Catalyst Manufacturing: MAGGI 2-minute Noodle wrapper project

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EXECUTIVE SUMMARY

The main product manufactured at Catalyst Manufacturing is MAGGI 2-minutes noodles. The noodle line consists of 8 lines which are designed to do 40 cuts x 4 lines a minute, yielding 160 noodle cakes per minute.

Catalyst Manufacturing is currently experiencing major problems within the production line, resulting in large overhead costs and a vast number of defective products.

2009 year-end statistics indicate an average noodle loss (noodle cake and dough) of 7.94% against an allowed loss of 4%. Rework that could not be absorbed during 2009 amounted to 328 tons at a product value of R 3.8 million.

The nature of this project will mainly focus on the application of simulation and management financing techniques applied in the production line at Catalyst Manufacturing.

The goal of the project is to allocate weight to each individual problem to establish the financial overheads associated with each area. By means of this data, a variety of cost-efficient solutions can be generated to reduce the overall losses in the system.

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CHAPTER 1 – INTRODUCTION

1. COMPANY BACKGROUND

"Libstar Manufacturing Solutions was founded in 2008 to provide food manufacturing and packaging solutions in the fast-moving consumer goods (FMCG) industry. This manufacturing arm of the Libstar Group, Retailer Brands comprises Catalyst Manufacturing, Dickon Hall Foods, Liqui-Pak, Montagu Foods, Retailer Brands and The Blenders.

Catalyst Manufacturing is fast becoming a key player in the food industry, thanks to blue-chip clients such as Nestlé.

The company concentrates mainly on manufacturing instant noodles for Nestlé. It also produces and co-packs South African brand legends such as Nescafé, Cremora Lite and Ricoffy – from single-serve coffee, coffee creamers and tea whitener to bulk packs of hot chocolate.

Quality forms the basis of the organisation, and the on-site laboratory ensures that various tests can be conducted effortlessly. Over and above this, the company also enjoys access to other laboratories within the group, ensuring that quality standards are continuously met. HACCP accreditation was completed in 2009 with ISO22000 being the objective going forward to 2010.

The company's packaging capabilities extend to various flexible pack options, such as 3- and 4-sided sealing, plastic jars and PET containers. These containers are filled, sealed, labelled, date-stamped, code-printed and palletised on site." (Libstar Manufacturing Solutions [Sa])

2. PROBLEM STATEMENT

The main product manufactured at Catalyst is MAGGI 2-minutes noodles. The noodle line consists of 8 lines which are designed to do 40 cuts x 4 lines a minute, yielding 160 noodle cakes per minute.

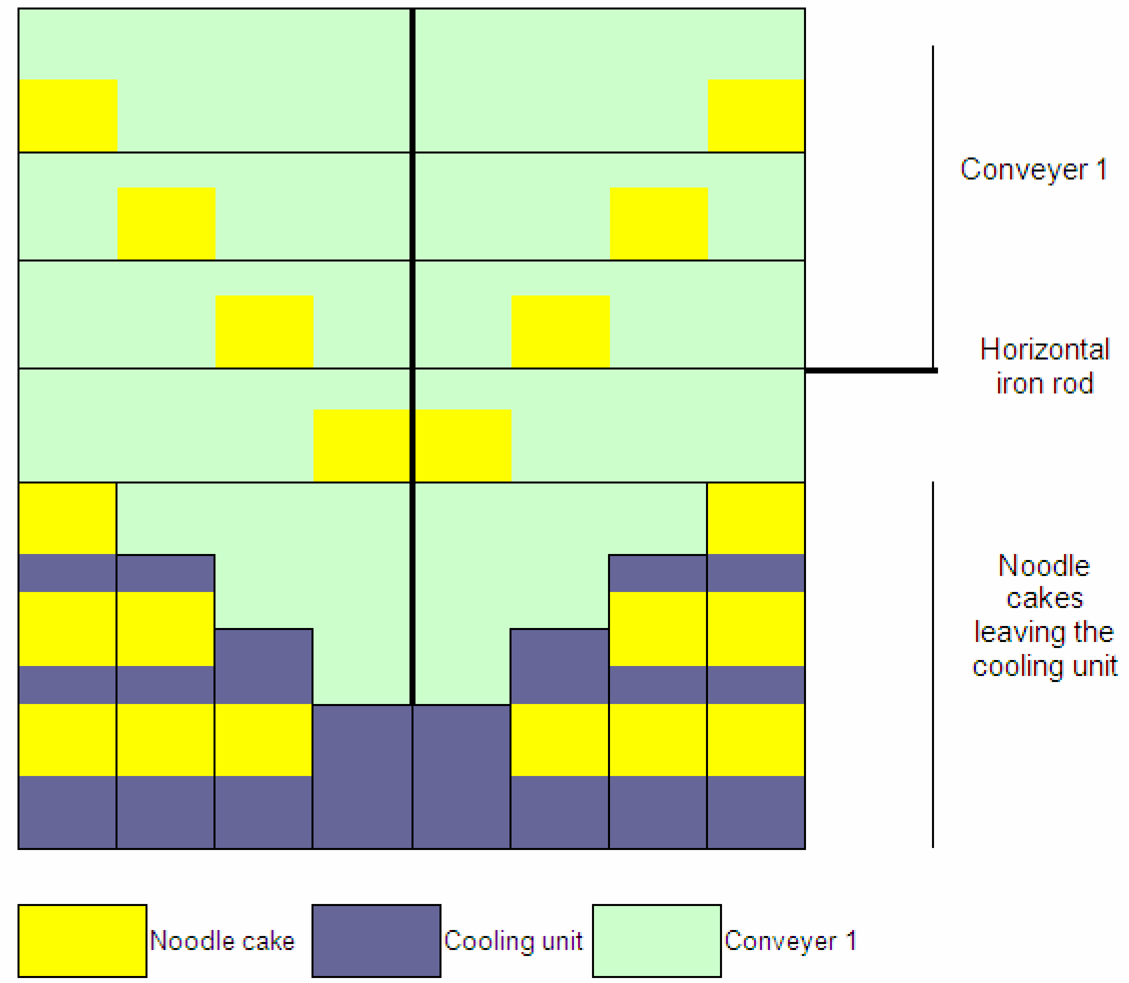
2009 year-end statistics indicate an average noodle loss (noodle cake and dough) of 7.94% against an allowed loss of 4%. Rework that could not be absorbed during 2009 amounted to 328 tons at a product value of R 3.8 million. The area of concern within the production line is schematically explained by means of a flow diagram in Appendix A.

The cooling unit consists of an 8-lane conveyer. The noodle cakes are split into two 4-lanes as they leave the cooling unit onto conveyers 2 and 3.

2.1 PROBLEM 1

The end of the cooling unit of the conveyor is step shaped. A rotating bar pushes the cakes, two at a time, onto conveyor 1. Conveyor 1 consists of horizontal iron rods that keep the cakes in place. Currently the rotating bars are perished and need constant maintenance. This results in 3 to 4 cakes between each horizontal rod. Conveyor 1 is narrowed before reaching conveyor 2 to create a single cake line. The excess cakes in each slot are pressed together, which results in portions of the cakes breaking off.

Figure 1 Top view of cooling unit/conveyer 1 under perfect conditions



2.2 PROBLEM 2

The two single rows of cakes are dropped onto conveyors 2 and 3. There is no instrument in place to control the orientation of the cakes as they move to conveyors 2 and 3. This results in a blockage at the entrance of conveyors 4 and 5 because cakes can only enter these conveyors lengthways. Currently, placing two workers at conveyors 2 and 3 solves this problem. Workers 1 and 2 are responsible to remove broken cakes from problem 1 and to rotate cakes lengthways.

2.3 PROBLEM 3

Conveyors 4 and 5 move the cakes to the in-feed. The in-feed machine shoots each cake individually onto a conveyor belt with plastic separating columns. These columns create single slots for each cake as it moves to the sachet dispenser. The conveyor carrying the cakes in slots moves from the in-feed to the sachet dispenser. The sachet dispenser places a flavour sachet on top of each cake. The cakes with sachets are moved to the wrapping area. Workers 5 and 6 man the wrapping unit. Every 40 minutes the wrapper will stop for ±2 minutes to change the foil in which the cakes are wrapped. The wrapper cannot be equipped with splicing equipment and would therefore always cause a stoppage. The rest of the production line cannot be stopped and is continuously producing 160 noodle cakes per minute.

3. PROJECT AIM AND SCOPE

3.1 PROJECT AIM

- Confirm that the area before the two flow-wrappers is where the most rework is generated.
- Reduce damage to cakes after leaving the cooling unit.
- Identify the route course for the rework generation.
- Create a solution to catch cakes when the wrapper is idle.
- Create a cost-efficient solution for the overall problem.
- Establish whether the number of workers can be reduced.

3.2 SPECIFIC OBJECTIVE/SCOPE

The scope is constrained mainly to the area between the cooling unit and the packaging area. The area before the two flow-wrappers will generate the most rework. Different industrial engineering methods, as well as trial and error runs will be used to reduce damage to noodle cakes after leaving the cooling unit.

A weight allocation will be given to each problem to establish the financial overheads associated with each area. With this data a variety of cost-efficient solutions can be generated to reduce the overall losses in the system.

Mechanical rework will be done on the production line with the overall goal to remove workers 1 and 2.

3.3 DELIVERABLES

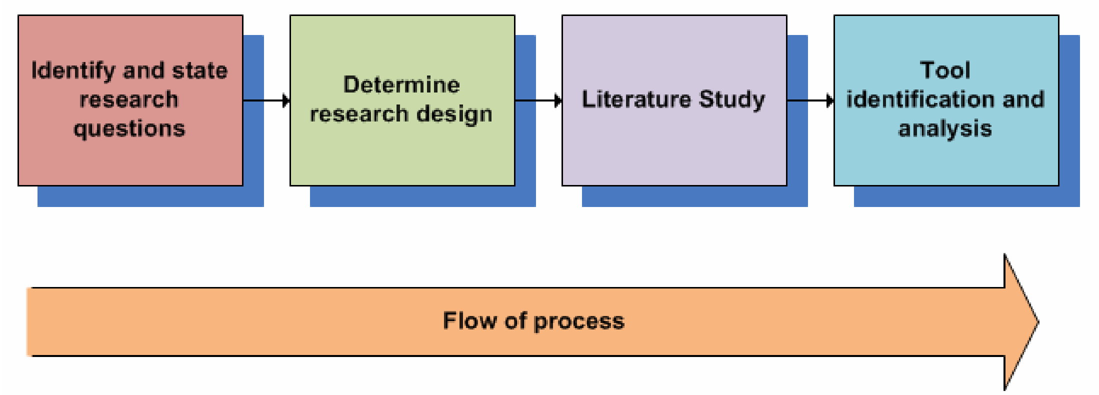
The deliverables of the project will consist of the following:

- Quality control charts, firstly to identify the cause of the different problems and to eliminate them, and, secondly, to control the improved system.
- A financial report of each problem area and possible solutions. This overview will be used to measure all the options and so achieve the most cost-effective solution.
- Mechanical and design rework to construct physical changes to the production line.

CHAPTER 2 – RESEARCH METHODOLOGY

The research methodology will be following the construction shown in figure 2:

Figure 2 Research Methodology



2.1 RESEARCH QUESTION FORMULATION

Research questions help formulate the objectives of the project. Before the formulations of the research question, Catalyst Manufacturing's projected expectations must be taken into account. The research question can be formulated and better understood by viewing all Catalyst's expectations and needs:

- How many workers can be removed from the problem area?
- Which stations produce the most defects?
- How to minimize defect?

Thus the research question:

How many workers can be removed from the most defect producing areas by minimising defects?

