Optimizing The Operation of Manufacturing: Case Study at Manufacturing Glass Company

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Abstract

The purpose of the study was to evaluate the optimisation of cutting and snapping of float glass operation. It is essential for any manufacturing industry to optimise their processes to increase productivity and compete in this ever changing manufacturing environment. This is a case study of glass manufacturing in South Africa, the leading manufacturer of float glass in South Africa. Questionnaire was designed to collect primary data and an experiment was conducted to collect secondary data. This design was preferred and allowed the researcher to collect easily onsite. Both quantitative and qualitative research was used in this study to explore and examine different variables linked to the cutting and snapping process at the company. The results revealed that the variables with the most impact on the cutting and snapping operation at the company as well as the ranges at which these variables should be set to achieve optimum cutting and snapping operation in float glass manufacturing. The relationship between these variables were also examine. However, the extent to which they are interlinked should be further studied. The study findings led to the conclusion that to optimize cutting and snapping the following variables must be considered. The cutting wheel must not be worn and must have not run more than 15km, temperature must be 59 to 60 at cutting and the ribbon must be stable. These variables must be continuously monitored and should be adjusted as outside conditions drastically change.

Keywords
Glass company, Manufacturing, Optimizing, South Africa

1. Introduction
The company where the study was followed is a leading manufacturer of float glass in South Africa. The company specializes in float glass and manufactures laminated glass commonly used for shop fronts, mirrors for both industrial and household, and sealant products. The company produces around 260 000 tons of high quality float glass each year. These products are supplied to customers across the country as well as abroad from the head office in springs. The company float glass is branded Clearview while laminated products are branded intruder proof and mirror products are branded images. The company is a division of the PG group and manufactures both building glass and automotive glass. The company has two float lines one for building glass and one for automotive glass. Both plants are capable of manufacturing building and automotive glass. As a part of the PG Group, the company is a R2.5billion (US$300million) a year organisation which employs 3 000 people at several factories and has some 200 outlets and warehouses around the world. Exports account for a significant portion of the Group's revenue. Through their Corporate Social Investment programme, they contribute towards the uplifting and sustaining the communities in which they operate. Float glass manufacturing operation can be divided into 5 major stages which are raw material mixture, furnace (heating and melting raw materials at 1600 degree Celsius), Bath (glass forming into thickness and width), Lehr (glass annealing) and glass cutting and snapping where glass is cut into sizes as per customer requirement. Optimising the operation of glass cutting and snapping must be done in stages or sequence as one stage affects the other. There are many variables within each stage that results in poor cutting and snapping yield over time. These variables are linked and all directly and indirectly results in cutting and snapping scrap.

Float Glass making process is a long automated process which requires a lot of manual inputs and is easily affected by a lot of variables such as ambient temperature, quality of cutting tools, glass strain and cooling temperatures. Cutting and snapping losses are in the top three of overall losses incurred by the process. Cutting and snapping losses are on the rise and the reasons for this are currently unknown.

To achieve optimal cutting and snapping of glass the best combination of most of the variables needs to be aligned. A study is necessary to understand the variables and how they negatively affect the cutting and snapping operation. The purpose of the study was to evaluate the optimisation of cutting and snapping of float glass operation. It is essential for any manufacturing industry to optimise their processes to increase productivity and compete in this ever changing manufacturing environment

1.1 Objectives

The objective of the research is:

- To find ways to optimise the operation of manufacturing glass particularly cutting and snapping of glass.
- To identify essential variables linked to cutting and snapping and evaluate the best combination of those variables involved.

2. Literature Review

Cutting and snapping is a complex and challenging part of glass making as poor cutting can result from multiple factors such as strain-related issues, glass cutting tools, and a simple scheduling and sequencing of similar sizes.
Strain-related issues affect cutting and snapping internally or during the process and affect offline cutting at a later stage. Poor annealed glass can be seen by splitting in half as it gets to the cold end when exposed to ambient temperature or a draft of wind. It can also be seen by glass breaking during cutting and center breaking skew during snapping. MornGlass (2020) has reported that glass which has not been annealed is liable to crack or shatter when subjected to a relatively small temperature change or mechanical shock.

Annealing glass is critical to its durability. If glass is not annealed, it will retain many of the thermal stresses caused by quenching and significantly decrease the overall strength of the glass. Pathirana, M (2017) has reported that glass panels need to be designed to withstand out of plane loads, such as wind pressure, blast pressure, and impact from various windborne debris. Poor sequencing of cut sizes means more size changes which increases cutting and snapping set up. Poor cutting tools and high/low cutting pressure directly affects the cutting and snapping instantly. These three factors (annealing, sequencing and cutting tools) should be discussed further to understand the impact they have on cutting and snapping.

Technology in Cutting and snapping.

The cutting and snapping stage requires a lot of operator interventions such as changing the cutting wheel, increasing pressure adjusting oil, etc. currently there is no technology that can replace these interventions. As long as human intervention still exists within the process, there will be optimization issues and challenges.
Cutting problems are linked with the complexity of the float glass manufacturing operation. Glass manufacturing plant life span on average is about 15 years at which the entire plant needs to be upgraded from the furnace to the cutting stage. The new technology on offer makes it easier for the company to fully automate the process during the upgrade, which presents other challenges of its own. Na, Byungsoo et al. (2013) has reported that, new technologies are allowing float glass manufacturers to increase the level of automation in their plants, but the question of how to effectively use the automation has given rise to a new and difficult class of optimization problems not yet studied in the literature.

Optimising Cutting through Sequencing.

process stability is significant when it comes to sequencing products. Glass cutting process takes about hour or two to settle and stabilise hence product changes cannot be made every two hours. Two changes arise that result in product change in the operations: width change and size change. Width change occurs when the product required by the customer is bigger than the standard sizes. A bus windscreen is bigger as a result there is a width change in the process to cut the bigger size glass. A size change on the other hand occurs when the required amount of glass is made according to the plan and another requirement needs to be manufactured.

Optimal sequencing is achieved when the same sizes and or similar sizes that do not vary by more than 5mm are grouped together in one width. One width can contain up to 10 sizes depending on the number of customers that order the glass size in that width. Glass size can have the same width but differ in length. Na, Byungsoo et al. (2013) reported it is not uncommon to have many orders of the same width. We have two different ways of breaking ties between such orders, leading to two slightly-different construction heuristics. Both tie-breaking methods are designed to help reduce the end effect. One tie-breaking method is to produce orders with shorter snap times to save longer-snap-time orders.

