Implementation of Single Minute Exchange of Die Techniques and an Individualistic Die Design to Shorten Change-over Time in a Roll Forming Environment.Validating Product and Process Conformity through Simulation and Time Considerations

In the context of global economic changes, the rapid rise in manufacturing competitiveness demands the highest-grade quality products, which conform to world-class standards and are produced at a minimal cost. Often overlooked, but a significant contributing factor to waste and production downtime is tooling change-over and tool setup. This paper considers the cold roll forming (CRF) process within the automotive industry and aims to examine the implementation of Single Minute Exchange of Die (SMED) techniques as an alternative to the current process. A South African automotive accessories manufacturing company was considered where tool change-over of the tube mill is performed in 500 minutes. SMED techniques were applied to the production line, time comparisons conducted, and potential savings recorded. An unorthodox approach was also investigated in the forming of the stainless-steel electric resistance welded (ERW) round tubes, to aid with achieving tool change-over in a singular minute. The application of a unique die design is aimed at replacing the multiple rollers with a singular tool to address the non-value-added activity of tool change-over and addressing the disadvantages of the conventional CRF process. The Cage forming operation was selected as a possible approach to achieving a low-cost flexible and Advanced Manufacturing System (AMS) to produce ERW tubes. The proposed machine design and process is deemed successful through; I) The interpretation of data retrieved from the simulation, concerning geometry II) Time evaluation of tooling change-over of an existing roll forming line to that of the proposed process.

Keywords: *tool change-over, Single Minute Exchange of Die (SMED), Advanced Manufacturing System (AMS), Flexible Manufacturing System (FMS), lean manufacturing*

Introduction

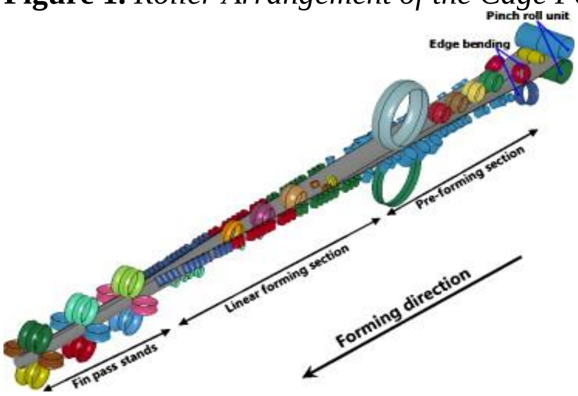
"One of the paramount objectives of a company is to generate the highest profits via gaining new markets or taking over companies" (Ulutus, 2011). Next Generation Manufacturing Systems also known as Factories of the Future or Factory 4.0, comprises of inventive progressions. In modern era manufacturing, product variety has been identified as one of the foremost competitive edges for manufacturing companies to meet customer's diverse demands (Nazarian, et al., 2010). Advancements have been made in the ability to respond to industrial demand with regard to manufacturing flexibility and feasibility. Consequent to the economic volatility more companies have adopted *"Lean principles"* to optimise production rates and maximise profitability. According to Toyota Production System (TPS), waste is regarded as a task or elements that add no value from the client's perspective. Seven types of wastes are generally identified (Assaf & Haddad, 2017): *1) Over-production 2) Inventory 3) Material transportation 4) People's movement 5) Unnecessary operations (over-processing) 6) Waiting 7) Product defects.*

Intricate and complex production systems are incorporated across vast platforms, ranging from hand-held computer devices to the much larger scaled aerospace industry. Given the contrast of manufacturing environments, the cost implications to business organisations are significant due to machine downtime. Non-Value-Added activities such as tool change-over and tool setup need to be streamlined, contributing to the efficiency of production in an Advanced Manufacturing System.

Cold Roll Forming is an immensely productive process that is adopted in a wide range of manufacturing industries which is spread throughout the world. The forming operation is a high-volume manufacturing process that plastically deforms metals by using a series of dies. Hard metals are shaped into the desired geometry at room temperature, hence the term "Cold". Long strips of metal, generally from a coil are sent through several stacks of rollers. The absence of heat results in an obligation for numerous stacks of rollers to add a minuscule amount of forming to the metal strip, so that the desired cross-section is achieved at the end of the lengthy process.

Cage forming is a system that is a continuous forming process. Groups of singular simple rollers, supporting inner and outer rollers of the material are used to achieve the continuity of the forming process, as seen in Figure 1 below. The objective of the setup is to save on high tooling costs, setup and change-over-time. The saving is achieved by not having to change all the rollers to produce varying geometric products.

Figure 1. *Roller Arrangement of the Cage Forming Process*



Source: Journal paper (Weiye Chena, et al., 2019)

Considering the precise and intricate process of cold roll forming, the challenge lies in achieving a tool change-over and setup without compromising on product quality and standards. The proposed solution was to adopt a constant forming ideal by replacing the multiple rollers required to achieve the desired geometry. Where tool change-over and setup is concerned, a singular die is interchanged, providing a significant advantage in achieving tool change-over in a singular minute.

This research determines the impacts of SMED techniques coupled with the continuous, singular forming die on a tube forming production line where 38.1, 50.8, 63.5 and 76.2mm diameter tubes are manufactured. The following describes the basic overview of the paper composition:

Literature review- examines the conventional CRF mill design process. SMED process is investigated to understand the process of implementation.

Methodology- highlights specific challenges, improvement areas and implementation of SMED techniques. Details of the simulation process are reviewed.

Results- time and cost savings after SMED implementation are recored. Observation of the simulation is interpreted.

Disscussion- findings and future suggestions reviewed.

Conclusion- the impact of the SMED exercise and die design is summarised.

