Investigation on a Multiscale Sustainable Manufacturing Approach to Production Changeover Complexity Reduction and its Implementation through Smart Surfaces and Process Optimization

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By

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Abstract

In the last two decades or so, we have seen rapid development in sustainable manufacturing and technologies, which have come to play an increasingly vital role in the manufacturing process improvement and agility enhancement at a manufacturing company. Manufacturers have to responsively compete in the market with a sustainable manner. The main aims of most production facilities is to minimize manufacturing costs while addressing the variety and quality needs of the products. This necessity endorses the importance of flexibility, reconfiguration and responsiveness. To be responsive to the customers' dynamic needs and reduce production costs, manufacturers often have to produce a variety of products on a single production system but further supported with technical means on agility and sustainability. It often takes time and resources to switch from one product to another on the same production system. Producing a variety of products on a single production system also increases the manufacturing complexity associated with the system and processes. Modern complex products or equipment may have thousands of parts and take a tedious number of manufacturing/assembly steps to make these products. The setup time and resources used in the changeover process are a completely loss while there is no production taking place.

For sustainable manufacturing there is an immediate need to eliminate or minimize these loses due to cleaning, changeover and setup while the manufacturing system and production line being shut down. This can be overcome by scientific analysis and understanding of each of the steps of production setup, and some sustainable techniques can be applied to reduce setup time/changeover and improve sustainability of the manufacturing system/process. It is essentially important to investigate the design of a sustainable manufacturing system and the underlying complexity in a scientific manner, so to minimize the production changeover and greatly enhance the productivity and efficiency from the view point of sustainability while supported by multiscale modelling and analysis.

This doctoral research aims to investigate the key bottleneck issues in a food packaging manufacturing system through the multiscale sustainable manufacturing approach and the associated implementation perspectives. The approach is described in details in chapter 3 and chapter 4. The research is focused on design of smart surfaces applicable to the packaging equipment and its impact on reducing production changeover and complexity towards a sustainable manufacturing system, which is thoroughly undertaken in light of multiscale modelling and analysis and system engineering simulations. A food manufacturing case study is conducted and actual data is used in liaison with an industrial partner company. In the study, three aspects are considered in production changeover both qualitatively and quantitatively, including reduction of complexity, cleaning of the equipment/machines, and sustainability. Different aspects of the complexity are discussed and explored, and corresponding experiments carried out but focused on using different micro surface structures. Most of the time consumed during changeover is on the cleaning of metal conveyors or machines. Therefore, metal surface structures in micro scale are studied in-depth. A self-cleaning property of ultra-hydrophobic surfaces is investigated and applied to reduce the frequency of the cleaning on the conveyor panel surfaces and thus to reduce the time consumed on their cleaning. Process mapping and facility layout are also studied and discussed during this doctoral study to improve the production changeover process at the macro scale. Additionally, recommendations for automation are made and explored to improve the manufacturing facility performance. A new simulation model is developed for the dedicated food packaging manufacturing system, which can be used as a 'virtual factory' and to help model the existing production setup and the process optimization while with the underlying thinking on the scales of both macro and micro combined in a sustainable manufacturing manner.

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Nomenclature

2D	Two-dimensional
3D	Three-dimensional
AD	Axiomatic design
CPC	Complexity in production changeover
DC	Data collection
DFA	Design for assembly
DFM	Design for manufacturing
DPS	Design parameters of system
DT	Down time
FP	Functional parameters
FR	Functional requirements
HP	Hybrid parameters
ISO	International standard organisation
LSE	Low surface energy
M & S	Modelling and simulation
MS	Machined surface
PC	Production changeover
RMS	Root mean square
SC	Self cleaning
SCF	Sustainable changeover features

SCM	Sustainable changeover model
SD	Sustainable design
SFLD	Sustainable facility layout design
SM	Sustainable manufacturing
SMED	Single minute exchange die
SP	Spatial parameters
SR	Surface roughness
SRM	Surface roughness measurements
SS	Smart surfaces
ST	Surface texture
TIC	Time independent complexity
VPL	Virtual production line
WM	Waste minimization

Fr	Functional requirements of the system
H	Surface height in bearing area
L	Characteristics length in (m)
P	Primary profile
p	Density of the fluid
Pa	Arithmetical mean
Pc	Mean height of profile element

Pdc	Section height level difference for the primary profile
Pdq	Root mean square slope for the primary profile
Pku	Kurtosis of the primary profile
Pmr	Relative material length rate of the primary profile
$Pmr(c)$	Material length rate of the primary profile (formerly tp)
Pp	Maximum profile peak height
Pq	Root mean square deviation
Psk	Skewness of the primary profile
Psm	Mean width of the primary profile element
Pt	Total height of profile
Pv	Maximum profile valley depth
Pz	Maximum height of the profile
R	Roughness profile
Ra	Arithmetical mean roughness
Rc	Mean height of profile element average value of the height of the curve
Rdc	Signifies the height difference in section height level c
Rdq	Root mean square of the local tilt along with sampling area
Re	Ratio between internal forces and viscous forces
Rku	Kurtosis of the assessed profile
Rmr	Rmr indicates the material ratio
$Rmr(c)$	Material ratio

Rp	Highest point of the profile in the evaluation length
Rq	Root mean square roughness
Rsk	Skewness uses the cube of the root mean square deviation
Rsm	Mean width of the profile element
Rt	Vertical distance between maximum profile peak height
Rv	Roughness profile valley depth
Rz	Maximum height of profile in sampling area
Sbi	Surface bearing index
Sci	Core fluid retention index
Sq	Root mean square height
Svi	Fluid retention in the valley zone
μ	Absolute dynamics fluid viscosity (N S / m^2)
V	Volume of the surface
Vc	Void volume
Vv	Void volume
vs	Mean fluid velocity
W	Waviness profile
Wa	Arithmetical mean waviness
Wc	Mean height of profile element
Wdc	Section height level difference for the waviness profile
Wdq	Root mean square slope for the waviness

Wku	Kurtosis of the waviness profile
Wmr	Relative material length rate of the waviness profile
$Wmr(c)$	Material length rate of the waviness
Wp	Waviness of the profile
Wq	Root mean square waviness for the waviness profile
Wsk	Skewness of the waviness profile
Wsm	Mean width of the waviness element
Wt	Maximum profile valley depth along the evaluation length
Wv	Waviness profile valley depth
Wz	Maximum waviness of the sampling area

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Chapter 1 Introduction

1.1. Background of the research

The rising demand for customized products for customers is an increasing trend in today's market. This has made a huge impact on manufacturing industries and means that manufacturing industry must be flexible to meet customers' demands and compete in the market. It also causes manufacturers to increase the variety of their products and reduce the batch size. Producing a variety of products on the same production line means more production changeovers. The design and operation of a production and manufacturing system have important effects on manufacturing productivity, return on investment and market share.

Despite the extensive literature describing and advocating continuous improvement programmes, we still lack a clear understanding of how continuous improvement efforts directed at different parameters of manufacturing systems, such as machine downtime, cleaning and setup time. The main reason for the investigation of manufacturing complexity is to understand the complexity in production changeover. Regular cleaning in the food industry involves resources such as sanitising material solutions, equipment and labour hours, and is necessary in order to maintain freshness on the typical surface encountered and utilised during production. It utilises resources and time. Therefore we study the surface of the production line and studied the surface texture. Sustainable product design and manufacturing is an important concern for every organization, and has its own importance in sustainable development. The principal goal is reducing the changeover complexity of engineered systems through the use of simple sustainable design based on fundamental principles so as to increase reliability, reduce the costs of development and sustainable operation and, subsequently, enhance performance [13][14]. The setup should be as simple as possible to minimize mistakes, and there is a need to ensure that no special technical skills are needed to carry out setup; this ensures that the person operating the machine can perform the setup with ease. We only consider the production changeover complexity of the case study and investigated its complexity. [21][24].

The challenges facing industry now are characterized by design complexity that must be matched with a flexible and complex manufacturing system as well as advanced agile business processes. Modern complex products or equipment usually have thousands of parts and take hundreds of manufacturing and assembly steps to be produced [93]. This makes the manufacturing system quite complex. Manufacturing complexity is fully discussed in [16] where there is a measurement of uncertainty in achieving the functional requirements (FRs) of a system due to poor design or to the lack of understanding and knowledge about the system. The design and operation of production and manufacturing systems have important effects on manufacturing productivity, return on investment and market share. Regular changes in production technologies and market demands makes the manufacturer produce a variety of products on same production line. Thus, the number of production changeovers has increased on the production line to produce the variety of products required to meet customer demands. In order to minimize the number of production changeovers and increase the efficiency and productivity of the process, many different factors need to be considered. Figure 1.1 shows the illustration of the research hypothesis and motivations

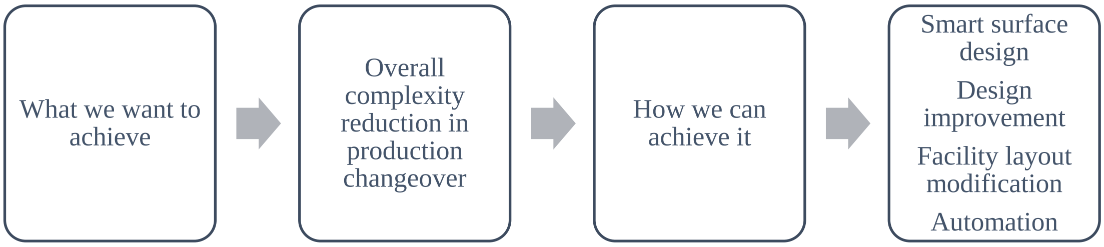


Figure 1.1 Illustration of the research hypothesis and motivations

Some of the vital factors are addressed below. This includes the complexity of the production changeover and the introduction of smart conveyor surfaces. Sustainable manufacturing is the creation of manufactured products using processes that minimize negative environmental impacts, save energy and natural resources, are safe for employees, communities and consumers, and are economically sound [21]. Various surfaces in nature exhibit a high intrinsic ability to clean themselves without any external intervention. Nature provides many examples of structure, material and surfaces that can be investigated in an effort to develop further understanding of the basic principles and that can be captured and developed into new technical applications [96]. One of the examples is that of the lotus leaf. The most fascinating properties in this case is the ability to self-clean, which means that the surface can repel contaminants with the action of rolling off water drops [95].Figure 1.2 shows lotus leaf. The contact angle of the lotus leaf is more than >150° therefore the water drops roll off and not stick to the surface. This kind of self-cleaning surface has both the ability of super hydrophobic and self-cleaning properties. Water drops roll off the lotus leaf and drag with them any dirt particles—and without leaving any residues. The hydrophobicity of the surface that requires strong water repellence depends on several factors, including surface energy, surface roughness and cleanliness [2][92][97]. From the literature, there are two possible approaches when seeking to generate such a hydrophobic surface, including the use of Low Surface Energy (LSE) material (lower than water) or the coating with such LSE materials, and the modification of surface roughness [4].

Figure 1.2 Lotus leaf [156]

The surface topography greatly influences not only the mechanical and physical properties of contacting parts, but also the optical and coating properties of various non-contacting components. The characteristics of surface topography in amplitude, spatial distribution and the pattern of surface features dominate the functional application in the fields of wear, friction, lubrications and fatigue [7]. In general, there are two routes to producing self-cleaning surfaces—both of which utilise specific surface design and chemistry when it comes to controlling wettability. In the super hydrophobic self-cleaning approach, water completely covers a surface with a continuous film and washes away dirt; the second approach utilises the opposite side of the surface wettability scale, with the self-cleaning property achieved with the help of high water-repellence or the super hydrophobicity of a surface [94]. In this paper, a case study of a crisps manufacturing company was studied. These problems are described in figures and are addressed in the case study. Figures 1.3 called large bucket and it is the part of production machine. It shows that flavour material is stick to the inside part. Figure 1.4 is storage conveyor and flavour These figures are crisps manufacturing firm, where material sticks to the metal conveyor during the production process. An effort has been made to use a micro textured surface with self-cleaning capability so as to reduce the cleaning time of the production changeover and accordingly reduce the frequency of cleaning. In order to achieve these characteristics, the machined surfaces have been studied and discussed in detail.

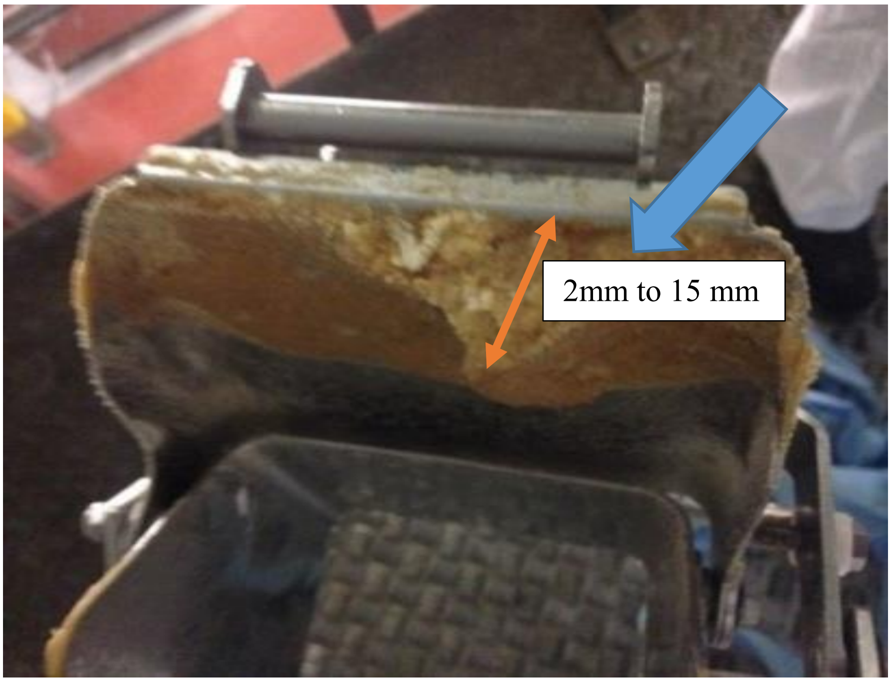


Figure 1.3 Major problem is flavour material sticking to parts surface

A food manufacturing case study has been conducted and actual data has been used. There are different aspects that have been considered in production changeover overall and sustainability is also considered along with reduction of complexity and cleaning of the machines. Different types of complexity also have been discussed and experiments carried out on different surface structures. Most of the time consumed during changeover is on the cleaning of metal conveyors or machines. Therefore, metal surface structures have been studied in depth. A self-cleaning property of ultra-hydrophobic surface has been used to reduce the frequency of the cleaning on the conveyor to reduce the time consumed on the cleaning. Process mapping and facility layout also have been discussed and considered during the study to improve the production changeover process. Some suggestions for automation have been proposed in the study to improve the manufacturing facility's performance. A new model has been generated which includes a virtual factory, the existing production setup and the proposed production setup. The material stick with the surface is due to many reasons which include rough surface, oily surface and flavour powder stick to the surface. In some part the thickness is more and in some part thickened is less depending on the usage of the part during production. Figure 1.3 shows that flavour material sticking to one of the surfaces. The thickness of this material varies depending on the material flavour and weather also. This thickness varies from 2mm to 15mm. Materials stick to those areas more where the size of the part is small, and snacks pass through a small area. The part shown in Figure 1.3 is called a 'bucket'. It is a small part and snacks pass through its small area quicker which is why material sticks to it more compared with bigger parts. For example, see Figure 1.4 which has a wider area and the material thickness is comparatively less than in Figure 1.3. In Figure 1.4 we can see the flavour material is sticking to the storage vibrating conveyor. The thickness of the material here is 3 mm to 10 mm.

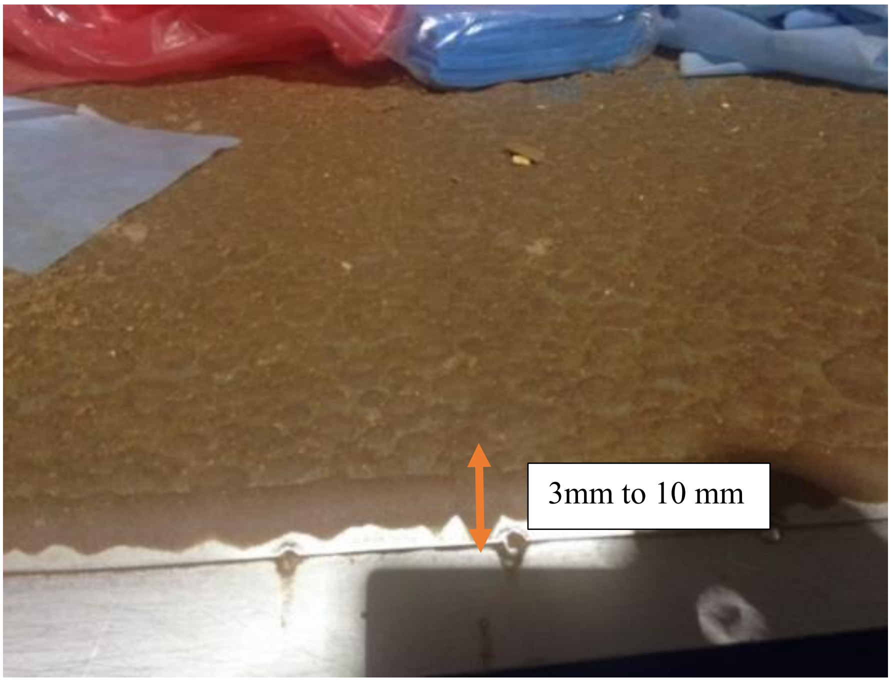


Figure 1.4 Thick material sticks on the storage conveyor surface

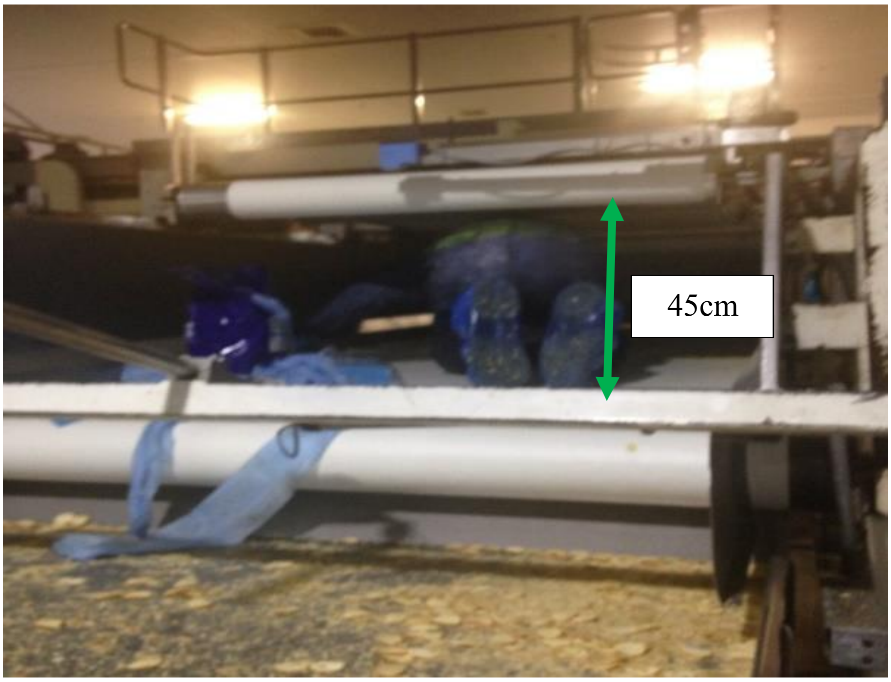


Figure 1.5 Photograph highlighting limited access during cleaning

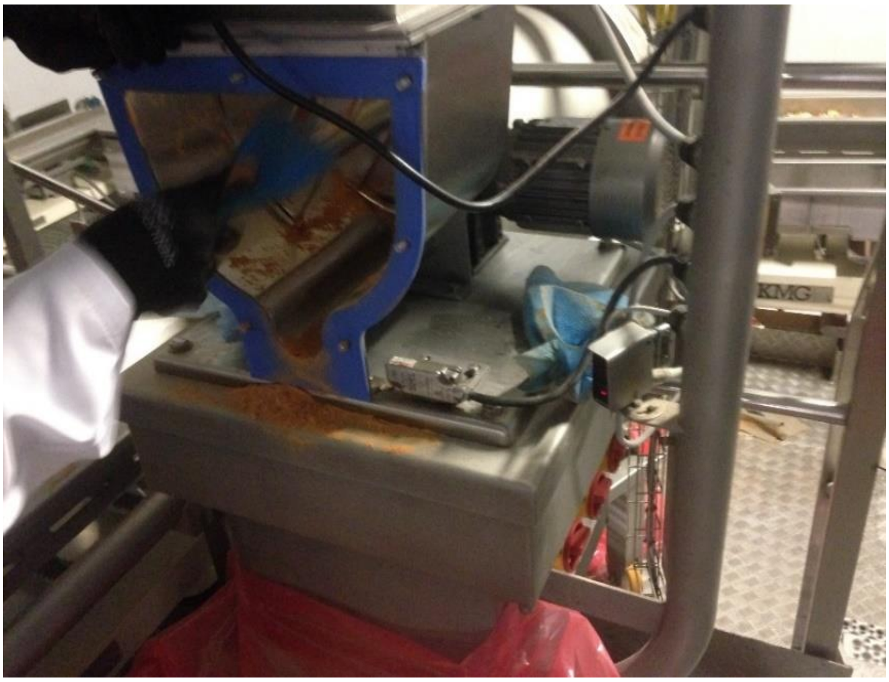


Figure 1.6 Process improvement of production changeover required.

Figure 1.5 shows that a staff member is cleaning storage conveyor from a narrow room which is hard for human to get inside the conveyor and do manual cleaning. Figure 1.6 is an example of flavour tank manual cleaning. Cleaning of the flavour tank is manual and it requires proper tool to be cleaned. These is discussed in more details in chapter

5. Most food manufacturers use stainless steel vibrating metal conveyors. The surface of the material is rough and takes more time to clean. An effort has been made to find a smooth smart surface which has a self-cleaning capability to reduce cleaning time in production changeover.

1.2. Aim and objectives of the research

This doctoral research aims to reduce the production changeover complexity to improve plant utilization with recommendations to improve sustainability in production changeover. One of the most important aspects is the use of smart surfaces for conveyors and facilities in food manufacturing, which have self-cleaning capability. Self-cleaning surfaces require strong water repellence, which is usually realized by either fabricating a rough surface from LSE material or modifying a rough surface with microstructure, [2][5][92]. There are a variety of functional applications of engineering surfaces. It is hard to define a functional parameter set to cover the whole area of functional applications. Therefore, mostly the functional parameters are concentrated on some important and frequently applied aspects. The vast majority of surface texture parameters are the field parameters. The term ‘field parameters’ refers to the use of every data point measured in the evaluation area. It allows the characterisation of surface heights, slopes, complexity and wavelength. Symbols for surface texture parameters that have a prefix that is the capital letter S or V followed by other lower case letters. For example, S_{bi}, S_{ci}, S_{vi} and for the letter V, V_{mp}, V_{vc} .

A production line is usually composed of many machining facilities and different facilities have completely different working procedures. Process information about parts can be seen as the collection of working procedures which usually have two features: working hours and working procedures [16]. One of the important factors in manufacturing facilities is the facility layout. There is no specific definition of facility layout. One view takes the facility layout as the arrangement of facilities with non-equal areas that could fit within the limits of the length and width of a factory to minimize the total cost of the material handling and optimize space usage (Zhang Lee, [72]. Another definition is that facility layout solves a problem of optimization that can produce effective arrangements, considering material flow systems, and different interactions between facilities. The performance of facilities strongly depends on the type of their layouts. Facility layout can be improved by virtual experimental modelling. The main benefit of virtual manufacturing and a virtual factory consists in multi-layered information related to various processes and activities depending on the area of focus. Managing waste from manufacturing is a growing area of research contributing to the field of sustainable manufacturing and energy efficiency as well as quite recently to the field of the circular economy[13][14].

The distinct objectives of this doctoral study include:

- Undertaking critical review of the research area to assess the state-of-the-art in the field and to identify the research and knowledge gaps.
- Development of the integrated holistic approach for addressing specific sustainable manufacturing and complex changeover issues at food manufacturing packaging production lines, which can bridge the gaps associated with the macro, meso and micro manufacturing aspects at the packaging production lines in a seamless integrated manner.
- Investigation of the complexity underlying the production changeover using the modelling analysis and discrete simulations.
- Design and analysis of self-cleaning smart surfaces applicable to food packaging production equipment and conveyor belt panels. The design and analysis of smart surface are based on 3D surface functional parameters.
- Further carrying out the industrial case studies in light of the research and development above against the manufacturing requirements at McVitie's food manufacturing packaging production lines.

1.3. Scope of the dissertation

The scope of the dissertation is illustrated using a flowchart diagram shown in Figure 1.7, following the mind-map of research hypothesis formulation, fundamentals and methodology development, research exploration and development, results evaluation and validation, knowledge contribution through research outcomes and publications dissemination.

Chapter 1 introduces the research background, scientific and technological challenges, the aim and objectives, and the structure of the thesis.

Chapter 2 provides the critical literature review of the research objective areas including production changeover complexity, its constraints, methods, smart surfaces and their applications. The chapter also elaborates the identification of knowledge gaps between the existing methods used in the manufacturing environment and the problem of the case study, the state-of-the-art techniques in production changeover linking to food production packing lines, and the proposed sustainable production changeover.

In Chapter 3, modelling and analysis of the precision machined surfaces are discussed in detail, 2D and 3D surface characterisation parameters are described consistent with ISO standards and the surface functionalities. Surface roughness measurements of micro textured surfaces, and their characteristics are further discussed.

In Chapter 4, the design and analysis of self-cleaning smart surfaces are discussed particularly for the food manufacturing industry. Super hydrophobic surfaces, which have a self-cleaning capability and are then discussed in-depth.

In Chapter 5, production models are developed to investigate the effects of micro textured surfaces on surface self-cleaning functionality, and the consequent productivity enhancement on the food production packing line through the sustainable production changeover.

Chapter 6 presents the industrial case study and experiments, which are focused on the surfaces' performance difference between using the original existing surfaces at the company packaging line and the proposed smart surfaces and textures. The results are further analysed through simulations.

In Chapter 7, the conclusions of the entire study are presented. It includes the contribution to knowledge from this doctoral research and recommendations for future research.