Figure 1 below shows an example of a 2920width with 11 sizes of similar width but different length. A width is divided by two to get the cut size of that width. Figure one shows a near perfect width where cutting set up is done once for 1460 size and cutting goes on until the width is complete without intervention.

Cycle no: 81 | Plan ID: 7 | Required width: 2920 | Substance: 20 2.0 MM

Item		Product	Length	Width	Order No	Planned qty	Prod. qty	Prod not in stk	Rema
28	177	ASGRN1 (LW	882	1460	19036893	37120	37120	0	0.00
29	177	ASGRN1 (LW	1,067	1460	19036894	5120	5120	0	0.00
30	177	ASGRN1 (LW	892	1460	19036895	5120	5120	0	0.00
40	177	ASGRN1 (LW	900	1440	19036998	5000	5000	0	0.00
41	177	ASGRN1 (LW	969	1442	19036999	2500	2500	0	0.00
42	177	ASGRN1 (LW	982	1460	19037032	5120	5120	0	0.00
43	177	ASGRN1 (LW	982	1460	19037033	3840	3840	0	0.00
44	177	ASGRN1 (LW	882	1460	19037034	5120	5120	0	0.00
48	177	ASGRN1 (LW	902	1460	19037035	2560	2560	0	0.00
49	177	ASGRN1 (LW	1,067	1460	19037036	2560	2560	0	0.00
52	177	ASGRN1 (LW	1,150	1460	19037068	2240	2240	0	0.00

Figure 1. a 2990 width and 11 sizes

However, this is not always the case as new cars are manufactured every day that require a different size windscreen as a result new sizes are created more often which requires re-sequencing the sizes per customer order. Figure two below shows a typical width grouping where sizes are not the same width hence size changes are done more often affecting cutting and snapping every time a new set up is done.

Cycle no: 81 | Plan ID: 3 | Required width: 2870 | Substance: 20 2.0 MM

Item		Product	Length	Wi...	Order No	Planned qty	Prod. qty	Prod not in stk	Remain Ho..
26	177	ASGRN1 (LW	952	1430	19036577	2000	2000	0	0.00
27	177	ASGRN1 (LW	1,075	1432	19036578	10500	10500	0	0.00
28	177	ASGRN1 (LW	1,000	1420	19036579	2000	2000	0	0.00
29	177	ASGRN1 (LW	1,021	1435	19036580	3500	3500	0	0.00
30	177	ASGRN1 (LW	1,010	1435	19036581	25000	25000	0	0.00
31	177	ASGRN1 (LW	1,019	1431	19036582	2000	2000	0	0.00
32	177	ASGRN1 (LW	1,060	1410	19036583	2000	2000	0	0.00
33	177	ASGRN1 (LW	955	1420	19036584	2000	2000	0	0.00

Figure 2. a 2870 width and different sizes

It is for this reason that sequencing is essential in cutting and snapping optimisation. Just like with any process there are limitations that possess challenges to optimisation. The one process limitation that affects sequencing is the production line size. most glass production lines have a width limit of 2700mm to 3800mm as a result glass size that require width below 2700mm is grouped with sizes that best fit 2700mm width. Figure 3 below shows the minimum width a glass production line can handle and sizes within that width. The smallest size is 1314 and the correct width for that size is 2628 but due to the limitations of the production line all size below 1350 is grouped in a 2700 width which results in size changes almost every 1.5 hours.

Cycle no	Plan ID	Required width	Substance	
81	8	2700	20	2.0 MM

Item		Product	Length	Width	Order No	Planned qty	Prod. qty	Prod not in stk	Remain Hours
36	177	ASGRN1 (LW	879	1326	19036951	2000	0	0	1.16
37	177	ASGRN1 (LW	994	1314	19036952	2500	0	0	1.64
38	177	ASGRN1 (LW	924	1318	19036953	5500	0	0	3.34
39	177	ASGRN1 (LW	974	1329	19036954	10500	0	0	6.73
40	177	ASGRN1 (LW	970	1334	19036955	2000	0	0	1.28
41	177	ASGRN1 (LW	960	1320	19036956	2500	0	0	1.58
42	177	ASGRN1 (LW	965	1348	19036957	19000	0	0	12.08

Figure 3. a 2700 size grouping

This limitation comes from the bath section of the process where glass is formed and shaped. A wide range of cut size required on width below 2700mm results in glass instability as it is too narrow to control. Bath requires heat to stabilize and that heat mainly comes from the glass itself when it flows from the furnace to the bath, the smaller the width the less the heat into the bath. O, Jesús et al. (2008) reported that the growth in demand for glass leads to an increase in productivity ratios, increasing the manufactured tonnes of glass or raising the production rate. Whatever the case, the float process is progressively over demanded, leading to higher temperature and velocity gradients inside the tin bath. This negatively affects the stability of the glass sheet as well as the planimetry of the lower surface of the ribbon.
In a with less than four off take devices, the process is limited to just one product at a time, resulting in more changes and interventions creating optimisation challenges. Glass sequencing alone plays a big part in optimising cutting and snapping as frequent changes to the cutting set up as a result of size change affects overall cutting and snapping.
Na, Byungsoo et al. (2014) has reported a paper that considers a cutting and scheduling problem of minimizing scrap motivated by float glass manufacturing and introduces the float glass scheduling problem.

A schedule can be defined to be a sequence of coveys where between two consecutive coveys, either one or more orders have finished and/or one or more orders have started. The optimization problem thus consists of determining a sequence of coveys that produce all orders such that the yield ratio is maximized.

Na, Byungsoo et al. (2013) reported the optimization problems combine aspects of traditional cutting problems and traditional scheduling and sequencing problems, the hybrid of which has not previously been modelled, let alone studied or solved. This paper defines and models the problem, and provides heuristic solution methods that produce manufacturing yields greater than 99%. These high-yield solutions can save millions of dollars; we currently implement out methods at a major float glass manufacturer. Abstract in automated float glass manufacturing; a continuous ribbon of glass is cut according to customer orders and then offloaded using robots.

3. Methods
The details attained from this case study can be used as a model in other glass manufacturing plants. The study was conducted in a glass manufacturing company in South Africa. Primary data was collected through questionnaires and secondary data through observation and experiments. Data collected was both qualitative and quantitative in nature.