2.2 RESEARCH QUESTION ANALYSIS

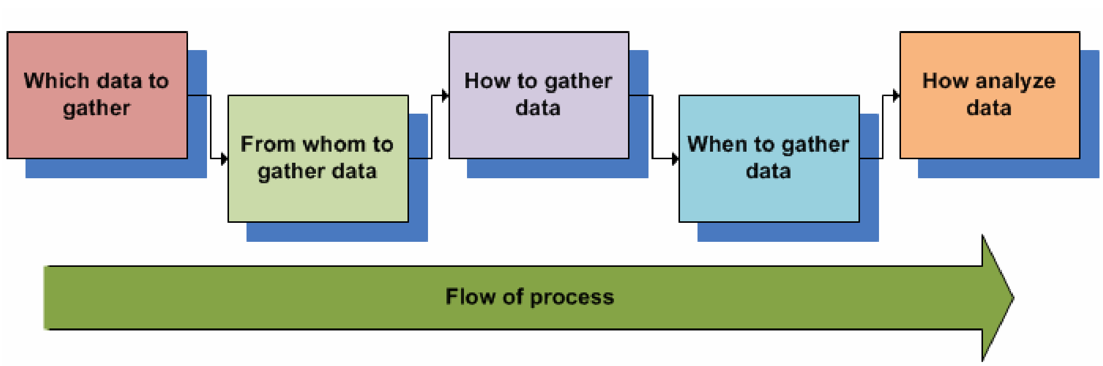
Different steps can be used to analyse the research question:

1. Reviewing similar projects that have been solved in the past, as shown in chapter 2.
2. Developing supplementary methods, tools and techniques.
3. Analysing data.
4. Developing conceptual design and solutions.

2.3 REASEARCH DESIGN

An illustration of the research design is shown in figure 3:

Figure 3 Research Design



Each design point is explained from left to right:

1. Which data to gather: Reviewing similar projects that have been solved in the past.
2. From whom to gather data: Journals, internet resources, textbooks and other literature-related data.
3. How to gather data: Electronically with the help of the University of Pretoria's Academic Information Service (AIS) and internet resources such as Google and Wikipedia. The University of Pretoria's library also provided a vast number of textbooks and journals.
4. When to gather data: Mainly in the second phase of the project, but research should be done throughout the entire duration of the project.

5. How to analyse data: Similar projects will be compared to the current problem. Different methods and tools used in the past can also be reviewed to get a better understanding of the task at hand.

CHAPTER 3 – LITERATURE STUDY

1. LITERATURE STUDY AIM

"A literature study can be defined as a systematic, comprehensive search for published material on a specific subject" (Botha & Du Toit, 1999).

The researched information in this literature study will be used as guidelines for the improvement and additional implementation of the MAGGI 2-minute noodle line.

The review is catorised according to the project deliverables:

- Cost-benefit analysis
- Quality control
- Mechanical design

2. COST-BENEFIT ANALYSIS

A.R. Prest and R. Turvey defines cost benefit as "...a practical way of assessing the desirability of projects, where it is important to take a long view (in the sense of looking at repercussions in the further, as well as the nearer, future) and a wide view (in the sense of allowing for side-effects), *i.e.* it implies the enumeration and evaluation of all the relevant costs and benefits" (A.R. Prest & R. Turvey, 1965, p.683). To clarify, the cost-benefit method is used to weigh certain options against one another.

Steven Kelman (2001, p.55) view cost benefit purely as efficiently thinking about decision making and also the course of action to be taken. He also assumes that frequent users of this method require a more wide-ranging prescription. The prescriptions comprise the following views:

- Only when the benefits dominate the costs should action be taken.
- In order to determine whether the benefits dominate the costs, all the benefits and costs must be compared with each other even if they do not have an established Rand value.
- Using cost-benefit techniques, it is important to understand the extent to which data must be gathered to undertake an effective cost-benefit study.

A.R. Prest and R. Turvey states two important *preliminary considerations* to be taken into account when using the cost-benefit method:

1) *Statement of the problem*

   "Cost-benefit analysis is a way of setting out the factors which need to be taken into account in making certain economic choices" (A.R. Prest & R. Turvey, 1965, p.685). These choices that have to be made consist of the maximisation and minimisation of certain areas in the production line. Prest and Turvey states, "The aim is to maximise the present value of all benefits less that of all costs, subject so specified constraints" (A.R. Prest & R. Turvey, 1965, p.686). A number of questions can be asked to compose the principles of the above discussion (A.R. Prest & R. Turvey, 1965, p.686):

   1. Which costs and which benefits are to be included?
   2. How are they to be valued?
   3. At what interest rate are they to be discounted?
   4. What are the relevant constraints?

2) *Valuation of costs and benefits*

Certain costs and benefits can be defined in monetary terms. It is important to compensate for the expected prices of future inputs and outputs. These inputs and outputs will have an effect on the relative price of the items involved. The general price level will not be influenced by the future inputs and outputs.

3. QUALITY CONTROL

Quality is defined as "… a predictable degree of uniformity and dependability, at low cost and suited to the market" (Gitlow, Oppenheim, Oppenheim & Livine, 2005, p.18).

Erwin M. Saniga (1989, p.313) states that "Statistical process control is an effective method for improving a firm's quality and productivity. The primary tool of statistical process control is the statistical control chart." According to James C. Benneyan (1998, p.69), control charts are chronological graphs of process data that are easily interpreted.

Reasons why quality control charts are useful in a system as quoted by James C. Benneyan (1998, p.69) are the following:

- "testing for and establishing a state of statistical control;
- monitoring an in-control process for change in process and outcome quality;
- identifying, testing and verifying process improvement opportunities."

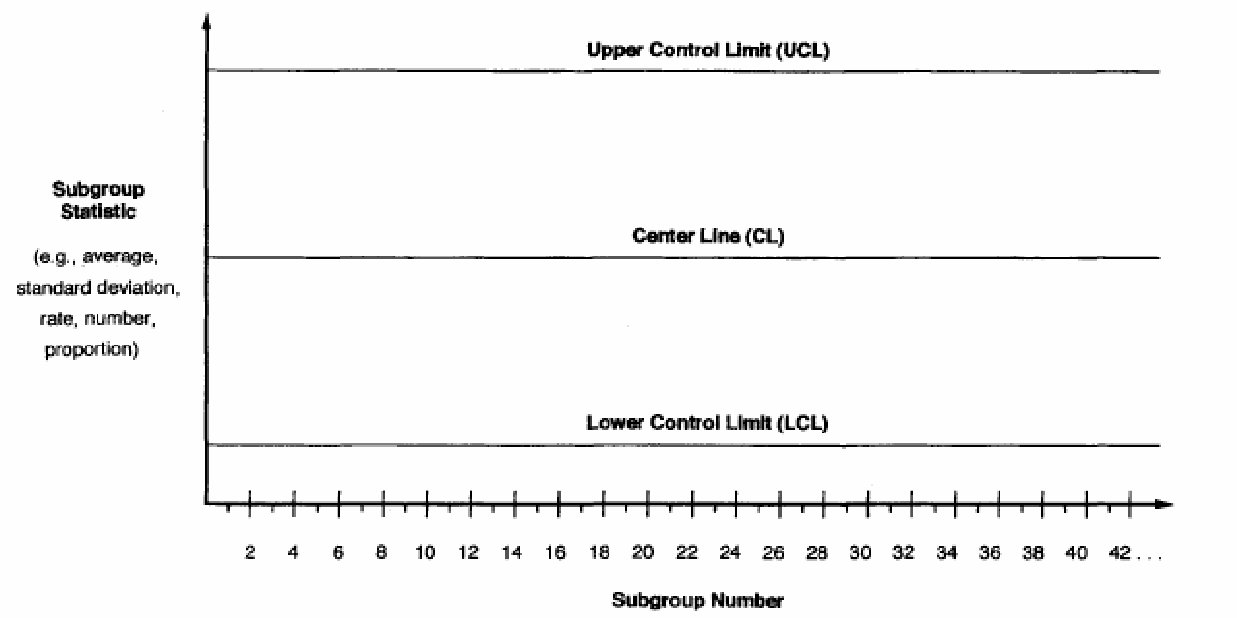
When designing control charts, a number of decisions have to be made. According to Erwin M. Saniga (1989, p.313), some of these decisions include:

- sample size;
- control limit width;
- sampling frequency.

William H. Woodall (2000) addresses the importance of choosing the correct control chart. By using the wrong data and the wrong chart, inaccurate system information will be generated and serves no purpose to the firm. When using the wrong chart, the areas that are “out of control” will remain undetected. Time will be wasted as the output of the charts will give false points that need attention.

James C. Benneyan (1998, p.70) illustrates the construction of a control chart. Firstly, data is collected in subgroups. A recommended subgroup size is 25. Secondly, both an upper control limit and a lower control limit must be calculated within the limitations of the process. Thirdly, each control chart has a centre line. This centre line measures the processes tendency to be “in control”. In most charts the centre line is simply the mean value of the process. Figure 4 (James C. Benneyan, 1998, p. 70) gives a general format of a quality control chart.

Figure 4 General format of a quality control chart



The term “out of statistical control” is explained by William H. Woodall (2000). A system is “out of control” when the chronological plotted data points are outside the specified control limits. Table 1 contains criteria for an “out of statistical control” process as stated by James C. Benneyan (1998, p.70).

Table 1 Criteria for not being in a state of statistical control

Control chart out-of-control signals
• Any single subgroup value outside either control limit
• Eight consecutive subgroups on one particular side of the centreline
• Twelve of fourteen consecutive subgroups on one particular side of the centreline
• Three consecutive subgroups beyond 2 standard deviations on a particular side of the centreline
• Five consecutive subgroups beyond 1 standard deviation on a particular side of the centreline
• Thirteen consecutive subgroups within ± 1 standard deviation (on both sides) of the centreline
• Six consecutive subgroups with either an increasing or decreasing trend
• Cyclical or periodic behaviour

4. MECHANICAL DESIGN

For the purpose of explaining the mechanical design of the process more clearly, patents with similar design is reviewed.

Table 2 United States Patent (Patent number: 4,998,528)

United States Patent [19]
Tomoda

[11] **Patent Number: 4,988,528**
[45] **Date of Patent: Jan. 29, 1991**

[54] **INSTANT NOODLES AND METHOD FOR MANUFACTURING INSTANT NOODLES**

[75] Inventor: **Yoshio Tomoda,** Tokyo, Japan

[73] Assignee: **Toyo Suisan Kaisha, Ltd.,** Tokyo, Japan

[21] Appl. No.: **387,857**

[22] Filed: **Jul. 31, 1989**

[30] **Foreign Application Priority Data**

Dec. 27, 1988 [JP] Japan 63-329766

[51] **Int. Cl.**^{5} **A23L 1/16;** A23L 1/162
[52] **U.S. Cl.** **426/557;** 426/451; 426/464; 426/549
[58] **Field of Search** 426/557, 547, 451, 443, 426/464

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,515,817	5/1985	Pavan	426/557
4,675,199	7/1987	Hsu	426/557
4,728,520	3/1988	Yamaya et al.	426/557
4,816,281	3/1989	Moriyama et al.	426/557

FOREIGN PATENT DOCUMENTS

52-35753	9/1977	Japan .	
60-6172	1/1985	Japan	426/557
61-21055	1/1986	Japan	426/557
1196389	6/1970	United Kingdom	426/557

Primary Examiner—Donald E. Czaja
Assistant Examiner—Drew S. Workman
Attorney, Agent, or Firm—Frishauf, Holtz, Goodman & Woodward

Table 3 United States patent (Patent number 5,042,369)

United States Patent [19]
Tomoda

[11] **Patent Number:** **5,042,369**
[45] **Date of Patent:** **Aug. 27, 1991**

[54] **APPARATUS FOR MANUFACTURING INSTANT NOODLES**

[75] Inventor: **Yoshio Tomoda**, Tokyo, Japan

[73] Assignee: **Toyo Suisan Kaisha, Ltd.**, Tokyo, Japan

[21] Appl. No.: **581,278**

[22] Filed: **Sep. 12, 1990**

Related U.S. Application Data

[62] Division of Ser. No. 387,857, Jul. 31, 1989, Pat. No. 4,988,528.

[30] **Foreign Application Priority Data**

Dec. 27, 1988 [JP] Japan 63-329766

[51] **Int. Cl.**5 .... **A23L 1/00**
[52] **U.S. Cl.** **99/353**; 99/483; 99/516
[58] **Field of Search** 99/353, 355, 474, 483, 99/516; 426/557, 451, 464, 549

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,515,817	5/1985	Pavan	99/353
4,619,189	10/1986	Kou	99/353
4,675,199	6/1987	Hsu	426/557
4,728,520	3/1988	Yamaya et al.	426/557
4,775,542	10/1988	Manser et al.	99/483
4,816,281	3/1989	Moriyama et al.	426/557

FOREIGN PATENT DOCUMENTS

52-35753	9/1977	Japan .
60-6172	1/1985	Japan .
61-21055	1/1986	Japan .
1196389	6/1970	United Kingdom .