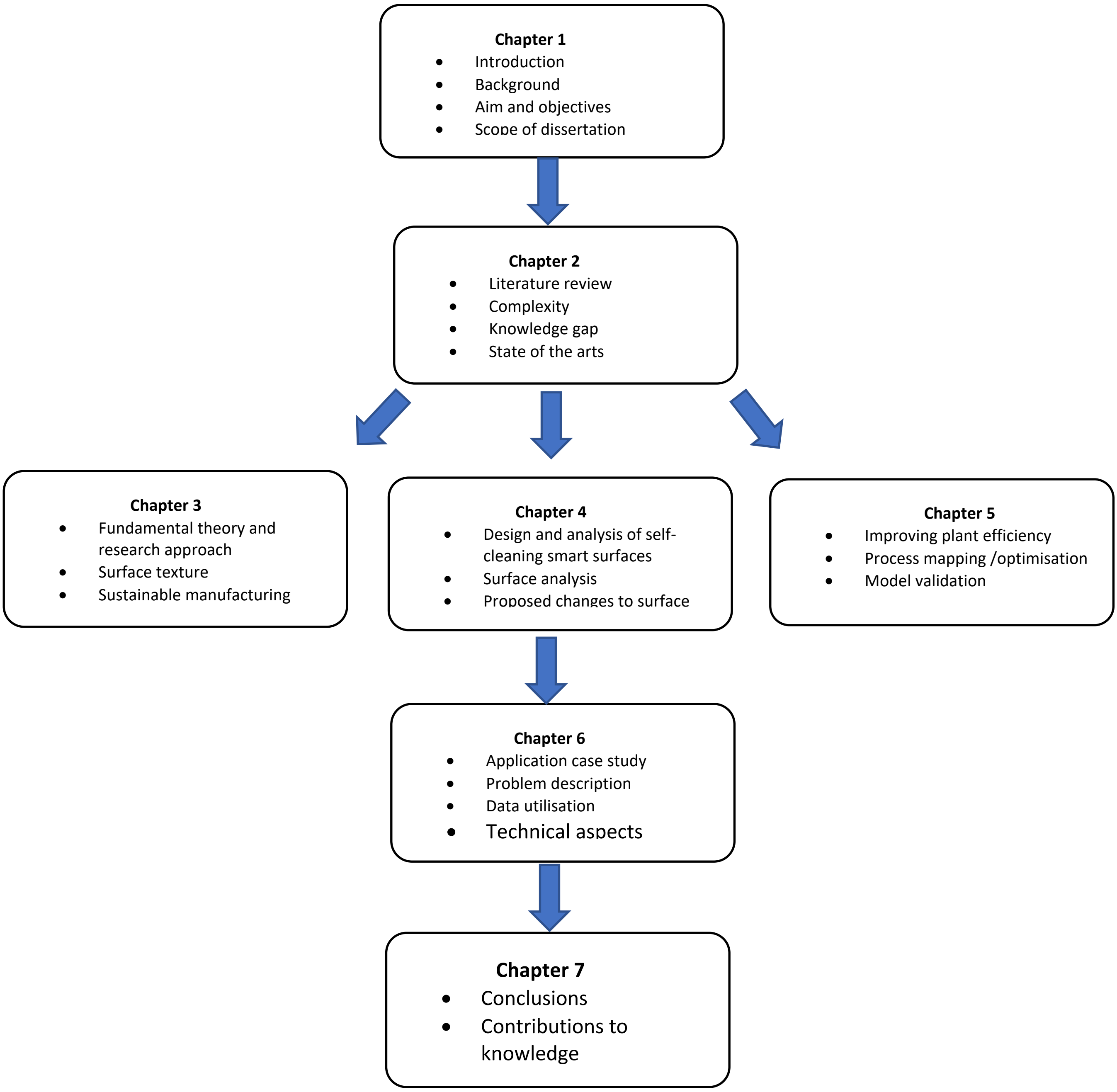


Figure 1.7 Illustration of the thesis structure and the chapter plan

Chapter 2 Literature Review

2.1 Introduction

In recent years the demand and variety of the product has been increasing dramatically and customised product design is common. As discussed previously, manufacturers produce verities or products on same production line. This makes the design of the manufacturing system more complex. There is a measure of uncertainty in understanding what it is we want to know about achieving FRs.

Complexity can be divided into two types dependent upon the domain, namely the physical and functional domains. Figure 2.1 shows both functional and physical domain complexities embedded at a typical food manufacturing system. Physical domain includes machines, equipment, raw material and processes. While in functional domain we have uncertainty in achieving functional requirements. These includes changing in customers demand. When we work on our goals using selected physical implements, the task should not be regarded as being complex. When we cannot achieve the functions that we want or find out what we want to know, the task comes to appear to be very complex. The functional requirements are defined, as in axiomatic design, as a minimum set of independent requirements that characterize with complexity the functional needs of the product in the functional domain. Uncertainty may be a result of poor design of engineered systems or a result of not understanding a system. In engineering the ultimate goal is to reduce the complexity of the system through the use of a rational design approach that is based on functional principles so as to increase the reliability, reduce the cost of the development and operations and enhance the performance of the engineered system. In manufacturing, we often deal with complex products, processes, operations and systems.

Our goal is to reduce or eliminate the complexity while satisfying the FRs of the products, processes, operations and system within the given constraints. Several different measures defining complexity have been proposed within scientific disciplines. Such measures of complexity are generally context dependent. Colwell [25] defines thirty-two complexity types in twelve different disciplines and domains. Such as in physical domain it is divided into static complexity (structural) and dynamic complexity (operational). Static complexity is time independent complexity because of the product and system structure while dynamic complexity is time dependent and deals with the operational behaviour of the system [1][25]. Rodriguez- Toro et al [25] argue that there are two types of complexity: one is component complexity which is related to the geometry of the components and second is assembly complexity which is related to the breakdown of the product and the number of operations required to assemble the product [17][25].

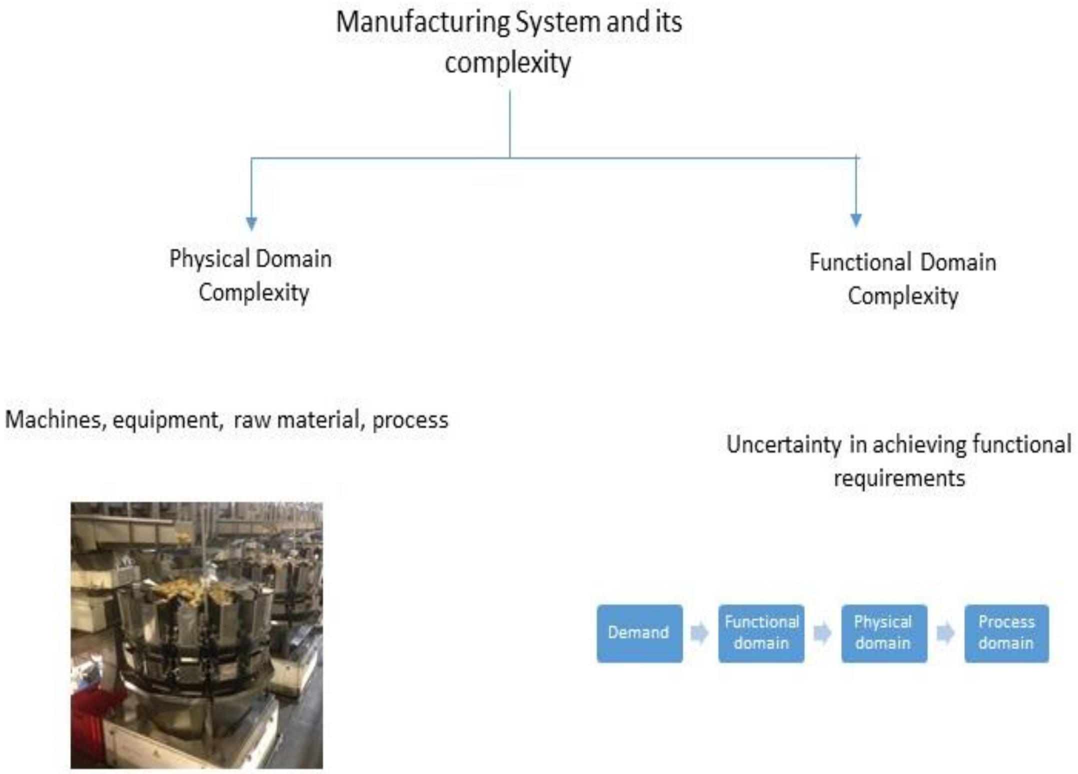


Figure 2.1 Manufacturing system and its complexity

There are two types of production changeover. One is internal setup changeover and other is external setup changeover. Internal setup changeover is when you can carry on the changeover when the production or machine is stopped. External setup is the activities that can be performed for changeover without stopping the production line. To reduce changeover time each of the steps of the changeover needs to be studied and time needs to be measured. First consider each activity involved in internal setup and check if this can be shifted to the external setup. This will help to reduce the time consumed in internal setup changeover.

Wastes are created in the food industry often through process inefficiencies, planning complexities, improper use of material or food deposit on the parts that needs to be removed, which results cleaning of machinery and parts along with the use of water and chemicals [86].

2.2 Complexity

To understand the complexity of the system we need to understand the basics of Axiomatic Design (AD) theory on which complexity is partly based. Axiomatic design theory provides a conceptual basis for complexity theory. Complexity theory provides a broad theoretical framework for understanding and designing complex systems. Complexity theory is applicable to the design of engineered systems and to understanding the behaviour of natural systems such as biological systems. Most people seem to know naturally what complexity is but when we examine their deeper perception and understanding, we find many different views on the subject. This is the situation that many research scholars in complexity find themselves in. They use the word ‘complexity’ with different ideas and perceptions. A major departure of the complexity theory described from various other notions of complexity stems from the observation that complexity must be defined in the functional domain not the physical domain. In the past physical things like machines, lines of code, computation time, biological cells were examined to understand their complexity which has resulted in many different definitions of complexity.

When designing a part for a manufacturing unit where possibly many products will be manufactured using the same pattern, it is essential to consider changeability at the outset and throughout the entire design process and life cycle of the part. Whenever we try to achieve a certain functional goal within a desired accuracy, our ability to achieve the desired functionality determines the complexity. Whenever we are able to achieve our desired functional goals using the selected physical implements, the task should not be considered as being complex. On the other hand, if we are not able to achieve the functional goals which we want to achieve then we call that task or system complex. If the system is unable to achieve what is required, this means that there is uncertainty which prevents the system achieving the desired goals. Uncertainty may be the result of poor design of the system or the result of not understanding the system. In this case complexity is a function of the relationship between the design range and the system range just as information content is. When there are many FRs (functional requirements from the system) that a system must satisfy at the same time, the quality of the design in terms of the independence of FRs affects the uncertainty of satisfying the FRs. A measure of uncertainty is understanding what it is we want to know or in achieving a functional requirement. Complexity management is an increasing challenge for industrial companies. Axiomatic design theory was advanced to provide a scientific basis for the design of engineering systems. It has provided designers with logical and rational thought processes and design tools. Axiomatic design theory has been used for the following specific purposes [3][85]:

- To provide a systematic way of designing products and large systems for engineers and designers
- To make human designers more effective and creative
- To reduce the random search process which saves time and resources
- To minimise the interactive trial and error process
- To determine the best design among those proposed
- To create systems structures that completely capture the constructions of the system's functions and provides ready documentation
- To give creative power to the computer

The complexity that follows directly from the information axiom of AD is time independent real complexity, which is the same as the information content defined in axiomatic design. In addition to time independent real complexity, there are three types of complexities. Time independent imaginary complexity, time dependent combinational complexity, and time dependent periodic complexity. When a functional periodicity is introduced into an engineered system, it reduces the time dependent complexity of the system and makes the system stable.

The relationship between design range and the system range may be static or dynamic, depending on whether or not the system range drifts as a function of time relative to the design range. Therefore, there are two kinds of complexity, time independent complexity and time dependent complexity as illustrated in Figure 2.2.

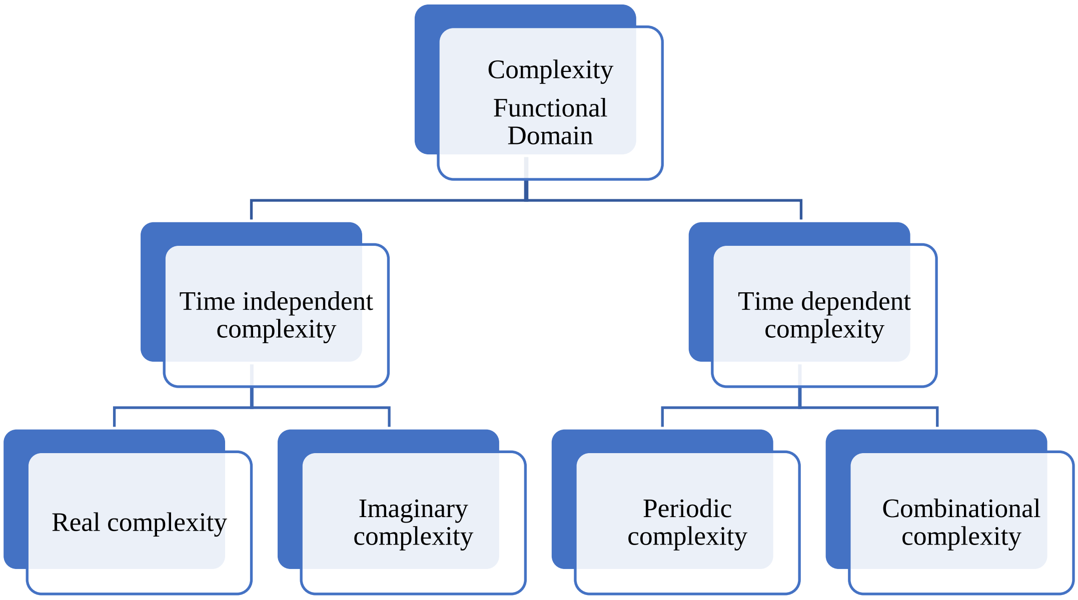


Figure 2.2 Complexity and its sub sections

2.2.1 Time independent complexity

TIC (Time Independent Complexity) is further divided into two different types: time independent real complexity and time independent imaginary complexity (Figure 2.3). Time independent real complexity is defined as a measure of uncertainty when the probability of achieving the FRs is less than 1.0 because the system range does not lie inside the design range. Real complexity may be reduced when the design is either uncoupled or decoupled. i.e. when the design satisfies the independence axiom. When a system is a coupled design the only way to reduce time, independent real complexity is by designing an uncoupled or decoupled design that satisfies the same set of FRs.

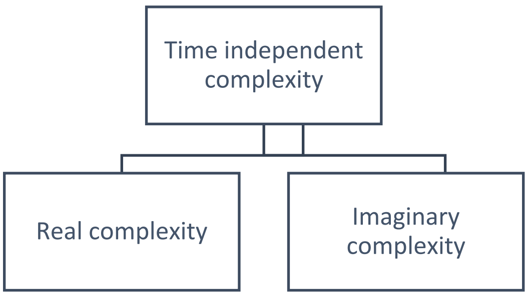


Figure 2.3 Time independent complexity

In the design and manufacturing of mechanical parts, it is commonly assumed that a system with many parts is more complicated than one with a smaller number of parts. This assumption is true only if the interface between the interconnected parts adds additional uncertainty in satisfying FRs. In other words, the mere presence of many interconnected parts does not necessarily make the system more complex[2].

2.2.2 Time dependent complexity

Time dependent complexity takes place because future events affect the system in different ways. Usually this results in a time varying system range. That is, the system range moves away from the design range. Figure 2.4 shows there are two types of TDC (time dependent complexity). One is real complexity and one is imaginary complexity. Time dependent real complexity is defined as a measure of uncertainty when the probability of achieving the FR is less than 1.0 because the system range does not lie inside the design range.

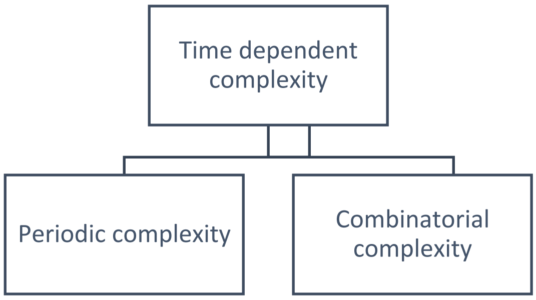


Figure 2.4 Time dependent complexity

Time dependent complexity occurs because future events occur in unpredictable ways and we do not have control over them. Often this results in a varying system time range that is, the system range moves away from the design range as shown in Figure 2.5. The combinational complexity is defined as the complexity that increases as a function of time due to a continued expansion in the number of possible combinations with time and this may lead to a system failure. Real complexity may be reduced when the design is either uncoupled or decoupled. i.e. when the design satisfies the independence axiom. When the system is a coupled design the only way to reduce time independent real complexity is by designing an uncoupled or decoupled design that satisfies the same set of FRs to meet the desired goals [2].

2.3 Static and dynamic complexity in manufacturing operations

The complexity of the physical system can be characterized in terms of its static structure or time dependent behaviour. Static complexity can be viewed as a function of the structure the system, connective patterns, variety of components and the strengths of interactions.

Part flow on the production line is governed by the type of parts being produced, type of material handing devices used, and machine capabilities. The variety of sub-systems are determined by the different types of resources and parts types in the system. Thus, static complexity can also be the measure of information needed to describe the system and its components. This definition clearly considers all the components of manufacturing systems required to make the selected set of parts. Static complexity can be described as follows:

- More than one-part type being produced in a single production line
- Each part type requiring multiple operations. i.e. any tasks that use the same tools to transform raw materials to finished goods
- Each operation, for a given part type, having multiple machine or processor options
- The set of operations needed to produce a given part type may or may not have precedence limitations

Dynamic complexity is concerned with the unpredictability in the behaviours of the system over a time period. The manufacturing environment consists of physical systems in which a series of sequential decisions needs to be made in order to produce finished good.

2.4 Real and imaginary complexity

This can be divided into two types: one is real complexity and the other is imaginary complexity. In time independent combinational complexity there are two different kinds of complexity involved. The real complexity is associated with uncertainties inherent in the system design and the imaginary complexity associated with uncertainties caused by a lack of design knowledge or ignorance during design. To remove the real complexity, the design of a system must satisfy the independence axiom in which the FR are maintained independently and then make the design robust so that the system range is in the design range. Time independent real complexity is defined as a measure of uncertainty when the probability of achieving the FRs is less than 1.0 because the system range does not lie within the design range. Figure 2.5 shows where the system range is outside the design range [3].

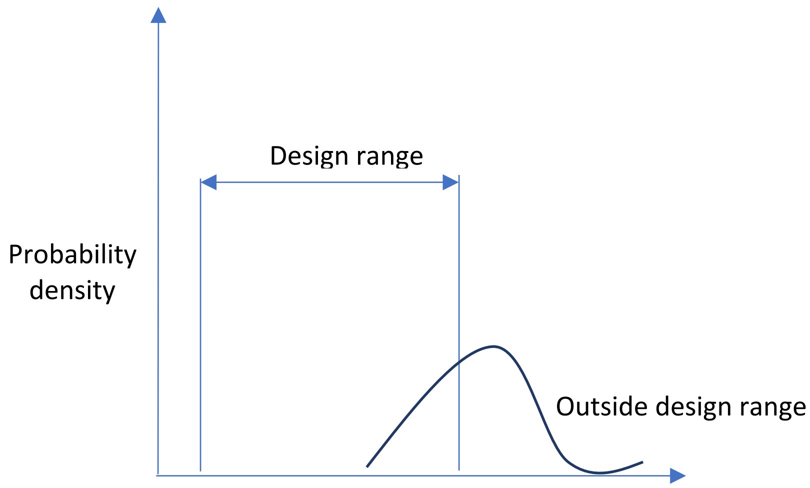


Figure 2.5 FRs outside range

2.5 Real complexity reduction

Nano technology has become a topic of intense interest in academia and industry because of its potential impact on various technologies and engineered system. As the size of the product becomes smaller, the corresponding design range also becomes smaller. The range of FRs and design parameters of a system (DPs) must be made small, since the probability of achieving the FRs or DPs decreases as the ratio increases. Therefore, the information content and thus the time independent real complexity of nano technology can be large because the large values of tolerance.

2.6 Imaginary complexity reduction

Imaginary complexity is defined as uncertainty that is not real uncertainty. But it appears due to the designer's lack of knowledge and understanding about the specific design of the system itself. When the design is good, i.e. consistent with both the independence axiom and the information axiom, imaginary or unreal uncertainty exists when we are ignorant of what we have. For example, a combination lock is easy to open once we know the sequence of numbers we have to activate but in the absence of the information on the combination it appears to be complex [3].

2.7 Complexity in design of manufacturing systems

One of the primary goals of the design and scientific effort is to reduce the complexity associated with the design of artefacts or scientific understanding to zero. A robust design is a design that has no time-independent real complexity and no time-dependent combinational complexity [5]. Qualitative approaches used by engineers to reduce complexity include values engineering, reduction of coupling, reduction of the number of parts and use of modularization. In addition, complexity in production changeover generally may be defined in terms of how a system is varied and interacted. Complexity in manufacturing changeover can be found in both products themselves and in their production, and the level of complexity in each of these varies depending on the industry and product type [7]. Manufacturing systems should be designed in such a way that waste is minimized at all levels. During changeover, raw materials are wasted. If a system is designed where raw materials are not sticking to the production line, then raw materials can be utilized in the finished goods. Similarly, if the system stops automatically when it is not producing products, it then can reduce the usage of power.

The complexity of the system can be caused by two factors, namely time-independent real complexity due to poor design of the manufacturing process and system, and time-dependent combinational complexity caused by the deterioration of the processes and system as a function of time [3]. The system needs to be designed in such a way as to use the minimum number of nuts and bolts required in changeover and so ensure there is minimum waste of raw material during a production changeover. Flexibility in design is able to reduce the complexity of product changeover, particularly in reducing the complexity and increasing the efficiency of setup by standardizing as much of the hardware and methodology as possible, such as:

- Making trial pieces and adjusting them
- Preparing for a changeover in advance
- Ensuring material-handling flexibility

- Completing preparation after process adjustment
- Using a minimum number of nuts and bolts during changeover
- Ensuring routing flexibility
- Ensuring setup operation flexibility
- Implementing a sustainable design to reduce the waste of raw material during setup
- Implementing a sustainable design to reduce the use of energy
- Applying modification flexibility in production setup
- Using less energy-intensive materials in design so as to reduce energy use.

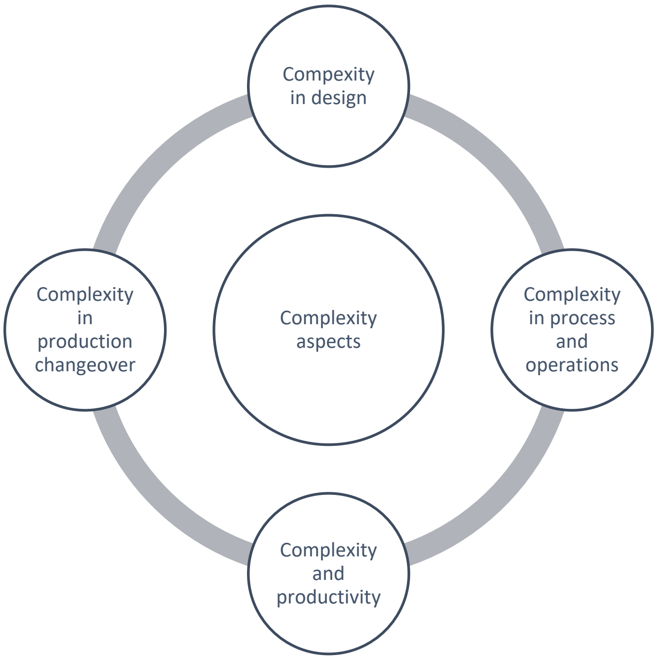


Figure 2.6 Aspects of food manufacturing complexities

The FRs of the system are to maximize its productivity, which is defined as total value added minus cost of manufacturing divide by total investment[3].To maximize the productivity of the system we must reduce the complexities. To make a system robust and reliable by satisfying the FRs, reduction in the complexity of production setup is very important. This is possible to some extent; however, various questions are posed. What should be measured? How is it to be measured? What units of measurement can be used?

It is important to categorize and measure complexity at all levels of the production changeover operation. There then needs to be work in relation to which it can be eliminated or reduced. Time-independent real complexity and the elimination of imaginary complexity can be reduced. Time-dependent combinational complexity also can be transformed into periodic complexity so as to reduce complexity [3][4][9][10]. It may not be necessary to carry out some of the activities during production changeover; these are non-value-added ones. However, there are some activities that are necessary and cannot be avoided or altered. Complexity can be reduced by transformation from time-dependent combinational complexity to periodic complexity, and also can be applied to a manufacturing system [3]. Figure 2.6 shows some aspects of the food manufacturing complexity. These are due to poor design which leads to complexity in production changeover. Complexity can be in process and operation which can reduce the productivity of the manufacturing system.

2.8 Complexity in process and operations

There are two factors that increase complexity in process and operations. One is the number and variety of the features to be manufactured, assembled and tested. Second is the number, type and effort of the tasks required to produce the features. This type of complexity has been defined as a measure of how product variety can complicate the production process. Similarly, there are two types of complexity in the supply chain. Structural complexity, which increases with the number of elements, and operational complexity, which increases with the uncertainty of information and element flows.

General manufacturing system complexity affects performance negatively while training and the man/ machine interface play importance roles in minimising the negative impact of the manufacturing operations. Several researchers have proposed the use of artificial intelligence, artificial neural networks, and machine learning techniques for managing complexity and uncertainties' in the manufacturing process[1]. There are many signals, i.e. force, torque, temperatures, mechanical vibration, conveyor vibration, sound emissions which are associated with the conditions of the manufacturing process and it is expected that sensor fusion or integration will come to offer significant benefits in controlling and monitoring of the manufacturing process. During study it has been observed that most of the theories of complexity management assume that proliferation of product variety is a main driver of operational complexity which, in turn, increases the operational cost. This makes many researchers use the number of products and internal parts as indicators of production complexity. Thus, according to this perception every system in the supply chain, production or distribution system that have to handle an extensive variety may be referred to as complex. While this can be true, the main lack of clarity is due to the definition of complexity that is used in these analyses the mass customisation systems [1][16].

2.9 Complexity reduction through improvement in food production

A manufacturing system is a combination of different machines, equipment, methods and people. As stated in the previous chapter, the aim of this research is to reduce the production changeover time in a food manufacturing company by overcoming the complexity in changeover time and improving productivity. The input is the raw material, manufacturing procedures, energy and human input. The output of the manufacturing system will be finished goods and scrap or waste from the manufacturing process. There are two strategies that can be considered for reducing changeover time, both of which have been successful, depending on the reduction required. The first strategy is to improve the existing set up through Kaizen (continuous improvement methodology). The reduction of changeover time should take place within an overall methodology aimed at ensuring success and sustainability. One of the main aspects of continuous improvement is to develop a self-cleaning capable surface which can be used for a vibrating conveyor which helps to clean itself or reduce the frequency of the cleaning of the surface. In a later section we shall discuss in detail the surface structure, its design and characteristics.

A second approach is to design and implement a completely new system which is an expensive option and many factors need to be considered. Improvements to an existing system can be divided or combined, for example, a methodological improvement and design improvement of that area which is more time consuming or a bottleneck during production changeover [1][15].