4. Data Collection
Data for this study was collected using three methods, questionnaire, observation and experiments. A pre structured form was used for each of the method to collect the data on different days, shift and time.

5. Results and Discussion

The following results were abstracted from the questionnaire that was conducted. Ten questions were asked; the results/findings are as follows from question one to ten. The following are the results of the closed questions.
What affects cutting and snapping the most?

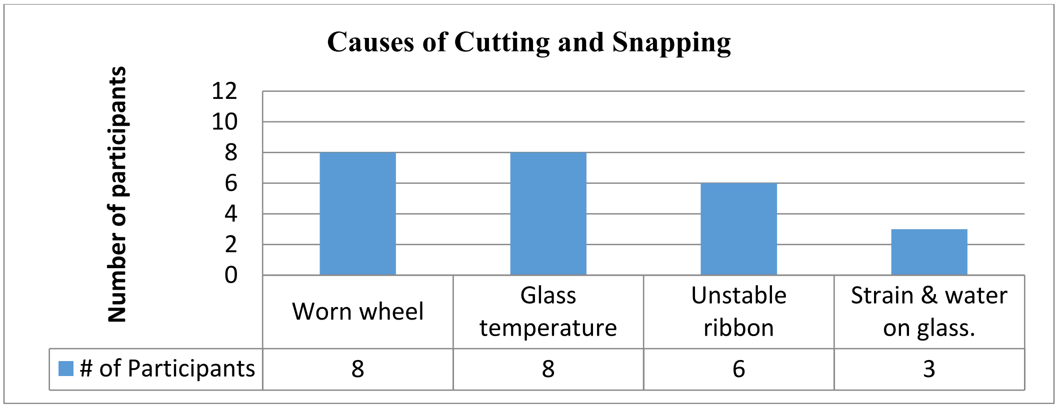


Figure 4. Causes of cutting and snapping

The first and arguably the most important question was what affects glass cutting and 8 off the 12 participants stated worn wheel and glass temperature as the main causes of cutting and snapping. Unstable ribbon was mentioned by six participants as one of the causes. All participants stated two or more variables as causes of cutting and snapping. From these results it is evident that there are not one but multiple variables that causes and affect glass cutting and snapping.
Which edge defects do you experience the most on shift?

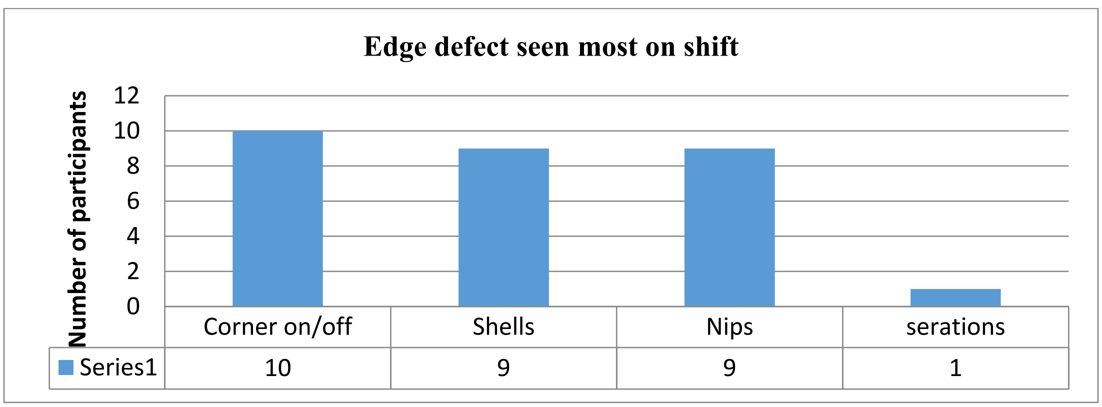


Figure 5. Edge defect seen most on shift

There is also multiple glass defect seen on shift as a result of poor cutting and snapping. Ten participants stated the most defects seen on shift are corner on/off and nine participants mentioned shells and nips. All participants stated two or more edge defects. When these defects appear on the cut glass a scanner notifies the operator and that is the first sign that cutting and snapping is not of higher quality, action needs to be taken to resolve edge defects.
Do you take the same action to correct the defect listed above?

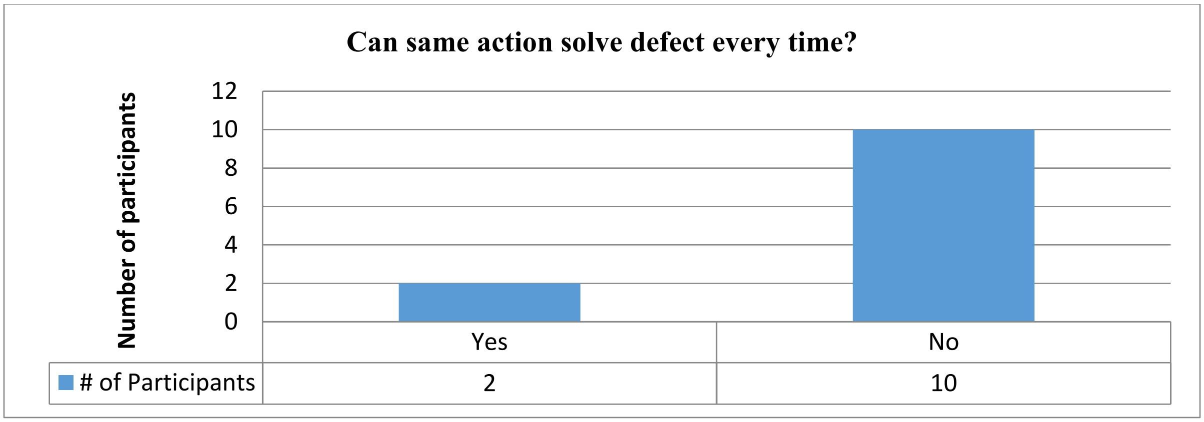


Figure 6. Same action takes to solve defect

Ten participants replied that the defects are not solved by just one action. From these results it is safe to conclude that more than one action is taken to correct the defects as a result of poor cutting and snapping. An action can resolve the defect today but not guaranteed it will solve it the next day.
Outside temperature has an effect on cutting and snapping?