Primary Examiner—George Yeung
Attorney, Agent, or Firm—Frishauf, Holtz, Goodman & Woodward

Both designs work in exactly the same way; only the claim of each patent differs.

According to U.S. Patent number 4,988,528, first water, maize and other secret ingredients are mixed together to form a dough. The dough goes through a multistage roll-noodle apparatus to reach the desired thickness of the noodles. See figure 1 (2a, 2b, 3a, 3b, 6a, 6b).

Secondly, the dough goes through a pair of cutter rolls (5a, 5b) that cuts the dough into linear strips. See figure 5.

Thirdly, the cut noodles move through a steam chamber (11) and are then cut to the correct noodle size cake (13).

The noodles finally move through an oil fryer (12) before they are cooled down (22) and packed.

Figure 5 Side view of production line

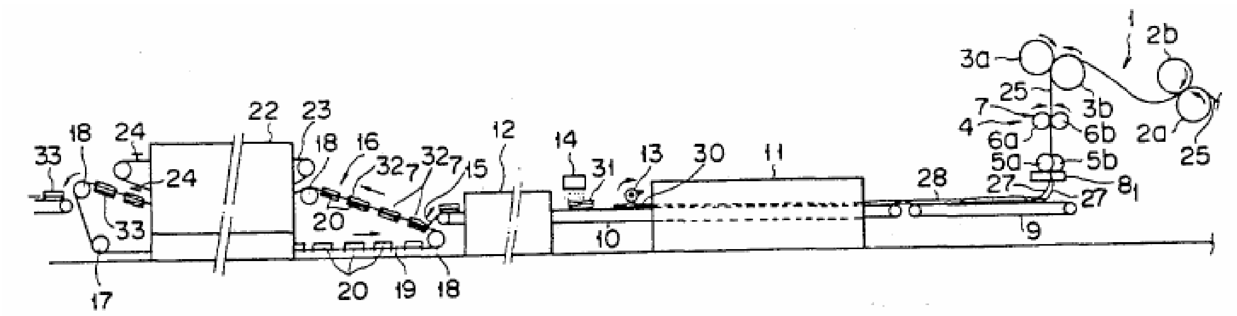
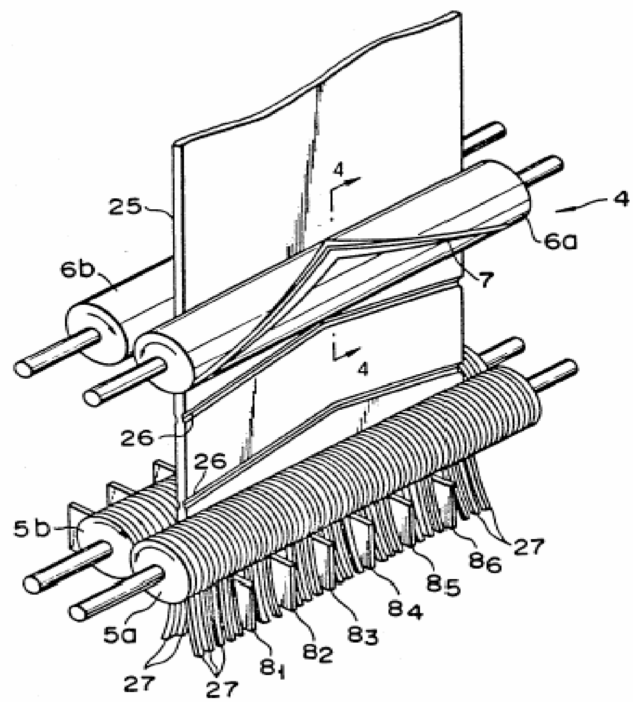


Figure 6 Dough through cutter rolls



5. CONCLUSION – LITERATURE STUDY

The goal of the cost-benefit approach is to allocate weight to each individual problem in order to establish the financial overheads associated with each area. With this data, a variety of cost-effective solutions can be generated to reduce the overall losses in the system. Costs and benefits of the different problem areas will be retrieved and weighed against one another to identify the best solution at the lowest possible cost.

The use of simulation modelling will be helpful in constructing a model of the production line. Modifications can be made to the model and the statistical outcome of each proposal can be identified without interrupting the physical production line.

Quality control charts will be used to identify the “out of control” point within the production line. These points can be investigated further to determine why Catalyst Manufacturing currently has so many defects.

CHAPTER 4 – ANALYSIS AND FINDINGS

1. QUALITY CONTROL

1.1 P CHART

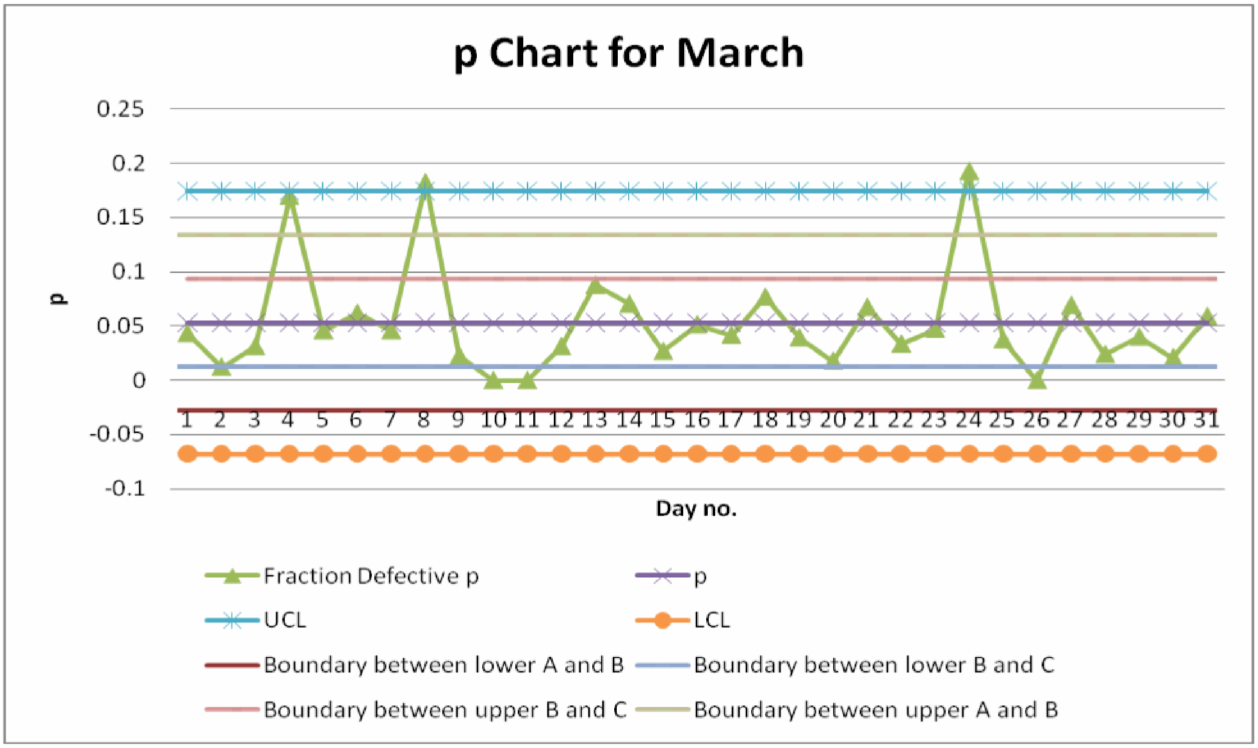
A p Chart is used to analyse the number of defects. The word “defects” implies all noodle cakes that are deformed either by the machinery or by means of material handling by workers 1 to 4. All data used to develop these quality control charts were taken for Catalysts Manufacturing’s database. For statistical data used, refer to Appendix B.

The data of March, April and May 2010 were chosen for the quality study. The chosen months show a relatively stable average with a few fluctuations. These fluctuations will help in understanding why the average noodle loss is more than the allowed loss of 4%.

Chart series explanation:

- Fraction Defective p: The fraction (cakes defective from total sample size observed) of defects removed from the line every day.
- p: The average defectives removed from the line during the particular month.
- UCL: Upper control limit.
- LCL: Lower control limit.
- Boundary between lower A and B: Two standard deviations (error) below the centerline.
- Boundary between lower B and C: One standard deviation (error) below the centerline.
- Boundary between upper B and C: One standard deviation (error) above the centerline.
- Boundary between upper A and B: Two standard deviations (error) above the centerline.

Figure 7 p Chart for March



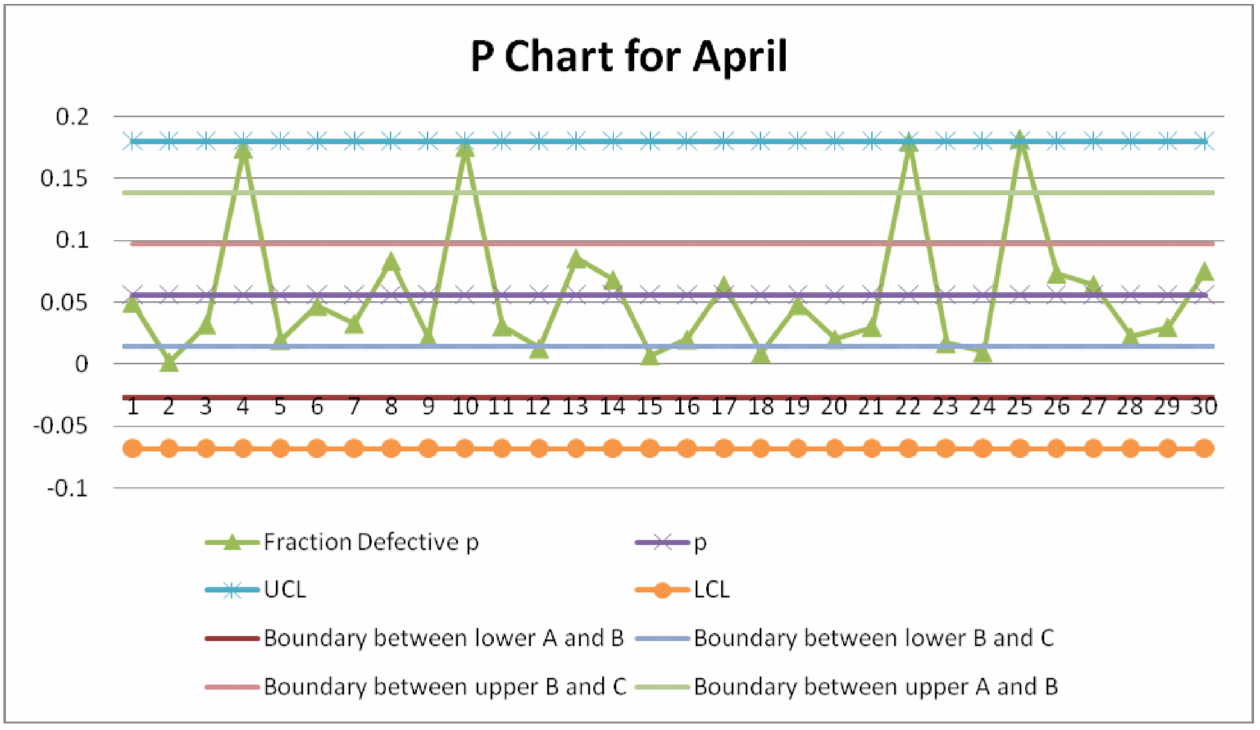
According to the March p Chart, two points are above the upper control limit and one point lies on the boundary of the UCL. According to the criteria for not being in a state of statistical control, as stated by James C. Benneyan in Table 1, none of the other out-of-control signals apply to the above chart.

The graph indicates an average defect percentage of 5.32% above the allowable 4%. After further investigation into the internal sub-division control points located at designated points in the production line, the following conclusions regarding the three points were made:

- On day 4, a cake and dough loss of 16.95% was recorded. During day 4 Catalyst Manufacturing had recurring power failures. At every restart point, the dough cutter rolls (refer to figure 4) need to be realigned. This takes ± 1 minute, causing the noodle cakes to be deformed and of uneven size.