2.10 Complexity and manufacturing productivity

There are different methods for dealing with complexity in manufacturing processes which is categorized as complexity of manufacturing parts, complexity in assembly as well as combinational complexity costs due to product variety. The manufacturing complexity is quantified through analysing the assembly of a product using such methods as design for assembly (DFA), which have demonstrated repeated success in reducing the assembly cost. Design for manufacturing (DFM) methods have been developed to reduce the complexity and cost of manufacturing. Complexity in manufacturing can be seen as similar to complexity in production design. Usually a manufacturing system is comprised of multiple manufacturing machines with different functions and various manufacturing processes. Therefore, the manufacturing process faces complexity. These complexities depend on the size of the manufacturing facility and the product itself. Major improvements can be obtained by studying the work methods. Several cases in different industries have shown that even with technically very well-designed equipment downtime can be long if the operators or machine setters lack a well-designed workload method. In such cases usually the equipment designer did not provide set up instructions or descriptions for changeover [1][24].

2.11 Complexity in production changeover

Complexity in Production Changeover (CPC) directly affects the performance of the production capacity. There is a relationship between complexity and manufacturing performance. Effort has been made to define and quantify complexity in product design and manufacturing and the impact of complexity has been studied to show its relationship to performance [8]. Therefore if we decrease the product variety, it will lead to productivity increases and lower costs based on practical evidence. On the other hand, if the complexity increases, the productivity or quality of the product will decrease. In engineering design, we need to satisfy the functional requirements of the designed system. When the system range is not fully inside the design range, we cannot satisfy the FRs at all times. And, when we cannot satisfy FRs of the system then the system is called a 'complex' system (Figure 2.7). Therefore, complexity is defined as a measure of the uncertainty in achieving the specified FRs. According to the definition, the relationship between the design ranges and systems range determines the complexity. In manufacturing, we often deal with complex products and processes, and operations and systems, which causes many intricate production setups. In order to lessen the severity of this issue, it is necessary to understand the nature of the system [2].

There are many different examples and methods of dealing with complexity in manufacturing processes. These can be described by the complexity of manufacturing intricate parts, the complexity of assembling various products on the same assembly line, and the setup costs due to product variety [1]. Our goal is to reduce, or eliminate, the complexity associated with setup. To maximize the productivity of a manufacturing system, we must design the system so that the functional requirements (FRs) of the system are easily satisfied [3][4][7].

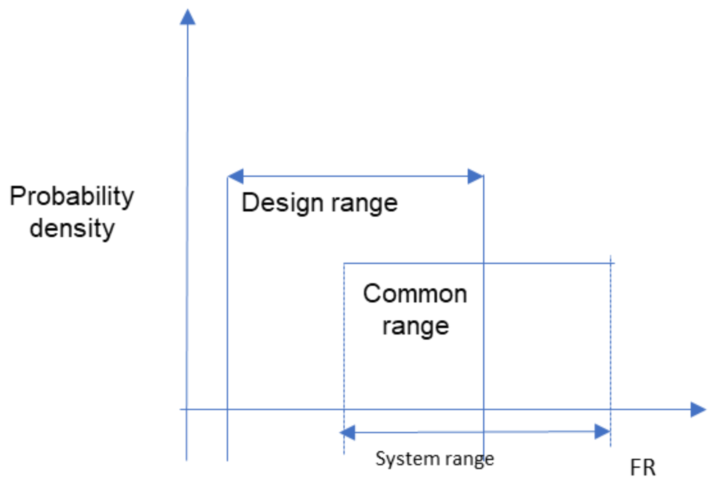


Figure 2.7 FRs design range diagram

Complexity commonly relates to the design of the machine, product and product variety, and the production process. To determine real complexity, one of the important goals of design, is to reduce the time-independent real complexity to zero; this is a consequence of the system's range falling outside of the design range. Therefore, real complexity might increase when the design range of an FR is made smaller [5]. Qualitative approaches used by engineers to reduce complexity include value engineering, the reduction of coupling, the reduction of number of parts and the use of modularization [1]. These further reduces the complexity of production setup, with further reduction achieved by means of a sustainable and simple design. Size, weight, number of clamps, number of changes needed to manufacture different products, usage of power, raw material waste and making machinery easy to clean in an effort to reduce waste should be considered during the design of a manufacturing system. The more complicated a design, the more time spent on production changeover. Designing systems with the aim of achieving a lower level of complexity, and accordingly mapping between product complexity and system complexity, are important issues. For the design of an engineered system that is acceptable from the ergonomics point of view, the FRs and constraints related to ergonomic issues must be identified and designed from the beginning to make it suitable and flexible for production changeover [9].

2.12 Complexity in food production changeover

There is a relationship between complexity and manufacturing performance: a decrease in product variety leads to higher productivity and lower cost per unit, whilst increased complexity decreases the overall probability of successful product development through observation of empirical cases [7]. Production changeover complexity may be reduced so as to make the changeover operation as simple as possible. A manufacturing system must be designed accurately to maximize the productivity and quality of products by clearly stating the FRs of the manufacturing system; it must be flexible so that changeover can be carried out quickly in the shortest possible time. The goal should be elimination or, as a minimum, reduction of the complexity associated with the manufacturing changeover [3]. Toyota's continuous improvement philosophy can be applied in the ongoing reduction in complexity and should be part of every worker's job [12].

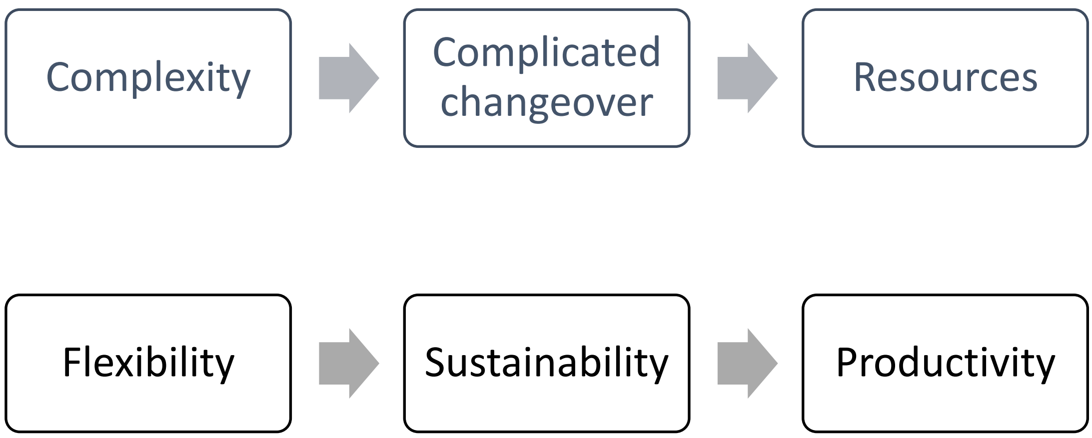


Figure 2.8 Complexity vs flexibility

Figure 2.8 shows that if the manufacturing system is complex and changeover is complicated then it need different resources to carry out changeover. These includes men hours, cleaning materials and cleaning equipment. If the system is flexible and changeover is not complex and easy to make changeover means that less effort is required to make changeover. Therefore less cleaning material and equipment will require and will take less time to complete changeover. This makes the manufacturing system sustainable and will increase productivity.

2.13 Reduction of complexities

In this section we will discuss many aspects how to reduce complexities in production changeover to make the changeover sustainable.

2.13.1 Reduction of changeover complexity in manufacturing system

To maximise the productivity of the system we must design the system where we can meet the FR completely. Manufacturing systems are the subsystems of the engineered system. For example, manufacturing parts for a large product is the subsystem of an engineering system. During the designing of the system, to meet full FRs, the aim should be the reduction of complexity if elimination is not possible. When the complexity of the system is finite, the productivity of the system can be less than the plant full capacity, and similarly the product quality will be not the best [3]. During the changeover process poor quality of items involved can affect the outcome. These can be poor parts, the machine itself, components or it can be the changeover process itself [8].

2.13.2 Complexity reduction by designing a flexible manufacturing system

When designing a manufacturing system, it is essential to consider changeability at the outset and throughout the entire design process and lifecycle. This flexibility in changeability also includes flexible production changeover. It is generally acknowledged that there is a lack of systematic design methodologies for reconfigurability and changeability as only a limited number of design methods and frameworks have been proposed for this purpose[8].

2.13.3 Complexity reduction by smart surfaces

The surface topography greatly influences not only the mechanical and physical properties of contacting parts, but also the optical and coating properties of various non-contacting components. The characteristics of surface topography in amplitude, spatial distribution and the pattern of surface features dominate the functional application in the fields of wear, friction, lubrications and fatigue. [7]. There are two ways to produce self-cleaning surfaces both of which utilise specific surface design and chemistry to control wettability. One approach is the super hydrophobic self-cleaning approach, water completely covers a surface with a continuous film and washes away dirt; Usually the complete wettability of the surface is achieved by incorporating photocatalytic chemical for example TiO_2, these photocatalytic chemical forms a very low contact angle with water <1°. The second approach utilises the opposite side of the surface wettability scale, with the self-cleaning property achieved with the help of high water-repellence or the super hydrophobicity of a surface. This approach was inspired by the natural world of varieties and plants benefit from the proper combination of surface chemistry and morphology to stay clean. For example the lotus leaf have the superhydrophobic surfaces have a very hight water contact angle >150° and a very low roll of angle allowing water droplet to roll at a very low tilt angle of a surface . In this paper, a case study of a crisps manufacturing process has been considered and studied where material sticks to the metal conveyor during the production process [9][152].

2.14 Managing changeover complexity by sustainable product design

Shigeo shingo's SMED methodology has been at the forefront of retrospective changeover improvement activity. The SMED methodology which emphasizes that improvement should be sought primarily by rearranging changeover elements into external time. SMED methodology including the sequential application of improvement techniques are assigned to those techniques. SMED methodology doesn't alone sufficiently promote some important improvement options, particularly those that seek to reduce the duration of existing changeover tasks or eliminate them altogether. Making necessary changes to design is also important for a quick changeover. Design complexity can be addressed through the axiomatic design framework with two essential design principles. One is the independence axiom to maintain the independence of functional requirements and second is the information axiom to minimize the information content. This is derived by a logarithmic function of the probability of functional requirements [4][7][20][115]. Variety within the product, i.e. product intra variety, is commonly employed to indicate complexity in product design and has been viewed from both structural and functional perspectives.

The following steps need to be considered for reducing the product and process complexity of product and process. These steps are not depended on each other's and can be identified and dealt with separately as per requirements.

- Define the scope of the products and process to be included in the analysis
- Conduct activity-based costing and categorise it accordingly
- Identify and quantify the most significant complexity cost factors
- Identify and quantify possible initiatives for the reduction of the complexity cost
- Evaluate and prioritise initiatives to establish a complexity cost reduction program [23]

2.15 Self-cleaning mechanism and super hydrophobicity

Nature provides many examples of structure, material and surfaces that can be investigated in an effort to develop further an understanding of the basic principles and can be subsequently developed into technical applications [6]. One of the examples is that of the lotus leaf. The most fascinating properties in this case include the ability to self-clean, which means that the surface can repel contaminants with the action of rolling off water drops [1]. This kind of SC (self-cleaning) surface has both the ability of super hydrophobic and SC properties. Water drops roll off the lotus leaf and drag with them any dirt particles—without leaving any residue. The hydrophobicity of the surface that requires strong water repellence depends on several factors, including surface energy, surface roughness and cleanliness [2][3][5]. From the literature, there are two possible approaches when seeking to generate such a hydrophobic surface, including the use of low surface energy (LSE) material (lower than water) or coating with such LSE materials, and the modification of surface roughness [4].

Currently microstructures can be made-up by ultraprecision machining with high accuracy, such as nanometric surface finish and sub micrometres form accuracy in one pass without the need for any subsequent processing. This provides an enabling and effective approach to producing a micro textured surface with self-cleaning properties.

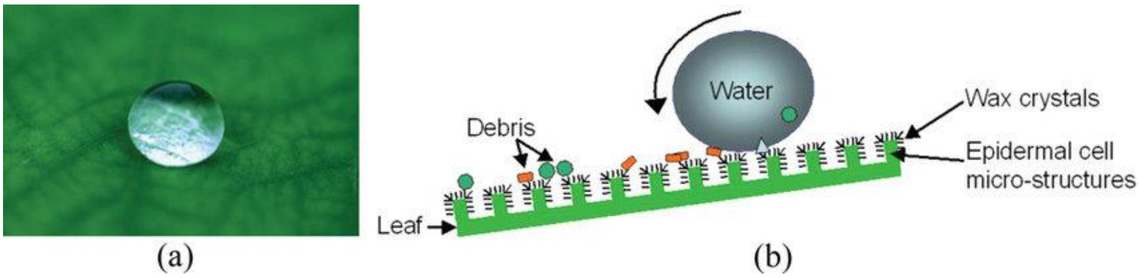


Figure 2.9 (a) lotus leaf (b) Water effect on lotus leaf (153)

Figure 2.9 shows lotus leaf with water droplet beading on it with static contact angle >150° degrees. Figure also shows the schematic illustration of lotus effect and debris or water drops not stick to the surface and roll over due to the high contact angle.

Superhydrophobic surfaces exhibit extreme water-repellent properties. The generation of self-cleaning surfaces requires strong water repellence, which is usually realized by either fabricating a rough surface from low-surface-energy material or modifying a rough surface with macrotextures. The advancement of ultra-precision machining technology enables the latter approach to be a more fruitful and flexible method to produce micro-textured self-cleaning surfaces. The design, fabrication and characterisation of three-dimensional patterned micro-textured surfaces with self-cleaning properties is achieved by using ultra-precision machining technology. Design of three-dimensional micro-textured surfaces based on the derivation and simplification of some microstructures possessing self-cleaning properties in nature, and theoretical analysis for water contact angle of the designed structures. According to the scales and patterns of the 3D microstructures, an appropriate ultra-precision machining method can be used to fabricate the microstructures. Hydrophobicity of the surface that requires strong water repellence depends on several factors, such as surface energy, surface roughness and its cleanliness. From the literature, there are two possible approaches to generate such hydrophobic surfaces, which include the use of low surface energy (LSE) material (lower than water) or coating with such low surface energy(LSE) materials, and the modification of the surface roughness [28][29].

2.16 Surface texture measurements

The characteristics of engineering surfaces can fall into two categories, i.e. ST (surface texture) and surface integrity (SR). Surface texture represents the geometrical properties of the engineering surfaces, and where surface integrity is concerned, with the physical condition of the engineering surfaces. Microstructures can be fabricated through ultra-precision machining with high accuracy, such as nonmetric surface finish and sub-micrometre form accuracy in one pass, without the need for any subsequent processing. Surface roughness is largely dependent on tool dynamics, as under-repetitive cycling loads, the relative displacement between tool and work piece becomes changeable and irregular, which results in the irregularity of the surface profile. The knowledge of the functional relationship between surface roughness and wetting properties constitutes the key to design and, hence, the efficient technological realisation of ultra-hydrophobic surfaces. The construction principle of ultra-hydrophobic surfaces is based on a combination of hydrophobic material properties and an appropriate surface roughness structure [5][10].

It is accepted that surface topography is three-dimensional in nature, and that any measurement and analysis of 2D profiles or sections—even if properly controlled—will therefore provide an incomplete description of the real surface topography. Fundamentally, only the 3D quantitative measurement (profiling or non-parametric) by which surface topography can be obtained by variation in its height as a function of position x & y [7] that can provide a complete description. Self-cleaning technology has been developed since the late-20th Century, with some achievements recognised as having led to practical applications, i.e. window glasses and solar cell panels. The drop of a very high angle of between 150- to 180-degree contact angles can wash out contaminated particles, whereas a low-contact angle will not clean the surface and will leave dirt and particles on the surface.

2.17 Complexity reduction through 3D smart surfaces

The design of an optimal super-hydrophobic surface requires attention to a variety of criteria that relate to various points of view, i.e. the wetting point of view, the apparent contacting point of angle, the roll of angle. When it comes to advances in quantitative measurement instruments for 3D surface topography, it is no longer difficult to obtain the topography of a practical surface over different scales. Figure 2.10 proposes the design, fabrication and characterisation of the 3D microstructure surface with self-cleaning properties. This proposed module encompasses a design method, manufacturing module and characterisation module of a 3D surface.

Surface roughness analysis and measurements: One of the most commonly employed methods for characterising roughness involves assessment of the roughness average by means of profile roughness . This roughness is effective roughness, that is the roughness measured by the gauging apparatus.

2.18 3D surface parameters

There are four 3D parameters, as defined by K J Stout [28] [39], two of which are referred to as amplitude whilst two pertain to the shape of the surface height distribution. There are further subcategories in different categories. Moreover, there are various 3D parameters in surface topography, namely amplitude parameters, spatial parameters, hybrid parameters and functional parameters. Here we will discuss functional parameters, which can be divided into the following:

Surface bearing index S_{bi}: This is the ratio of root mean square (RMS) deviation over the surface height at 5% bearing are. i.e.

$$S_{bi} = \frac{Sq}{\eta 0.05} = 1/h0.05 \quad (2.1)$$

where h0.05 is the surface height at 5% bearing area.

Core fluid retention index S_{ci}: This is the ratio of the void volume of the unit sampling area at the core zone over the root mean square deviation i.e.

$$S_{ci} = \frac{Vc}{Sq} \quad (2.2)$$

where Vc is the void volume and Sci indicates good fluid retention zone.

Valley fluid retention index S_{vi}: This is the ratio of the void volume of the unit sampling are at the valley zone over the root mean square deviation, i.e.,

$$S_{vi} = \frac{Vv}{Sq} \quad (2.3)$$

where Vv is the void volume of the unit sampling area at the core zone. S_{vi} indicates fluid retention in the valley zone [7].

The design of an optimal super-hydrophobic surface requires a variety of criteria that relate to various points of view, i.e. the wetting point of view, the apparent contacting point of angle and the roll of angle. When it comes to advances in quantitative measurement instruments for 3D surface topography, it is no longer difficult to obtain the topography of a practical surface over different scales.

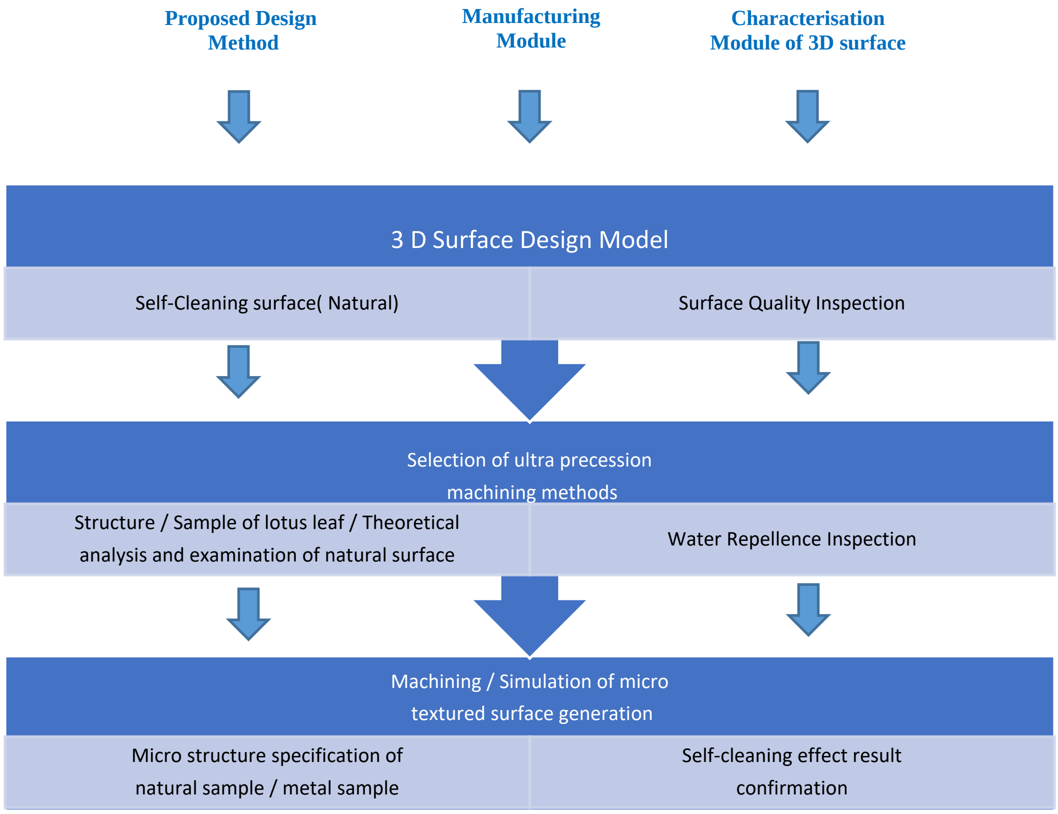


Figure 2.10 Proposed 3D manufacturing module

Figure 2.9 shows the proposed design method and example of natural self-cleaning surface in nature i.e. lotus leaf. It also proposes the design, fabrication and characterisation of the 3D microstructure surface with self-cleaning properties. Figure 2.10 also proposes a module that encompasses a design method, manufacturing module and characterisation module for a 3D surface [128][129].

2.19 The state of the art

To increase the productivity of the plant there are different ways and approaches for improvement. Production changeover can be defined as the time between the production of the last product of the batch and production of the first product of a new batch. This is a complete waste of time and resources and it contains various activities depending on the size and nature of the manufacturing system.

2.19.1 Improved Sustainable facility layout design with lean help

Spending a little time to plan the arrangements before installation can prevent unnecessary losses. Planning that layout at the outset before building the plant or office is the best way to reduce the cost significantly. Producing products or delivering services at a high quality at low cost and in the shortest possible time using the fewest resources is the objective of properly managing a facility inside a manufacturing system. The essence of improving sustainable facility layout design (SFLD) is the optimal location of objects and facilities, which can be departments, workstations and machines. Process mapping consists of constructing a model that shows the relationship between the activities, people, data and objects involved in the production of a specified output. It is inexpensive and helps in the improvement and redesign of the process. There are common facility layouts among manufacturing systems and the choice usually depends on the product and process characteristics [2][22][116]. Figure 2.11 shows the process mapping.

The main objective of the SFLD is to minimise the total material workflow or the material handling cost. But, the material workflow is the most often used objective function, because the material workflow is linearly proportional to the material handling costs. SFLD provides the possibility of defining the optimal arrangement of the workstations on the manufacturing site. In addition, the number of workstations can also be reduced by the application of lean methods. For example, line balancing, process modifications and improvements.

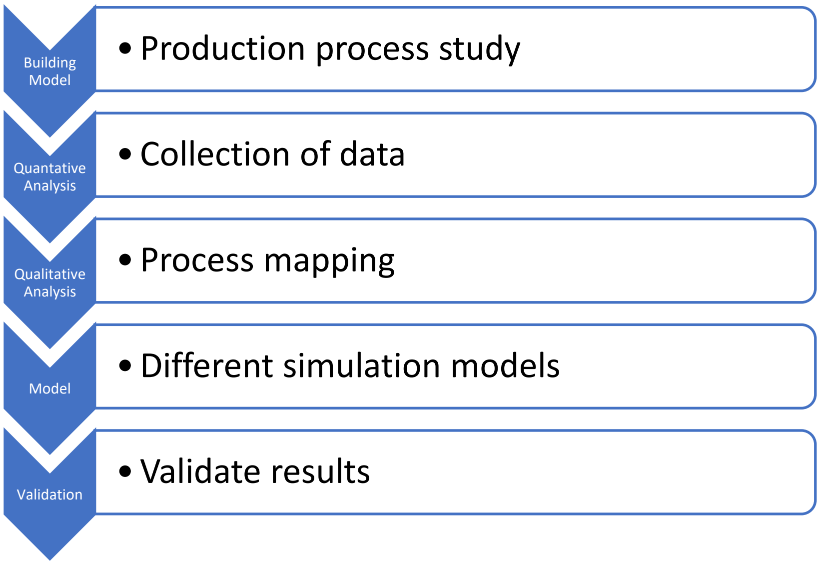


Figure 2.11 Sustainble facility layout process

The layout of the production facility must be adjusted from time to time to meet the production plans and process since the production line may have to produce different products with higher volume and variety. In the sustainable facility layout design (SFLD) procedure the number of alternatives is infinite and the evaluation of all the possible alternatives is impossible. Therefore, the global optimal solution is very difficult or impossible to define. Since the number of possible alternative layouts is huge, it has to be reduced taking into consideration the requirements of the (SFLD) i.e. the design aim to reduce the complexity of the production changeover, design constraints and limitations, practical applicability and designer experience. The best layout has to be selected which suits the main aim of the changes to the layout, which is to be production changeover friendly.

Run-down - Running the last of the batch through the manufacturing system ready for the next or new production batch.

Set-up- This involves disassembling those tools, equipment and material on the production line which are not required for the next batch production and replacing them with the new (often called the 'out-in phase') followed by a rough setting of the various adjustments or assembling the required parts onto the production line to prepare for the next production run.

Run-up – this involves a series of fine adjustments to the production line and checks that are carried out during the production until an acceptable quality level and output speed have been reached and smooth production achieved.

As discussed before, the aim of our case study is to reduce production changeover complexity to maximise the productivity and reduce the wastage of resources, particularly in production changeover. One of the objectives is to improve plant facility layout as compared to the existing one. [124][125][149].

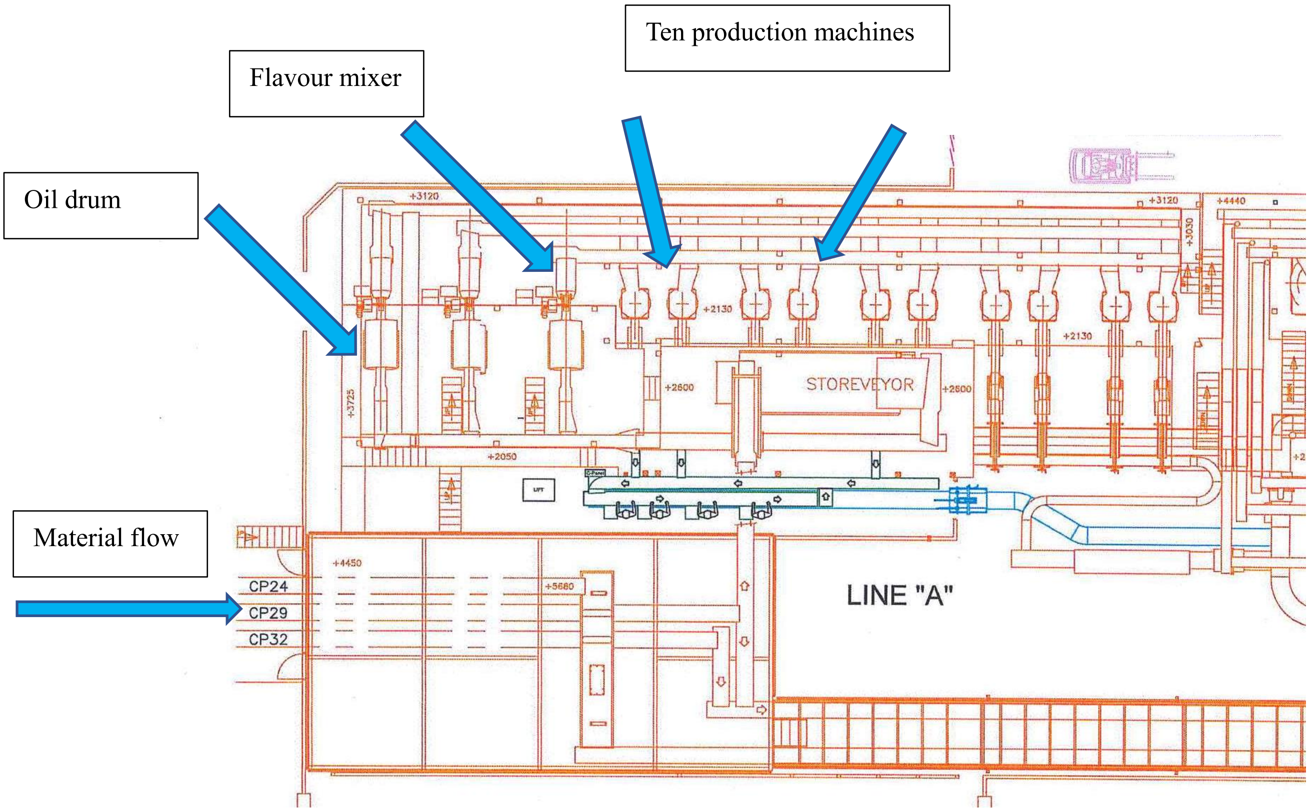


Figure 2.12 Plant A layout

Figure 2.12 shows the plant layout which consists of various machines and includes three oil drums which spray oil on the snacks. Then at the second stage, there are three further machines which spray flavour onto the snacks. The cleaning take place on the production line. The details of the case study with production data is discussed in later chapters.