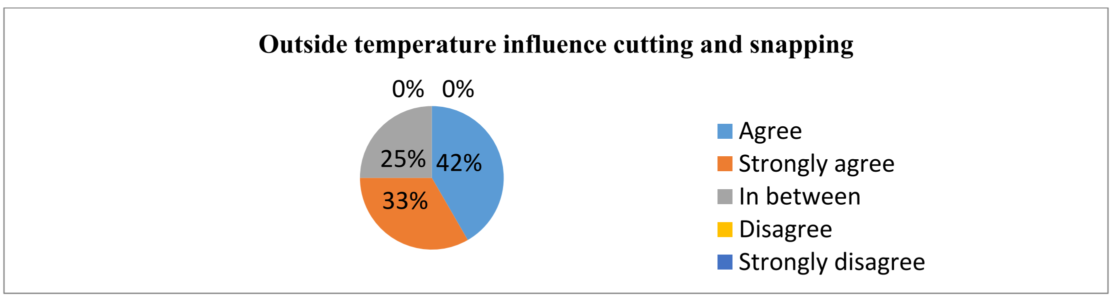


Figure 7. Outside temperature influencing cutting and snapping

From the 12 participants, 42% agree that cutting and snapping are influenced by outside temperature, 33% strongly agree that outside temperature affects cutting and snapping, and 25% neither agree nor disagree with the same notion.
Which action solves cutting and snapping the most on shift?

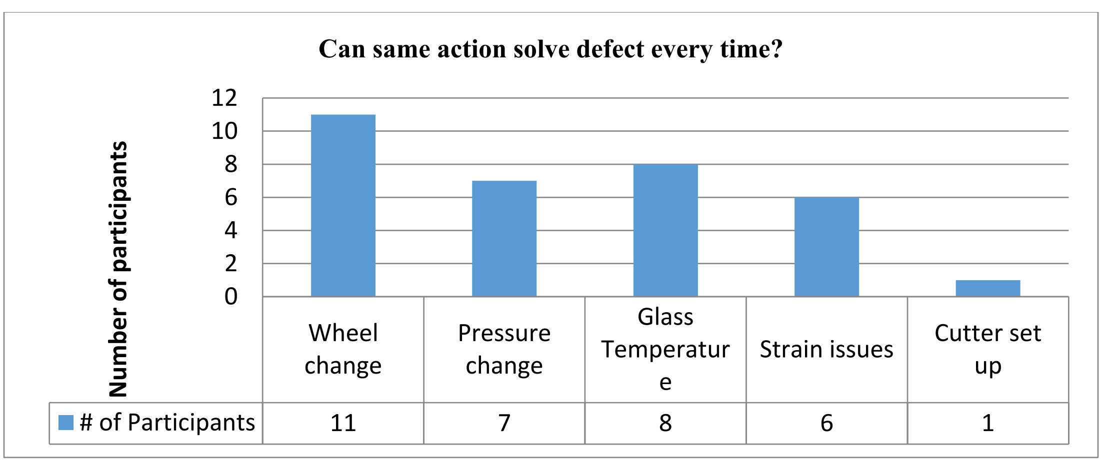


Figure 8. Same action solving defect.

Wheel change was selected as the most action taken to solve cutting and snapping issues by 11 participants. Glass temperature change was selected by 8 participants followed by cutting pressure change and strain issues. Just as with causes of cutting and snapping, 83% of the participants selected more than one action. This indicates that there is more than one solution to poor cutting and snapping. Wheel change seems to be the easiest variable to change. Changing a wheel might solve the problem temporarily as new wheel is still sharp and can cut into glass is not properly cooled but for how long can it last?

At what time during shift does the ribbon temperature drop?

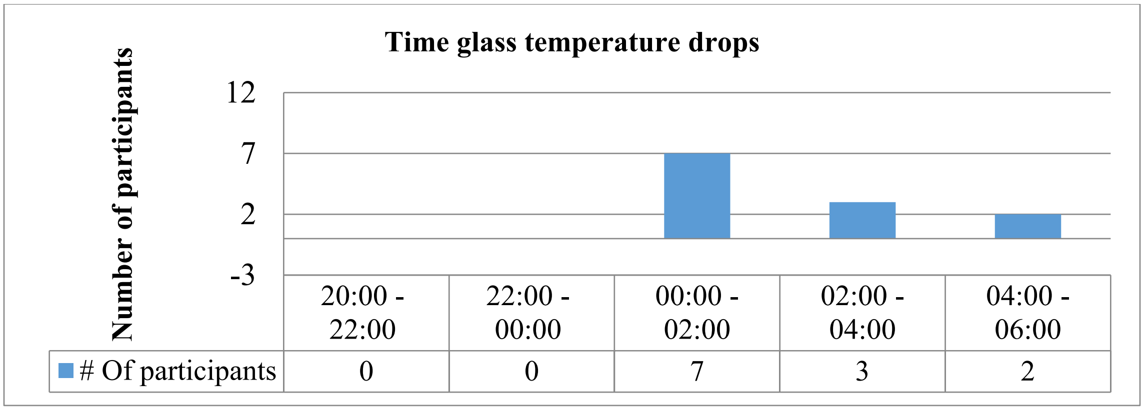


Figure 9. Time glass temperature drops

All participants replied glass temperature drops during the night. Ten participants indicated from midnight 00:00 glass temperature drops. That could be because from midnight ambient temperature is at its lowest and from the question above it has been established that outside temperature influence temperature at cutting.
At what time during shift does the ribbon temperature increase?

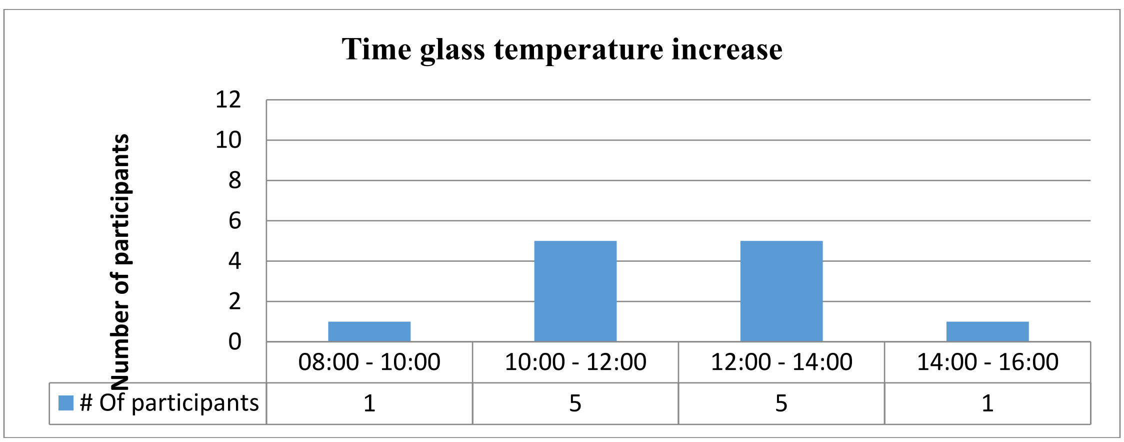


Figure 10. Time glass temperature increase.