Literature review

Tool Change-Over

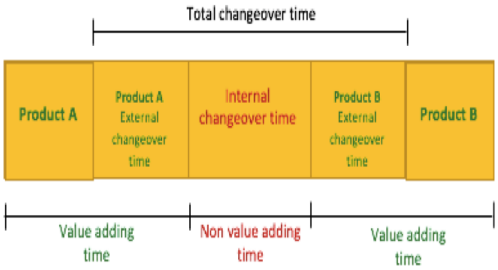
A machine change-over is the time required to arrange a machine or a process from producing the last good product from the previous production run to the first good product of the next production run (Madhav, et al., 2017). Preparing for the change-over involves single or multiple changes where parameters, inputs, components and aspects are modified to support the production of goods for the new production demand (Vermaak, 2008). Tool change-overs can potentially be very time consuming, different manufacturing organisations must adopt a variety of lean procedures to reduce time lost during tool change-over. Imperative to the effectiveness of procedures to reduce tool change-over times is the complete understanding of change-over capabilities to a specific production line. The consensus surrounding production efficiency, optimised operations and manufacturing cost reduction in an organisation is the purchase of new, latest machinery and expansion of facilities. Though this approach is certainly effective, it may not be the best use of a company's resources. Overall Equipment Effectiveness (OEE) is a quantitative measure absorbed into manufacturing processes for observing and controlling the productivity of production equipment (Anon., 2018). OEE starts with planned production time and inspects efficiency and productivity losses that occur, with the aim of minimising or eliminating these losses.

The three main factors of OEE are:

- Availability- considers downtime losses.
- Performance- considers speed losses.

- Quality- considers losses due to quality.

Figure 2. *An Overview of the Definition of Change-Over Time and the Two Different Components*



Source: Thesis paper

OEE is the ratio of fully productive time to planned production time, and is calculated from the below equation:

OEE = Availability × Performance × Quality

Where;

Availability = Operating Time ÷ Planned Production Time

Performance = Ideal Cycle Time ÷ (Operating Time ÷ Total Pieces)

Quality = Good Pieces ÷ Total Pieces

Single Minute Exchange of Die (SMED)

Change-over and setup time is critical to reducing losses due to disturbances within the manufacturing environment and is assisted with a time program like SMED. In the 1950's Shigeo Shingo developed SMED as part of the Toyota Production System. This was the response to the developing need of increasing smaller production run sizes to meet the flexible and unpredictable customer demands. The idea of SMED was essentially to reduce the setup time on a machine. The investigation was originally developed by the study of a die change process. The term "Single minute" does not suggest that all start-ups and change-overs should take only one minute, but that they can be performed in less than 10 minutes (singular minute).

Shingo divided the setup into two parts (Dave & Sohani, 2012): *1) Internal setup;* the setup operation that can be performed only when the piece of machinery is shut down (attaching or removing of dies) *2) External setup;* the setup operation that can be performed while the piece of machinery is still running.

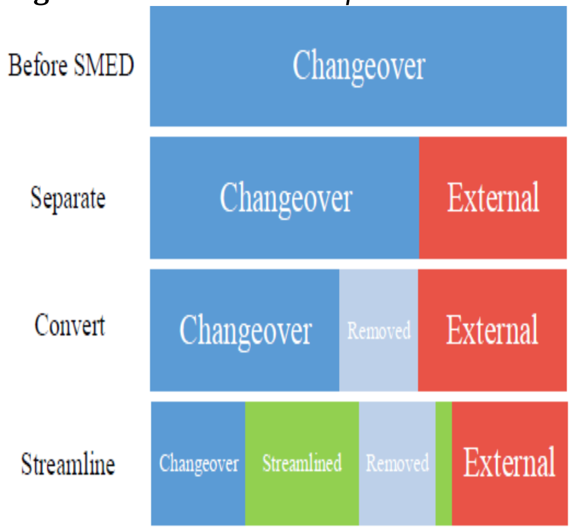
The concept of SMED is to make as many process activities external from being internal. Previous work done on SMED methodology suggests that effective implementation necessitates fundamental requirements, like; visual factory control, teamwork, performance measurements and Kaizen.

SMED can be summarised in three main steps, as seen in Figure 2 below:

1. **Separate-** elements that can be performed with miniscule or no change whilst the equipment is running are identified and moved externally to the change-over and setup.

2. **Converting-** remaining elements are revised to determine if they can be modified in any way to be external or possibly eliminated completely.
3. **Streamlining-** remaining elements are reviewed and optimised so that they can be completed in a reduced time frame.

Figure 3. *Free Elements of SMED*



Source: Online

The requirements for the application of SMED principles are (Moreira & Pais, 2011):

1. Tool change-over is long enough where there is room for improvement.
2. Historically, there has been a lot of variance in the change-over times.
3. The operation is done frequently.
4. All employees involved in the change-over process have been trained and have buy-in for the change.
5. The process has been a bottleneck in the overall operation, meaning changes will have immediate impact.

SMED is also used as a tool to improve flexibility. The greatest benefit from the reduction in change-over time is the ability to produce parts in smaller batches. This creates a sense of confidence for customers, that all their demands can be met, considering changes to products.

Conventional CRF Mill Design Process

CRF is a continuous bending exercise, where the bending occurs incrementally in multiple forming steps, from an undeformed strip to a finished profile. The forming process is highly sophisticated, as forming does not occur due to the forming stands (die/tools) only but occurs between the stands as well (where no tooling is present). Multiple factors influence a roll forming design process to achieve a desired geometry. Concerning the tool design, the designer must first determine how many forming steps are necessary. The required steps are dependent on the shape of the cross-section, thickness of material, material properties and tolerance (Lindgren, 2007).