2.20 Manufacturing complexity reduction by SFLD

There are some common facility layouts in the manufacturing system which usually depend on the product and process characteristics. Facility layout design is related to the optimization of the arrangement of facilities of a production line to maximise the performance and minimise the material handling and operating cost. A well-organized layout not only considers maximising profit but also needs to consider the sustainability of the manufacturing process such as energy consumption, pollution, optimal material flow between facilities, reduction of waste and safety of the shop floor operators [18][19]. The main purpose of the SFLD is to minimise total workflow. Therefore, to improve productivity it is necessary to reduce the total distance of the material flow. There is a need to have a manufacturing facility layout that is energy efficient, green, with a low carbon footprint, high in safety standards and flexible in operation, along with easy production changeover when required with minimum waste [19][126][127]. Figure 2.13 shows the process of the SFLD.

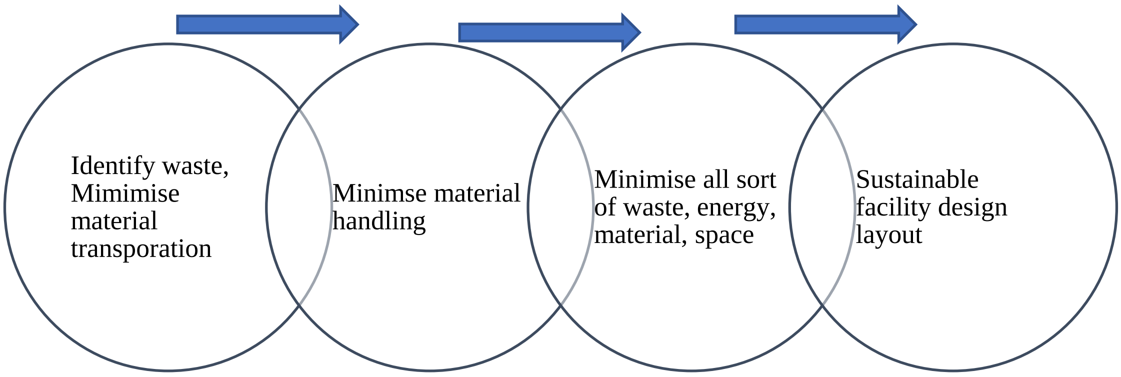


Figure 2.13 The procedure of SFLD

SFLD is an optimisation procedure, a non-overlapping planar orthogonal arrangement of a rectangular workstations that must be achieved on a rectangular (Lx × Ly) manufacturing site. During the optimisation process, all the possible dissimilarities of facility layout must be recognised taking into consideration the design constraints. The most important design constraints are the following: space requirements of the objects to be located on the shop floor, architectural characteristics of the building, bases of machines and workstations (fixed or portable), logical relations of the objects (orders of workstation), noise and vibration of machines, relationship to the internal and external material flow ways.

2.21 Research and gap knowledge

The need to keep the price of the product low while keeping the quality high is increasing day by day in any industry. Even though there is a need for cost effectively producing more variety and volume, the food industry has restricted flexibility in their systems due to food hygiene regulations and the need to maintain the quality of the food. The theoretical background has identified gaps that only traditional methods like single minute exchange die (SMED) have been used to fill so far.

Developing responsive production setup and process capability is increasingly important as product ranges and varieties in manufacturing companies are growing rapidly and, at the same time, production business models are operating towards being more customer oriented.

It has now been few decades(1950s) since Shingo's book [61][73] was published describing the SMED (single minute exchange die) methodology to improve changeover performance. Furthermore, different conventional methods have been used to manage complexity in production changeovers. The first definition of a SMED concept drawn from what Shingo describes as the four conceptual stages of his improvement processes:

Stage 0 Internal and external set up conditions are not distinguished

Stage 1Separating internal and external set up

Stage 2 Converting internal to external setups

Stage 3 Streamlining all aspects of the set-up operations

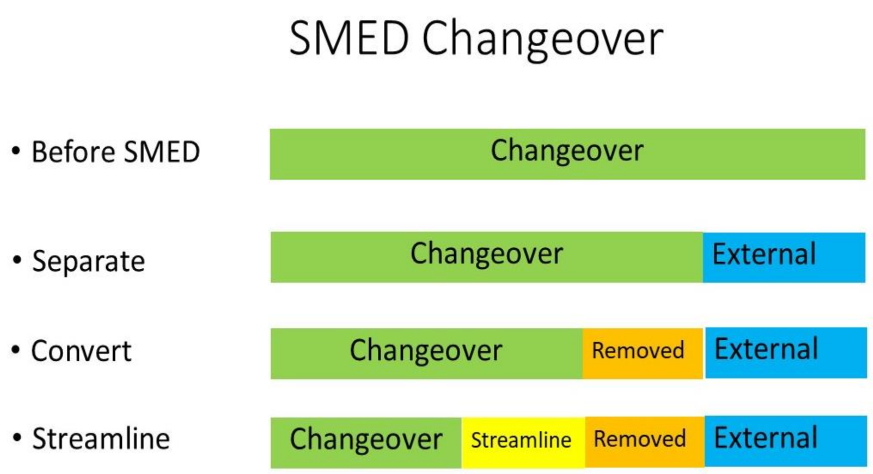


Figure 2.14 Single minute exchange die description

Shingo sets out four stages of his SMED methodology. In which he identifies three separate improvement concepts: identification of the task, separation and conversion of the task from internal to external. Shingo states that only the first step (identifying and separation internal and external) alone usually accounts for a 30-50% reduction in changeover time. Currently, changeover improvements are commonly sought largely based on performing as many tasks as possible before the production line is stopped and this is the principal objective of Shingo's SMED methodology. Figure 2.13 shows the single minute exchange die description.

Streamlining provides the opportunity to reduce the duration of the task but it can be difficult, certainly without reference to techniques that are allocated to the streamlining concept on which basis this improvement can be achieved: streamline all conceptual aspects of the setup operation and improve the storage and transportation of blades dies, jigs, fixtures, gauges and tools . Practical aspects of streamlining include: implementing of parallel operations, using functional clamps and jigs, fixtures, eliminate adjustments.

One of the frequently used methods is the single minute exchange die which is comprised of a lean manufacturing production system. The aim of using single minute exchange die is to reduce waste and standardize the production changeover time.

SMED is still a very useful tool but we should not only depend on this tool. Therefore, other possibilities have also been considered and discussed in Chapter 3, where the surface of the conveyor belt has been studied to reduce the changeover time. Also, sustainability and competitiveness development in a manufacturing company needs to be scientifically addressed by managing manufacturing complexity [6][8][121][151].

In this research, various new approaches have been explored to reduce the overall complexity of production changeover, along with improving the sustainability and competitiveness in manufacturing companies. This includes the use of smart metal surfaces which have self-cleaning capability and have hydrophobic characteristics. SS (smart surfaces) in food manufacturing to reduce the frequency of the cleaning of the conveyor has never been discussed before. These are from the sustainable design of the process chain through to reducing the waste of raw material, through the machine operations in an energy-efficient manner and to the process adaption in responding to production changeover to reduce complexity. It has been observed that no researcher has considered SS, i.e. super hydrophobic micro textured surface so far in food industry to improve production changeover. It is also observed that automation is not introduced to reduce the cleaning or setup time. To overcome all these, different techniques have been introduced, considered and recommended to reduce the complexity of changeover. These include SMED where possible, simple flexible design, use of smart surface, improved layout.

The gap has been filled with the following work carried out:

- Micro textured smart surfaces with self-cleaning capability
- Design and proposed automation on conveyor belt to reduce cleaning time
- Process modification of the existing production changeover process

2.22 Summary

In this chapter complexity is discussed in detail for a food manufacturing company, also possible recommendations for the reduction of complexity in production changeover. This includes the use of a micro texture superhydrophobic surface which is smoother and will help to reduce the frequency of the cleaning of the surface of production conveyors. The use of a hydrophobic surface which has self-cleaning capability is also introduced. There are different aspects to be considered in selection of material and use of micro textured superhydrophobic surface. Most important is the contact angle of the surface. Production changeover activities has been observed and data is gathered to find out the root cause and bottle neck of the complexity. The use of conventional methods of SMED is also discussed and can be utilised for waste reduction and productivity enhancement. Facility layout improvement is also discussed, and in a later chapter it is discussed in more details.

Chapter 3 Formulation of the Research Methodology and Fundamentals

3.1 Introduction

Engineered surface textures play a vital role in the functionality of a component. Engineering surfaces are the interfaces of the product / component when it is in use. The performance of the product or component depends much on its dimensional accuracy and surface quality. The surface topography of a part can affect things, such as how two bearing parts slide together, how light interacts with the part during operation. The surface features can become the dominant functional features of a part and may become large in comparison to the overall size of an object. The understanding of surface phenomena, particularly at a micro and nanometre scale played a vital role in the development of many advanced fields, such as electronics, information technology equipment and tribology. Due to these changes we can observe miniaturization. The availability of technologies that permit the manufacture and control of micro / nano surface features is another key issue for miniaturization.

Surface finish is a very important aspect for designing mechanical elements and it is also a quality and precision indicator for manufacturing processes. Therefore, a proper knowledge of the geometry of parts is necessary which considers both macro geometry and microgeometry. Manufacturing processes do not allow the theoretical surface roughness to be achieved due to defects appearing on machined surfaces mostly generated by insufficiencies' and inequities in the process. This means that measuring procedures are necessary that allow us to stablish the actual state of the surfaces. This requires measuring the surface quality of manufactured parts accurately. Thus, in material removal processes an improper selection of cutting conditions causes a surface finish with high roughness and dimensional errors to be obtained and it is even possible that dynamic phenomena due to auto excited vibration may appear [33][36][37]. Figure 3.1 shows the surface attributes which includes functional properties of the surface, surface measurements and surface texture and its applications.

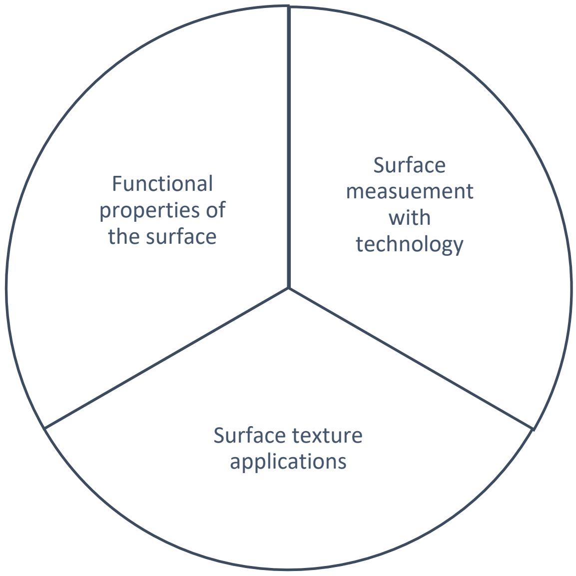


Figure 3.1 Surface attributes

3.2 Precision machined surfaces

Machining is one of the most important parts of the manufacturing process. Engineering surfaces are the immediate interface of the product / component with its environment or other products and components when it is in use. Almost all machines go through a machining process to make the machine itself or any part of the machine. Surfaces characterises the interface through which a large number of phenomena occur. The availability of advanced instruments, such as scanning probe microscopes, in addition to improved visualisation techniques, permits a better characterisation of surfaces and, consequently, facilitates the investigation of the relationship between surface and functions. Surface characterisation comes through the measurement of all the phenomena related to the required function - i.e. force temperature distortion, properties of the material used. Which allows for enhancement of the performance of the surface. Metal machining is a traditional material removal method to produce a mechanical part. Worldwide investment in metal machining machine tools continues and in the recent years there has been a vast improvement in ultraprecision machining. One of the reasons for this is that metal machining is capable of high precision, part tolerance of 0.1 to 1 µm and surface finishes of 0.01 to 0.1 µm are easily achievable. Ultra-precision machining based on single point diamond turning and ultra-precision diamond grinding even enable production of advance components with machining accuracy better than 0.1 μm and surface finish down to several nanometres. This capability attracted research on different aspects of the machining. Similarly, we are considering it to improve the surface roughness and make it smoother for better and sustainable changeover. The basic mechanics of cutting can be explained by analysing cutting with a single cutting edge since most practical cutting operations involve two or more cutting edges inclined at various angles to the direction of cut. Machining processes produce component surfaces with specific attributes - e.g. topography, dimensions, residual stress, deformation level, microstructure surface - that enable products to perform the desired functions during manufacturing for which the part is designed and machined [33][42].

3.2.1 Characterisation of machined surfaces

A surface may be machined using either an abusive or gentle regime, these being directly related to the cutting process and associated feeds and speeds. However, this is not the full picture for surface integrity, as many other interactions influence the surface during either its forming or generating process. Machining being a complex relationship of interrelated factors, affects the outcome of the production process. Making specific part production using computer numerically controlled machine tools is common in modern manufacturing. It depends on the accuracy and surface finish requirements for that particular part and these machining parameters have significant impact on the part quality, need to be set properly. The machining parameters are an important part of the process plan which can be determined from user experience, test experience and relevant reference materials.

On other hand, improper set parameters may cause undesirable complications in machining. For example, chatter represents overwhelming, excessive vibration which will produce an undesirable surface quality[33][114]. The properties of the product/component depend much on its dimensional accuracy and surface quality. In addition to the surface generated in the last stage of machining the cutting tool, deflection of the machine tool or workpiece, vibration, chatter and flexibility of the machine or work piece, the error in the slideway. These all leave their marks on the machined surface in the form of roughness, waviness and topography respectively (Figure 3.2). In summary, these problems may be categorised into these groups:

- Surface conditon, surface texture and roundness
- Microstructual changes
- Surface displacement
- Surfaces /subsurfaces microhardness

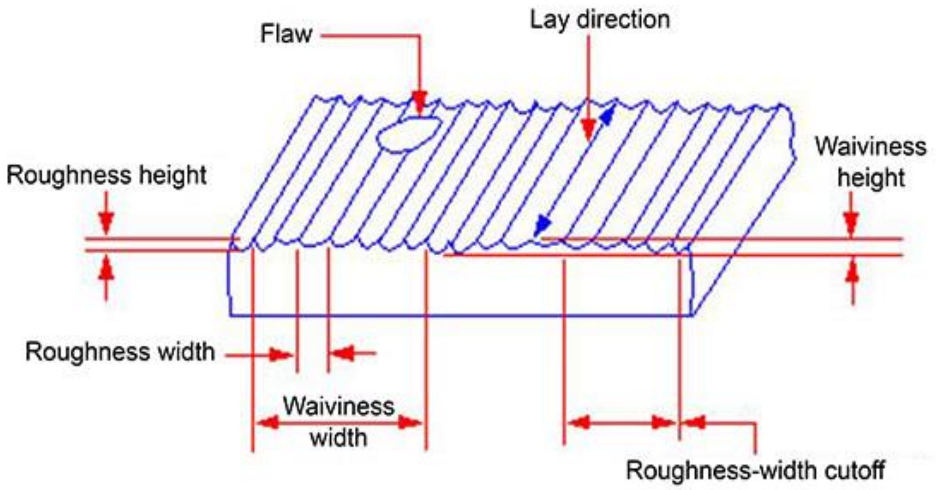


Figure 3.2 Example of machined surface [88]

Figure 3.2 shows machine surface and its characteristics. Machined surfaces are even more complex than they seem at first glance. Their performance can be influenced by external layers. These can be chemical transformation or plastic deformations. In internal zones, there is strong possibility of metallurgical transformations and residual stresses. The residual stresses in a component are a function of the previous material process route, in combination with its machining history. The fact that residual stress levels are present may either improve or, more likely, damage the functional behaviour of a machined workpiece. Internal stresses in a component are generally unbalanced and, over a reasonable period of time, can produce alteration in either the dimensional size or geometry. Any residual stresses acting inside a component or part occur without external forces or moments. Internal forces form a system that is presently in a state of equilibrium and, if sections of this body are removed by machining, the equilibrium status is usually redistributed, resulting in potential deformation This distortion resulting from the machining conditions is well known to industrial engineers [14], for example, when machining one side of a thin component or part. If either a forging or casting has not been heat treated for stress relief and requires uneven machining, it will distort somewhat after unclamping from its work holding device in the machine tool. Component distortion is approximately proportional to be the removed cross section of material. Any further finishing is usually concerned with removing only a thin layer of material, minimising any negative effects of residual stresses resulting from the previous production processing route [31][33][43][113].

3.2.2 Surface textures

The assessment of surfaces using two-dimensional surfaces profile has been employed since the early 1930s. In those early days of the development of new measurement techniques, engineers had concluded that they needed to understand more about surfaces to be able to judge how they interact. As the subject progressed further, combined analogue and machinal devices were developed. A consequence of machinal technology and simple analogue value driven electronic, the early instruments were only capable of measuring and displaying profile information with numerical data obtain by averaging the signal obtained from the movement of a mechanical stylus. Figure 3.3 shows a sample surface profile which shows surface roughness and different parameters of the surface. For example Ra is the arithmetic average of the absolute values of the profile height deviations from mean line, Rq root mean square deviation and Rz is the difference between the tallest peak and deepest valley of the sample surface.

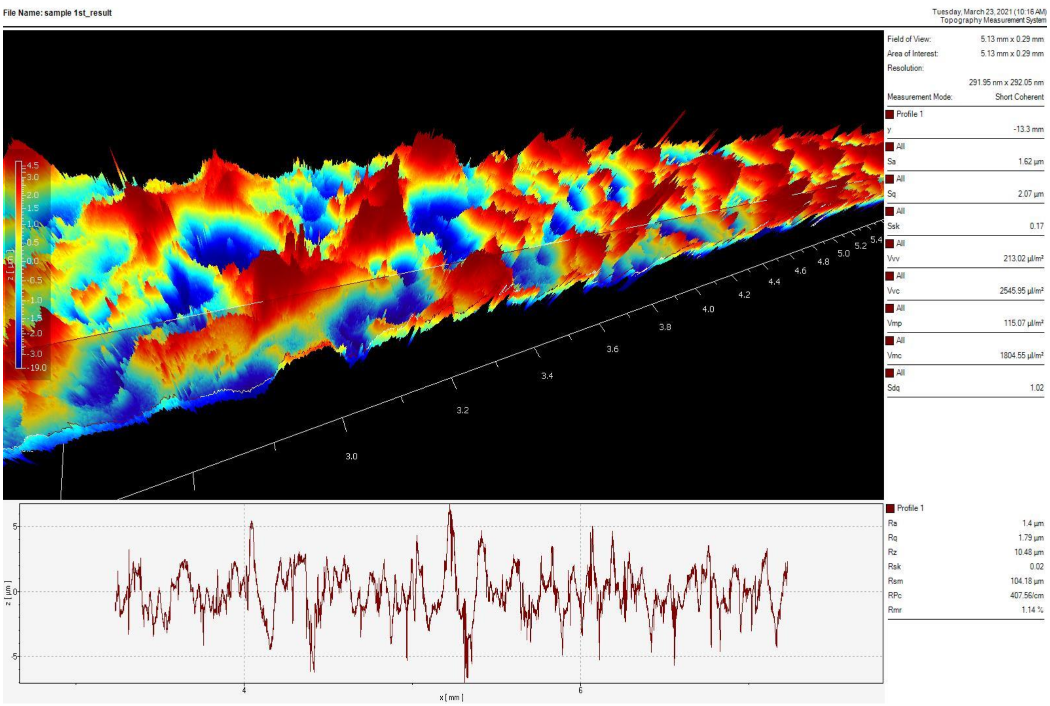


Figure 3.3 Sample surface profile

The resulting average roughness parameter eventually became an accepted measure of the surface. The basic simple parameters of peak to height became the surface roughness parameters. Unfortunately, the parameters average roughness and peak to valley roughness (Ra and Rt,) respectively had very limited value in relation to their functional effectiveness.

ISO 4287 and ISO 4288 define the number of default values for various parameters that are used for surface profile characterisation. Equipment called Zygo5000 has been used to measure the sample surface. The zygo system is general purpose three dimensional surface structure analyser. It provides graphic images and high resolution numerical analysis to accurately characterise the surface texture of the sample part. Figure 3.4 shows rms and ra of the sample surface. A surface texture parameter will be its profile or areal. These are used to give the surface texture of a part's quantitative value which may be used to simplify the description of the surface texture, to allow comparisons with the other parts or part areas and to form a suitable measure for a quality system.

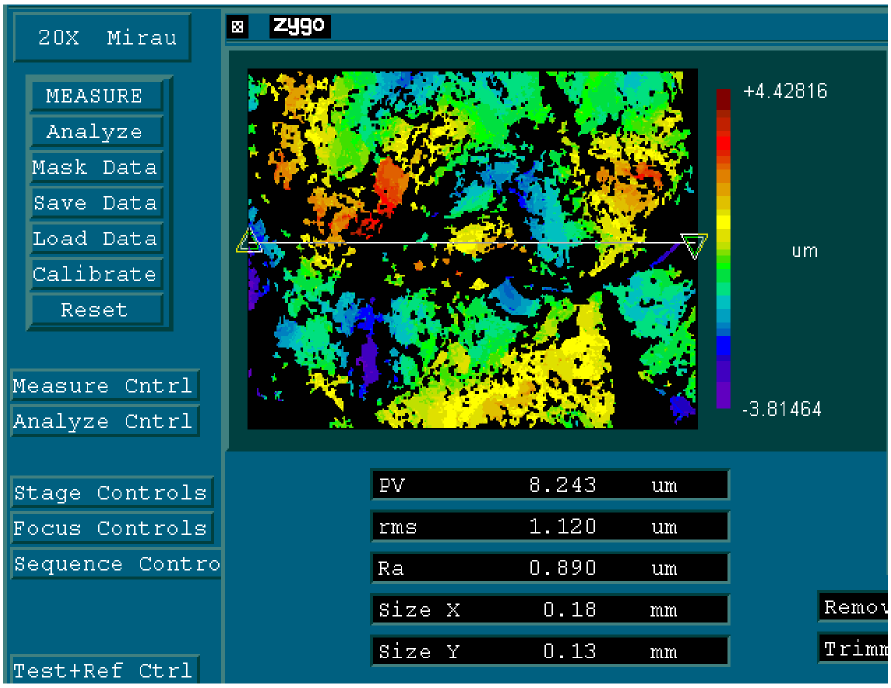


Figure 3.4 3D surface texture measurements

3.2.3 3D micro-textured surface design

Surface engineering techniques is one of the important areas of research in manufacturing industries due to its uniqueness. The design and development of macrotexture surfaces can minimise sliding friction eventually resulting in improved part performance and life, which also helps to improve the performance of the machine and part. Among the various surface engineering techniques, laser micromachining principles has received a wide acceptance owing to its capability of generating microstructures of intricate shapes with high processing speed and precise geometrical quality. Textured surfaces can be used to enhance the productivity and efficiency of manufacturing processes. Standard and aggregate coated abrasive products have abrasive grains randomly placed on a backing and this causal geometry produces unreliable grinding results in terms of abrasive life. By shaping the abrasive into pattern geometries each consisting of an erodible structure containing multiple abrasive particles, heat generation is reduced and belt life is extended. Engineering technologies have also been used to produce scented abrasive as well as easy identification of the abrasive belt [42].

Manufacturing of the components with micro structured surfaces has been studied with various fabrication methods The significance and application of such surfaces have been enhanced due to their great functionality in, for example, corrosion resistance, chemical industry separation, self-cleaning capability, antibacterial surfaces and dynamic fluids transportation [37]. The fabrication of these types of features and the functionality of different designs are still challenging for industrial applications because of their high production cost and low production efficiency in the prototyping phase. The fabrication technology of these surfaces has been advanced and evolved from traditional manufacturing to more advanced methods in practice. The additive manufacturing process has undergone outstanding advancement recently and becomes more widespread in different industries for parts production. Several manufacturing approaches for fabrication and preparation of microtextured surfaces were investigated. The functional surfaces are frequently fabricated by nanotechnology to create technologically advanced products and parts. Many researchers have investigated the dynamic behaviour of water droplets hitting a textured surface, which is intrinsic to the practical application of superhydrophobic surfaces.

Hydrodynamic properties have a large influence on the application of textured surfaces. At a small scale, a channel diameter of around 100 nm to several hundred micrometres are used. Surface forces must be overcome in relation to mass forces and factors such as surface tension, energy dissipation and fluidic resistances that govern the system. The fluid flows at the micro scale act differently from that in the macroscopic scale. At a small scale the Reynolds number (Re) assumes values at least one order of magnitude smaller than unity. Re is defined as the ratio between internal forces and viscous forces:

$$Re = \frac{PVs\,L}{\mu} \tag{3.1}$$

Where p is the density of the fluid in $/KG/m^3$, vs is the mean fluid velocity in m/s, μ is the absolute dynamics fluid viscosity in N S / m^2 and L is the characteristics length in m, of the system [42].

3.2.4 Selection of materials

The science of surface engineering, by controlling surface attributes, is important in the improvement of the efficiency of the surface. One of the branches of surface engineering is the creation of textures on surfaces. Many researchers have attempted to produce special surfaces by using different processes and hence examine the effectiveness of texture in related industries. The creation of micro/nano textures on the surfaces makes changes in their attributes such as tribological behaviour, wetting behaviour, and the improvement of transfer behaviour. Wettability behaviour depends on two factors. One is the level of surface energy which is dependent on the chemical composition of the surface. Materials with high surface energy create more hydrophilicity. This is because the surfaces of these materials need more energy to break molecular bonds between the surface and the liquid in contact with it. On the other hand, materials having low surface energy cause more hydrophobicity in the surface created by those materials. The second factor is the roughness and topography of the surface. The creation of microtextured surfaces can boost both hydrophilicity and hydrophobicity [48].