All participants indicated glass temperature increases during the day as ambient temperature increases. There is a direct link between ambient and glass temperature. Trial results below will further show that correlation.
What edge defects do you see when the ribbon temperature drops?

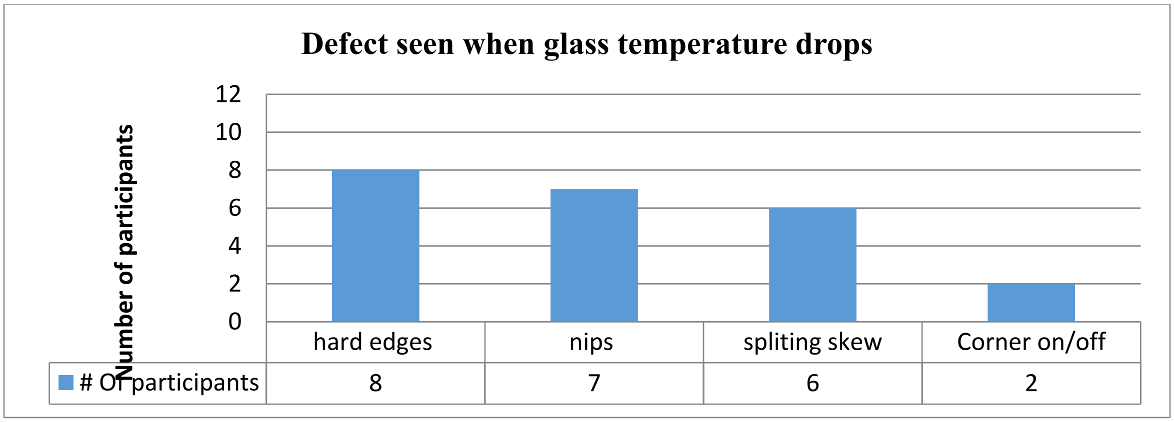


Figure 11. Defect when glass temperature drops.

The results show that hard edges, nips and glass splitting skew are as a results of temperature drops. When glass is too cold it becomes hard and breaks when it is being cut. Trial results below will show the same results.
What edge defects do you see when the ribbon temperature increase?

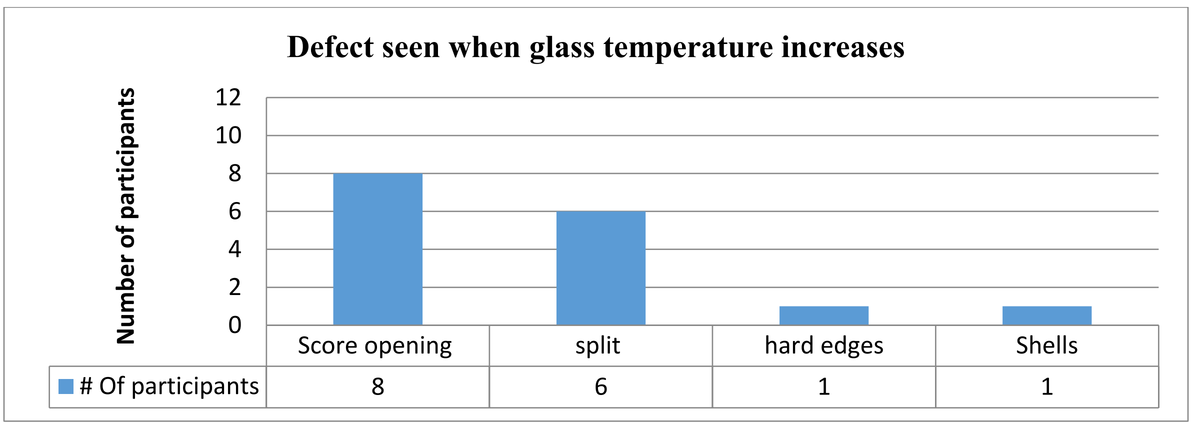


Figure 12. Defect when glass temperature increases

The results show that score opening and split are results of temperature increase. When glass is too hot it becomes soft and splits when it is being cut. Trial results below will show this in more detail.
Is there a step by step procedure to follow for every edge defect?

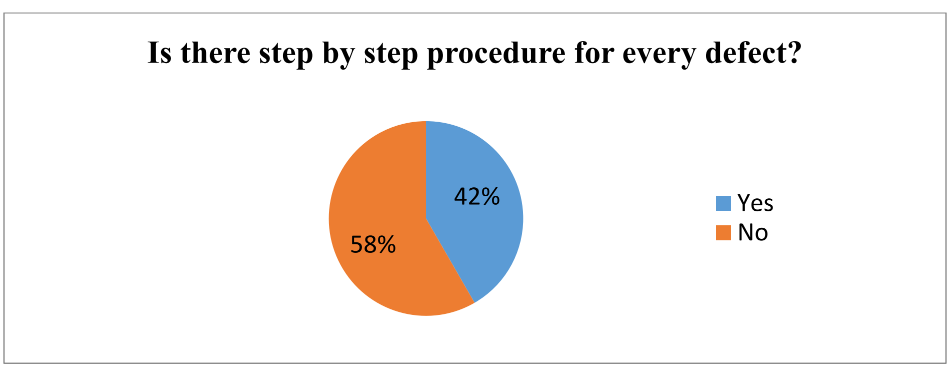


Figure 13. Procedure for every defect

58% of the participants indicated that there is no step by step procedure to follow when solving each defect, on the contrary 42% of the participants indicated there is a procedure to follow for each defect. The results are in conclusive none the less a procedure needs to be developed and shared with all process controllers.
At which ribbon temperature do you experience less cutting and snapping issues?

