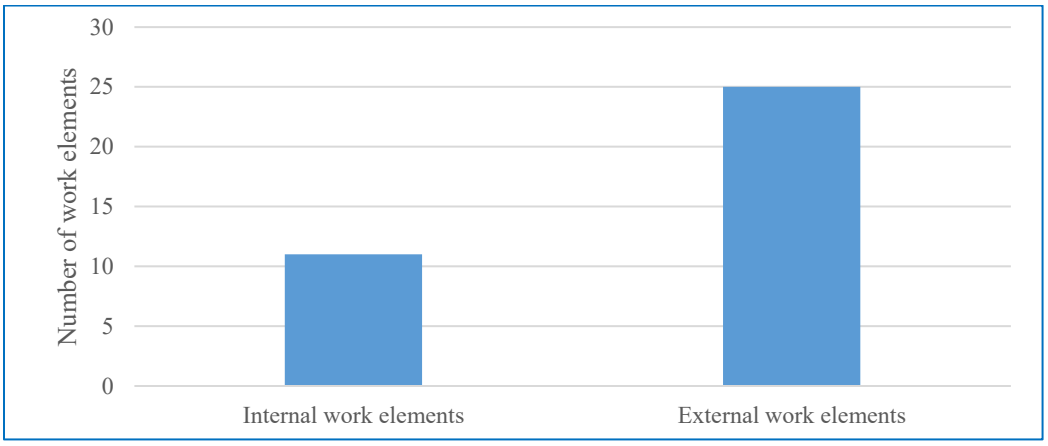

Figure 1. Work element categorization

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.

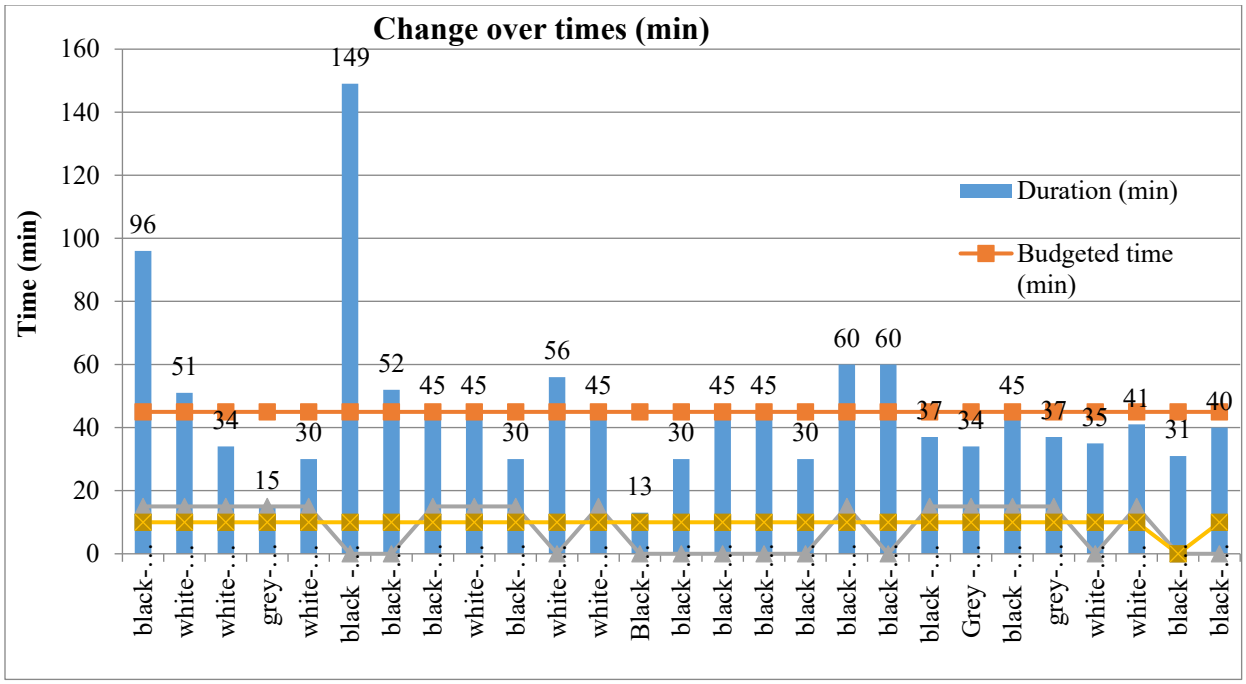

Figure 2. Changeover times for purging from one material colour to the next

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.

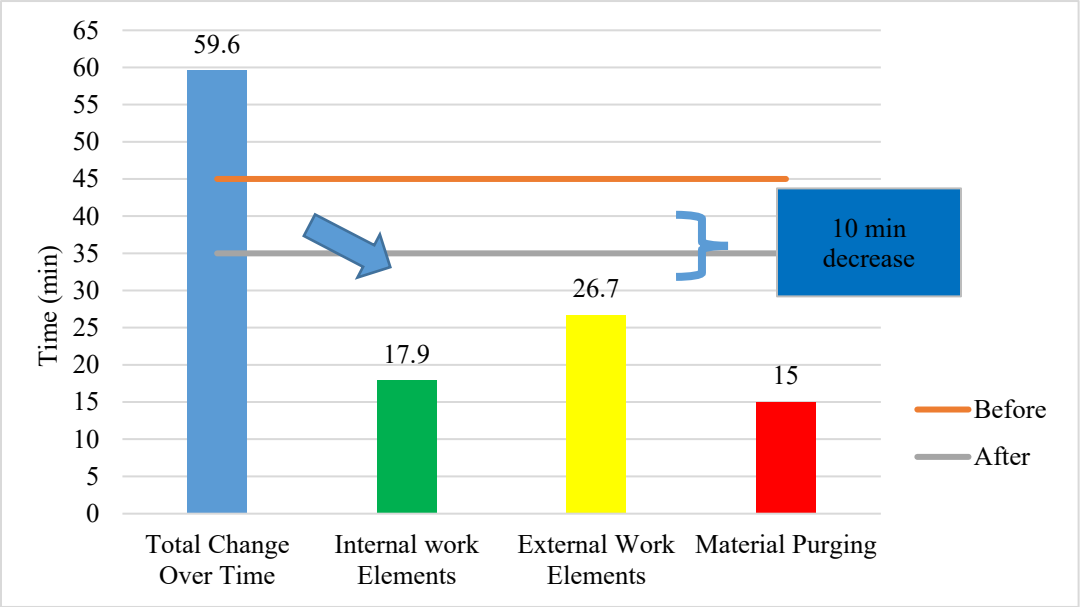

Figure 3. Proportion of changeover work element

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.