Hydrophobic surfaces have advantages in corrosion resistance, biocompatibility and extreme environments. Surface microstructure preparation and low surface energy modifications are the two aspects to improve surface hydrophobicity. There are many methods to produce micro texture and obtain superhydrophobic surfaces by changing the surface morphological structures. These can be shot blasting, chemical etching, machining and plasma etching . Laser surface texturing technology can prepare large surface functional areas through simple and rapid processing and be applied to industrial production with high reproducibility. Ultrashort pulse laser, including femtosecond and picosecond lasers have higher precision for preparation of micro textured surfaces.

Textured surfaces can enhance the functionality and performance of industrial components and are widely used in various industries for applications including self-cleaning. To promote the broad use of textured surfaces, high performance manufacturing technologies for the fabrication of microstructure with arbitrary complex geometric features are critically required [36][44][45][46]. The creation of micro / nano textured surfaces can be performed by using several methods which include mechanical methods, lithography, laser surface texturing, incremental stamping, electro chemical deposition, sandblasting, chemical synthesis, micro rolling-based texturing [47].

3.2.5 Surface topping

We have discussed 3D surface measurement and how we can use this data to obtain useful information. It is vitally important that consideration of 3D surface characterisation involves the appropriate separation of roughness, waviness and form error as well as multi scalar features. The components to be separated carry rich surface topographical information resulting from the manufacturing procedure or relating to the functional performance of the products themselves. These details can be used to:

- Find that whether the manufacturing process or manufacturing conditions are effective or out of control, whether events in manufacturing process such as tool breakage, tool wear have controlled.
- Interpret functional properties of surface topography, such as actual contact stress, loaded area, asperity volume of the components and the lubricating regimes [30][31] [39].

When measuring surface topography, all the measurements are related to the two length profile measurements required which are (x and z) and in areal measurements three are required which is (x, y and z). The traceability of length measurements can be illustrated best by the example of a simple length measurement in practice.

Methods to modify surface properties have been developed in many industries. Technologies range from sand-blasting to innovative grinding systems that exploit the mechanical, electronic, and chemical properties of the material. The characterisation of surface topography is a complicated branch of metrology with a huge range of parameters available. Modification of surface topography is in relation to the manufacturing methods that improve or exploit surface functions, it mainly considers micro texturing i.e. the methods of modifying surface topography and creating regular patterns. The main attributes, advantages, disadvantages and applications of each texturing method are explained. The proliferation of surfaces texture characterisation parameters has been referred to as 'parameter rash'. At any one time there can be over one hundred parameters to choose from [30][38][42].

3.3 Research objectives, focuses and knowledge gaps

We have discussed different aspects of the material surface, its measurements, its attributes and characteristics of the surfaces. We have discussed the impact of the different surfaces, the characteristics of the surface, surface textures and their behaviour.

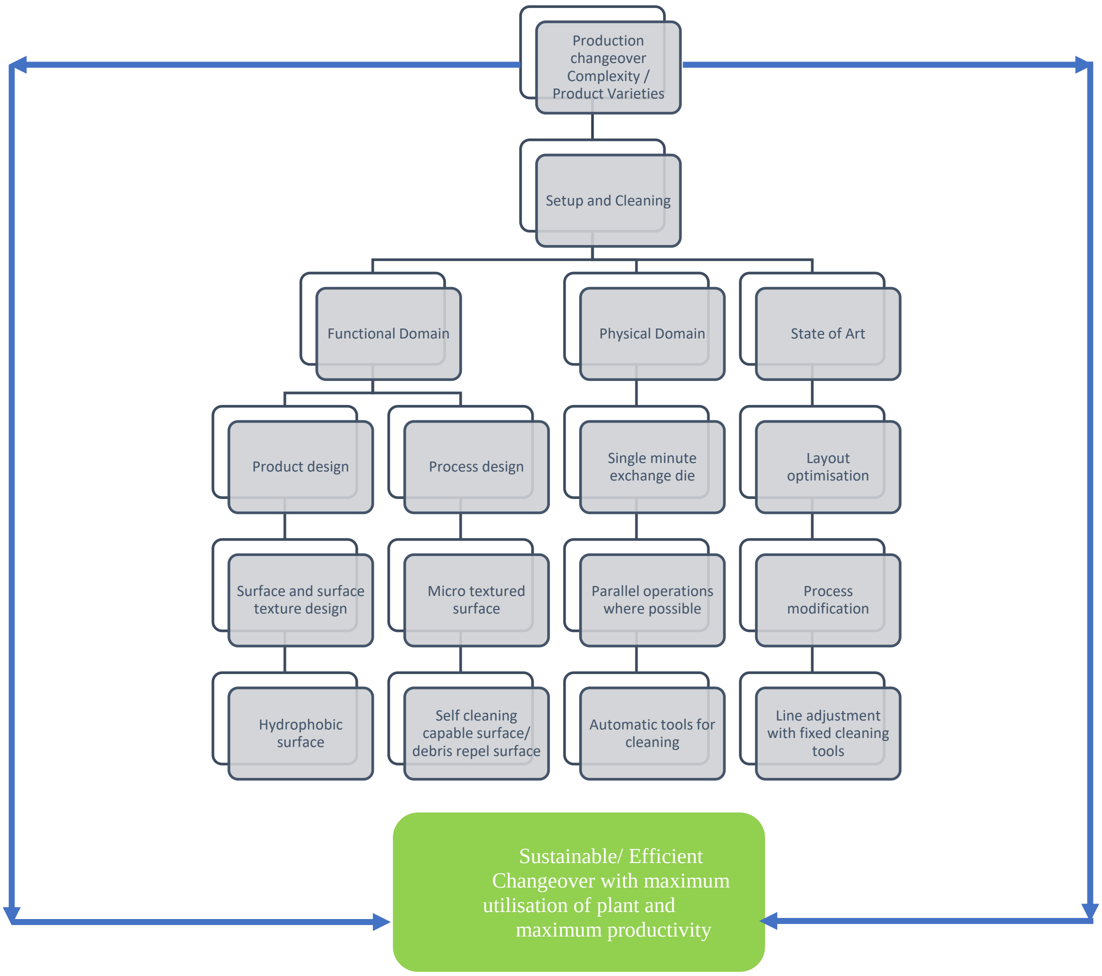


Figure 3.5 Research objectives

The main objective of studying different aspects and characterisation of metal surfaces and their structures is to find suitable surfaces which can help to reduce the production changeover time, or reduce the frequency of the cleaning of the surface during production changeover to enhance the productivity of the manufacturing facility.

There is lack of the research in this area and most of the research has been on 3D surfaces, micro textured surfaces, surface with high hydrophobicity capability but there is gap. It has not been considered in the context of food manufacturing processes to reduce the complexity of production changeover. We tried to work on, and to utilise, micro textured surfaces which have high hydrophobic characteristics and are able to repel debris from the surfaces. This reduces the frequency of cleaning the surface and will improve the changeover procedure.

Figure 3.5 shows the research objective of this study which starts from production changeover complexity due to product variety. The main aspect of the changeover is setup and cleaning time in our case study. This is elaborated in detail and further divided into the functional domain, physical domain and state of the art (Figure 3.5).

3.4 Characterisation of 2D surface and its parameters

Surface roughness is an important requirement in analysing component life and performance. 2D surface parameters are usually used in industry to quantify surface roughness. According to ISO 4287: 1997 there are three series of 14 parameters which include P- parameters for the unfiltered profile, R-parameters for the roughness profile and W-parameters for the waviness profile (Table 3.1).

For convenience of understanding (Prof Brian Griffith)[28][39], the range of parameters can be divided into the following classes that describe different attributes of the profile [40]:

1. Amplitude parameters which relate simply to height and depth of profile
2. Amplitude distribution parameters which relate to the amplitude distribution function, bearing area curve or cumulative distribution function that describe its shape
3. Slope parameter which relates to the differential of heights
4. Spatial parameters which relate to the longitudinal spacing features
5. Combined amplitude and spacing

Table 3.1 2D parameters explained in ISO 4287: 1997

Pp	Rp	Wp	Maximum profile peak height
Pv	Rv	Wv	Maximum profile valley depth
Pz	Rz	Wz	Maximum height of profile
Pc	Rc	Wc	Mean height of profile element
Pt	Rt	Wt	Total height of profile
Pa	Ra	Wa	Arithmetical mean deviation of the assessed profile
Pq	Rq	Wq	Root mean square deviation of the assessed profile
Psk	Rsk	Wsk	Skewness of the assessed profile
Pku	Rku	Wku	Kurtosis of the assessed profile
Psm	Rsm	Wsm	Mean width of the profile element
Pdq	Rdq	Wdq	Root mean square slope of the assessed profile
$Pmr(c)$	$Rmr(c)$	$Wmr(c)$	Material ratio of the profile
Pdc	Rdc	Wdc	Profile section height differences
Pmr	Rmr	Wmr	Relative material ratio

3.5 Smart surfaces represented by 3D surface parameters

The goal in any three-dimensional characterisation of surface topography is to integrate the surface features in a representative manner as accurately as possible. Many methods have been utilised to obtain a degree of surface visual characterisation, with especially the best technique at present being to define the surface condition by a predefined series of parameters which can be measured then related to the practical operational permanence .

A categorically important consideration for 3D characterisation must be the appropriate separation of surface components in terms of roughness, waviness and form, as we multiscale topographical features which support the value of the information conveyed by a multiplicity of parameters. Professor Ken Stout and Dr Liam Blunt have devoted tremendous efforts towards making a clear 3D surface characterisation standard [28][39]. In order to differentiate between 2D and 3D parameters, different names are given to the 3D parameters. It is proposed that S is for surface and should be used in 3D instead of the letter R in 2D. Therefore, all 3D parameters are denoted by 'S', the primary parameters set for the characterisation of 3D surface. These parameters are fourteen in total which characterize some major aspects of the topography features. There are four parameters for describing the amplitude and height distribution properties, four parameters for describing spatial properties, three parameters for describing hybrid properties and three parameters are for functional properties [38][39][40].

3.5.1 Amplitude and height parameters

The 3D height parameters are shown in Table 3.2. Root mean square deviation and ten-point height are height parameters:

- **Root mean square deviation, Sq** - the root mean square value of the ordinates. The Sq parameter is defined as the root mean square value of the surface departure. Z (x, y), with the sampling area.
- **Ten-point height of surface, Sz** - an extreme parameter defined as the average value of the absolute height of the five highest peaks and the depth of the five deepest valleys within a sampling area.

  Similarly, skewness of surface and kurtosis of surface height are the area height distribution parameters.
- **Skewness of surface height distribution, Ssk** - skewness is the ratio of the mean cube value of the height values and the cube of Sq within a sampling area.
- **Kurtosis of surface height distribution, Sku** -this parameter is the ratio of the mean of the fourth power of the height values and the fourth power of Sq within the sampling area [38][39][40].

Table 3.2 Area height and area height distribution parameters

Symbol	Parameters	Equation and description
Sq	RMS Average (Root mean square deviation)	$\sqrt{\frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} Z^2\,(x_I, y_{j)}}$
Sz	Ten-point height	$Sz = \frac{1}{5}\left[\sum_{i=1}^{5} z_{pi} + \sum_{i=1}^{5} Z_{vi}\right]$
Ssk	3D Skew (Skewness of height distribution)	$Ssk = \frac{1}{MNSq^3}\sum_{j=1}^{N}\sum_{i=1}^{M} Z^3\left(X_i, y_j\right)$
Sku	3D Kurtosis (Kurtosis of height distribution)	$Sku = \frac{1}{MNSq^4}\sum_{j=1}^{N}\sum_{i=1}^{M} Z^4\left(X_i, y_j\right)$

3.5.2 Hybrid Parameters

HP (Hybrid Parameter) is a combination of amplitude and wavelength. In hybrid parameters many researchers, [a], (Stout, 2000; Blunt, 1999; Brian Griffith, Richard Leach) indicates three parameters. i.e. RMS slope (SΔq), mean summit curvature (Ssc) and interfacial area (Sdr). These parameters are dependent on height and spacing and will be sensitive to the sampling interval used. The details are shown below along with each equation in Table 3.3.

Hybrid parameters are divided into three types:

- **Root mean square slope of a surface, SΔq.** Root mean square slope of the surface is the root mean square value of the surface slope within the sampling area. Its equation is shown in Table 3.3.
- **Arithmetic mean summit curvature of a surface, Ssc.** The arithmetic mean summit curvature of the surface Ssc is defined as the average of the principle curvature of the summits within the sampling area. The equation is further explained in Table 3.3.

- **Developed interfacial area ratio Sdr.** The developed interfacial area ratio is the ratio of the increment of the interfacial area of the surface over the sampling area. The equation is shown in Table 3.3.

Table 3.3 Area hybrid parameters

Symbol	Parameters	Equation and description
$S\Delta q$	RMS Slope (Root mean square slope)	$S\Delta q = \sqrt{\frac{1}{(M-1)(N-1)}\sum_{j=2}^{N}\sum_{i=2}^{M}\left[\left(\frac{n(x_i,y_i)-n(x_{i-1},\ y_j)}{\Delta_x}\right)^2+\left(\frac{n(x_i,y_i)-n(x_{i-1},\ y_{j-1})}{\Delta y}\right)^2\right]}$
S_{dr}	Developed interfacial area ratio	$S_{dr}=\frac{\sum_{j=1}^{N-1}\sum_{i=1}^{M-1}A_{ij}-(M-1)(N-1)\Delta_x.\Delta_y}{(M-1)(N-1)\Delta_x.\Delta_y}$
S_{sc}	Mean summit curvature	$S_{sc} = -\frac{1}{2}.\frac{1}{n}\sum_{k=1}^{n}\left(\frac{n(x_{p+1},y)+n(x_{p-1},y_q)-2n(x_p,y_q)}{\Delta^{x^2}}+\frac{n(x_p,y_{q+1})+n\left(x_p.y_{q-1}\right)-2n(x_p,y_q)}{\Delta y^2}\right)$

3.5.3 Spatial Parameters

SP (Spatial Parameters) relating to a surface's spatial property offer some difficulty in their characterisation, due to their general wavelength randomness combined with multi wavelength variation, which in turn are coupled to their high sensitivity to the sampling interval (SP). Spatial parameters are divided into four types, these are the density of summits (Sds), the texture aspect ratio (Str), the texture direction (Std) and the fastest decay correlation length (Sal). The last three of these could be called texture parameters since they are able to tell something about the lie and directionality of the surface texture in a way that was not possible with 2D parameters [33][37][43].

- **Density of summits of surface, Sds -** This is the number of summits in a unit sampling area. It is the number of summits within the scanned area in terms of summits per mm^2. Its equation is shown in Table 3.4. This parameter is significantly influenced by the sampling interval of the measurements.

- **Texture aspect ratio of a surface, Str -** This parameter is a measure of surface texture patterns, directionality and anisotropy. Stout et al. state that this ratio defines *the long crestness or uniform texture aspect*. It is defined by the areal autocorrelation function and its equation is shown in Table 3.4.
- **Texture direction of a surface, Std -** The texture direction parameter (Std) gives the direction of the dominant surface with the reference to the measurement direction. It gives the direction of surface texture with respect to the y axis, which gives you the lay direction with reference to a datum. This is described by Stout *pronounced direction of the surface texture*. The texture direction of surface equation is shown in Table 3.4.
- **Fastest decay autocorrelation length, Sal -** The fastest decay autocorrelation with length dimension parameter. Sal unit is µm. It also gives information about the dominant lay and fastest decay to 0.2µm in any possible direction. Stout et al. have explained this parameter as the shortest *autocorrelation length that the areal ACF decays to 0.2* µm. The Sal is the shortest autocorrelation length during which the AACF decays to 0.2 in any possible direction. The fastest decay autocorrelation length equation is shown in Table 3.4. Figure 3.6 shows 3D surface waviness of the sample surface. The peak height of the surface is +4.428µm and peak depth is -3.814 µm of the sample surface.

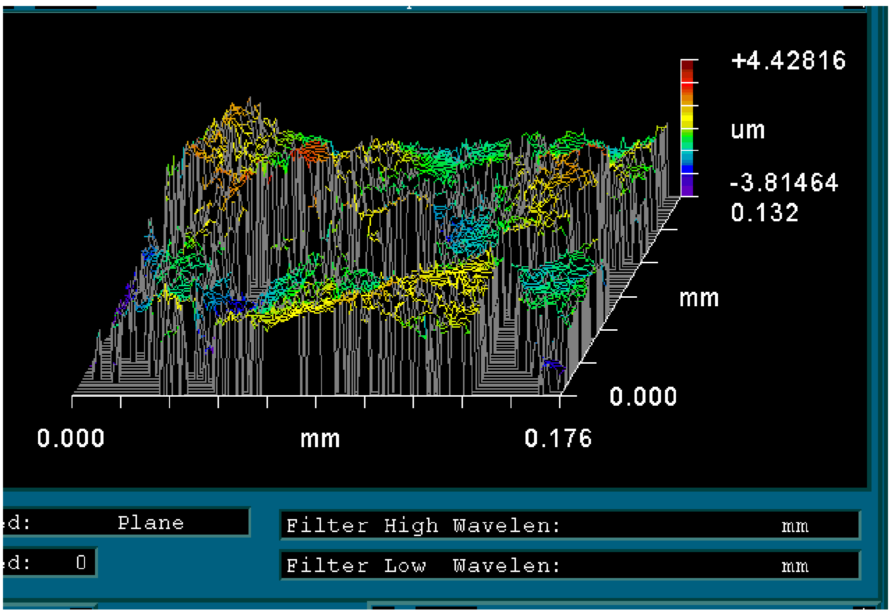


Figure 3.6 3D surface waviness diagram

Table 3.4 Area spatial parameters

Symbol	Parameters	Equation and description
Sds	Density of summits	$Sds = \frac{Number\ of\ summits}{(M-1)(N-1)\Delta_x \Delta_y}$
Str	Surface texture aspect ratio	$0 < S_{tr} = \frac{The\ fastest\ decay\ distance\ to\ 0.2\ distance\ in\ any\ direction}{The\ slowest\ decay\ distance\ to\ 0.2\ distance\ in\ any\ direction} \leq 1$
Sal	Fastest decay auto-correlation length	$S_{al} = \min\left(\sqrt{t\frac{2}{x} + t\frac{2}{y}}\right), R\left(t_{x,} t_{y,}\right) \leq 0.2$
Std	Texture direction	$S_{td}\begin{cases} -\beta, & \beta \leq \frac{\pi}{2} \\ \pi - \beta, & \frac{\pi}{2} < \beta \leq \pi \end{cases}$

3.5.4 Functional Parameters

In FP (functional parameters) there are many parameters because there are many functional situations. It is impossible to define a functional parameter set to cover the whole area of functional applications. Therefore, the definition of functional parameters is concentrated on some important and frequently applied aspects. However, Stout explained four of them which are Surface bearing index (Sbi), Core fluid retention index (Sci) and valley fluid retention index (Swi).

Surface bearing index, Sbi, $S_{bi} = \frac{Sq}{n0.05} = \frac{1}{h0.05}$ (3.2)

is the ratio of the RMS deviation over the surface height at 5% bearing area, the equation of the Surface bearing index is shown in Table 3.5 where $h_{0.05}$ is the surface height at

5% bearing area. A larger surface bearing index indicates a good bearing property. For a Gaussian surface, the surface bearing index is about 0.608.

Core fluid retention index, Sci , $S_{ci} = \frac{Vc}{Sq}$ (3.3)

is the ratio of the void volume of the unit sampling area at the core zone over the RMS deviation. The equation of core fluid retention index is shown in Table 3.4.

Valley fluid retention index, Svi $S_{vi} = \frac{Vv}{Sq}$ (3.4)

This is the ratio of the void volume of the unit sampling at the valley zone and the RMS deviation. Valley fluid retention equation is shown in Table 3.5 where Vv is the void volume of the nil sampling area at the core zone. For a Gaussian surface, this index is about 0.11.

Table 3.5 Functional parameters

Symbol	Parameters	Equation and description
S_{bi}	Surface bearing index	$S_{bi} = \frac{Sq}{n0.05} = \frac{1}{h0.05}$
S_{ci}	Core fluid retention index	$S_{ci} = \frac{Vc}{Sq}$
S_{vi}	Valley fluid retention index	$S_{vi} = \frac{Vv}{Sq}$

3.6 Surface profile measurement

The practice of areal measurement can be traced back to about 300 years ago, when the first microscope was invented. Surface topography was viewed through the microscope, but no quantitative surface height information could be obtained. Today there are contact (stylus) measurements, optical measurements and other technical solutions. Typical measuring methods are comparison with standards, the contact stylus and the optical methods. Optical specular reflectance was another early areal measurement technique, but it provided neither quantitative surface topology nor an image of the surface.

Surface profile measurement is the measurement of a line across the surface that can be represented mathematically as a height function in which lateral displacement is Z (X). With a stylus or optical scanning instrument, profile measurement is carried out by traversing the styles across a line on the surface. However, a parameter that represented root mean square roughness (RMS) was presented. By measurement, we mean something more than simple inspection. One of the currently available commercial optical instruments for 3 D surface topography measurement is the focus detection instrument. Several techniques of focus detection were developed in 1980s and 3D measurement was introduced into this technique. We will define measurement in the present context as a process which gives, or is capable of giving, quantitative information about the individual or average surface heights. There is some general consideration in choosing measuring instruments, cost, ease of operation, size and robustness. Characterisation of surface irregularities are described by a number of measurement methods which examine the surface from different point of views and provide different information. There are three measuring techniques which are divided into two types according to whether the result is quantitative or visualisation [130].

3.6.1 Surface roughness measurement

For our case study we used a Zygo machine (Figure 3.8) for (SRM) surface roughness [34][35]. There has been a general tendency to approach the problem of amplitude characterisation by two different methods, one is measuring peaks, and the other is to control the process by measuring average values. The measurement of peak parameters is more difficult than measuring the averages. Moreover, the average parameters are more suitable for quality control of the manufacturing process because of their statistical stability. Peak measurements are essentially divergent rather than convergent in stability. The bigger the length of the profile or length or assessment, they converge to the true value, the larger the number of values taken. An increase in the reliability of the amplitude measure can be obtained by using all the profile signals rather than just the maximum and minimum values. Figure 3.7 shows 3D surface parameters of the same surface and these reading are taken with the help of zygo equipment mentioned in figure 3.8.

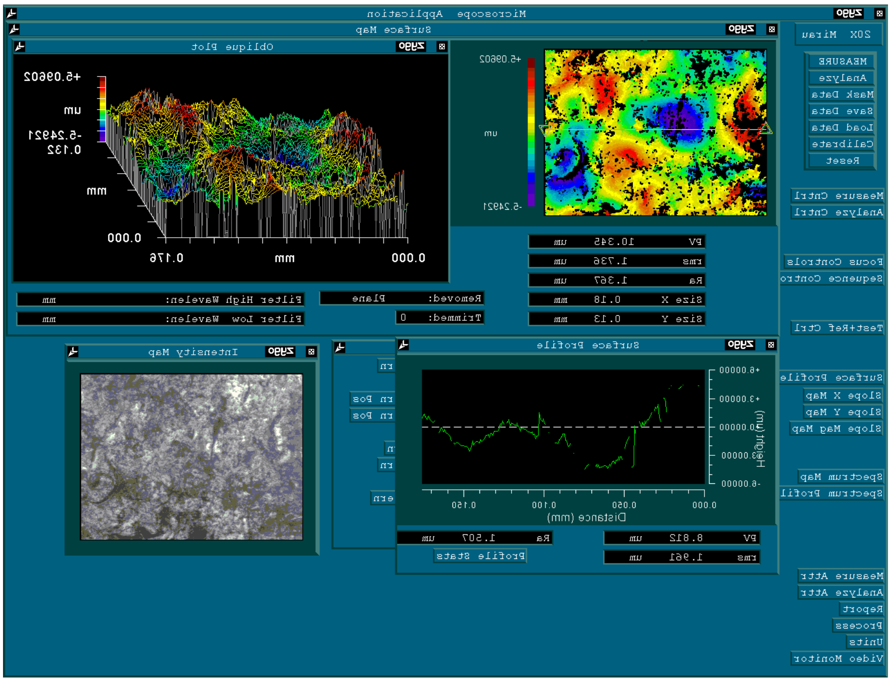


Figure 3.7 3D surface parameters and dimensions

In general, the roughness parameters will mainly depend on the manufacturing conditions employed, that is feed, depth of cut, cutting speed, machines tool and cutting tool right, among others. Therefore, a complete modelling of these parameters should consider the previous parameters. It can be shown that the main parameters affecting the surface roughness are the cutting speed, the depth of cut and the feed.

The most common and frequently used parameters is the surface roughness average donated by R_a, defined from the mean reference line. Another, more frequently used, parameter is R_q which is the root mean square deviation, defined relative to a mean line. Due to wide acceptance of these parameters and their usefulness, it appears that the R_a and Rq values will continue to hold their place as the primary amplitude measurement [4]. Roughness average R_a according to the ISO 4287, *is the arithmetic mean of the deviation of the roughness profile from the central line (lm) along with measurement.* It contains low information since the value of R_a is not particularly sensitive to the roughness of the profile. For finely machined surfaces, R_a is unusable in some cases as it only shows the average of surface roughness as if the surface roughness of the peak and regular various recesses would shape that length [33][35]. The maximum height of profile Rz according to the ISO 4287 *is sum of height of the largest peak height and the largest profile valley depth within a sampling length.* The value of the maximum height of the Rz profile is used to evaluate the equality of the surface but still does not allow the detection of surface characteristics and working conditions [33][34][35][38].

Figure 3.8 Zygo equipment for 3D surface roughness measurements

As discussed previously the surface roughness average is one of the most important parameters used in the manufacturing industry and it is included in the majority of roughness measurement equipment. Therefore, the surface roughness average R_a was taken as a parameter for the design of any part of the equipment. The roughness average R_a, according to ISO 4287, *is the arithmetic mean of the deviation of the roughness profile from the central line (lm) along with measurement.* This definition is set out in equation 3.5 where y(x) is the profile values of the roughness profile l is the evaluation length.

$$Ra = \frac{1}{l} \int_0^1 \; y(x)I \; dx \qquad (3.5)$$

One more roughness parameter is important for industrial use is the roughness quadratic average. This is defined in equation 3.6. Unlike R_a, it is more affected by isolated errors. Thus, it provides a better means of detection of these errors. Rq does not differentiate whether it is an isolated error or general failing tendency of the surface.

$$R_q = \sqrt{\frac{1}{l}\int_0^1 y^2 dx}. \qquad (3.6)$$

Rq is associated with the central line or average line. This line is defined as the one in which the area of roughness peaks are above it and is equal to the area of the ones below it. On the other hand, Rq is usually related to the least square average line of the distance from the effective points of the profile to such a line is the minimum. [33][34][35][38].

3.7 Sustainable manufacturing

Sustainability will be the driving force of the twenty-first century as automation was in the twentieth century and steam was in the nineteenth century. Sustainability involves the rearrangement of technological, scientific, environmental, economic and social resources.

As sustainability is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs, there are multi-dimensions of sustainability development: economy, environment and society. These multi-dimensions are considered as the pillars of sustainability development and they should be taken into consideration when building the model of sustainability.