Halmos (Halmos, 2006) details the step by step procedure to designing a CRF mill. The following highlights the basics of a CRF design process;

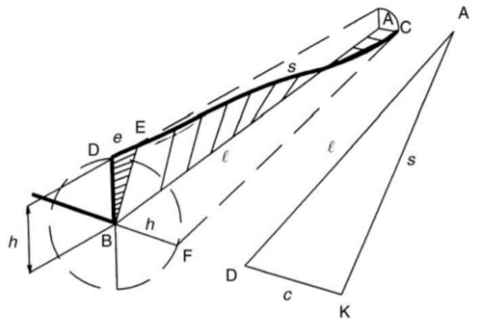
- Product cross-section: The cross-section of a product is the most significant factor in roll design. Consider Figure 4 below, where;
  ℓ, length of the bend line traveling from point A to B.
  h, strip edge travels in a helical pattern for the length and upward by a height of the leg.
  s, overall length of the travel.
  c, arc length from point F to D.

  The length of the material travel is given as;

$$s = \sqrt{\ell^2 + c^2}$$

$$s = \sqrt{\ell^2 + \frac{h^2}{4}\pi^2} \quad (2.3.1)$$

Figure 4. *Theoretical Path of Strip during Forming*



Source: Journal paper (Soyaslan, 2018)

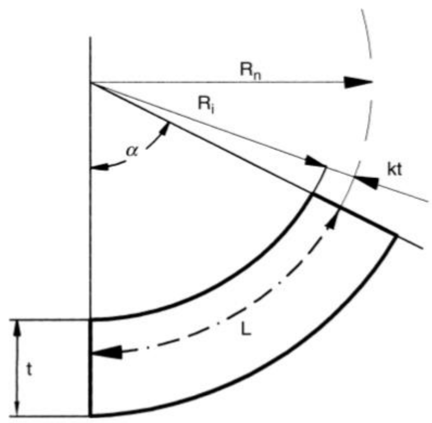
- Orientation of forming: Prior to calculating the number of passes required for forming, the orientation of the finished section must be determined. Given the simplicity of the tube geometry and manufacturing nature of ERW tubes, welding generally occurs at the top of the formed section, thus forming should ideally occur symmetrically. The simpler the geometry of product, the fewer the required number of passes.
- Number of passes: Numerous attempts have been made to introduce science into roll forming. Halmos, has developed an empirical formula to serve as a guideline to determine the number of passes required, this serves as a mere guideline, simulation and software packages tend to be more accurate and aid in the design process:

$$n = [3.16h^{0.8} + \frac{0.05}{t^{0.87}} + \frac{\alpha}{90}][\frac{Y^{2.1}}{40U}]^{0.15} s(1 + 0.5z) + e + f + 5zs \quad 2.3.2$$

Where,
n, is the estimated number of passes
h, is the maximum height of the section
t, is the material thickness
α, is the sum of the formed angles on one side of the guide plane
Y, is the yield strength (MPa)
U, is the ultimate tensile strength (MPa)
z, is the pre-punched hole/notch and strip continuity factor
s, is the shape factor
e, is the number of extra passes for other operations
f, is the tolerance factor

- Strip width: To accurately determine the strip width of a coil the final cross-section must be divided into straight and curved elements. For the purpose of the strip width calculation it is assumed that the length of the straight elements does not change during the forming process. During forming, it is assumed that the theoretical neutral axis of the bent element moves from half of the thickness location towards the inside radius. Consider Figure 5 below, where;
  L, length of the curved element.
  t, thickness of the material.
  R_N, neutral axis radius.
  R_i, inside radius.
  k, "k" factor (Determined from tables and theoretical equations).

Figure 5. *Length of a Curved Element*



Source: Book

For a circular tube section, the cross-section will be divided into four equal parts.

- Roll design: The flower diagram is the cross-section at each pass, superimposed from the flat strip to the finished geometry. This is used as a guideline to predict the sequence and magnitude of bending at each pass. The roll design begins with the designer calculating the top and bottom roll surfaces at each pass, including the side rolls. For every roll designer, the approach to designing the rolls are different. This used to be a very manual and experience dependant process, however as technology has improved the trigonometrical calculations by using log tables have been advanced to mechanical and electronic calculators. The computer aided design process is expressed further in section 2.4 below.

Finite Element Modelling (FEM) and Finite Element Analysis Applied to the CRF Process

The CRF environment has notoriously been known for demanding high levels of labour and experience from operators. These demands become highly unproductive when it comes to troubleshooting, problem solving and costly (given the lengthy change-over times).

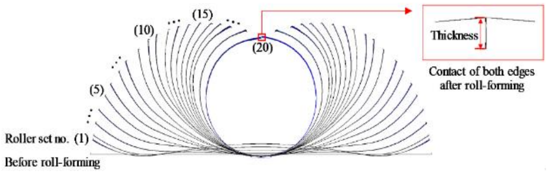
Presently, there are numerous computer programmes available that can support the overall requirements (design and problem solving) of the CRF environment. FEM is a numerical approach to determine approximate solutions

$$L = \frac{\pi}{180}(R_i + \mathrm{kt})\,\alpha \qquad 2.3.3$$

to boundary value problems. The application of FEM to simulate and analyse sheet metal forming processes has become more common over the years, however this is not necessarily the case in CRF. The programs and software are simplified formulas, unfortunately the conclusions are limited due to the complex geometry of the deformed strip and the simplifications in their design rules (Lindgren, 2005). Significant strides have been taken into developing software for FEA, some of the packages are COPRA, MARC/ MENTAT, ABAQUS and PROFILE, to name a few. Further details of the software operation can be found in (Lindgren, 2005).