- On day 8, a total loss of 18.2% was recorded. The rubber grips on the rotating bars, which pushes the cakes on to conveyer 1 (refer to problem 1), were perished. This resulted in 4 to 5 cakes in each slot on conveyer 1. Due to the narrowed end of the conveyer, the access noodle cakes in each slot are pressed together which results in parts of the cakes breaking off.
- On day 24, a cake and dough loss of 19.26% was recorded. During day 24, the wrapper experienced a vast number of foil jams. The wrapper was stopped in between the allocated 40 minute intervals (refer to problem 3). The rest of the production line could not be stopped and still produced 160 noodles per minute. As a result of excessive material handling by workers 1 to 4 capturing cakes still being produced, the noodle cakes were deformed.

Figure 8 p Chart for April

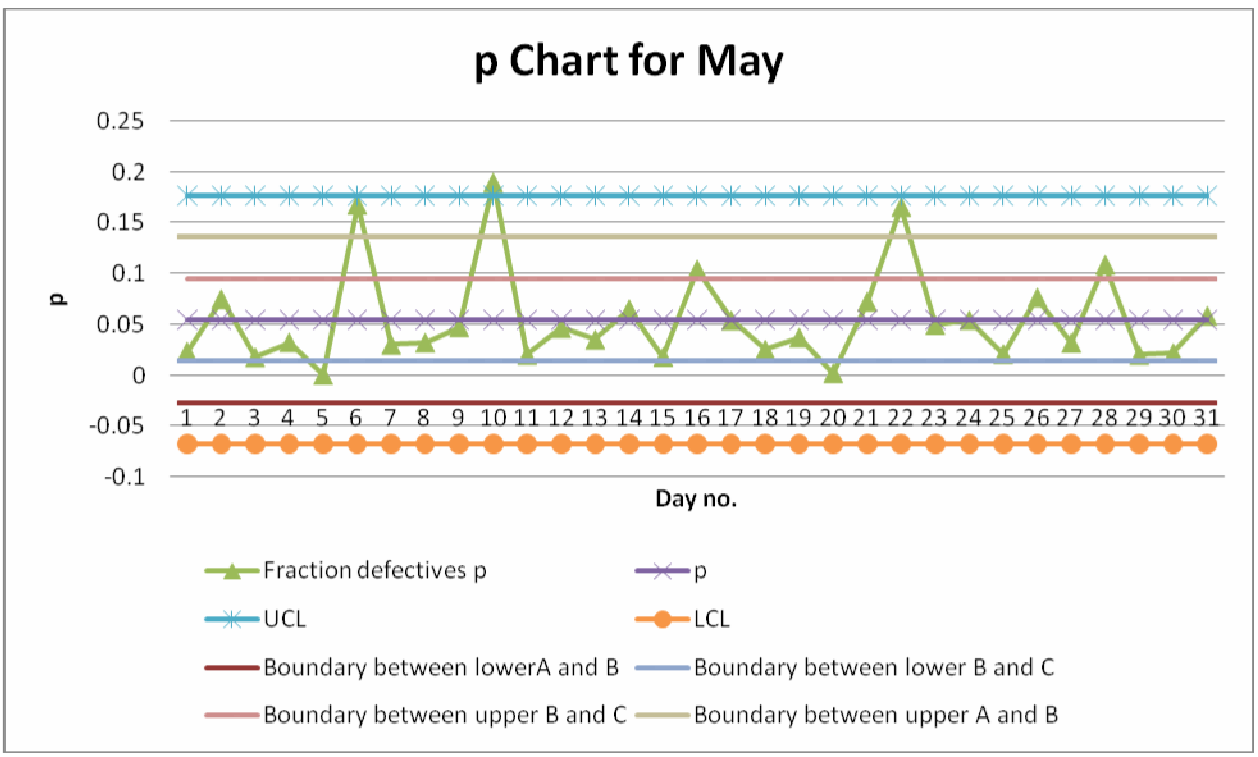


According to the April p Chart, four points lie on the boundary of the upper control limit. According to the criteria for not being in a state of statistical control, as stated by James C. Benneyan in Table 1, none of the other out-of-control signals apply to the above chart.

The graph indicates an average defect percentage of 5.62% above the allowable 4%. After further investigation into the internal sub-division control points located at designated points in the production line, the following conclusions regarding the three points were made:

- As a result of the wrapper not performing optimally at points 4 and 10, a total dough and cake loss of 17.41% and 17.53% respectively was recorded. As a result of excessive material handling by workers 1 to 4 capturing cakes that were still being produced, the noodle cakes were deformed.
- On day 22, a total loss of 18.03% was recorded. A rotating bar broke out of the rotating casing, and as a result, four cakes were aligned in one horizontal slot on conveyer 1. Due to the narrowed end of the conveyer, the access noodle cakes in each slot were pressed together, which resulted in parts of the cakes breaking off.
- On day 25, the dough rollers were not synchronized and produced out of shape cakes. This resulted in a total loss of 18.21%.

Figure 9 p Chart for May



According to the May p Chart, one point is above the upper control limit and two points lie on the boundary of the UCL. According to the criteria for not being in a state of statistical control as stated by James C. Benneyan in Table 1, none of the other out-of-control signals apply to the above chart.

The graph indicates an average defect percentage of 5.46% above the allowable 4%. After further investigation into the internal sub-division control points located at designated points in the production line, the following conclusions regarding the three points were made:

- Similar to the previous two months, the wrapper experienced problems on day 6 and 22, creating a total loss of 16.73% and 16.52% respectively.
- On day 10, a total dough and cake loss of 18.9% was recorded. This was a result of abnormalities occurring in the frying unit.

1.2 STABILISED P CHART

By eliminating the out-of-control points, the number of defects will fall within the allowable percentage. This can only be done by solving the current problems, such as the wrapper stop intervals and the amount of material handling. It is clear that the rotating bars that push the cakes on to conveyer 1 require continuous maintenance to prevent the current number of defects. For stabilised data, refer to Appendix C.

Examples of a stabilised process of each month:

Figure 10 Stabilised p Chart for March

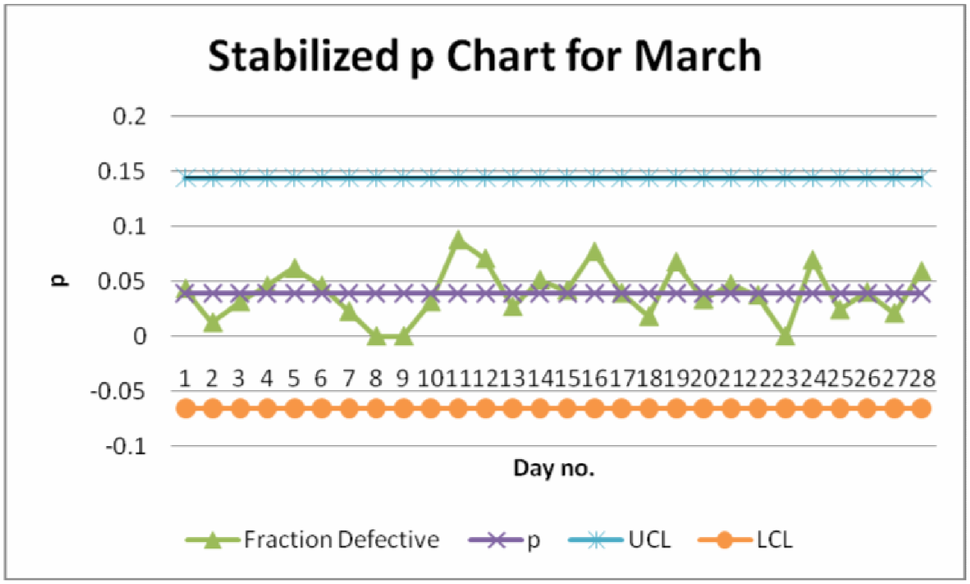


Figure 11 Stabilised p Chart for April

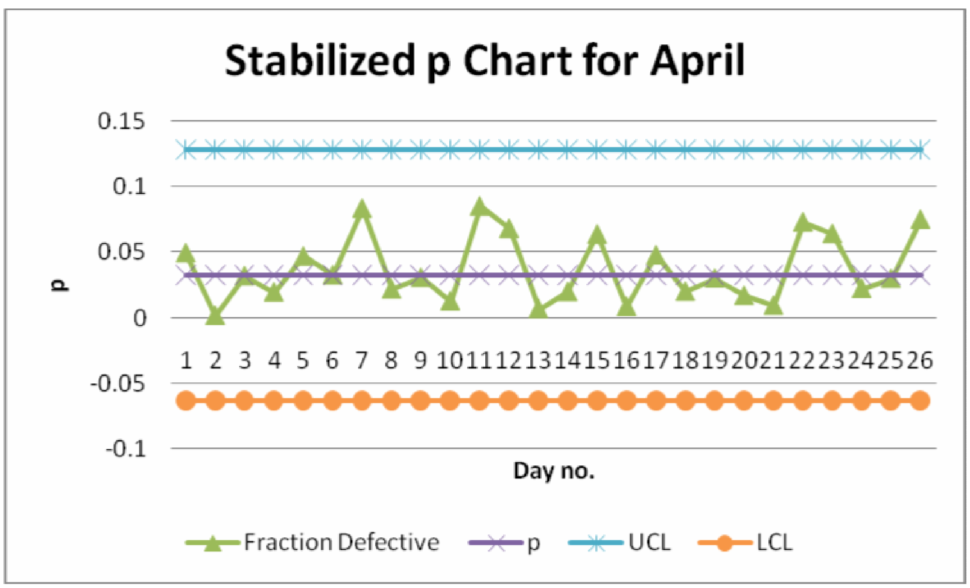
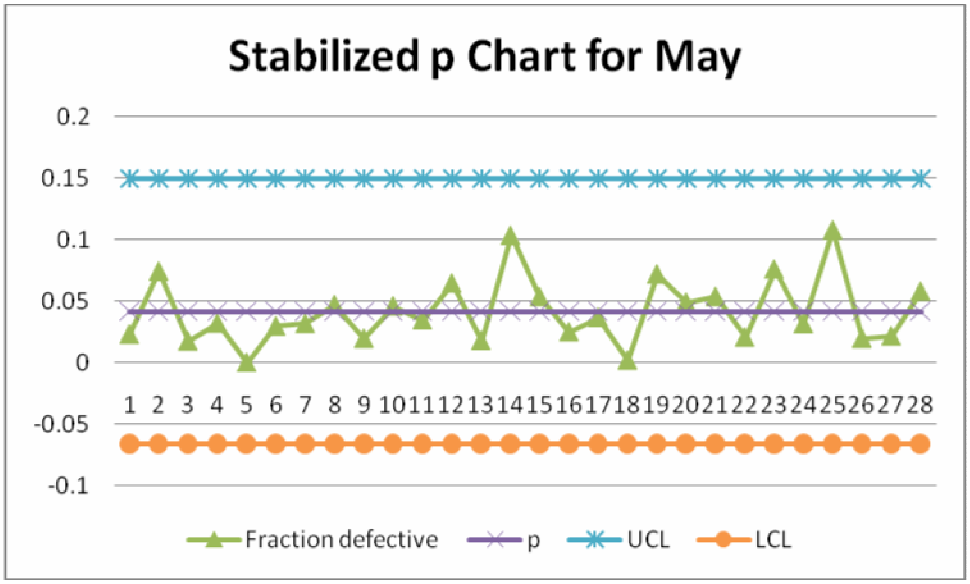


Figure 12 Stabilised p Chart for May



1.3 P CHART CONCLUSION

From the above statistical control charts it can be confirmed that the area before the two flow-wrappers generates the most rework. When the wrappers are idle, the line is still producing 160 noodle cakes per minute. This causes excess material handling in order to capture the cakes. These noodle cakes have to be placed back on to the line as soon as the wrapper is running again.

Information from the graph and internal sub-division control points also confirms that the area between the cooling unit and conveyer 4 and 5 (refer to APPENDIX A) are contributing to the most defects.

The number of defects can be reduced by continuously maintaining the rotating bars that push the cakes on to conveyer 1.

The charts also indicate that the dough rollers contribute to the total loss in the production line. This part of the line falls outside the boundaries of the initial project scope and will be incorporated in further findings and conclusions.

1.4 X-R CHART

In order to investigate the defects between the cooling unit and the wrapping area, an X-R Chart is used. Random observations were taken from the data provided by Catalyst Manufacturing during the period from March to May 2010. Catalyst Manufacturing requires a noodle cake weight of 73 grams. Each set of 6 measurements makes up a subgroup. For statistical data used, refer to Appendix D.