Sustainable manufacturing is defined by Garretson et al. [147] as the creation of goods or services using a system of processes that simultaneously addresses economic, environmental and social aspects in an attempt to improve the positive, or reduce the negative, impacts of production by means of responsible and conscious actions. Sustainability in manufacturing will surely be one of the most important contributions to sustainability. Sustainability in manufacturing is presented in its various aspects since it is a complex problem and it has many dimensions. Sustainability is a quality that allows us to preserve, to keep, to maintain something. In the past, sustainability was considered as environmentally oriented only. Now it is a term with more widely ranging ramifications; for example, there is strong relationship between sustainable manufacturing and design along with other objectives such as functions, profitability and productivity. Manufacturing provides goods and services of primary importance for supporting the quality of the human life, also sustainability contributes to the world economy. Manufacturing involves all industrial activities from the customers to the factory and back to the customer.

Sustainable manufacturing can be defined as the ability to intelligently use natural resources for manufacturing by designing new products that are able to satisfy economic, environmental and social objectives [58][136][146][147]. It has improved the performance of the industrial process through innovation and technology to create complex, yet reliable and affordable products for society. Manufacturing process is defined as any type of activity that uses some form of energy to transform material or intermediate products into an intended product.

3.7.1 Research gap - sustainability in production changeover

During this study it has been observed that sustainability is mostly concerned with environmental aspects, energy efficiency, product quality, the economy and society as a whole. There is research gap that sustainability is not considered in complex production changeover. In our case study we have considered sustainability in production changeover and different aspects and possible recommendations has been made. These include process optimisation, smart conveyor surface, improved process layout, improved changeover procedures, suitable automatic tools for efficient cleaning and automation to the production line for efficient changeover and cleaning [144][148]. The sustainable product design is not really about new technologies, but about reconsidering how to meet the need for flexibility of the production changeover and sustainability of the changeover at the same time. Figure 3.9 shows sustainable manufacturing gap.

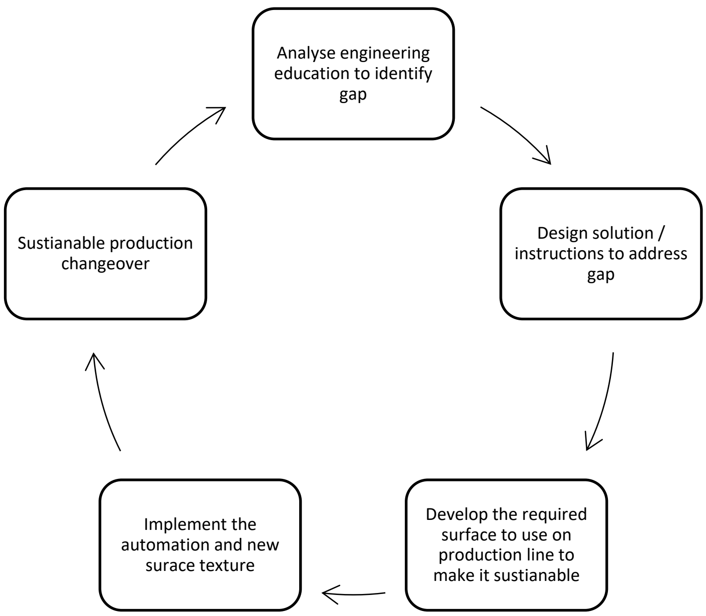


Figure 3.9 Sustainable manufacturing gap

The idea of sustainable production changeover will become increasingly important in food manufacturing. This will also link all three basic pillars of sustainability - society, economy and environment - with sustainable production changeover design.

3.7.2 Sustainable design

A sustainable design approach for new products and services with a much better environmentally sustainable performance will be a key element to achieve sustainability. An innovative approach to sustainable design may have a broad application for improving industrial products, product service systems and manufacturing processes, as well as production machines and systems. Traditional manufacturing system design is involved in the determination and analysis of such factors as material-handling methods, system capacities, production methods, material flow, shop-floor layouts, and operations. Nevertheless, there is a production changeover consideration that needs also to be addressed to make the manufacturing facility sustainable.

This leads to a new challenge for manufacturing system designers to develop an effective approach by incorporating sustainable design, parameters or constraints. To develop a sustainable manufacturing system, system designers need not merely to apply traditional methods to improve system efficiency and productivity. Here we will include sustainable design to improve productivity through sustainable production changeover.

Design involves an interplay between what we want to achieve and how we decide to satisfy the need, to systematize the thought process involved in this interplay, the concept of domains that create demarcation lines between four different kinds of design activities provides an important foundation of axiomatic design. The world of design is made up of four domains: the customer domain, the functional domain, the physical domain and process domain [135][136][143].

A design for sustainable manufacturing should have several objectives but in this case study we will concentrate only on sustainable production changeover. For the design, we should consider the following aspects shown in figure 3.10. Customer needs leads to the functional requirements of the product ,design parameters of the product and sustainable and flexible design of the product.

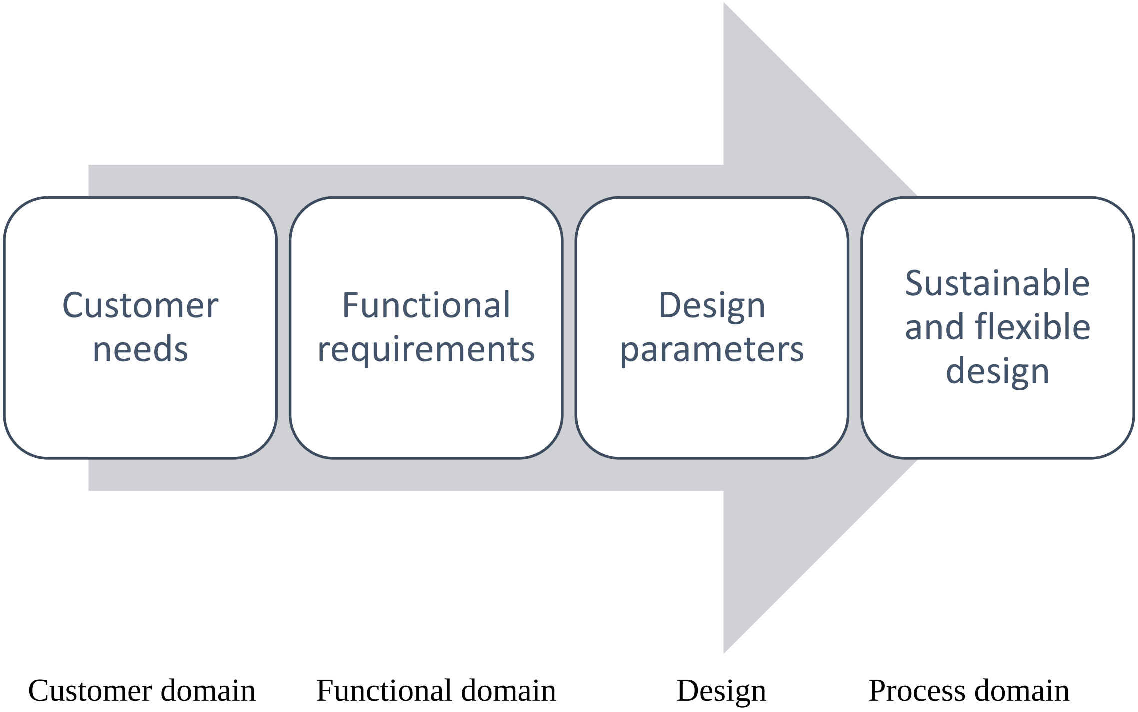
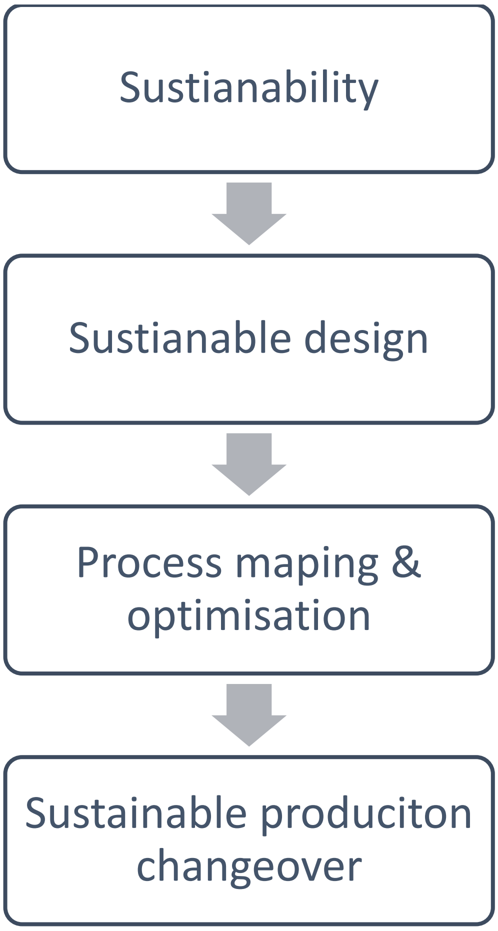


Figure 3.10 Sustainable design process

- Design of the component for flexible changeover. The component or part should be designed so that if a manufacturer needs it, changeover can be easily made.
- Design of component or part in which there should be room for continuous improvement.
- Design of the component which is cost effective and optimal use is possible. For example, the down time of the part or component should be zero or minimal during production changeover.
- Design the product surface to have a self-cleaning capability and have a specific function
- Design to product to have zero waste

Figure 3.11 shows what can improve the production changeover more sustainable. The main contents are mentioned on the left side and on the right side these actions can makes the production changeover sustainable.



- Process simplification
- Less material
- Selection of material for surface design
- Improved process performance
- Integrated process
- Automatic tools for cleaning
- Functionality of the surface used
- Waste reduction
- Reduce labour hours
- Reduce disposable cleaning materials
- Flexible design
- Automation where possible
- Easy to dismount
- Easy to assemble
- Sustainable production changeover

Figure 3.11 Sustainable design map

3.7.3 Role of sustainable manufacturing design

The concept of SM (sustainable manufacturing) is identified and analysed through three main levels, namely sustainable product, sustainable process and sustainable systems levels (Figure 3.12). The interaction among these levels provides the required sustainable target. With regards to the product level, the perspective of sustainable manufacturing focusses on the recycle, reuse approach.

In a traditional manufacturing system design, engineers used to focus on indicators of system performance in terms of production output, plant capacity utilization, efficiency and other production-related parameters. Production changeover considerations are almost overlooked as part of manufacturing systems analysis, design and performance evaluation. An effort has been made to develop a multi-objective optimization for making a sustainable manufacturing system for sustainable production changeover which includes automation of the plant, waste reduction in terms of changeover time, changeover complexity and resources to get maximum utilization of the production facility.

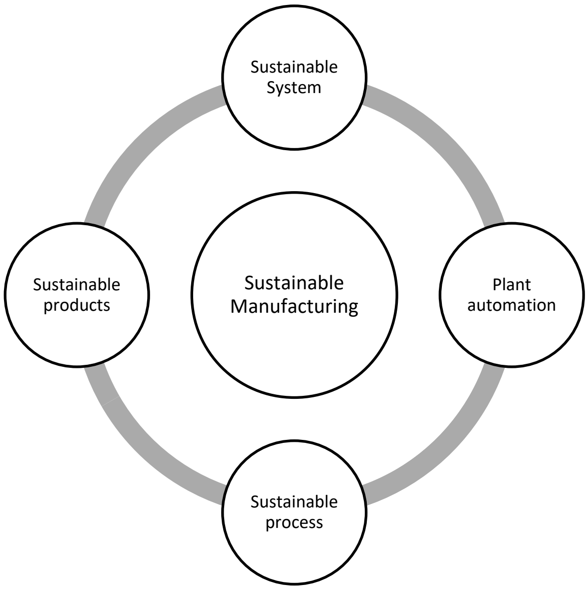


Figure 3.12 Sustainable design system

SD (sustainable design) considers the environmental, economic and social impacts of the entire product life cycle. In our case study, we will talk about sustainable design in terms of sustainable production changeover. Design helps to solve complex ecological problems and is also a suitable source of solutions. Sustainable design is considered to be a method that may help to obtain a solution and contribute to sustainable development [48] [49][137][138]. It can help flexible production changeover (Figure 3.13).

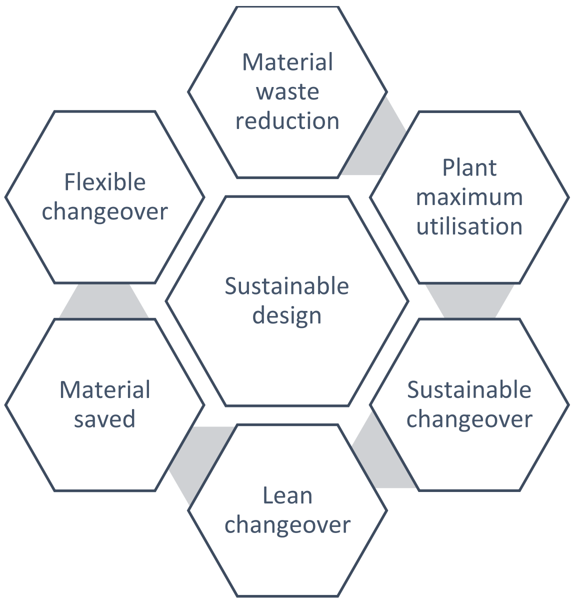


Figure 3.13 Sustainable design and its outcome

Sustainable manufacturing is essentially a complex systemic problem, and it is difficult to deal with it by existing methods because these methods mainly consider production and process only.

3.7.4 Flexible design

Design for sustainability has enlarged its scope and field of action over time, as observed by variolous researchers. The focus of sustainable design has expanded from the selection of resources with low environment impact to the life cycle design of the products, equipment and machines. Manufacturing industries need to be able to adapt quickly to market challenges and take advantage of them. Flexible manufacturing systems ease the effect of demand uncertainties. Mass customisation and build to order manufacturing system should be design flexible to meet the required goals and be able to produce both volume and variants of the products. Flexibility and adaptability enables manufactures to meet customer demands and compete.

- Sustainable design (how things are designed) with a focus on process and equipment (machine-tool, facility). Linked disciplines are production engineering and sustainable production changeover.
- Automatic tools – the use of automatic tools for cleaning during production changeover: evolving, flexibility, increasing autonomy and increasing efficiency.
- Developing new or improving technologies, products and services focus on reductions in complexity and reduction in production changeover process which enables resource efficiency [143].
- Sustainable smart manufacturing, Sustainable product design covering the entire life-cycle of products.

Table 3.6 Sustainable and flexible manufacturing

Sustainable manufacturing system	The creation of goods or services using system processes that simultaneously address economic, environmental and social aspects in an attempt to improve the positive, or reduce the negative, impacts of the manufacturing system on society. A sequence of events that transform natural and human work into finished goods. These include processes, activities and machine devices.
Input to the manufacturing system	Physical material used to produce finished goods with the help of machines, equipment and labour. Material, energy, resources enter the manufacturing system as input and produce finished good products.
Sustainable manufacturing measurements	A unit of measure used in evaluating a system, machine, processes and activities involved in the process. A variety of metrics can be used to assess the sustainability of the manufacturing process using a sequence of operations with necessary instruments, machines and tools and having the desired goals of determining the value of an indicator.
Sustainable production changeover	Observe production changeover process Record all activities Introduce automation to the manufacturing process Use of smart surface(micro textured) on the conveyor belt which has self-cleaning capability Use of suitable tools for cleaning Use of smart surface with high contact angle
Sustainability outcome	Smooth production changeover Less time in production changeover Reduced frequency of cleaning of production line Reduced number of changeovers all over Sustainability improved in production changeover and overall production process.

3.8 Summary

In this chapter we discuss the material, material surface and its characteristics. We discuss the hydrophobic surface, micro textured surface, self-cleaning capability surface. We also discuss the 2D parameters and 3D parameters of the surface texture and its importance. We have talked about sustainable design and sustainable production changeover. The main objective of this discussion is to develop a system where the production changeover is more sustainable and has minimum waste of resources.

Sustainable design of the manufacturing process chain not only helps mitigate the potential negative effects of the complexity in manufacturing changeover but also maximizes its associated benefits. High complexity in the design of a manufacturing system should only be adopted if it really maximizes the benefits of that manufacturing system, i.e. in terms of the increased number of products, with low costs and without compromising on quality, with the inclusion of options that a manufacturer can offer to the customer. If it does not do so, it should be minimized as much as possible in an effort to decrease costs and maximize profit. The results illustrate the benefits of implementing the proposed approach, including the reduced manufacturing setup times, increased machine utilization, reduction of the raw material waste, reductions in energy consumption and improved productivity.

It is unlikely that the complexity of a manufacturing system can be reduced to zero with everything being kept under control all the time. Nevertheless, the manufacturing facility should be adaptive and responsive to the unforeseen requirements and dynamic changes from the global marketplace. Using a sustainable manufacturing oriented approach to managing manufacturing changeovers and frequent setups is essential and an indispensable method and tool for a manufacturing company to strive towards the comprehensive development of global competitiveness and sustainability [135]. Quantitative analysis-based modelling and simulation is the basis of the approach, which is still under development, particularly through a number of selected industrial case studies.

We discover a new aspect and consider in sustainable design in production changeover with process optimization and automation, which are discussed in details in Chapters 4 and 5.

Chapter 4 Design and Analysis of Self-cleaning Smart Surfaces Applied to Food Production

4.1 Introduction

Increasing demand for individual products is having a big impact on manufacturing industry since the flexibility of the production line must be increased. This means manufacturing more products with greater variety on the same manufacturing line and, therefore, more production changeovers. Changeability is a general characteristic of manufacturing for accomplishing planned adjustments of structures and processes on all levels which are economically feasible. Changeability can be accomplished at multiple levels within the manufacturing enterprise generally categorised into different changeability classes. In every manufacturing company, different externally and internally triggered change drivers create a need for specific changes, which impact the design of the manufacturing system and its characteristics.

When designing a manufacturing system, it is essential to consider changeability at the outset and throughout the entire design process and life cycle of the system. This also includes production changeover or flexible changeover. Thus, essential decisions regarding change drivers, change objects, change extent and the appropriate enablers should be considered and supported. Manufacturing processes to become leaner, more efficient and more agile may well be recognised as economic and competitive forces and these developments may also provide new opportunities. To be more viable, the manufacturing system needs to be configured to allow a greater range of possible outcomes to produce a variety of products. Therefore, self-cleaning surfaces and coatings are currently becoming attractive in the field of energy conservation because of the ever-increasing demand for uncontaminated, self-disinfected and hygienic surfaces. Such surfaces have been adopted in various industries such as plate glass, windshields and solar panels . In our case study we will consider the use of the self-cleaning capability surface in the food industry [52][53]. The design of the product or part itself can have a major impact, particularly if it has been designed in an unrestrained environment in which no manufacturing constraints have been imposed or techniques such as design for manufacture and variety reduction have not been employed. Low cost, minor product changes can made that greatly assist the changeover performances of a system [62]. These thesis is about the reduction of production changeover complexity and makes the changeover sustainable and more flexible therefore the causes of the production changeover are mentioned in Figure 4.1.

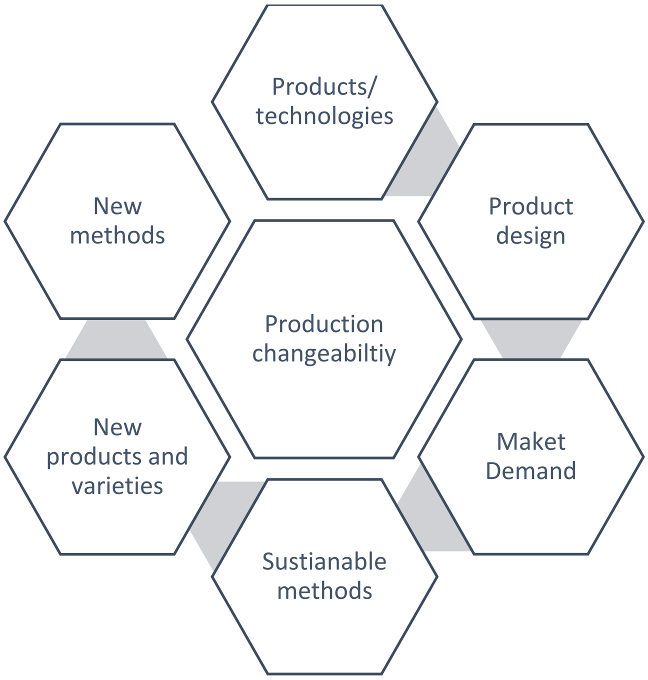


Figure 4.1 Production changeover causes

Product variety is the strategy for developing the product offering for the customer and it is directly related to the production changeover. It is generally acknowledged that there is a lack of systematic design methodologies for changeability in production changeover [50][51]. For flexible changeovers, the design of smart self-cleaning surfaces can be one of the options. Fundamentally, increased changeover capability eases the changeover processes and is based on technical improvements. There is less variability to improve the changeover capability during the operational phase compared to the developmental phase of the production machine. Therefore, the consideration of design rules to improve changeover capability is one of the objectives.

Different methods have been studied for flexible sustainable production changeover and a proposal has been made for the case study in later sections and chapters.

4.2 The scope of research methodology

Every manufacturing process has periods of time where equipment is unavailable due to tooling changes, material changes, part changes, product changes, programme changes or any other changes to production that must be performed while equipment is stopped. Collectively these events are referred to as changeovers or setup. Changeover operations are a crucial aspect of the manufacturing environment. In most manufacturing firms, there are some kind of changeover operations which may range from a physical setup operation that requires replacement of the machine parts to intensive cleaning operations which involve the use of cleaning agents, or it may involve both types at the same time. Changeovers are critical for a wide range of industries, however the environmental and economic impacts as a result of changeover operations are not well understood in all respects. So far, the main interest in changeovers has been due to the significant loss of production time. Therefore, the main objective is achieving faster changeovers. This research has tried to capture the root causes of changeover impacts to support the improvement process and providing a better understanding of how changeover impacts the production output and its environmental and economic effects. To find out the root causes of the complex production changeover, data relevant to the changeover has been gathered and are categorised in later sections. Many aspects of the production changeover operations are discussed which can result in smarter sustainable changeover which includes smart surfaces, facility layout improvement and process improvement.

Cost of production changeover = Cleaning costs + Production loss + Time and resources losses

First, it is very important to understand operations / processes of the production machines in order to find where improvements can be made. In order to measure change over time accurately, it is important to create a clearly defined standard and sustainable procedure. The majority of changeover time reduction initiatives have concentrated exclusively on the setup aspects of the changeover and have often been called ‘setup reduction initiatives’. It has been observed that achieving a faster setup can lead to an increase in the run-up time, if the quality of the setup is not addressed at the same time. It is also typical to lose up to ten times as much time during the run-up stages as in the setup stage of a changeover. It is thus important to improve the totality of the changeover not just the setup [62]. The reduction of changeover time should take place within an overall methodology aimed at ensuring success and sustainability.

During this study many journals and articles have been studied and different methods are discussed in the next chapter and recommendations made that a superhydrophobic / oleophobic surface needs to be used with high contact angles.

The research methodology is divided into five sections:

- Data collection
- Parts improvement through smart surfaces
- Process improvement to improve plant efficiency
- Data collection and performance analysis
- The experimental setup

Various plant visits have been made to monitor production. There are three strategies which can be adopted for reducing changeover time. The first one is to improve the existing system with the help of shop floor staff and with a continuous improvement programme, for example, by doing the existing procedures better. The other possibility is to design and implement a completely new system. to perform everything better. The third possibility is to improve some part of the changeover or manufacturing system which causes the majority of the losses. To overcome this problem, the plant manufacturing process has been studied in depth to find out the root causes of major losses. For this, a large data set has been collected and studied. Improving the existing process is discussed in the process improvement section in detail. Similarly, the data that has been collected, and improvement through smart surfaces, are also discussed in later sections.

4.2.1 Data collection

The goal of this work is to find out the major cause of the plant down time and work on it to improve it. Data is a key source for improvement in smart manufacturing. However, data in its raw form is not so useful to provide the required information. This data needs to be transformed into something more useful and this is usually done by various stages and it also varies from plant to plant or what is required or what is the target to achieve.

This has been done by collecting down time data from the production report and filter it and only production changeover and cleaning down time has been taken. See table 4.1 and table 4.2 for details. Almost every component and parts in the production process is a potential source of data. Within the production environment, systems, such as the manufacturing process system, has some sort of data related to it. The data collected is not useful but needs to be processed in such a way that it can be made useful. *Data from different sources will make the processes and systems more coordinated, thereby resulting in higher productivity, efficiency and profitability* [63][64].

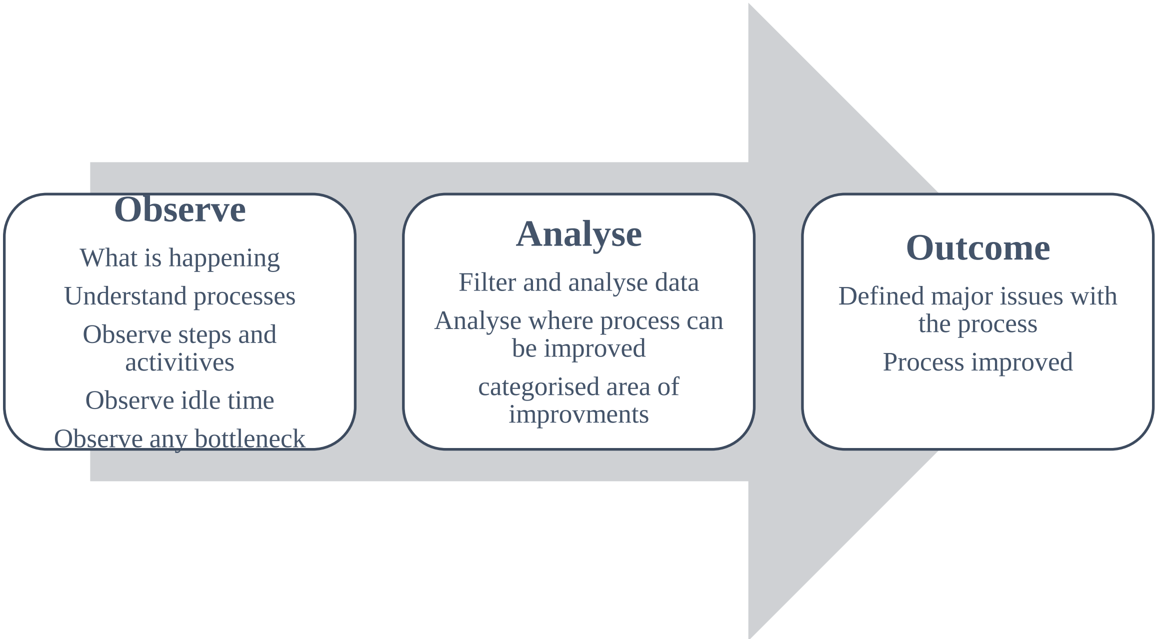


Figure 4.2 Data collection process

Factory information relates to the current status of factory elements such as objects, resources, plans and schedules and is often referred to as 'real time information'. This information can be obtained from a real production system to reflect the current status of the factor or can be adjusted to perform either manually or automatically for the plant optimisation [65]. Figure 4.2 shows the data collection process.