The initial design process of a roll forming mill is generally based on a "*Flower pattern diagram*." This diagram consists of the superimposition of the cross-section of the strip at each forming stand on a single plane, the diagram is a 2D representation of the 3D process. Figure 6 below represents a typical flower diagram for the forming of a round tube;

Figure 6. *Flower Diagram of a Circular Tube during Forming*



Source: Journal paper

The representation of the flower diagram on the various FEM packages is an indication of the advantages of simulation software packages. Errors and possible defects can be picked up initially instead of downstream where changes could prove to be time consuming and costly.

Methodology

Organisation Background and the Production Details

The company under investigation is one of the premium automotive accessory manufacturers in South Africa. The products manufactured by the organisation include, nudge bars, styling bars, sports bars (used on light motor vehicles like SUV's) and bull bars (used on heavy vehicles like trucks). Though the variety of products have their unique purpose and function on a vehicle, they all have one thing in common, they require a circular or oval stainless steel or mild steel tube, bent in a geometrically specific orientation. The high demand for the tubing warrants the organisation to manufacture the tubes inhouse as opposed to purchasing them from tube manufacturers. The different sized tubes manufactured are:

- 76.2mm, round and oval.
- 63.5mm, round and oval.
- 50.8mm, round and oval.
- 38.1mm, round and oval.

All tubes are produced in stainless steel and mild steel.

Provided, the tube manufacturing sector is not the primary focus of the business, optimising the manufacturing process has been neglected. The basic procedure from raw material to a completed tube is:

1. **Receiving of coils-** Coils are purchased from various suppliers that are cut to the slit width required for a diameter tube (no slitting takes place online).
2. **Inventory of the coil-** Coils are purchased based on demand and minimum order quantity (MOQ), the coils are stored away from where the tube mill is situated.
3. **Coil is placed on tube mill-** A forklift is used to assist with placing the coil on the coil feeder. This is a two-man operation.

4. **Forming of tubes-** the tubes are formed and cut to standard lengths.
5. **Inventory of tubes-** the tubes of the same diameter and length are stored together.

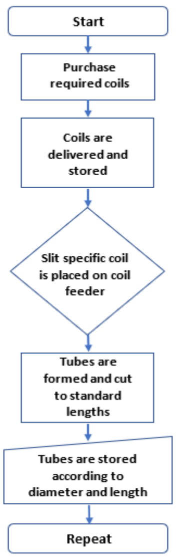
The organisation has two tube mills, tube mill one and tube mill two, of which will be referred to TM1 and TM2 respectively. TM1 is approximately 15 years old and TM2 approximately 10 years old. Both sets of machinery are have significant wear and tear, resulting in additional inconsistencies. TM1 and TM2 produce an average of 1.3 meters of tube per minute. For a 9-hour shift 663m of tube is formed, and for a 12-hour shift 813m of tube is formed.

Challenges facing the current tube forming process and procedure are;

- Lengthy change-over and setup times.
- Loss in capacity.
- High inventory.
- Large batch sizes.

For the purpose of this research, the area of concern will be the time required for tool setup and change-over only.

Figure 7. *Flow Chart of the Tube Manufacturing Process*



Source: Own work

Change-Over and Setup Process

The variety of tubes and the production process sets the stage for the implementation of SMED techniques. The discussed manufacturing procedure meet all five requirements highlighted in the previous chapter (Moreira & Pais, 2011).

Depending on the diameter of the tube to be manufactured, specific components and dies are selected, transported and loaded by forklifts, then assembled and fastened by experienced individuals. A case study regarding tool change-over, conducted over one month for TM2 is highlighted in Table 1 below. The average change-over for the month is 519 minutes and average setup scrap is 12.1m.

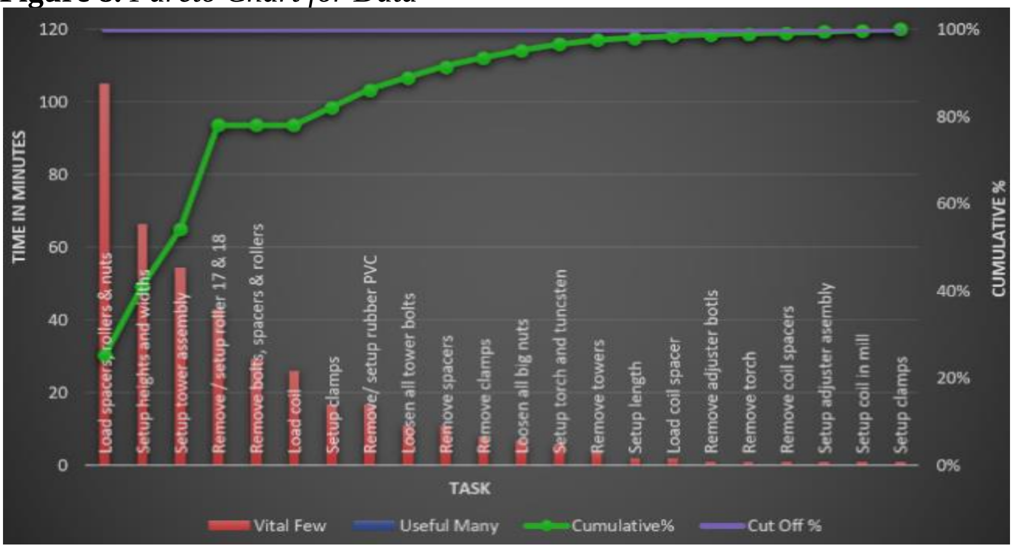
Table 1. *Details of Change-Over Conducted in a Month*

Change-over	Time required	Diameter change	Scrap
1	507 min	38.1 to 50.8	4.4m
2	576 min	50.8 to 76.2	12.8m
3	403 min	63.5 to 50.8	14.7m
4	588 min	50.8 to 76.2	19.5m

Source: Own work

Figure 8 below, illustrates the breakdown and the total process time for a typical tool change-over and setup for a diameter change. The times stipulated in the process flow chart depict a change-over conducted on one day. From the start of the dismantling stage, to the end of the assembly stage the total time required is 436 minutes (considering time wastage, which is not indicated in the flow chart), with the dismantling contributing 88 minutes and the assembly contributing 332 minutes.