Figure 13 R Chart

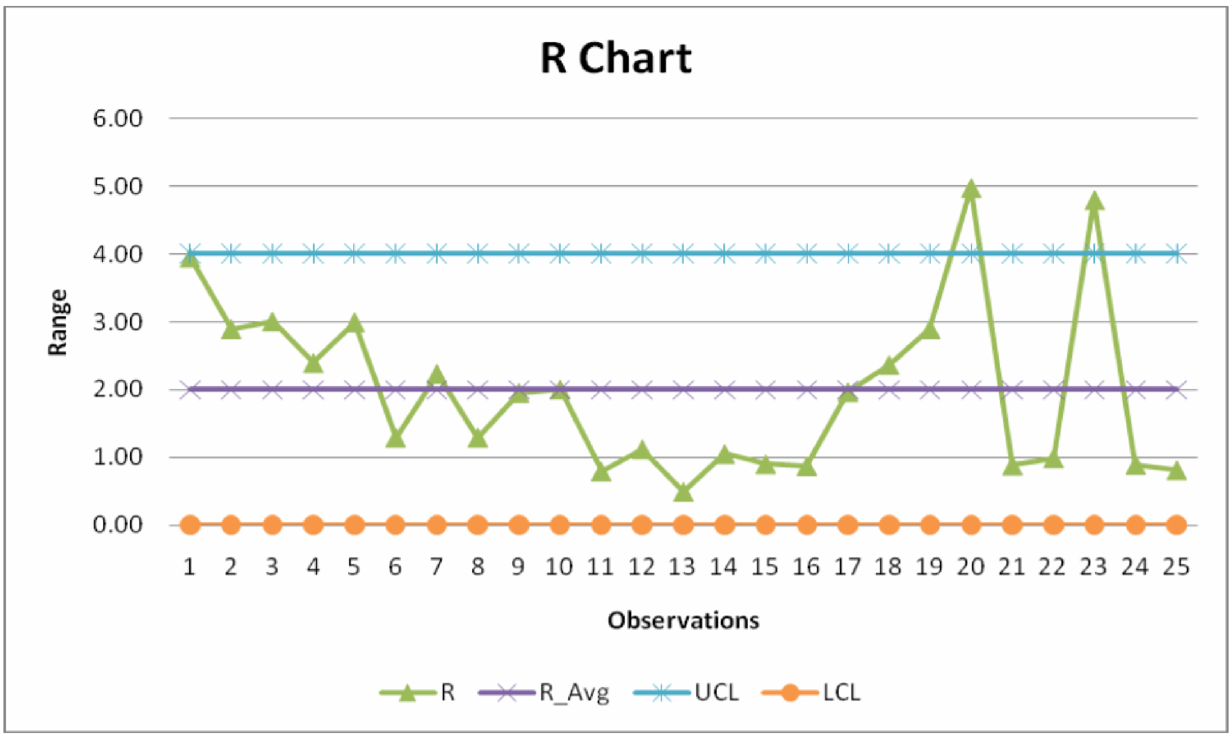
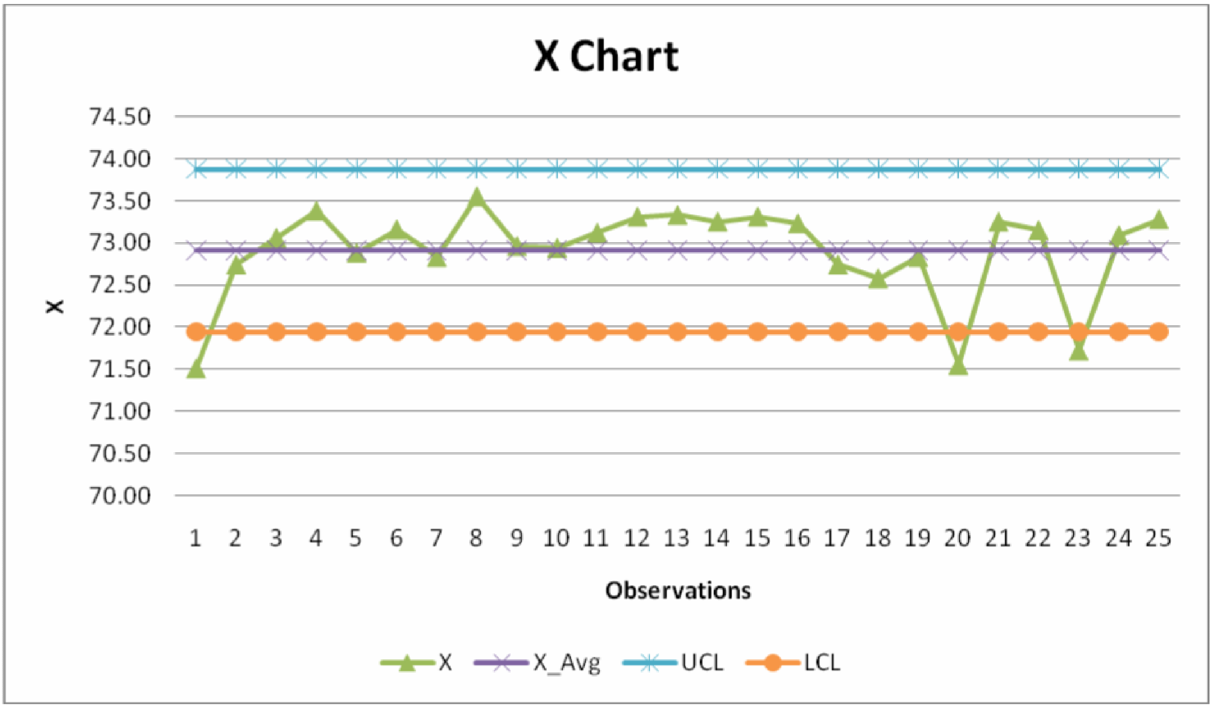


Figure 14 X Chart



From these control charts it is evident that 3 point falls outside the out-of-control limits. After further investigation, it is evident that most noodle cakes become deformed between the cooling unit and the wrapping area. This deformation can be ascribed to the narrowing end of conveyor 1 and material handling by the workers stationed on the line. The line currently produces an average noodle weight of 72.91 grams, which is less than the required 73 grams.

1.5 STABILISED X–R CHART

By eliminating the out-of-control points and therefore removing the greatest cause of deformed cakes, the line would stabilise and produce an average noodle cake weight of 73.06 grams. This can only be done by solving the problem of the narrow end at conveyor 1 and the amount of material handling. The next figures will illustrate the stable system if it were possible to eliminate all the points in question. For stabilised data, refer to Appendix E.

Figure 15 Stabilised R Chart

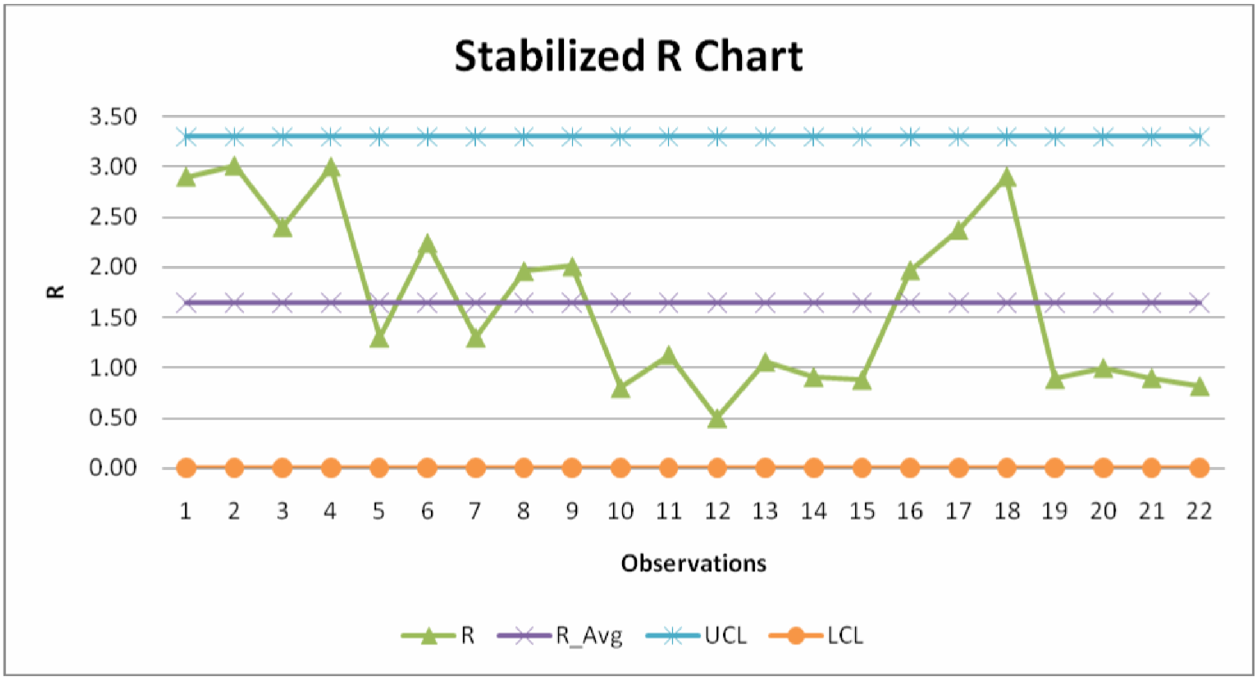
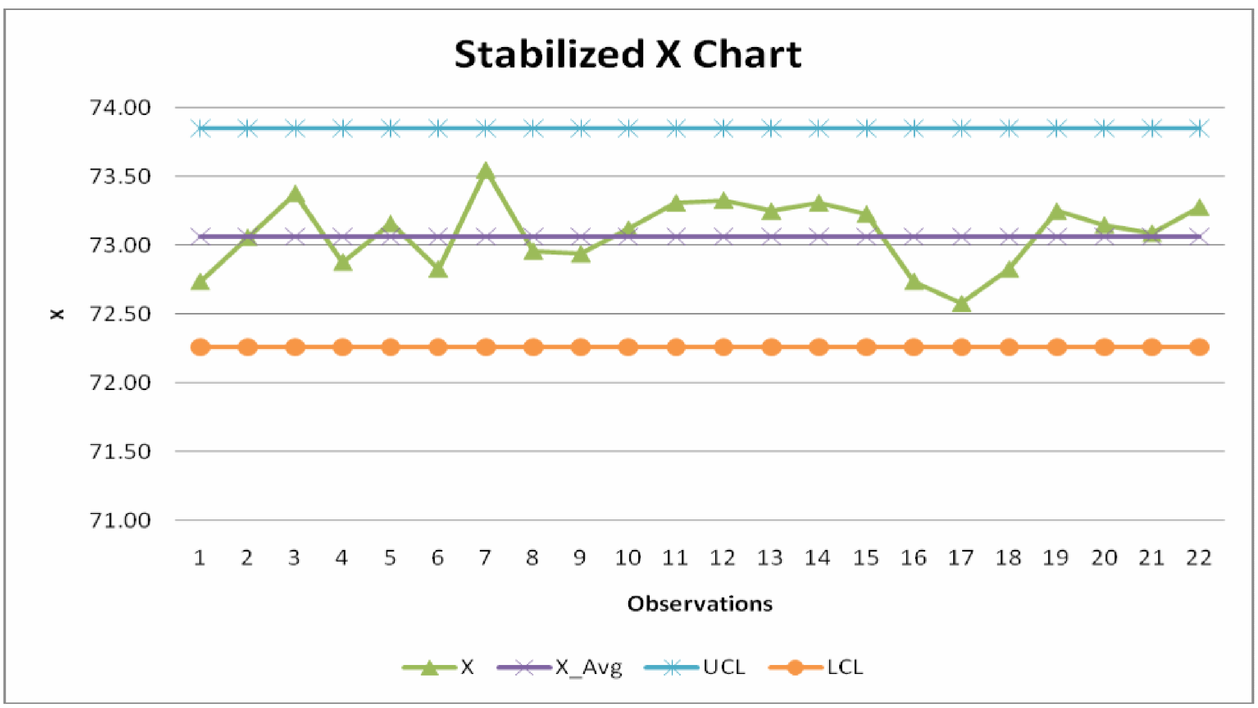


Figure 16 Stabilized X Chart



1.6 X-R CHART CONCLUSION

From the above statistical control charts it can be confirmed that the area before the two flow-wrappers generates the most rework. When the wrappers are idle, the line is still producing 160 noodle cakes per minute. This results in an excess material handling in order to capture the cakes. These noodle cakes have to be placed back on to the line as soon as the wrapper is running again.