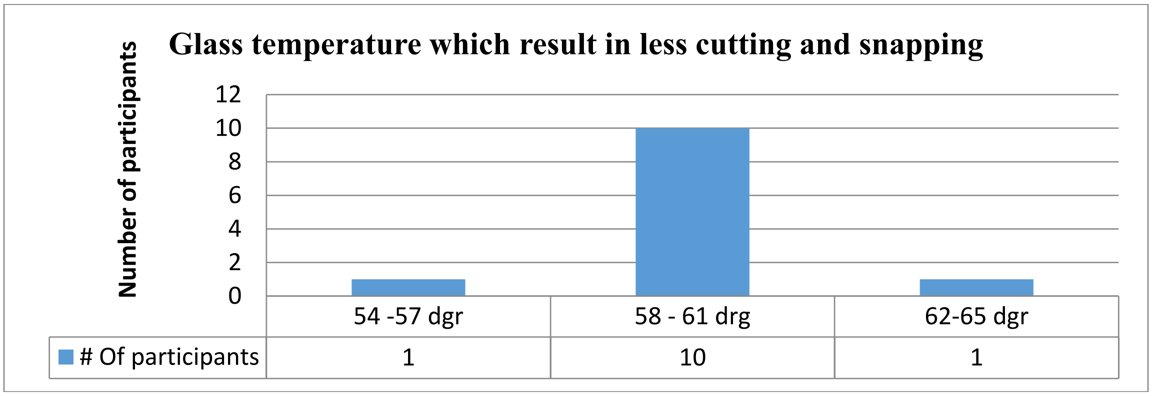


Figure 14. Temperature resulting into less cutting and snapping

83% of the participants indicated they experience less cutting and snapping issues when the glass temperature is around 58 to 61 degrees. From the observation it was identified that the given temperature at cutting is 55 to 60 form an operating procedure. From these results it is clear that less cutting issues occur when the glass temperature is on the higher side of the recommended temperature.
Does the general line set up work all the time?

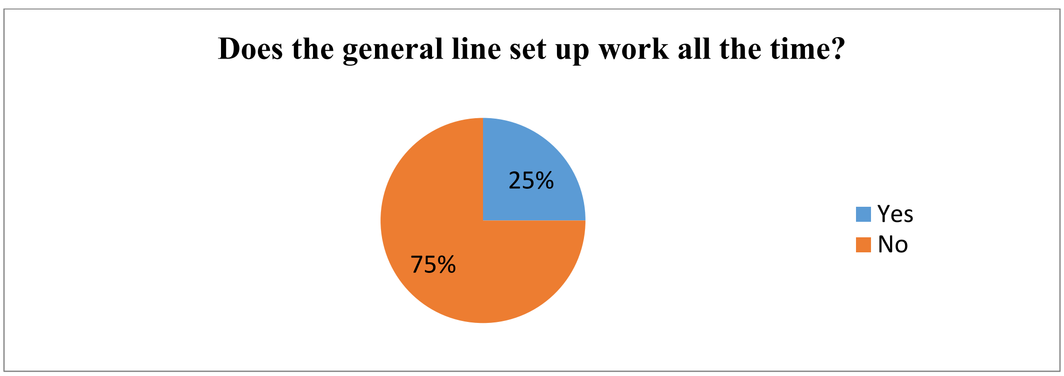


Figure 15. Line general set up time.

Does the general line set up work all the time, 75% of the participants does not think so and 25% of the participants think it always work? As conditions changes all the time and outside conditions influence the process, operators have to compensate as conditions changes hence majority would think that the general line set up does not work.
The operator does not always know which action to take to solve cutting and snapping issue?

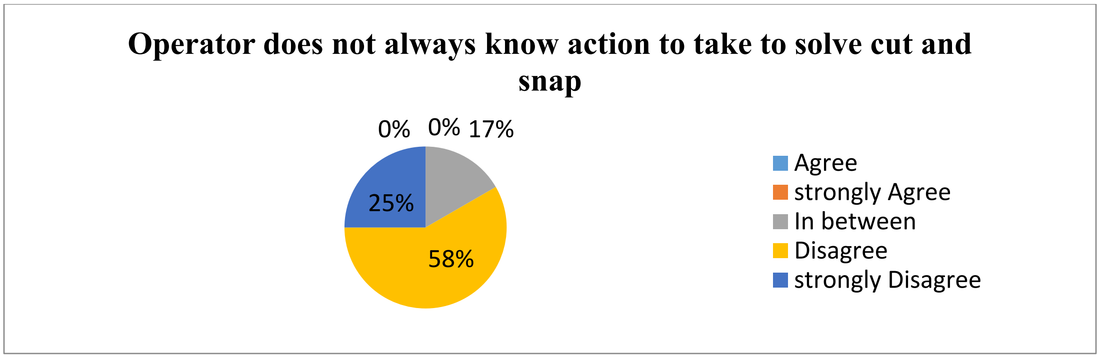


Figure 16. Knowledge of action to solve cut and snap.

An operator does not always know which action to take to solve cutting and snapping issues, 58% of the participants disagree with the notion, 25% strongly disagree to the notion meanwhile 17% neither agree nor disagree. This means 83% of the participants think operators always know how to solve cutting and snapping issues but whether the correct variable is changed to solve the problem is not known as multiple variables can be changed to solve the same problem as the other results indicated.
The overall results indicate that the causes of cutting and snapping are known just in general but the degree at which they affect the cutting and snapping shown by the results from the trials conducted.

Experiment and Trials Results
The following results were abstracted from the trials that were conducted. A total of six trials were conducted. And only one variable was changed to see how the rest of the variables behave. The glass temperature at the beginning of the lehr was changed in each trial to see how the temperatures in the different sections downstream are affected and subsequently cutting and snapping.
Stage by stage temperature comparison.