Figure 8. *Pareto Chart for Data*



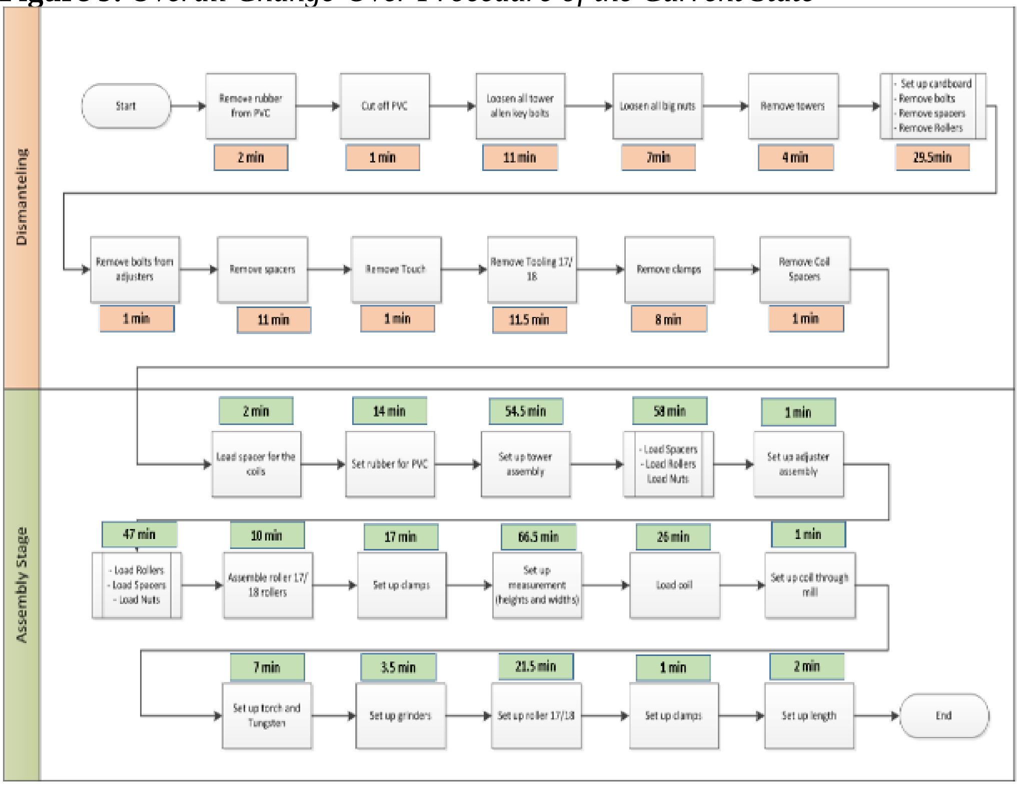
Source: Own work

The largest contributor to the change-over downtime is concerning tooling (rollers, spacers and fasteners), contributing 24% of the total change-over. The nature of the change-over can be conducted as a project. A project is defined as a temporary endeavour that is conducted to create a unique product, service or result (Stojčetović, et al., 2015). In project management numerous quality tools are used, a Pareto analysis is one of them. A Pareto analysis is a statistical technique used in decision making for the selection of a limited number of tasks that produce a significant overall effect (Talib, et al., 2010).

From Figure 9, it is evident that the tasks involving the tooling to manufacture a specific diameter tube consumes the most time. This proves to be the costliest area of the overall change-over. J.M Juran applied the 80:20 rule to quality control and realised that 80 percent of problems stem from 20 percent of the possible causes (Juran, 1998). Juran stated that the main point is to focus on the vital few problems instead of the trivial many, to make the most significant improvements to quality.

Theoretically, if the specific components to (rollers, spacers and fasteners) manufacture a tube can be changed in a singular minute, the overall change-over has the potential to be completed in 331 minutes. Though 331 minutes is a considerable time to lose to production, achieving this target will be a huge achievement in cost saving. This justifies the research into the single forming die design and concept discussed in further detail in section 3.4.

Figure 9. *Overall Change-Over Procedure of the Current State*



Source: Own work

Implementing SMED

The current state consists of 53 elements to successfully conduct a tool change-over. For the purpose of implementation, only those elements that have been identified to convert from internal to external activities and elements that can be removed will be elaborated on.

Stage 1, Separating Internal and External Activities

Figure 10. *Identifying Possible Internal Elements to Change to External Elements*

	Operation time (min)		Change-over catagories		
Change-over element	Element	Elapsed	External	Internal	Waste (sec)
Wait for forklift	10	93		✓	600
Storage of tools, fetch new tools	8	101		✓	0
Prepare cleaning solution to wipe spacers	3	104		✓	0
Wipe horizontal rollers and insert onto machine	47,5	163		✓	90
Wipe vertical rollers and insert onto towers	18,5	181,5		✓	0
Wipe and insert rollers at the front of machine	16	201		✓	0
Clean cut-off saw clamping area	14	251,5		✓	60
Fetch coil from outside	10	346,5		✓	0
Load coil	11	357,5		✓	0
Insert coil onto coil feeder	5	362,5		✓	0

Source: Own work

Stage 2, Converting Internal to External Activities and Eliminating Elements where Possible