Information from the graph and internal sub-division control points also confirms that the area between the cooling unit and conveyer 4 and 5 (refer to APPENDIX A) are contributing to the most defects.

1.7 PROCESS CAPABILITY

The purpose of process capability is to state if the stabilised process has the ability to meet specifications in one summary statistic. Four process capability indices are commonly used: C_p, CPU, CPL and C_{pk}.

Table 4 Statistical data from stabilised X-R Chart

R	1.65	**d2**	2.534
X	73.06	**d3**	0.848
n	6	**D3**	2.004
A2	0.483	**D4**	0.00

Catalyst Manufacturing requires a noodle cake weight of 73 grams.

Nominal = 73.00

Tolerance = 1.00

- Upper Specification Limit:

  USL = Nominal + Tolerance

  = 73.00 + 1.00

  = 74.00

- Lower Specification Limit:

  LSL = Nominal – Tolerance

  = 73.00 – 1.00

  = 72.00

- Mean = 73.06

- Standard Deviation (σ) = R/d2

  = 1.65/2.534

  = 0.65

- Upper Natural Limit:

  UNL = X + 3σ

  = 73.06 + 3*0.65

  = 75.01

- Lower Natural Limit:

  LNL = X - 3σ

  = 73.06 – 3*0.65

  = 71.11

- The C_p index is used to summarise a process's ability to meet two-sided specification limits:

  C_p = (USL – LSL)/(UNL – LNL)

  = (74.00 – 72.00)/(75.01 – 71.11)

  = 0.51

- The CPU is used to summarise a process's ability to meet a one-sided upper specification limit:

CPU = (X – LSL)/(UNL – X)

= (74.00 – 73.06)/(75.01 – 73.06)

= 0.48

- The CPL is used to summarise a process's ability to meet a one-sided lower specification limit:

CPL = (X – LSL)/3σ

= (73.06 – 72.00)/(3*0.65)

= 0.54

- The C_{pk} is used to summarise a process's capability to meet two-sided specification limits when the process is not centered on nominal:

C_{pk} = (USL – LSL)/3σ

= (74.00 – 72.00)/(3*0.65)

= 1.03

1.8 PROCESS CAPABILITY CONCLUSION

Table 5 Process capability conclusion

Capability Indices	Definition	Value	Conclusion
C_p	The ability of the process to comply with two-sided specification limits	0.51	The natural limits are twice as wide as the specification limits. The process will generate 86.64% of its output within specification limits. Even though the process is already stabilized, it can still be improved. A process capability of 1.0 indicates that a process will generate virtually all of its output within specification limits.
CPU	The ability of the process to comply with one-sided upper specification	0.48	The UNL of the process is greater than the USL, giving a CPU of less than one. As UNL minus USL increases, the fraction of process output that is out of specification will increase geometrically.
CPL	The ability of the process to comply with one-sided lower specification	0.54	The LNL of the process is bigger than the LSL, giving a CPL less than one. As LNL minus LSL increases, the fraction of process outputs that is out of specification will increase geometrically.

C_{pk}	The ability of the process to comply with two-sided specification limits when the process in not centered on the nominal	1.03	Catalyst Manufacturing is operating in defect prevention mode, thus striving for a C_{pk} value equal to one or bigger than one. It can be seen that if the out-of-control point were to be eliminated, the process will be capable.

2. COST-BENEFIT ANALYSIS

The cost-benefit analysis method is used to weigh options against one another and so achieve the most cost-effective solution. The first step is to identify the problem areas that need to be eliminated or reduced.

From the quality control study conducted, it is clear that the main problem areas on the production line are at:

- Conveyors 2 and 3, as a result of excess material handling by workers 1 and 2.
- The dough rollers, which contribute to the total loss in the production line. This part of the line falls outside the boundaries of the initial project scope and will be incorporated in further findings and conclusions.

The first option is to remove workers 1 and 2 by mechanically redesigning conveyors 1, 2 and 3. This redesign will control the orientation of the cakes as they move to conveyors 4 and 5, a task currently done by workers 1 and 2. Workers 1 and 2 are also responsible for removing defective cakes which are either deformed by the dough cutter or by the rotating bar breakdowns. The main objective would be to determine if it would be more cost effective to reduce the workers and only remove the defective cakes at the control point where the noodle cakes have already been supplied with a flavour sachet and wrapped.

The second option is to stop the whole production line when the wrapper is idle. The number of defects produced when the dough cutter is restarted will be weighed against the number of defects due to material handling at conveyors 2 and 3 where workers 1 and 2 have to remove cakes from the line that are still producing 160 cakes, even when the wrapper is idle.

2.1CURRENT SITUATION

Table 6 Current situation: Number of defective cakes per annum

Current situation		
Single unit direct production cost		
Noodle cake	R	0.58
Sachet	R	0.20
Wrapping	R	0.05
Total	R	0.83
Average loss percentage		
Average loss (noodle cake and dough)		7.94%
Average loss due to material handling		4.92%
*Other losses		3.02%
Unit production rate current situation		
Production hours/day		23
Production minutes/day		1,380
Units produced/minute		160
Maximum capacity – units/day		220,800
Maximum capacity – units/annum		80,592,000
Current loss/annum @ 7.94% of units		6,399,005
Current loss due to material handling		3,965,126
Current loss due to *other losses		2,433,878
Acceptable loss/annum @ 4% of units		3,223,680
Sale price per unit	R	1.40
Contribution/unit	R	0.57

*Other losses: Defective noodle cake production due to the structure of the current line. These problem areas exceed the boundaries of the project and will remain constant throughout the analysis.

Table 7 Current situation: Relevant costs and losses

Current situation		
Manpower cost to man conveyor belts 2 & 3		
Worker 1 (R3 500/month) x 13	R	45,500
Worker 2 (R3 500/month) x 13	R	45,500
Total direct labour cost	R	91,000
Production loss		
Current loss @ 7.94%	R	3,711,423
Current situation total loss	R	3,802,423

Currently, Catalyst Manufacturing's statistics indicate an average noodle loss (noodle cake and dough) of 7.94% against an allowed loss percentage of 4%. Table 6 provides a breakdown of the total loss percentage. Excess material handling occurring at conveyers 2 and 3 contributes to 4.92% of the total loss percentage. Table 6 also provides a single unit production cost breakdown.

A complete production day consists of 23 hours. One hour is allocated to cleaning and shift changes. Maximum capacity indicates the amount of noodle cakes that can be produced if no defects occurred.

Currently, workers 1 and 2 man conveyor belts 2 and 3. Their salaries, including a thirteenth cheque, contribute to the total variable cost and are therefore incorporated into the cost-benefit analysis.

2.2 OPTION 1

Table 8 Option 1: Number of defective cakes per annum

Option 1		
Single unit direct production cost		
Noodle cake	R	0.58
Sachet	R	0.20
Wrapping	R	0.05
Total	R	0.83
Average loss percentage		
Average loss (noodle cake and dough)		5.00%
Average loss due to material handling		1.98%
*Other losses		3.02%
Unit production rate option 1		
Production hours/day		23
Production minutes/day		1,380
Units produced/minute		160
Maximum capacity – units/day		220,800
Maximum capacity – units/annum		80,592,000
Estimated loss/annum @ 5% of units		4,029,600
Estimated loss due to material handling		1,595,722
Estimated loss due to *other losses		2,433,878
Acceptable loss/annum @ 4% of units		3,223,680

*Other losses: Defective noodle cake production due to the structure of the current line. These problem areas exceed the boundaries of the project and will remain constant throughout the analysis.

Table 9 Option 1: Relevant costs and losses

Option 1		
Manpower cost to man conveyor belts 2 & 3		
Worker 1 (R3 500/month) x 13	R	-
Worker 2 (R3 500/month) x 13	R	-
Total direct labour cost	R	-
Additional cost for option 1		
Additional cost of directional arms	R	5,000
Additional wrapping lost	R	201,480
Production loss		
Current loss/year @ 5% of units	R	2,337,168
Option 1 Total loss	R	2,543,648

The first option is to remove workers 1 and 2 by mechanically redesigning the dropdown slide after the noodle cakes leave conveyor 1. This redesign will control the orientation of the cakes as they move to conveyors 4 and 5, which is currently done by workers 1 and 2. This will be done by implementing a directional arm that will ensure that the cakes drop onto conveyor belts 2 and 3 at a 45° angle. An additional cost will be incurred (material cost plus labour cost) if the rotating arm is to be implemented. By removing and replacing the workers, material handling defects will decrease to 1.98%. Currently workers 3 and 4 are idle when the wrapper is stopped. These workers will remove the cakes still being produced when the wrapper is stopped to refoil.

Workers 1 and 2 are also responsible for removing defective cakes which are either deformed by the dough cutter or by the rotating bar breakdowns. If the workers are removed, the defective cakes will only be detected at the control point where the noodle cakes have already been supplied with a flavour sachet and wrapping. The flavour sachet will not be incorporated into the additional cost, as workers at the control point remove the sachets from defective finished products. The additional wrapping cost form part of the analysis, as it cannot be reused.

2.3 OPTION 2

Table 10 Option 2: Number of defective cakes per annum

Option 2		
Average loss percentage		
Average loss (noodle cake and dough)		7.94%
Average loss due to material handling		4.92%
*Other losses		3.02%
Single unit direct production cost		
Noodle cake	R	0.58
Sachet	R	0.20
Wrapping	R	0.05
Total	R	0.83
Unit production rate option 2		
Production hours/day		23.00
Production minutes/day		1,380.00
Units produced/minute		160.00
Maximum capacity – units/day		220,800.00
Maximum capacity – units/annum		80,592,000.00
Number of wrapper stoppages per day		34.00
Minutes per stoppage		2.00
Machine down time/day (minutes)		68.00
Units lost during down time/day		10,880.00
Units lost during plastic down time/annum		3,971,200.00
Sale price per unit		1.40
Contribution/unit		0.57
Units lost per restart		16
Units loss per day during restart		544.00
Units lost per annum during restart		198,560.00
Acceptable loss/annum @ 4% of units		3,223,680

*Other losses: Defective noodle cake production due to the structure of the current line. These problem areas exceed the boundaries of the project and will remain constant throughout the analysis.

Table 11 Option2: Relevant costs and losses

Option 2		
Manpower cost to man conveyor belts 2 & 3		
Worker 1 (R3 500/month) x 13	R	45,500
Worker 2 (R3 500/month) x 13	R	45,500
Total direct labour cost	R	91,000
Lost contribution if stopped during wrapper downtime	R	-
Reduced losses if stopped during wrapper downtime	R	2,303,296
Losses during restart in Rand	R	-115,165
Option 2 Total loss	R	2,279,131

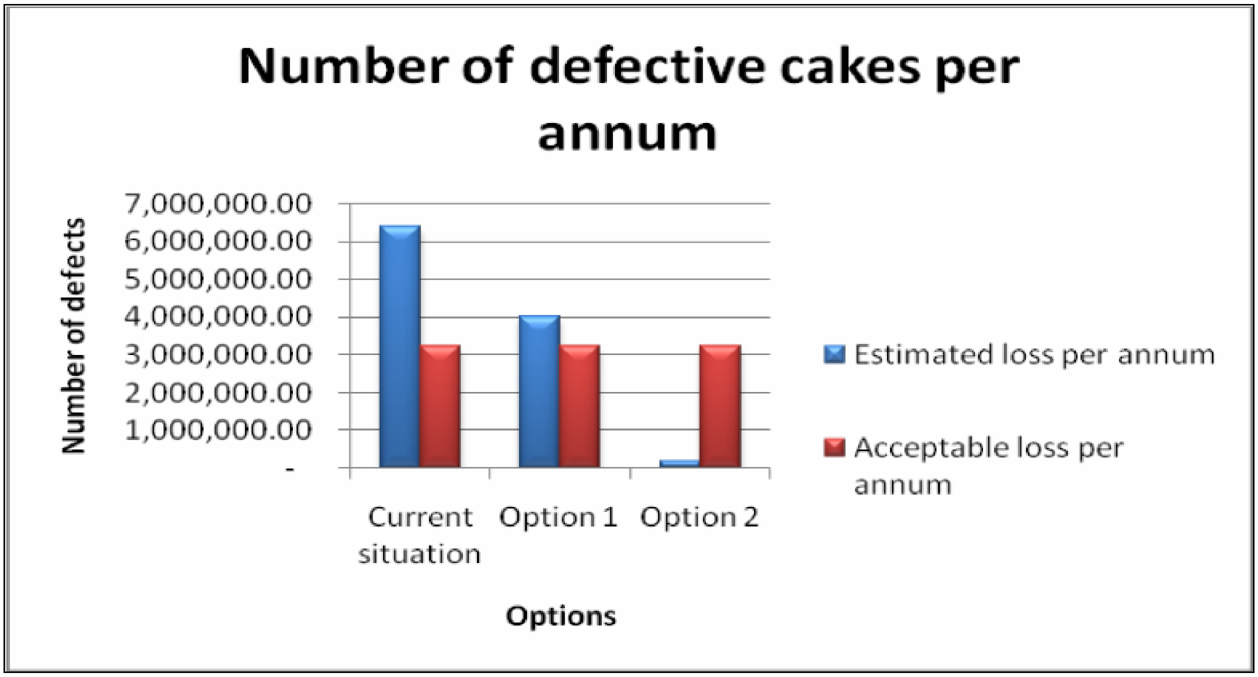
The second option is to stop the whole production line when the wrapper is idle. The wrapper stops every 40 minutes for ± 2 minutes. If the dough cutter is stopped as well, 320 cakes will not be produced with each stoppage. This stoppage does not contribute to the total loss as the cakes will never be produced. Only the total number produced per day will decrease.