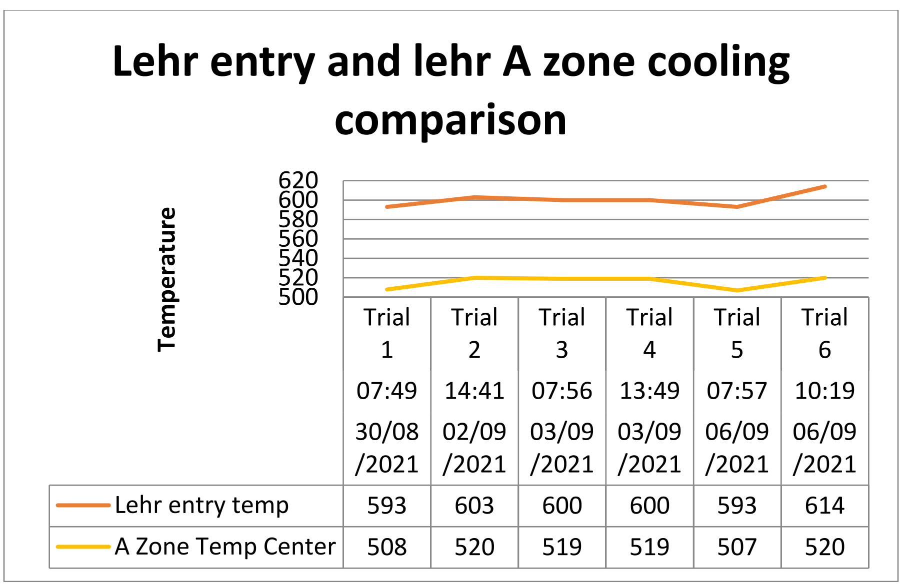


Figure 17. lehr entry and A zone cooling comparison

Lehr entry temperatures and the temperature after zone A cooling show a similar trend On all trial dates. This shows A zone cools the glass by an average of 85 degrees.

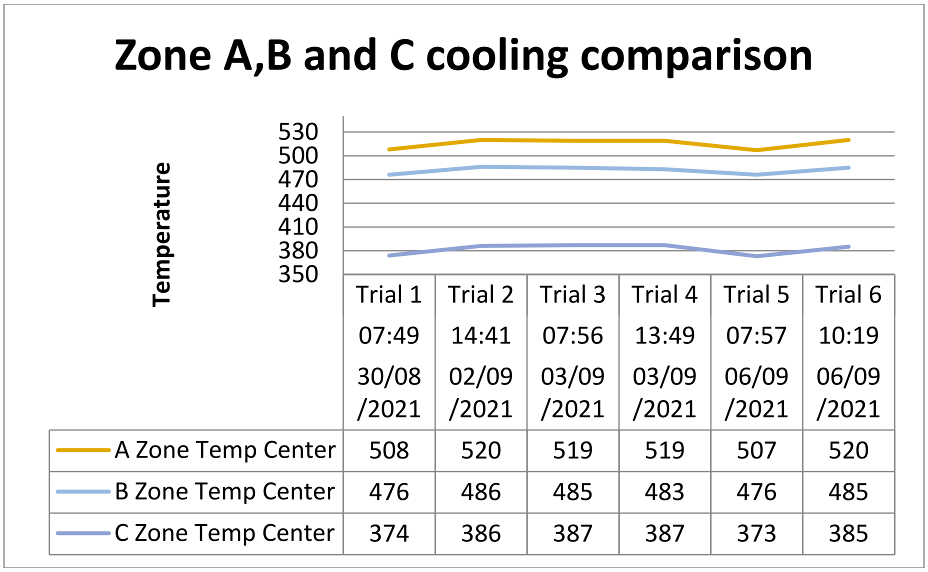


Figure 18. zone A, B and C cooling comparison

Zone A temperatures and the temperature after zone B cooling show a similar trend On all trial dates. This shows B zone cools the glass by an average of 33 degrees. Zone B temperatures and the temperature after zone C cooling shows a similar trend on all trial dates. This shows C zone cools the glass by an average of 100 degrees.

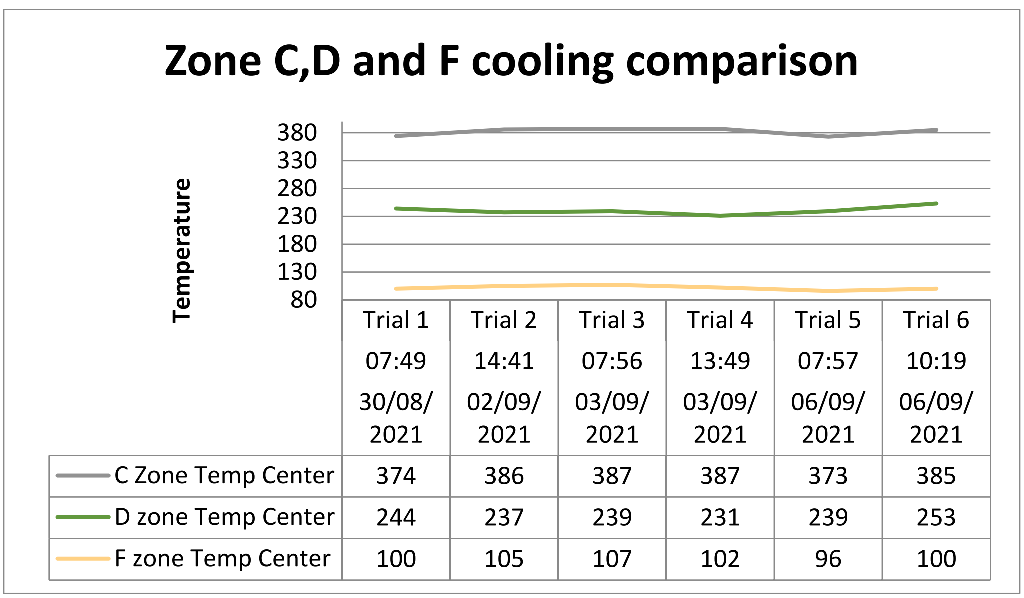
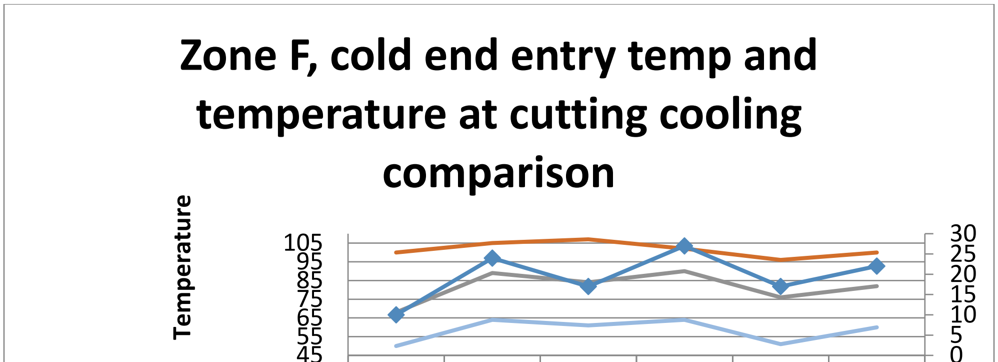


Figure 19. Zone C, D and F cooling comparison

Zone C temperatures and the temperature after zone D cooling does not show a similar trend on all trial dates. This shows D zone does not cool the glass at the same rate. There is a difference of 26 degrees cooling rate between the trials. This could be because D zone is next to F Zone which is exposed to ambient temperature as it is open and not sealed.