Figure 11. *Converting Internal to External Activities*

	Operation time (min)		Change-over catagories					Internal to	
Change-over element	**Element**	**Elapsed**	**External**	**Internal**	**Waste (sec)**	**Improvement plan**	**Eliminate**	**external**	**Reduce**
Loosen tower spacer	7	7		✓	25	New spanner & nuts	3		
Unbolt the towers	11	18		✓	0	Implement air tools	5		
Lay cardboard on floor to place towers	1,5	20,5		✓	0	External process		1,5	
Remove towers from machine	3	24,5		✓	0	Design trolley	1		
Remove vertical rollers	11	58		✓	0	Design trolley	5		
Remove horizontal rollers	5,5	44		✓	30	Design trolley	2,5		
Wait for forklift	10	93		✓	600	External process		10	
Storage of tools, fetch new tools	8	101		✓	0	External process		8	
Prepare cleaning solution to wipe spacers	3	104		✓	0	External process		3	
Wipe horizontal rollers and insert onto machine	47,5	163		✓	90	External process		30	
Wipe vertical rollers and insert onto towers	18,5	181,5		✓	0	External process		10	
Wipe and insert rollers at the front of machine	16	201		✓	0	External process		8	
Clean cut-off saw clamping area	14	251,5		✓	60	External process		7	
Set towers	14	281		✓	120	Removable rulers	7		
Bolt towers of horizontal rollers	20	301		✓	30	Implement air tools	10		
Remove cardboard	1	304,5		✓	0	External process		1	
Fetch coil from outside	10	346,5		✓	0	External process		10	
Load coil	11	357,5		✓	0	External process		11	
Insert coil onto coil feeder	5	362,5		✓	0	External process		5	
							138		

Source: Own work

Stage 3 Streamline the Internal and External Elements

The elements discussed in stages 2 and 3 are actions that have been completed. After closer analysis other areas of the process can be streamlined and will be discussed as future action plans later on. The changes made to the manufacturing process have reduced the change-over time by 138 minutes. Details of the changes and flow chart will be discussed later in the results section. The suggested alterations have improved the change-over time by a mere 27%. This is still a long way from achieving a change-over in a singular minute. Coincidently the changes did not have the desired impact, this has reaffirmed the alternative die design that replaces the multiple rollers by a singular forming die. Details of which will be discussed in the next section.

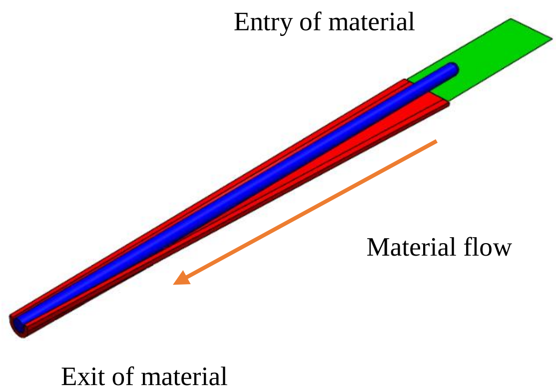
Forming Die

The cage forming operation was developed to improve the flexibility of the conventional CRF process and achieve smoother deformation of the metal strip (Tanimoto, et al., 2004). After conducting the SMED exercise it is obvious that emphasis should be placed on the number of forming tools required to for the forming process. The intricate process demands high levels of concentration and precision when removing and installing the rollers. To achieve a change-over and setup in a singular minute (as stated by SMED) the idea of replacing the multiple rollers from the standard CRF operation and cage forming operation with a singular forming die is considered. Figure 11 below, of a computer aided drawing (CAD) shows the concept of the proposed prototype. The model shows only three parts of the entire concept, all the parts shown are directly involved in the forming of the metal strip. Details of the individual components contributing to the assembly are;

- Forming die- Red component.
- Mandrel- Blue component.
- Metal strip to be formed- Green component.

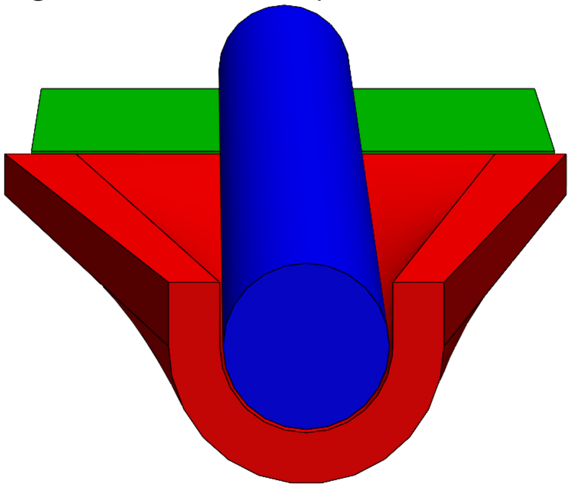
The colours in the assembly are for illustration purposes only to distinguish the different parts that make up the assembly.

Figure 12. *Isometric View of Continuous Forming Die Assembly*



Source: Own work

Figure 13. *Front View of Continuous Forming Die Assembly*



Source: Own work

Figure 13 above illustrates the front view of the proposed continuous forming process. The die (represented in red) replaces the multiple forming rollers required for deformation. The geometry of the die superimposes the multiple increment forming stands into a continuous forming geometry. As the metal strip (represented in green) moves forward, the material is formed into the geometry governed by the top surface of the die and the bottom surface of the mandrel. Large amounts of forming will occur at the exit of the forming die, the mandrel (represented in blue) aids with keeping the material in constant contact with the die and helps control the geometry of the metal strip at exit prior to welding. The dimensions of the die and mandrel will have to accommodate spring-back and aid with overbending the metal strip prior to exit from the die.