Each time the dough cutter is restarted, 16 cakes will be deformed. Workers 1 and 2 will remove the defective cakes produced with each restart and control the orientation of the cakes as they move to conveyor belts 4 and 5. Since the workers remain stationed at conveyors 2 and 3, the same average loss percentage is used as with the current situation.

2.3 COST-BENEFIT ANALYSIS CONCLUSION

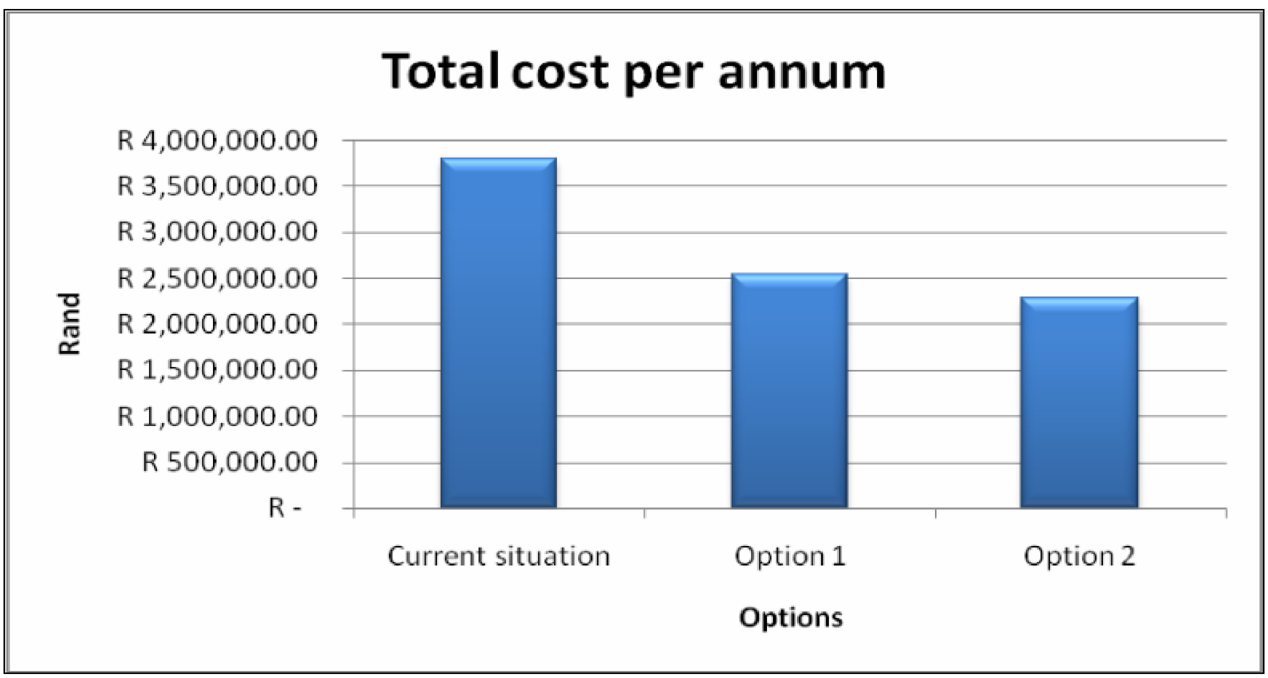
From the above analysis it can be seen that option 2 produces fewer defects than the acceptable loss of 4%. By stopping the entire production line when the wrapper is idle, fewer units are produced but also less deformed noodle cakes are created through material handling. Even though the current situation is producing more cakes than option 2, the current situation has an average loss of 7.94%. By stopping the entire production line, the number of defects produced in the current situation will break even with the units not produced in option 2.

Figure 17 Number of defective cakes per annum



Option 2 indicates the lowest total cost even with workers 1 and 2 instated. It is more profitable to produce less noodle cakes per annum with a lower defect percentage.

Figure 18 Total cost per annum



3. CONCLUSION

Catalyst Manufacturing is currently experiencing major problems within the production line, resulting in large overhead costs and a vast number of defective products. The area before the two flow-wrappers generates the most rework. When the wrappers are idle, the line is still producing 160 noodle cakes per minute. This results in excess material handling in order to capture the cakes. The area between the cooling unit and conveyer belts 4 and 5 (refer to APPENDIX A) are contributing to the most defects. The dough rollers contribute to the total loss in the production line. This part of the line falls outside the boundaries of the initial project scope and was incorporated into the final analysis.

According to a cost benefit analysis, stopping the entire production line when the wrapper is idle will result in fewer units produced. Moreover, fewer deformed noodle cakes will be created through material handling. By stopping the entire production line, the number of defects produced in the current situation will break even with the units not produced when the stoppage occurs. It is more profitable to produce less noodle cakes per annum with a lower defect percentage.

If Catalyst Manufacturing were to implement the cost-benefit approach, it can be seen that workers 1 and 2 do not have to be removed, as they play an essential role in removing defect noodle cakes before the deformed cakes are wrapped.

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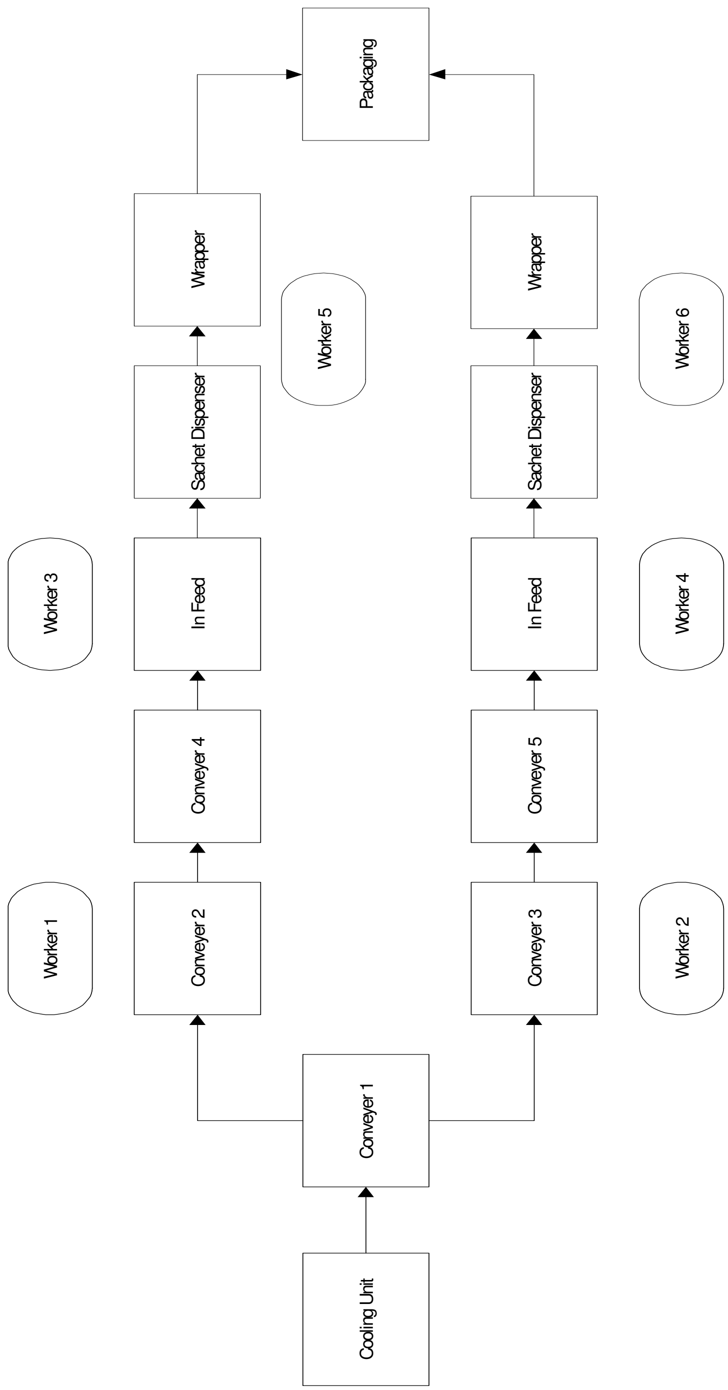
APPENDICES

APPENDIX A

Figure 19 Flow diagram



APPENDIX B

Table 12 Statistical data - March p Chart

Day	No. Inspected	No. Rejected	Fraction Defective p	$\overline{p}$	UCL	LCL	Boundary between lower zones A and B	Boundary between lower zones B and C	Boundary between upper zones B and C	Boundary between upper zones A and B
1	10000	432	0.0432	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
2	10000	124	0.0124	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
3	10000	312	0.0312	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
4	10000	1695	0.1695	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
5	10000	458	0.0458	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
6	10000	618	0.0618	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
7	10000	458	0.0458	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
8	10000	1820	0.182	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
9	10000	226	0.0226	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
10	10000	0	0	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
11	10000	0	0	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
12	10000	312	0.0312	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
13	10000	876	0.0876	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
14	10000	704	0.0704	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
15	10000	268	0.0268	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
16	10000	512	0.0512	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
17	10000	417	0.0417	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
18	10000	768	0.0768	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
19	10000	392	0.0392	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
20	10000	179	0.0179	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
21	10000	674	0.0674	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
22	10000	334	0.0334	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
23	10000	472	0.0472	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
24	10000	1926	0.1926	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
25	10000	374	0.0374	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
26	10000	0	0	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
27	10000	692	0.0692	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
28	10000	240	0.024	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
29	10000	400	0.04	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
30	10000	209	0.0209	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
31	10000	591	0.0591	0.053171	0.174067	-0.06773	-0.02743	0.012872	0.09347	0.133769
Total	310000	16483								
Average	10000	531.7097								
Centreline	0.053171									

Table 13 Statistical data - April p Chart

Day	No. Inspected	No. Rejected	Fraction Defective p	$\overline{p}$	UCL	LCL	Boundary between lower zones A and B	Boundary between lower zones B and C	Boundary between upper zones B and C	Boundary between upper zones A and B
1	10000	496	0.0496	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
2	10000	18	0.0018	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
3	10000	321	0.0321	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
4	10000	1741	0.1741	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
5	10000	197	0.0197	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
6	10000	471	0.0471	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
7	10000	328	0.0328	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
8	10000	836	0.0836	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
9	10000	219	0.0219	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
10	10000	1753	0.1753	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
11	10000	307	0.0307	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
12	10000	128	0.0128	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
13	10000	854	0.0854	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
14	10000	683	0.0683	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
15	10000	70	0.007	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
16	10000	200	0.02	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
17	10000	639	0.0639	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
18	10000	88	0.0088	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
19	10000	480	0.048	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
20	10000	203	0.0203	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
21	10000	302	0.0302	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
22	10000	1795	0.1795	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
23	10000	170	0.017	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
24	10000	96	0.0096	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
25	10000	1821	0.1821	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
26	10000	732	0.0732	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
27	10000	643	0.0643	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
28	10000	224	0.0224	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
29	10000	300	0.03	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
30	10000	752	0.0752	0.056223	0.180341	-0.06789	-0.02652	0.014851	0.097596	0.138968
Total	300000	16867								
Average	10000	562.2333								
Centreline	0.056223									