Zone D temperatures and the temperature after zone F cooling does not show a similar trend on all trial dates. This shows F zone does not cool the glass at the same rate. There is a difference of up to 23 degrees cooling rate between the trials. F zone is exposed to ambient temperature requires trial and error to get the cooling rate the same every time.

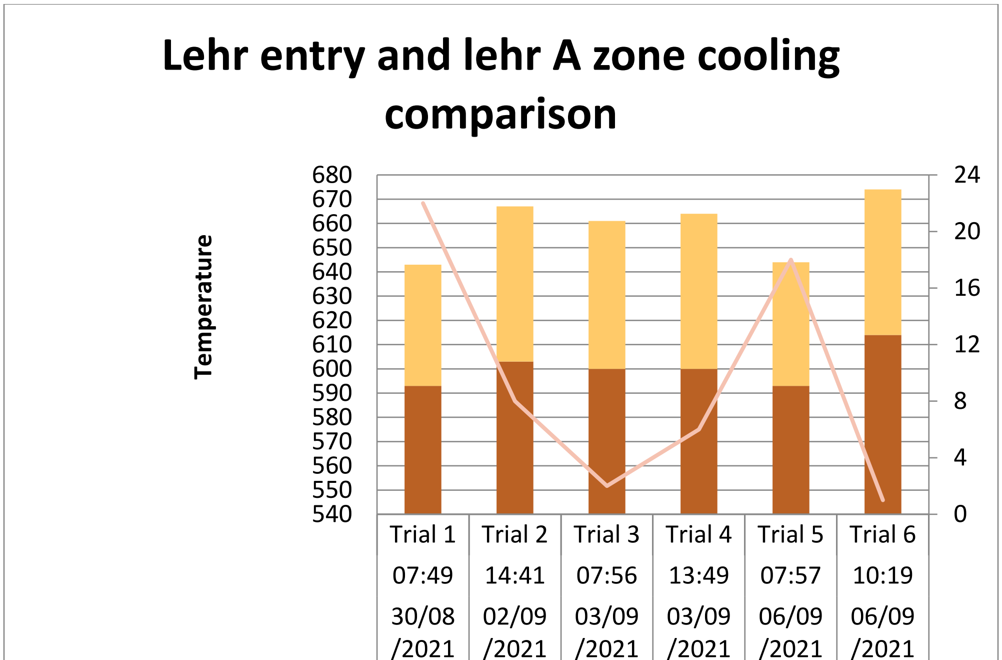
This shows that the higher the temperature at entry the higher it will be at cutting. Ambient temperature will still affect the glass but 60 degrees at cutting can still be achieved to maintain better cutting and snapping.



	Trial 1 07:49 30/08/2021	Trial 2 14:41 02/09/2021	Trial 3 07:56 03/09/2021	Trial 4 13:49 03/09/2021	Trial 5 07:57 06/09/2021	Trial 6 10:19 06/09/2021
F zone Temp Center	100	105	107	102	96	100
Cold End entry Temp	68	89	84	90	76	82
Temp at cutting	50	64	61	64	51	60
Ambient Temp	10	24	17	27	17	22

Figure 20. Zone F and temperature at cutting

Zone F temperature does not have the same trend as cold end entry temperature. When the glass enters the cold end it is exposed to ambient temperature as it is in the open and there are no heaters to keep the glass warm compared to F zone. There is a distinct similarity between the cold end temperature, temperature at cutting and the ambient temperature taken at the time of the study. When the ambient temperature was low temperature at cutting was low and when the ambient temperature was high, temperature at cutting was also high. There is a correlation between the ambient temperature and glass temperature at cold end.



	Trial 1 07:49 30/08 /2021	Trial 2 14:41 02/09 /2021	Trial 3 07:56 03/09 /2021	Trial 4 13:49 03/09 /2021	Trial 5 07:57 06/09 /2021	Trial 6 10:19 06/09 /2021
Temp at cutting	50	64	61	64	51	60
Lehr entry temp	593	603	600	600	593	614
Plates rejected during the trial (one hour trial)	22	8	2	6	18	1

Figure 21. lehr entry and temperature at cutting

From the trials conducted it is evident that the lower the glass temperature at the entry of the lehr where glass cooling starts the lower the temperature at the end of the cooling process which becomes even lower at cutting area as it is exposed to ambient temperature. Trial one and five results show a lehr entry temperature of 593 and temperature at cutting 50°C and 51°C respectively. At 50°C plates rejected as results of lower temperature were high. Trial 3 and 4 were conducted on the same day one in the morning and the other in the afternoon.

6. Conclusion

The objective of the study was to optimise the glass cutting and snapping operation by reducing losses and scrap related to cutting and snapping and identify the best combination of settings for all variables involved in cutting and snapping. To optimise the operation of cutting and snapping in float glass reduce waste associated with it one needs to understand what influences and causes cutting and snapping in the first place. The study identified three main variables that cause cutting and snapping and the defects created when those variables are out of normal range. The study identifies cutting equipment (worn cutting wheel) glass temperature (strain) and unstable ribbon as a result of product changes as the main contributors to poor cutting and snapping. To optimize cutting and snapping and reduce defects the cutting wheel must not be worn, temperature must be 59 to 60 at cutting and the ribbon must be stable. The process controllers should always strive to have these variables within targets and continuously monitor them and compensate as outside conditions changes. The objective of the study was met however an in depth understanding of these variables together as a unit needs to be further studied assuming the worst conditions as well as normal conditions to understand how they interlink. This will give guidelines to process controllers on how to compensate during the worst conditions.

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Mpho Mulaudzi is a young passionate, hardworking individual who is self-motivated and self-driven to only achieve the best results in everything he does. He started his career in Engineering when he enrolled for Industrial Engineering course at the University of Johannesburg where he achieved his B-tech in Industrial engineering with over 55% distinctions. Over the years he has acquired skills in problem solving through six sigma green belt methodologies and achieved a Middle Management programme certificate at the University of Stellenbosch. He recently achieved a Postgraduate diploma in Operations Management which will greatly add value to his current position as a Process Manager in Automotive Manufacturing industry.