Observations

SMED Implementation

Unfortunately, after applying SMED techniques to the production line of the tube roll forming section in the organisation, tool change-over and setup is yet to be achieved in a singular minute. Though room exists for significant improvement, the changes incurred by the production line has resulted in significant annual savings. Details of the cost savings are listed below;

Current state- Refer to section 3.2:
Total time lost to change-over per month: 2074 minutes
Loss to production in meters =
2074 × 1.3m = 2696.2m/month

Future state-
Time saved from internal awareness = 83 minutes.

Time saved from internal to external = 138 minutes.
Total time saved per change-over = 221 minutes.
Total time saved per month = 884 minutes.
Total time to conduct change-over after SMED
= 2074 – 884
= 1190 minutes per month
Loss to production in meters = 1190 × 1.3m
= 1547m

Potential saving = 2696.2 – 1547.2
= 1149.2 per month.

Over-head cost per meter is R43.60 per meter.
Monetary savings = R50 1050 per month.
= R601 261.44 pe annum.

The above-mentioned cost saving was only achieved through equipment investment. Details of the cost are listed in Table 2.

Table 2. *Cost of Investment*

Item	**Cost**
Manufacture of two trolleys	R2650.00
New tool trolley toolbox	R2300.00
Flogging spanner	R3100.00
Tower locknuts (14 off)	R7650.00
Air tool	R1500.00
	R17 200.00

Source: Own work

After consideration to the equipment investment and the potential monthly savings, the investment cost will be paid for within the first month.

Figure 14. *Proposed Trolley Design to Aid with Roller Change-Over*

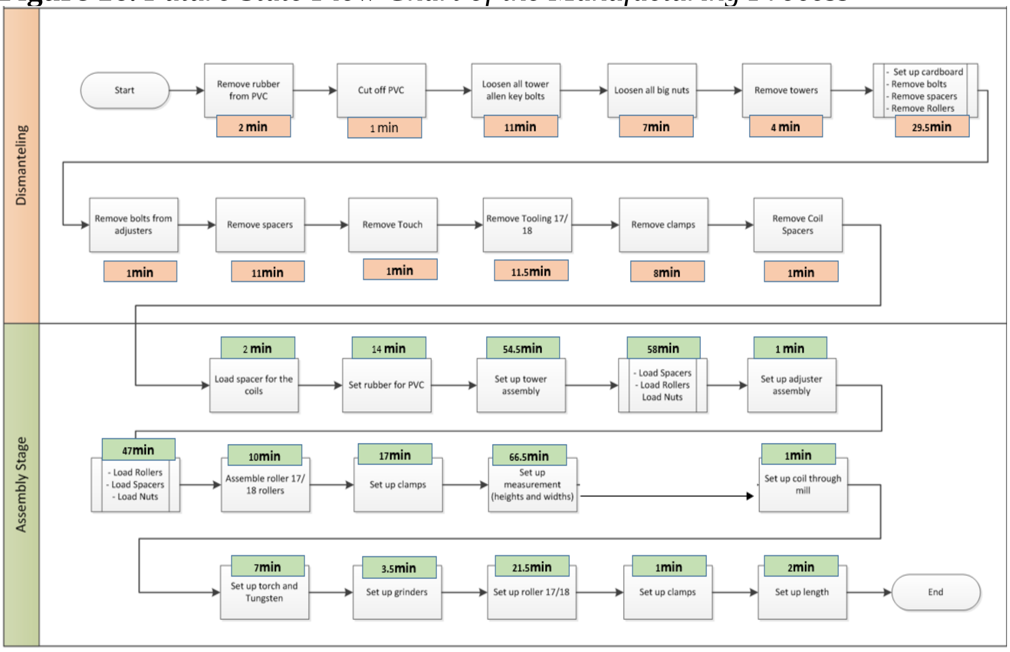
Source: Own work

Figure 15. *Roller being Removed from Tube Mill onto Trolley*

Source: Own work

The proposed trolley introduction creates the ease of removing an installing the rollers during change-overs, as seen in Figures 14 and 15 above. However, for a more direct impact, each roller that needs to be replaced will have to have its own individual trolley. This will prevent the operator from having to load the roller onto the trolley during the change-over. This can potentially become an external exercise for an added cost savings.

Figure 16. *Future State Flow Chart of the Manufacturing Process*



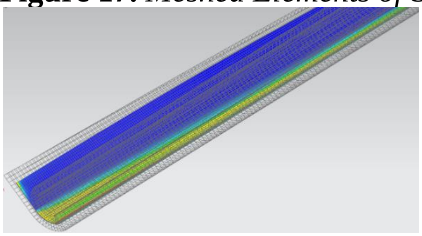
Source: Own work

Simulation of the Forming Process

The continuous forming die assembly was modelled in Solidworks and imported into Siemens NX to create the simulation. To generate the simulation and results, symmetrical parts were modelled in Siemens NX, as seen in Figure 18. From images below, the left side of the model was visible for the analysis, this was to enable the simulation to solve faster.

Forming begins with an unformed strip at the start of the die and ends with a curved section at the end of the die. The strip is modelled as a 0.5mm thick solid element. When using a shell element, the model did run faster, however the element did not seem stable. The solid element seemed more accurate, the behaviour through the thickness of the strip is accounted for more realistically. The length of the strip of material has no indication of the actual length, a shortened strip is modelled instead of the entire coil for ease of simulation and to reduce solving time. Two contact regions are created; I) The bottom surface of the metal strip and the top surface of the die II) The top surface of the metal strip and the bottom and side region of the mandrel. A force is applied to the front of the strip to simulate a pulling force, this aids in avoiding winkling of the material during the forming process. During this simulation friction was omitted to introduce simplicity to the simulation for proof of concept. This makes the feeding mechanism extremely unrealistic as the nature of the process introduced by the forming die concept will tend to increase frictional forces dramatically.