Table 14 Statistical data – May p Chart

Day	No. Inspected	No. Rejected	Fraction Defective p	$\overline{p}$	UCL	LCL	Boundary between lower zones A and B	Boundary between lower zones B and C	Boundary between upper zones B and C	Boundary between upper zones A and B
1	10000	230	0.023	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
2	10000	745	0.0745	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
3	10000	174	0.0174	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
4	10000	321	0.0321	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
5	10000	0	0	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
6	10000	1673	0.1673	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
7	10000	297	0.0297	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
8	10000	318	0.0318	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
9	10000	471	0.0471	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
10	10000	1890	0.189	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
11	10000	196	0.0196	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
12	10000	460	0.046	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
13	10000	347	0.0347	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
14	10000	647	0.0647	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
15	10000	178	0.0178	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
16	10000	1037	0.1037	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
17	10000	536	0.0536	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
18	10000	249	0.0249	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
19	10000	368	0.0368	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
20	10000	18	0.0018	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
21	10000	720	0.072	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
22	10000	1652	0.1652	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
23	10000	491	0.0491	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
24	10000	538	0.0538	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
25	10000	206	0.0206	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
26	10000	761	0.0761	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
27	10000	316	0.0316	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
28	10000	1082	0.1082	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
29	10000	196	0.0196	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
30	10000	216	0.0216	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
31	10000	582	0.0582	0.054565	0.176945	-0.06782	-0.02702	0.013771	0.095358	0.136151
Total	310000	16915								
Average	10000	545.6452								
Centreline	0.054565									

APPENDIX C

Table 15 Stabilised data – March p Chart

Day	No. Inspected	No. Rejected	Fraction Defective p	$\bar{p}$	UCL	LCL	Boundary between lower zones A and B	Boundary between lower zones B and C	Boundary between upper zones B and C	Boundary between upper zones A and B
1	10000	432	0.0432	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
2	10000	124	0.0124	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
3	10000	312	0.0312	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
5	10000	458	0.0458	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
6	10000	618	0.0618	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
7	10000	458	0.0458	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
9	10000	226	0.0226	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
10	10000	0	0	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
11	10000	0	0	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
12	10000	312	0.0312	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
13	10000	876	0.0876	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
14	10000	704	0.0704	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
15	10000	268	0.0268	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
16	10000	512	0.0512	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
17	10000	417	0.0417	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
18	10000	768	0.0768	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
19	10000	392	0.0392	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
20	10000	179	0.0179	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
21	10000	674	0.0674	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
22	10000	334	0.0334	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
23	10000	472	0.0472	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
25	10000	374	0.0374	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
26	10000	0	0	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
27	10000	692	0.0692	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
28	10000	240	0.024	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
29	10000	400	0.04	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
30	10000	209	0.0209	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
31	10000	591	0.0591	0.039436	0.144305	-0.06543	-0.03048	0.004479	0.074392	0.109349
Total	280000	11042								
Average	10000	394.3571								
Centreline	0.039436									

Table 16 Stabilised data – April p Chart

Day	No. Inspected	No. Rejected	Fraction Defective p	$\overline{p}$	UCL	LCL	Boundary between lower zones A and B	Boundary between lower zones B and C	Boundary between upper zones B and C	Boundary between upper zones A and B
1	10000	496	0.0496	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
2	10000	18	0.0018	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
3	10000	321	0.0321	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
5	10000	197	0.0197	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
6	10000	471	0.0471	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
7	10000	328	0.0328	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
8	10000	836	0.0836	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
9	10000	219	0.0219	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
11	10000	307	0.0307	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
12	10000	128	0.0128	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
13	10000	854	0.0854	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
14	10000	683	0.0683	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
15	10000	70	0.007	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
16	10000	200	0.02	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
17	10000	639	0.0639	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
18	10000	88	0.0088	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
19	10000	480	0.048	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
20	10000	203	0.0203	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
21	10000	302	0.0302	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
23	10000	170	0.017	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
24	10000	96	0.0096	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
26	10000	732	0.0732	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
27	10000	643	0.0643	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
28	10000	224	0.0224	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
29	10000	300	0.03	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
30	10000	752	0.0752	0.032523	0.128101	-0.06305	-0.0312	0.000664	0.064383	0.096242
Total	300000	9757								
Average	10000	375.2692								
Centreline	0.032523									

Table 17 Stabilised data – May p Chart

Day	No. Inspected	No. Rejected	Fraction Defective p	$\overline{p}$	UCL	LCL	Boundary between lower zones A and B	Boundary between lower zones B and C	Boundary between upper zones B and C	Boundary between upper zones A and B
1	10000	230	0.023	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
2	10000	745	0.0745	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
3	10000	174	0.0174	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
4	10000	321	0.0321	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
5	10000	0	0	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
7	10000	297	0.0297	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
8	10000	318	0.0318	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
9	10000	471	0.0471	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
11	10000	196	0.0196	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
12	10000	460	0.046	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
13	10000	347	0.0347	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
14	10000	647	0.0647	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
15	10000	178	0.0178	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
16	10000	1037	0.1037	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
17	10000	536	0.0536	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
18	10000	249	0.0249	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
19	10000	368	0.0368	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
20	10000	18	0.0018	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
21	10000	720	0.072	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
23	10000	491	0.0491	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
24	10000	538	0.0538	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
25	10000	206	0.0206	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
26	10000	761	0.0761	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
27	10000	316	0.0316	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
28	10000	1082	0.1082	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
29	10000	196	0.0196	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
30	10000	216	0.0216	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
31	10000	582	0.0582	0.041786	0.149602	-0.06603	-0.03009	0.005847	0.077725	0.113663
Total	280000	11700								
Average	10000	417.8571								
Centreline	0.041786									

APPENDIX D

Table 18 Statistical data – X-R Chart

	Weight (grams)						Nominal weight 73.00 grams	
OBS #	1	2	3	4	5	6	R	$\bar{X}$
1	73.52	71.20	71.89	73.89	73.05	72.50	3.95	71.51
2	74.00	73.80	73.70	71.10	72.50	72.00	2.90	72.74
3	73.40	72.80	73.23	72.97	72.74	73.21	3.01	73.06
4	71.00	74.60	71.95	73.90	73.82	73.60	2.40	73.38
5	72.90	71.10	73.60	71.95	72.00	72.99	3.00	72.88
6	73.20	73.12	73.16	72.80	73.16	73.07	1.30	73.16
7	73.50	71.62	73.12	72.99	73.06	73.14	2.24	72.83
8	74.20	72.90	73.92	73.00	72.95	73.00	1.30	73.55
9	73.02	71.64	73.60	73.21	72.80	73.03	1.96	72.96
10	72.87	71.80	73.70	73.81	72.63	73.05	2.01	72.94
11	73.52	73.60	72.80	72.80	73.43	72.99	0.80	73.12
12	73.07	73.06	73.90	73.50	72.90	72.88	1.13	73.31
13	73.00	73.00	73.87	73.32	73.07	73.10	0.50	73.33
14	72.80	73.50	73.02	73.86	73.24	72.99	1.06	73.25
15	73.11	72.89	73.80	72.99	72.67	73.09	0.91	73.31
16	72.72	73.44	73.30	73.71	73.30	72.60	0.88	73.23
17	71.60	73.01	73.57	73.00	72.00	72.83	1.97	72.74
18	74.00	71.63	72.00	72.40	71.85	72.77	2.37	72.58
19	73.70	70.80	73.09	73.03	73.40	73.08	2.90	72.83
20	73.98	73.10	69.00	71.50	70.63	69.00	4.98	71.55
21	73.89	73.00	73.60	73.02	72.65	73.21	0.89	73.25
22	73.00	73.00	73.54	72.54	73.40	73.03	1.00	73.15
23	73.90	72.60	73.47	69.99	69.10	73.00	4.80	71.72
24	73.50	73.42	72.60	72.97	73.00	73.20	0.90	73.09
25	73.60	72.78	73.58	73.76	73.11	72.73	0.82	73.28
						Total	49.98	1822.75

Table 19 Statistical data – R Chart

Obs #	$\bar{X}$	R	R_Avg	UCL(R)	LCL(R)	Boundary between lower zones A and B	Boundary between lower zones B and C	Boundary between upper zones B and C	Boundary between upper zones A abd B
1	71.51	3.95	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
2	72.74	2.90	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
3	73.06	3.01	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
4	73.38	2.40	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
5	72.88	3.00	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
6	73.16	1.30	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
7	72.83	2.24	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
8	73.55	1.30	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
9	72.96	1.96	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
10	72.94	2.01	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
11	73.12	0.80	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
12	73.31	1.13	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
13	73.33	0.50	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
14	73.25	1.06	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
15	73.31	0.91	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
16	73.23	0.88	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
17	72.74	1.97	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
18	72.58	2.37	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
19	72.83	2.90	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
20	71.55	4.98	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
21	73.25	0.89	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
22	73.15	1.00	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
23	71.72	4.80	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
24	73.09	0.90	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
25	73.28	0.82	2.00	4.01	0.00	0.6614	1.3307	2.6693	3.3386
Total	1822.75	49.98							

Table 20 Statistical data – X Chart

Obs #	$\bar{X}$	R	X_Avg	UCL(X)	LCL(X)	Boundary between lower zones A and B	Boundary between lower zones B and C	Boundary between upper zones B and C	Boundary between upper zones A abd B
1	71.51	3.95	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
2	72.74	2.90	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
3	73.06	3.01	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
4	73.38	2.40	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
5	72.88	3.00	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
6	73.16	1.30	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
7	72.83	2.24	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
8	73.55	1.30	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
9	72.96	1.96	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
10	72.94	2.01	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
11	73.12	0.80	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
12	73.31	1.13	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
13	73.33	0.50	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
14	73.25	1.06	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
15	73.31	0.91	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
16	73.23	0.88	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
17	72.74	1.97	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
18	72.58	2.37	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
19	72.83	2.90	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
20	71.55	4.98	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
21	73.25	0.89	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
22	73.15	1.00	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
23	71.72	4.80	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
24	73.09	0.90	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
25	73.28	0.82	72.91	73.88	71.94	72.67172	72.79086	73.02914	73.14828
Total	1822.75	49.98							

APPENDIX E

Table 21 Stabilised data – R Chart

Obs #	$\bar{X}$	R	R_Avg	UCL(R)	LCL(R)	Boundary between lower zones A and B	Boundary between lower zones B and C	Boundary between upper zones B and C	Boundary between upper zones A abd B
2	72.74	2.90	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
3	73.06	3.01	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
4	73.38	2.40	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
5	72.88	3.00	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
6	73.16	1.30	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
7	72.83	2.24	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
8	73.55	1.30	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
9	72.96	1.96	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
10	72.94	2.01	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
11	73.12	0.80	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
12	73.31	1.13	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
13	73.33	0.50	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
14	73.25	1.06	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
15	73.31	0.91	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
16	73.23	0.88	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
17	72.74	1.97	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
18	72.58	2.37	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
19	72.83	2.90	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
21	73.25	0.89	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
22	73.15	1.00	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
24	73.09	0.90	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
25	73.28	0.82	1.65	3.30	0.00	0.551380	1.093874	2.245561	2.754664
Total	1607.27	36.25							

Table 22 Stabilised data – X Chart

Obs #	$\bar{X}$	R	X_Avg	UCL(X)	LCL(X)	Boundary between lower zones A and B	Boundary between lower zones B and C	Boundary between upper zones B and C	Boundary between upper zones A abd B
2	72.74	2.90	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
3	73.06	3.01	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
4	73.38	2.40	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
5	72.88	3.00	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
6	73.16	1.30	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
7	72.83	2.24	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
8	73.55	1.30	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
9	72.96	1.96	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
10	72.94	2.01	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
11	73.12	0.80	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
12	73.31	1.13	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
13	73.33	0.50	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
14	73.25	1.06	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
15	73.31	0.91	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
16	73.23	0.88	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
17	72.74	1.97	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
18	72.58	2.37	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
19	72.83	2.90	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
21	73.25	0.89	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
22	73.15	1.00	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
24	73.09	0.90	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
25	73.28	0.82	73.06	73.85	72.26	72.53172	72.79086	73.32194	73.59288
Total	1607.27	36.25							