4.2.2 Performance analysis

DC (data collection) has been explained in the section 4.2.1. Data is filtered and used to achieve the desired goal which is the reduction of complexity in production changeover. Those data have been only used which is the major part of the (DT) down time of the manufacturing plant (Table 4.1).

Table 4.1 Plant efficiency

Down Time	**Unit**	**Days**	**Nights**	**Total**
Line Standard	KG			29,279
Actual Line Performance	KG			25,604
Efficiency	%			87.45%
Run Time	Hours			18.01
Waste	%			4.85%

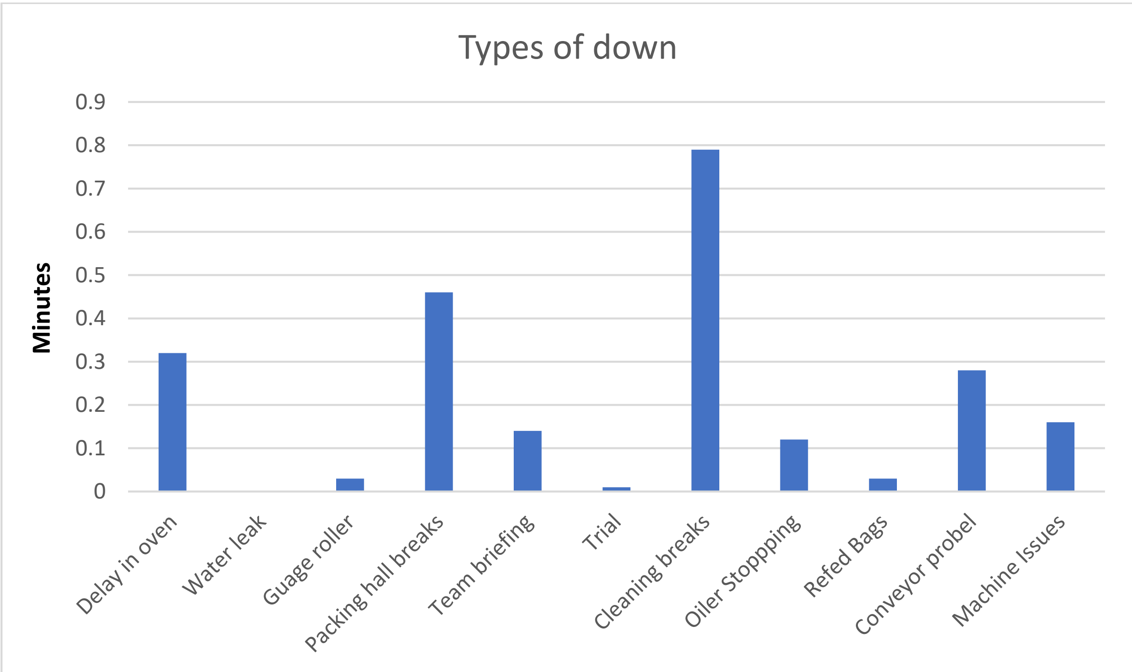


Figure 4.3 Types of down time

Table 4.2 Different types of plant totals down time (on daily basis)

Down Time	Unit	Days	Nights	Total
Delay in the Oven	MINUTES	19	13	32
Water Leak from the rai n TC1		0	0	0
Gauge Roller		1	2	3
Packing Hall Breaks		23	23	46
Team Briefing		4	10	14
Trial		1	0	1
Cleaning Breaks		40	39	79
Oiler Stopping		7	5	12
Refed Bags		3	0	3
Conveyor Problem		16	12	28
Machine Issue		11	5	16
TNA Issues		2	0	2
Set up and Change Over		27	28	55
Cute Wrap Up		1	1	2
Operator Assessments		0	4	4
Plant total down time		**155**	**142**	**297**

Table 4.2 shows the average time lost per twenty four hours is two hundred ninety seven minutes and down time for the cleaning is seventy nine minutes and for changeover is fifty five minutes. The total time for both cleaning and set up is 134 minutes. The average of this time is 45.11% of the plant totals DT (down time). Figure 4.3 shows the relative amounts taken by different types of down time.

Table 4.3 Production changeover down time (Daily Average)

Down Time	Unit	Time	Plant total down time (297 minutes)
Cleaning Breaks	Minutes	79	23.23%
Change Over		55	16.50%
Total Down Time		**134**	**45.11%**

In table 4.3 the down time of the cleaning and production changeover has been taken. The down time of the cleaning and production changeover is one hundred thirty four minutes which is equal to 45.11 % of plant total down time. Production changeover and cleaning breaks DT (down time) is the largest. Therefore, the micro textured surface has been proposed which has a self-cleaning capability and much smoother than the existing surface. According to our simulation model it reduces the cleaning time. The results are shown in a later section.

As discussed, many plant visits have been carried out to understand the whole process and to find out where the worst bottleneck is. During studies the down time of the plant has been studied thoroughly. There are many types of down time and these below down times has been taken from the daily production data and example can be found in appendixes and are gathered in table 4.2. Please see below examples of down time.

- Packing hall breaks
- Oiler disk tightened up
- Delay in oven

- Water leak from the rain TC1
- Gauge roller
- Team briefing
- Trial
- Oiler stopping
- Refed bags
- Conveyor problem
- Machine issue
- TNA issues
- Operator assessments
- Dismounting for cleaning
- Cleaning breaks
- Mounting after cleaning
- Setup time
- Deep cleaning

In the plant visits when the production is carried out and the processes have been studied and recorded it has been observed that various types of cleaning take place which require the production line to stop completely, or some part of it depending on the requirements. Some of them need regular cleaning and some of them need deep cleaning. Both have been recorded and observed attentively. It also needs parts to be removed from the machine and then mounted back to resume production. So, both setup time and cleaning time needs to be considered together in our case study.

One-year of production data has been gathered and filtered. It is found that cleaning and production changeover is the most time consuming and take up a major portion of all plant down time. Therefore, the main objective is to reduce the production changeover time complexity.

The most time consuming part of the process which has been recorded is deep cleaning. Each activity has been recorded along with the time consumed to carry out each activity. Deep cleaning has been recorded three times and below is the mean of deep cleaning. Deep cleaning is divided into many steps.

Table 4.4 Oil mixer drum deep cleaning and setup process (Deep cleaning)

Step No	Part and process Description	Time consumed
1	Oil drum pulled from production line for cleaning	2 minutes 3 seconds
2	Cleaning where pipe feeding oil with wet wipes	4 minutes 28 seconds
3	Cleaning drum outer side with wet wipes	5 minutes 12 seconds
4	Cleaning of stand with dry wipes	5 minutes 32 seconds
5	Moving oil drum in different positions to clean all angles inside the oil drum	6 minutes 10 seconds
6	Cleaning the front cover outer side of the drum with wet and dry wipes	3 minutes 52 seconds
7	Cleaning the front cover inner side of the drum with wet and dry wipes	2 minutes 45 seconds
8	Cleaning the side cover outer side of the drum with wet and dry wipes	5 minutes 22 seconds
9	Cleaning the side cover inner side of the drum with wet and dry wipes	2 minutes 42 seconds
10	Cleaning the oil drum from inside and each corner inside the drum	9 minutes 12 seconds
11	Cleaning the inner edges of the oil drum	3 minutes 6 seconds
12	Cleaning the outer edges of oil drum	3 minutes 12 seconds
13	Cleaning of small narrow place under the powder tunnel with thin long blue brush, wet wipes and then dry wipes	6 minutes 14 seconds
14	Cleaning the oil drum from outside	5 minutes 13 seconds
15	Cleaning of oil spray pipe. Removal of particles from it	5 minutes 5 seconds
16	Start removal of flavour powder from conveyor before oil drum	6 minutes 15 seconds

17	Fix bin bag under to collect waste	2 minutes 5 seconds
18	Wipe down the conveyor	3 minutes 14 seconds
19	Wipe down oil drum with wet wipes	2 minutes 18 seconds
20	Cleaning of oil drum stand	4 minutes 8 seconds
21	Wipe and clean oil spray pipe	3 minutes 22 seconds
22	Cleaning of lower stand before oil drum	3 minutes 41 seconds
23	Floor cleaning with brush	2 minutes 6 seconds
24	Mixer drum stand cleaning with brush and collect waste in bin bag	4 minutes 28 seconds
25	Scratching of hard debris with blue rubber brush	6 minutes 35 seconds
26	Vacuum cleaning to clean inside	4 minutes 17 seconds
27	Steam cleaning inside drum	3 minutes 20 seconds
28	Dry wipe final touch	4 minutes 13 seconds

Total time consumed to clean oil drum mixer = two hours zero minutes and ten seconds.

Each activity of cleaning oil drum has been recorded and shown in below Figure 4.4 indicates different activities during oil drum cleaning process.

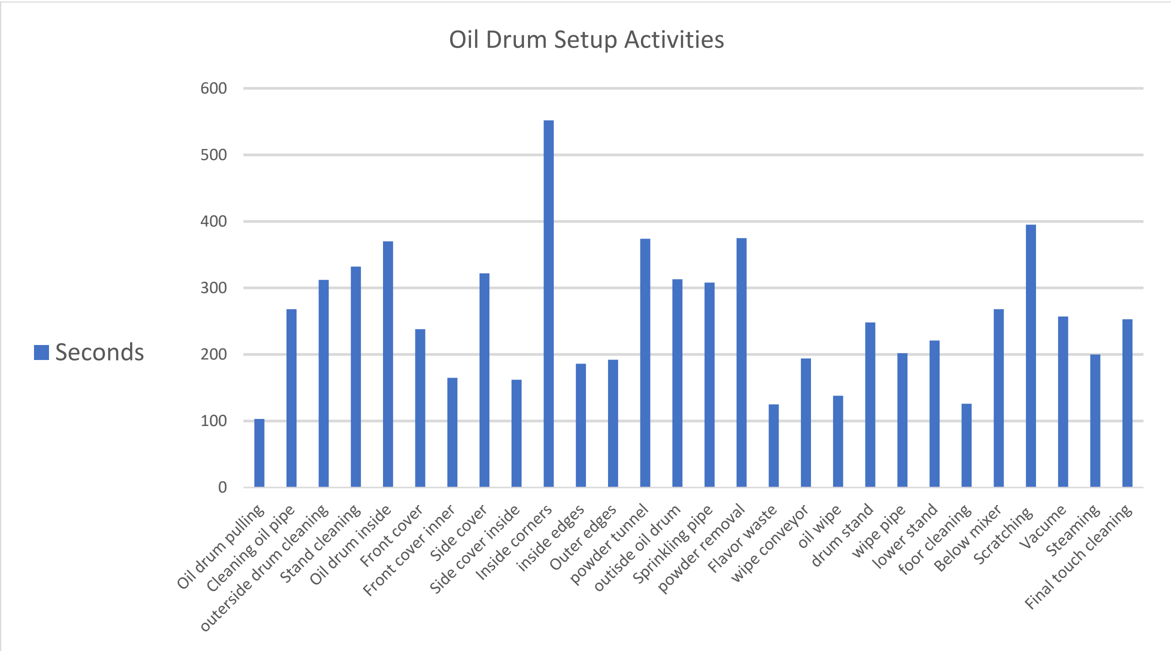


Figure 4.4 Activities in oil mixer drum setup and cleaning

Table 4.5 Flavour mixer drum and tank cleaning and setup processes (Deep Cleaning)

Step No	Part and process Description	Time consumed
1	Pull the flavour mixer from production line for cleaning	1 minute 56 seconds
2	Unscrew black bolts	3 minutes 44 seconds
3	Unscrew the screws and nuts at the back of the motor to remove cover	9 minutes and 13 seconds
4	Disassembling of rotating shaft rod. This needs to remove screw to take it out	10 minutes and 5 seconds
5	Remove blue rubber from flavour tank and disassembly	10 minutes 35 seconds
6	Vacuum cleaning outside flavour drum	12 minutes 10 seconds
7	Vacuum cleaning inside rotating drum to remove powder flavour	13 minutes 51 seconds
8	Cleaning the top with brush and dry wipes to remove flavour powder	23 minutes and 31 seconds
9	Cleaning the top net cover	11 minutes 07 seconds
10	Cleaning flavour powder tank inside	22 minutes
11	Pulling powder tunnel feeder and cleaning	8 minutes 37 seconds
12	Wet wipe cleaning inside powder tank	8 minutes 31 seconds
13	Floor vacuum	2 minutes 42 seconds
14	Dismounting flavour drum	3 minutes 39 seconds
15	Flavour tank steam cleaning	2 minutes 10 seconds
16	Wet wipes cleaning inside	2 minutes
17	Middle of the machine rotating area where rotating shafts is and powder tunnel	8 minutes 28 seconds
18	Cleaning stand of the flavour tank	11 minutes 20 seconds
19	Conveyor station between oil drum and flavour	9 minutes 10 seconds
20	Wipes the flavour drum from outside	12 minutes 32 seconds

Total time consumed to clean flavour drum and tank = Three hours seven minutes forty three seconds.

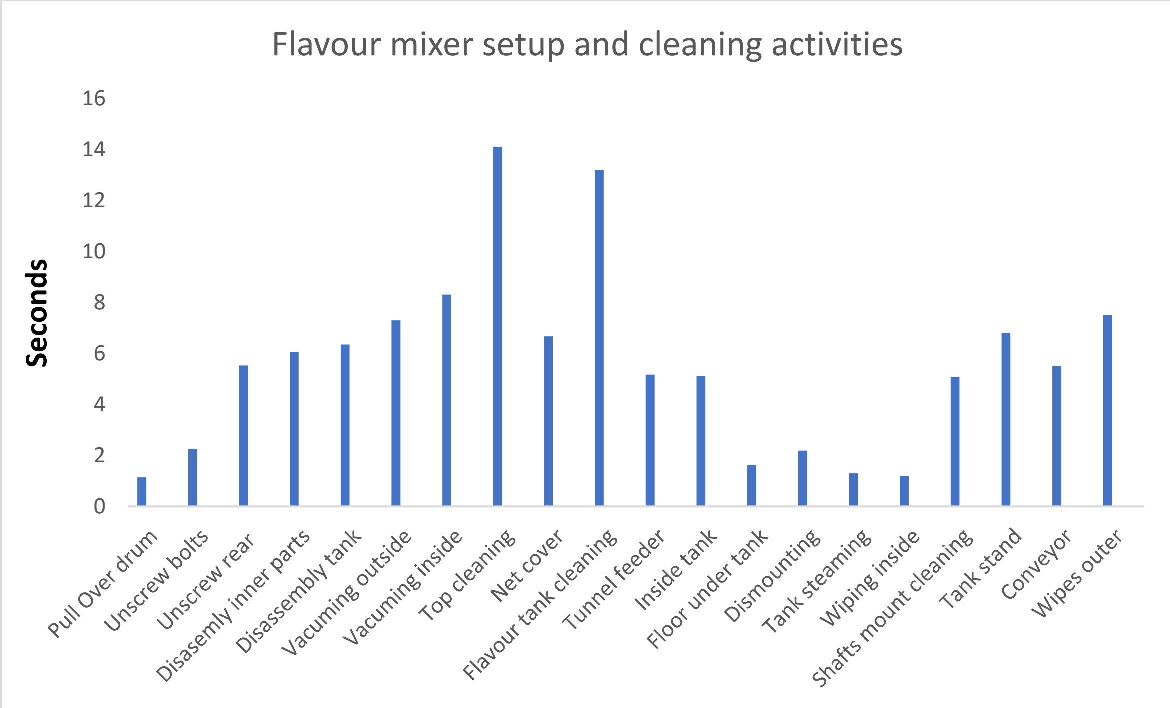


Figure 4.5 Flavour mixer setup and cleaning activities

Figure 4.5 shows all activities carried out during flavour mixer disassembling, cleaning and assembling. Please further see Figure 4.17 for flavour mixer drum and Figure 6.7 for oil mixer drum. In Figure 4.17, it can be seen that it is quite large size of drum and takes sustainable amount of time to clean. Similarly oil mixer also takes time to clean. There are three oil mixer and three flavour mixer drum. Due to the plant layout it is not possible to have spare oil mixer and flavour mixer.

4.3 Parts surface improvement through smart surfaces

After careful study and observation of the manufacturing process it has been observed that the most critical steps are the setup, changeover and cleaning time. Process improvement will be discussed in detail in section 4.4. In this section we will discuss the plant optimisation with parts and equipment improvements. These improvements are related to the surface texture only. There are many parts where this texture can be applied. The proposed surface texture has a repellent capability and will not allow flavour debris to stick to the surface or minimise the content. The purpose of specifying a surface using texture parameters is to create a parametric description that can be used to control the processing or to predict the performance of the surface to achieve the desired goals. The parameter used in the parametric description must be relevant for the process or function. The profile parameters can be suitable as a simple method for controlling manufacturing processes rather than specifying surfaces for functional performance. A manufacturing process that produces surfaces that function satisfactorily can be monitored by monitoring the surface texture. Changes in the process bring about changes in the surface texture. However, profile parameters rarely provide a straight link between surface texture and functional performance. More functionality related specification can be accomplished by carefully selecting a suitable combination of filtering and parameters for characterisation or by using advanced features-based approaches [66][150].

4.4 Process improvement to improve plant efficiency

During study it was observed that there was room for process improvement but, as in any other industry we need to work closely with the shop floor staff. It has been observed that the production changeover is completely manual. There are many possibilities for improvement which we shall try to explain.

Figure 4.6 shows a snacks machine producing snacks. There are many parts in this machine which can be disassembled for cleaning purposes. One of the parts is below which is the top lower part of the machine where the snacks fall and are equally distributed between fourteen buckets.

Figure 4.6 Crisps machine with many parts

Figure 4.7 shows the upper side of the snacks machine part which is found on top of the production machine and Figure 4.8 shows the other side of the part.

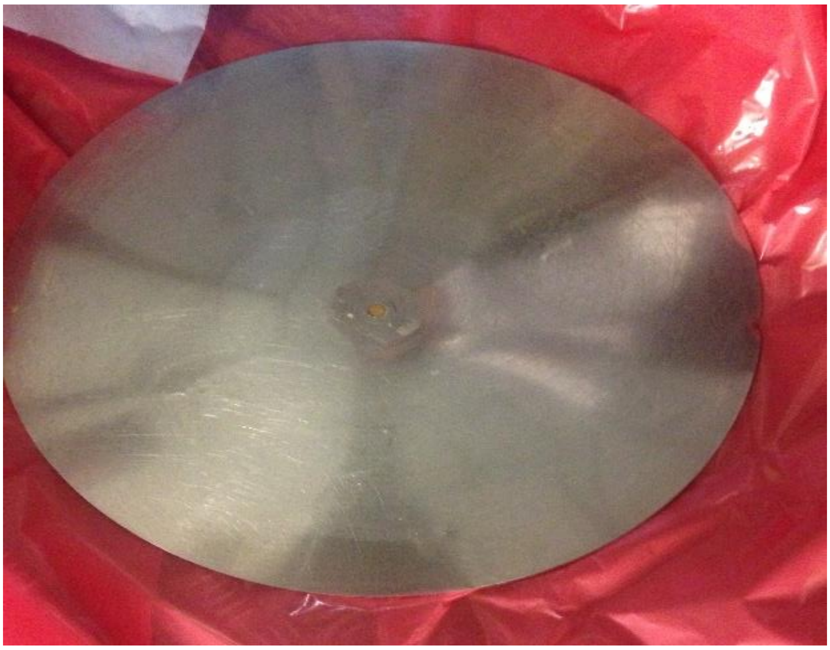


Figure 4.7 Upper side of the crisps machine part

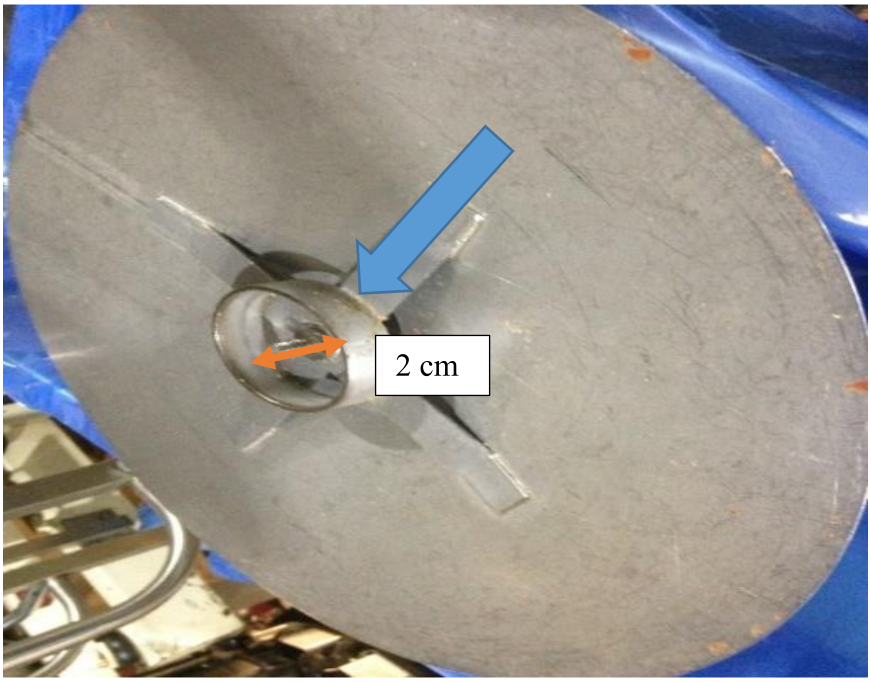


Figure. 4.8 Lower side of the crisps machine part which placed on top of the production machine

Figure 4.9 Part fixing base where screw fixed

To remove this part from the machine the staff have to rotate it to unscrew it which takes about 20 seconds and, similarly, after cleaning it takes the same amount of time to reassembled it. If it is designed without a screw and just needs to be lifted and fixed back without using a screw, it can save more than 50% of the time. Figure 4.9 shows the part of the machine where the part shown in Figure 4.8 is placed.

Similarly, it is possible to use automatic or pneumatic equipment to clean the surfaces instead of manual cleaning. For example, the company could use one of the following tools to remove debris from surface:

Figure 4.10 Large wide part of the storage conveyor

Figure 4.11 Plastic spatula to clean the conveyor

Figure 4.10 shows the part of the storage conveyor where flavour material sticks to the surface and has to be cleaned regularly. Figure 4.11 shows one of the tools which staff use to clean the metal conveyor surface. There are many conveyors in the whole process where the material sticks to the conveyor surface and the staff have to clean it regularly. Figure 4.12 shows the manual cleaning of food debris from a conveyor where the conveyor must be stationary for cleaning.

Figure 4.12 Manual removal of debris from conveyor

The material sticks to the conveyor surface and the staff have to clean it regularly. Once it is clean from the debris then the staff member wipes the surface with wet wipe to clean it further. Figure 4.12 shows manual cleaning of a soft belt conveyor.

Figure 4.13 Manual cleaning of soft conveyor with wipes

Figure 4.14 Storage vibrating metal conveyor while in operation

The cleaning process may be improved with slight modification. For example, a soft brush is fixed with the conveyor end to continuously remove debris from the conveyor. It will reduce the frequency of the cleaning and cleaning will be easier due to less debris on the surface. One more example is shown in Figure 4.14 which is the storage conveyor from where snacks move to another small conveyor and are distributed to various drums and machines.

Figure 4.15 Storage conveyor cleaning process with narrow place to clean from inside

We can see in Figure 4.15 that a staff member is in difficult position to clean the surface from inside. The total time consumed to clean this storage conveyor is 60 minutes. This can be sped up to some extent with some minor modifications. For example automatic cleaning brush can be fixed to soft fabric conveyor.

Figure 4.16 Proposed location where fixed cleaning brush can be Mounted to clean soft fabric conveyor during operation

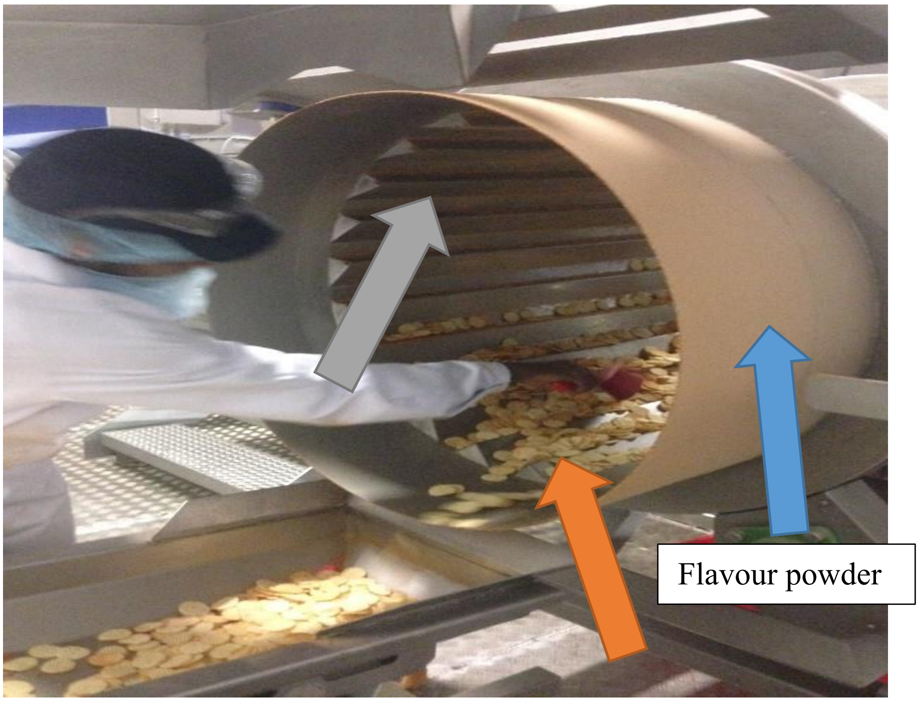


Figure 4.17 Flavour mixer drum manual cleaning process from inside

It has been discussed with the staff members during visit that if soft brush is fixed at the outer side of the soft moving conveyor then it will keep removing debris from the conveyor. The arrow shows where the brush can be fixed. So, when conveyor is moving during production it will clean the belt itself. It will help the cleaning time to be reduced. Another proposal is that to clean the soft belt conveyor from outside where the arrow is rather then staff member going inside to clean it which could be dangerous too and it's not good working posture for the staff. For that conveyor belt needs to be running so staff member can clean it while standing where arrow is in the Figure 4.16.

Figure 4.17 shows a staff member cleaning a flavour mixer drum manually. There are powder flavour stick to the flavour mixer drum which needs to be removed and clean. These are indicated with arrows. There are three different coloured arrows. The blue arrow shows where a staff member is removing snacks from the flavour mixer drum manually. The orange arrow shows where flavour powder is sticking all over the drum outer side which needs to be cleaned, also manually. Finally, the green arrow shows the inside of the mixer drum. There are lines inside where the flavour powder sticks. Each of these lines has to be cleaned manually. First the flavour powder needs to be removed and then the whole drum will be wiped out with wet wipes. The total time to clean the flavour mixer drum is more than one hour. This can be reduced by proper tools and use of smart surfaces. Smart surfaces are further discussed in Sections 5.7 and 5.8.