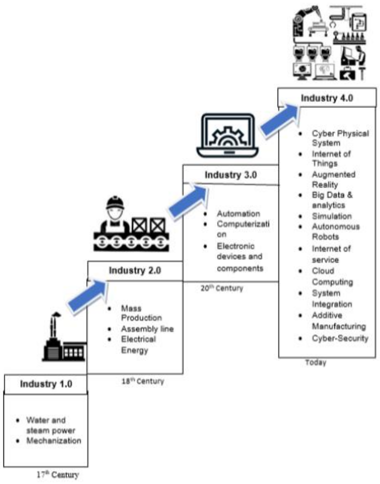
Figure 17. *Meshed Elements of Simulated Model*



Source: Own work

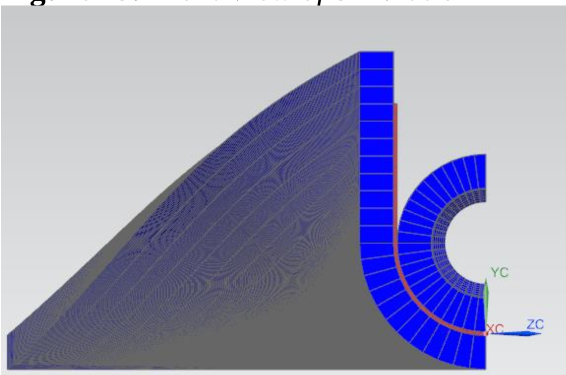
Figure 17 above indicates the meshed elements of the die, mandrel and the metal strip, with the metal strip being at the end of the forming process. The strip is governed by the geometry of the die and mandrel. Figure 15 below indicates the geometry of the formed material at the end of the forming process.

Figure 18. *Industrial Revolution*



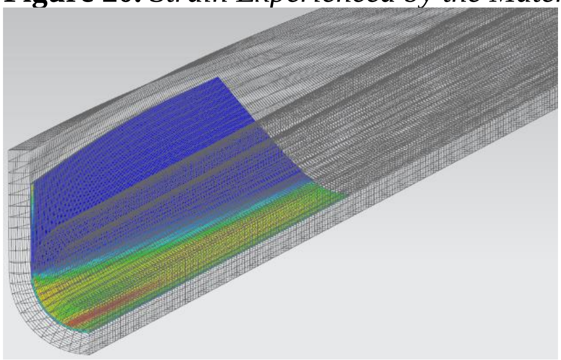
Source: Own work

Figure 19. *Front View of Simulation*



Source: Own work

Figure 20. *Strain Experienced by the Material*



Source: Own work

Figure 19 above highlights the strain experienced by the material at the end of the forming process. As with the cage forming process, the most amount of deformation occurs at the final stage of the process. This is generally the final stage prior to welding.

Figures 17, 18 and 19 provide an insight into the capabilities of the continuous forming die concept. To achieve a change-over in a singular minute the suggestion of replacing the multiple rollers with the singular die may impact the change-over time considerable. This concept however needs further investigation to determine if all the concerns of the standard CRF and cage roll forming process are met.

Future Improvements

During the investigation and implementation of SMED it was apparent that the presence of Industry 4.0 traits was lacking in the process. Industry 4.0 permits the manufacturing sector to become more digitalised with built-in sensory devices virtually in all manufacturing components, products and equipment (Tay, et al., 2018).

From Figure 20 above, it can be concluded that unfortunately the production line is still being operated as if it were in the 18th century. This is concerning the nature of the current economic state and the requirement of modern-day manufacturing companies. Future studies into the application of Industry 4.0 characteristics to the production line need to be conducted. These characteristics are summarised in Figure 21 below (Erboz, 2017).

Figure 21. *Characteristics of Industry 4.0*

THE CONCEPTS	THE DEFINITIONS OF THE CONCEPTS	THE EXAMPLES OF THE CONCEPTS
BIG DATA	Large,complex datasets that affect the decision making of companies	Big data analytics, algorithms, software programs
AUTONOMOUS ROBOTS	Solve complex tasks which cannot be solved by human	Kuka Iwaa has the learning ability to achieve some certain tasks
SIMULATION	Mathematical modelling, algorithms that optimize the process	Software programs
HORIZONTAL&VERTICAL SYSTEM INTEGRATION	Integration of inside of the factory and SCs	Smart factories, cloud systems
INTERNET OF THINGS	Connection of the physical objects and systems	Smart network
CLOUD COMPUTING	Shared platforms that serve to the multiple users	Google Drive, BlueCloud, Windows Azur
ADDITIVE MANUFACTURING	3D printing technology, producing in mass customization	3D printers to produce smart phones

Source: Journal paper

A thorough FEA and simulation needs to be conducted to determine if the proposed die concept satisfies the requirements of a conventional cage forming process and produce parts that are free of defects similar to a flexible roll forming process. Shape defects of the flexible roll forming process are as follows and to name a few (Woo, et al., 2019);

- Inhomogeneous elongations or contractions inside the blank.
- Non-uniform plastic deformations over the thickness or width directions result in waviness.
- Edge wave or longitudinal bow.
- Wrinkling.
- Uncontrolled deformation.
- Spring back
- Buckling

Conclusions

The application of SMED techniques to the roll forming production line was conducted successfully. The results obtained from the exercise did not meet the requirements defined by SMED, of achieving a tool-change-over in a singular minute. Further research, investment and training will have to be conducted to achieve this goal. Though the objective was not reached, a significant cost saving was reached and the foundation for future improvements has been laid.

The continuous forming die concept is yet to be proved concerning the impact on tool change-over and the ability to produce defect free useable tubes. A lot of research still needs to go into the concept, the idea needs to be simulated accurately to gain accurate results. The results are required to be scrutinised intensely prior to conducting any physical trials or testing.

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