Figure 4.18 Flavour tank and its internal parts manual cleaning process

Similarly, we can see in Figure 4.18 where one of the staff members is disassembling the flavour drum. Many parts have been removed, next the flavour powder has been removed and then each part needs to be cleaned separately.

Figure 4.19 Flavour powder waste collection process

Dry cloths, brushes and wet wipes have been used to clean these parts and the drum itself. In Figure 4.19 we can see that flavour powder has been collected in the red bin bag and Figure 4.20 shows the flavour tank after cleaning.

Figure 4.20 Flavour mixer tank

Figure 4.21 Crisps waste on the floor during cleaning

Figure 4.21 shows the waste on the floor during cleaning. These could also be saved if the cleaning process were carried out carefully.

4.5 Sample surfaces

The metal sample surface functional parameters measurements have been taken and it was found that the surface is not smooth. Figure 4.22 shows the surface roughness of the sample. Sample is not the part of the production machine. Sample is given by the company and they have taken from the same supplier who manufactured plant A machines. The dimension of the surface is approximately 3cm x 3cm. We have measured the surface roughness only. Surface roughness and contact angle reading has been taken. Ultraprecision and micro machining of metals, ceramics and polymers is producing ultra-smooth surfaces and rough surfaces with controlled textures. Precision grinding, diamond turning and micro milling are important for generating textured surfaces in many industries. Ultraprecision grinding, diamond turning, and micromachining are finding ever wider applications, either for the direct fabrication of surface features or as a means of manufacturing tooling for replication and moulding processes. Many surfaces are manufactured with some specific functional properties such as those measured by surface bearing index Sbi, core fluid retention index Sci, and valley fluid retention index Svi. On reviewing the literature it was found that there are no studies to date which are focused on smart surfaces for the food production industries which can lead to sustainable production changeover [54][55][59]. Figure 4.23 shows the sustainable changeover and its outcomes.

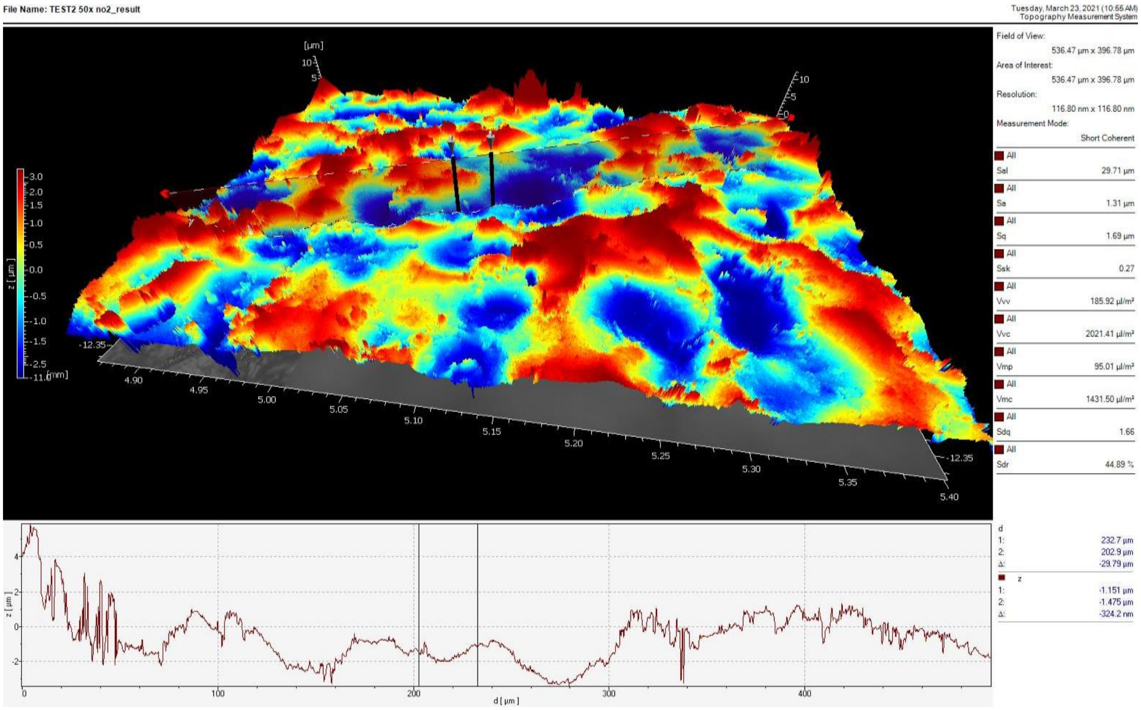


Figure 4.22 Surface roughness measurements

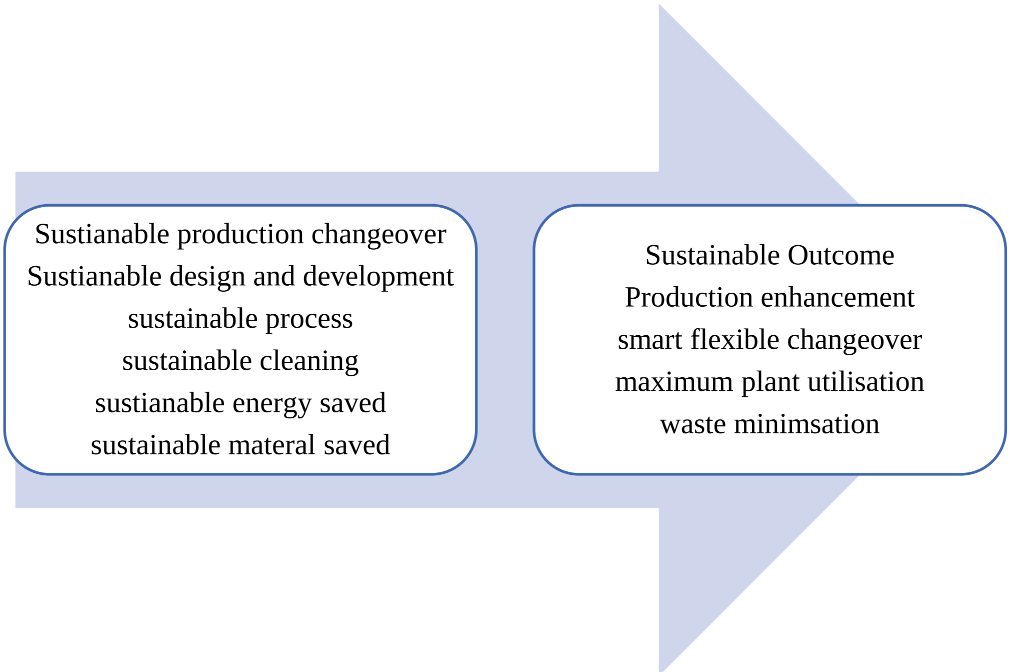


Figure 4.23 Sustainable changeover and its outcomes

Sustainable product design and manufacturing is an important concern for every organization, and has its own importance concerning sustainable development. The ultimate goal is reducing the changeover complexity of engineered systems through the use of simple sustainable design based on fundamental principles so as to increase reliability, reduce the costs of development and sustainable operation, and subsequently enhance performance. The setup should be as simple as possible to minimize mistakes, and there is a need to ensure that no special technical skills are needed to carry out setup; this ensures that the person operating the machine can perform the setup with ease. A robust design is a design that has no time-independent real complexity and no time-dependent combinational complexity. Complexity in production changeover generally may be defined in terms of how a system is varied and intra connected. Complexity in manufacturing changeover can be found in both the products themselves and in their production, and the level of complexity in each of these varies depending on the industry and product type. Manufacturing systems should be designed in such a way that waste is minimized at all levels.

The complexity of the system can be caused by two factors, namely time-independent real complexity due to poor design of the manufacturing process and system, and time-dependent combinational complexity caused by the deterioration of the processes and system as a function of time. The system needs to be designed in such a way as to use the minimum number of nuts and bolts required in a changeover and so as to ensure there is minimum waste of raw material during a production changeover. Extra care needs to be taken to ensure no metallic debris has contaminated the area when nuts and bolts are tightened.

Flexibility in design can reduce the complexity of product changeover, particularly in reducing the complexity and increasing the efficiency of setup by standardizing as much of the hardware and methodology as possible, such as:

- Making trial pieces and adjusting them
- Preparing for changeovers in advance
- Ensuring material-handling flexibility
- Completing preparation after process adjustment

- Using the minimum number of nuts and bolts during changeover
- Ensuring routing flexibility
- Ensuring setup operation flexibility
- Implementing a sustainable design in mind of reducing the waste of raw material during setup
- Implementing a sustainable design to reduce the use of energy
- Applying modification flexibility in production setup
- Using less energy-intensive materials in design to reduce energy use.

4.6 Sustainable operational model

Industrial sustainability has become one of the key requirements of sustainable developments as manufacturing industries become the largest consumer of energy and natural resources. Advantages of sustainable manufacturing include cost reduction through resource efficiency and regulatory compliance improvement, better brand reputation, new market access, less labour turnover by creating attractive workplaces and long-term business approach by creating opportunities. Sustainable manufacturing is the creation of manufactured products using processes that minimize negative environmental impacts, save energy and natural resources, are safe for employees, communities and consumers, and are economically sound. Sustainable product design and manufacturing is an important concern for every organization, and has its own importance concerning sustainable development. Figure 4.24 shows the sustainable design possible activities. Sustainability means the rearrangement of technological, scientific, environmental, economic and social resources in such a way that the resulting heterogonous system can be maintained in a state of temporal and spatial equilibrium. The focus is the elimination of waste and includes all the activities that do not add any value to the organization or customer.

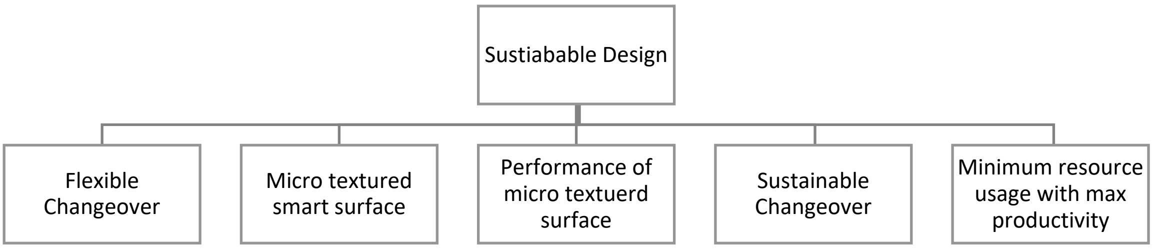


Figure 4.24 Sustainable design possible activities

There are different aspects that contribute to a positive sustainable manufacturing strategy implementation. The development of sustainability indicate policies, companies' cultures and internal conditions for sustainability. The ultimate goal is reducing the changeover complexity of engineered systems through the use of simple sustainable design based on fundamental principles to increase reliability, reduce the costs of development and sustainable operation, and subsequently enhance performance [56][57][58][60]. Figure 4.25 shows the sustainable manufacturing changeover model.

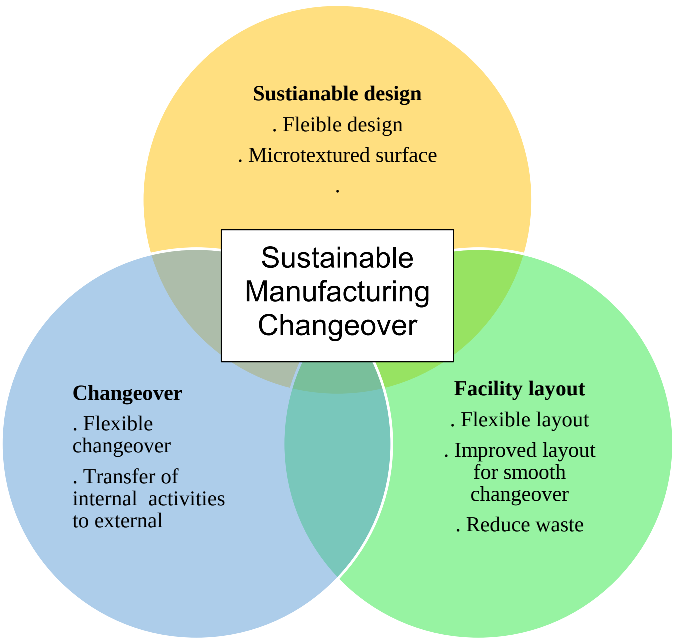


Figure 4.25 Sustainable manufacturing changeover

Table 4.6 Resources utilisation

Complexity Categories	Challenges	Recommendations
Design complexity in production changeover	Customer requirements, complicated design, many parts, product variety, global supply chain, new technology	Simple design; smaller number of nuts, bolts, dies, screws; design for manufacturability; reduce variety where possible; use same size of nuts and bolts; minimum number of clamps; less weight
Manufacturing process complexity	Complicated manufacturing process, quality control, less operational flexibility	Sustainable design, design easier to clean, skilled workers, continuous improvement, process modification, process sequence adjustment, job balancing, flexible and responsive manufacturing
Operational complexity	Multiple products on same production line, large-scale orders, small-scale orders, uncertainty, many production changeovers, raw material wastage, resources wastage, time wastage	Simplification of process use robust planning and control system, reconfigurable and changeable manufacturing, reduce number of mechanisms, eliminate the need to remove non-changeover parts, try to reduce hand tools and use automatic tools.

Table 4.6 shows resource utilisation and is divided into complexity categories, its challenges. In the third column the recommendations has been made to overcome these complexities and challenges.

4.7 Waste minimisation

In the manufacturing system there are many types of waste in the overall cycle from the beginning with the raw material to delivering finished good to the customers. These are defined by Sataya R Shah [60] as over production, transportation, motion of workers, over processing, defective finished goods and excess inventory. These main waste types are only the obvious sources of waste in the whole manufacturing cycle and there could be many other types of waste - referred to as ‘hidden waste’ - that need to be identified separately. A research study highlights a group of eight deadly waste types that could have been caused by the fact that the companies did not usually apply the staff’s insights, hence their creative comments and ideas were not being used despite their benefits for process improvements. However, our main target is to eliminate or reduce waste in the production process. Furthermore, in the production process the main emphasis is only on the setup and changeover costs as sources of waste as they are highly sensitive processes and non-value-added activities such as financial inspections are necessary as part of the process that also adds value to the company. The WM (waste minimisation) techniques would be critical in terms of manufacturing advancements, and hence, it is required for waste and value to be identified, the knowledge management strategies to be developed and to realise that the main task is to look for continuous improvements and the sustainability of the manufacturing operation.

On the whole, manufacturing processes have a great impact on the environment since they consume a significant amount of energy and they produced undesirable waste. Numerous initiatives have been developed to reduce the impact of manufacturing processes on the environment. In general, most of these initiatives aim to reduce energy consumption or unwanted wastes, recover resources and make efficient use of materials. The concept of waste management is to aim to reduce waste in order to improve sustainability during the manufacturing process. Energy utilisation is also crucial in manufacturing processes. A reduction in energy consumption will lead to a reduction in manufacturing costs [59]. The aim of our whole project is sustainable production changeover. This also includes (WM) waste minimisation in the cleaning processes. As we have seen, the largest part of the down time is cleaning time. Cleaning materials are used to clean the production line. Reducing the amount of cleaning and its waste is a major concern in our case study. We can apply the concept of lean production to waste reduction which can be helpful in eliminating waste in the setup of the machines and cleaning of the machines and conveyors; and, it can make the changeover more flexible which reduces manufacturing cost and time. All the possible causes that could generate waste during the setup and cleaning processes have been considered including idle time of the machine, operator error, removal of parts and mounting of parts. All sorts of causes of down time are explained in table 4.2.

4.8 Proposed changes in existing setup

An effective and efficient changeover process is an important element of the manufacturing industry in our case study. Pursuing high changeover performance is a way to enable agile and responsive manufacturing processes by improving line productivity and reducing downtime losses and this is even more important if the demand is highly complex. Thus, it can shorten the production lead times and help in achieving higher quality standards. The most significant positive impact of having a small changeover time is the batch size reduction in a production system. In other words, it continuously supports the one-piece flow concept that is critically needed for the high product variety demands type of production. There are many advantages of short and simple setup time which include: expenses reduction, faster production, increased output of the plant, lead time reduction in production. Generally setup time is the time required for preparing the necessary resources. The setup is one of the elements in changeover. The first element is rundown which is running the last unit of the finished good. It may include the initial preparation to start the production which can include many tasks, for example, fixing of jigs and parts, then setup which includes removal of existing parts, materials from the production conveyor, bringing new tools [61][69]. Figure 4.26 shows different activities of sustainable design to reduce production changeover complexity.

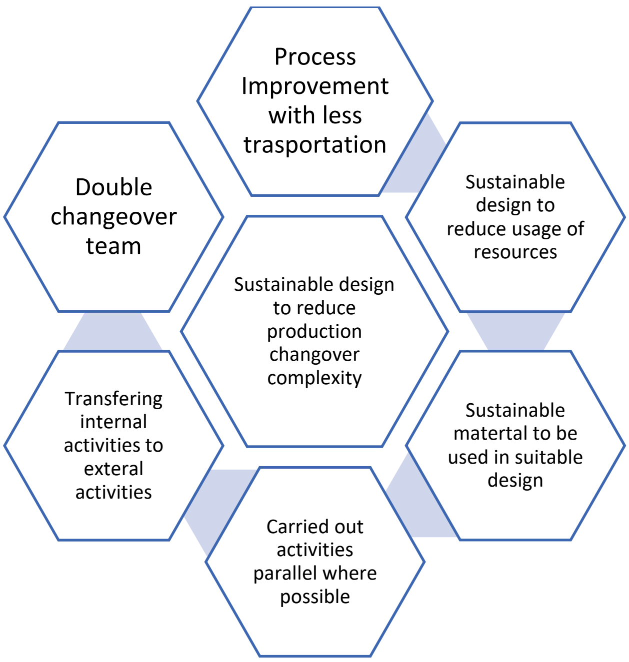


Figure 4.26 SCM (Sustainable changeover model)

These changes may involve many activities and could be time-consuming. If these changes not adding any value to the system then its waste. Some activities in changeover are mandatory and time consuming and these can be reduced by improving production changeover and time saved in production changeover can be utilised in producing finished goods. To eliminate or reduce losses each activity needs to be recorded. Some of these activities will be internal activities whilst some may be external activities. Internal activities are those activities that cannot be performed until the production line has stopped for changeover. External activities are those tasks that can be performed whilst the production line is running and therefore can be performed during production changeover. There may be an activity that is considered unnecessary. If we eliminate any unnecessary activity and transfer any internal activity to external, then complexity can be reduced and, as a result, setup times can be decreased. Modern complex products or equipment may have many thousands of parts and take hundreds of manufacturing and assembly steps to be produced. Having many parts involved in the manufacture of single products, complicated designs and diverse types of production on the same production line makes the manufacturing system and changeover/setup more complicated [131][132][133].

These are some possible sources of complexity:

- Complicated design
- Too many changes during production changeover, i.e. parts, jigs and fixtures, nut, bolts.
- Fast and frequent change in production plan
- Varieties of product
- Customer requirements
- Human abilities and ergonomics
- Size of equipment/machine
- Technological changes
- Complicated setup

  These sources of complexity has been observed during production changeover. For example customer requirements changes that makes to make changes in production plan and ultimately production changeover. Similarly there are three flavours produced on the production line. Size of the oil mixer and flavour drum replacement is not possible due to the layout of the plant A therefore needs to be cleaned on the production line.

4.9 Experimental setup

Surface roughness has been measured and discussed in section 4.5. In our case study there is use of oil and oil stick with the production line and as and favour stick to the oily surface of the machines. Therefore we carried out an experiment on the sample metal surface and put cooking oil spray on it. Crisps were placed on it for some time to find out how much oil is stuck to it. During the experiment it was found that oil stuck to the surface quickly. The thickness of the oil had been measured by using poly top mop micro view equipment shown in figure 5.8. The equipment has many lenses to measure the characteristics of the sample surface. . Figure 4.28 shows the sample surface with and oil coating on it. The reading on the picture shows the oil thickness on the two spots, i.e. 28.002 µm and 25.176 µm. This shows that oil coating easily stick with the metal surface and if the production line is running 24/7 then these coating thickness can be more thick. Figure 4.27 shows different parameters of surface roughness and Figure 4.28 shows the measurements of oil thickness on the sample surface.

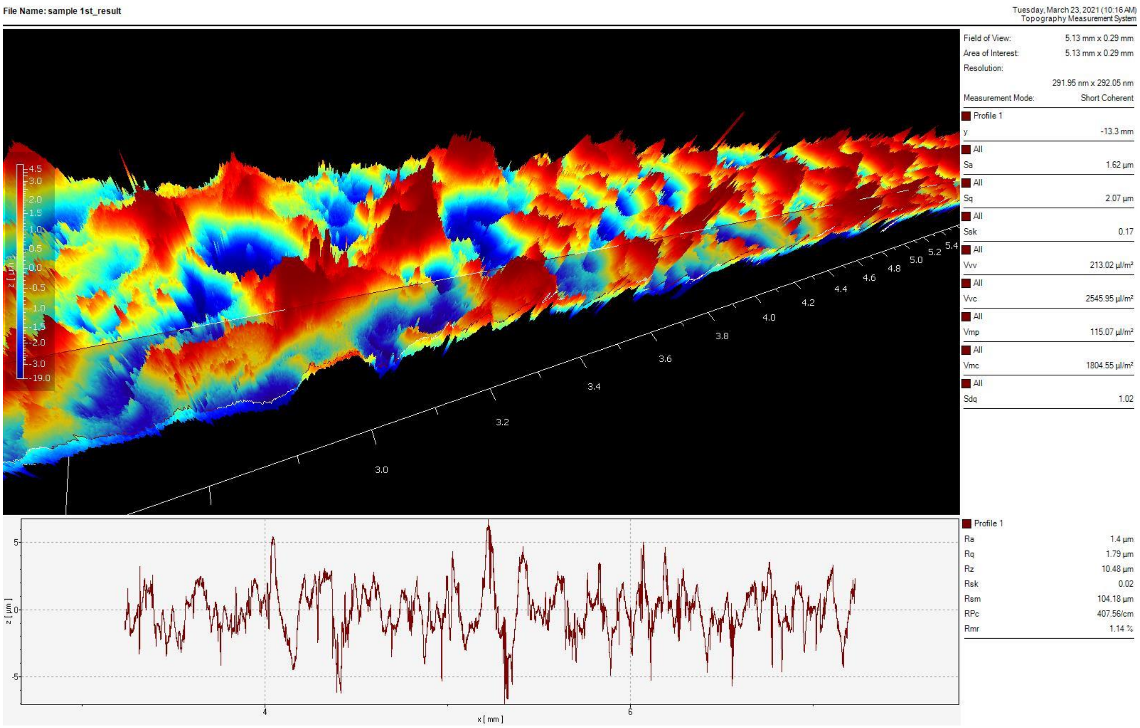


Figure 4.27 Sample surface texture with oil coating

Figure 4.27 shows different values of the sample surface include surface roughness. For example Sa, Sq, Vvv and Vvc.

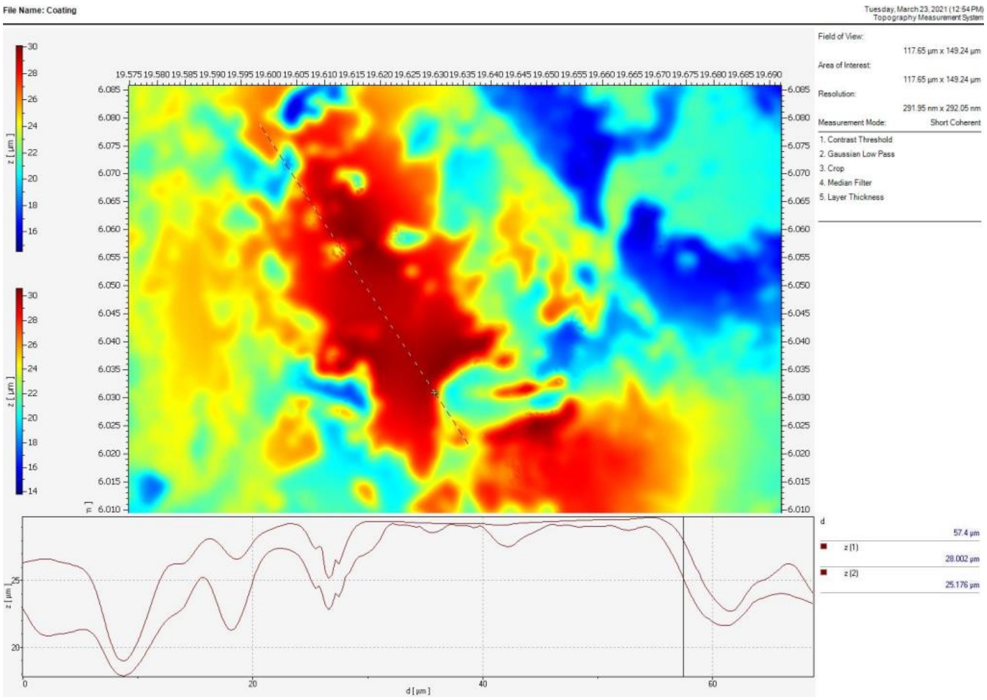


Figure 4.28 Sample surface with oil coating thickness

4.9.1 Measurement of contact angle and surface energy

Figure 4.29 shows the instrument that was used to find the contact angle of the sample surface. The equipment used is called FTA 1000B manual drop shape analyser and the model is B23A 110.This equipment measures the contact angle of the surface. Two readings were taken: one was while using water on the sample surface and the second was when cooking oil was used to find the surface energy and contact angle of the surface.

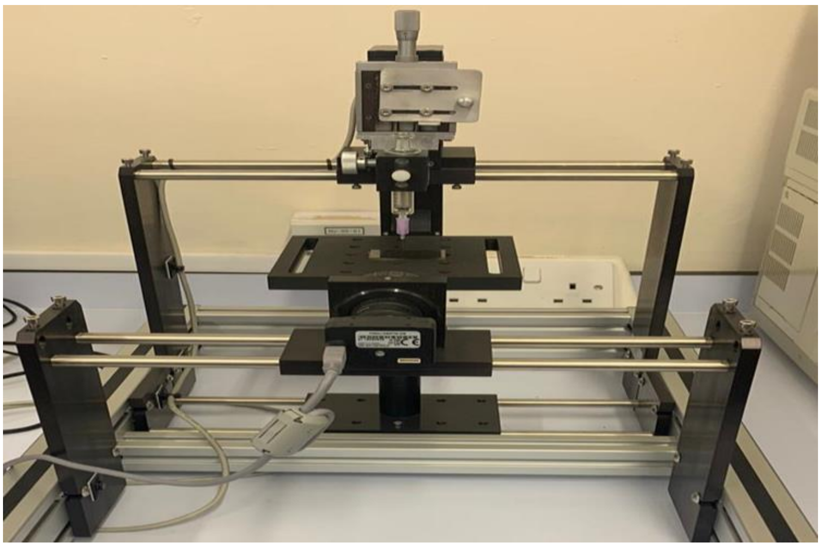


Figure 4.29 Instrument for contact angle measurements

The experiment was carried out to find the contact angle of the surface. The first contact angle was measured with water on the surface and found to be < 68.64°, which is rather low.

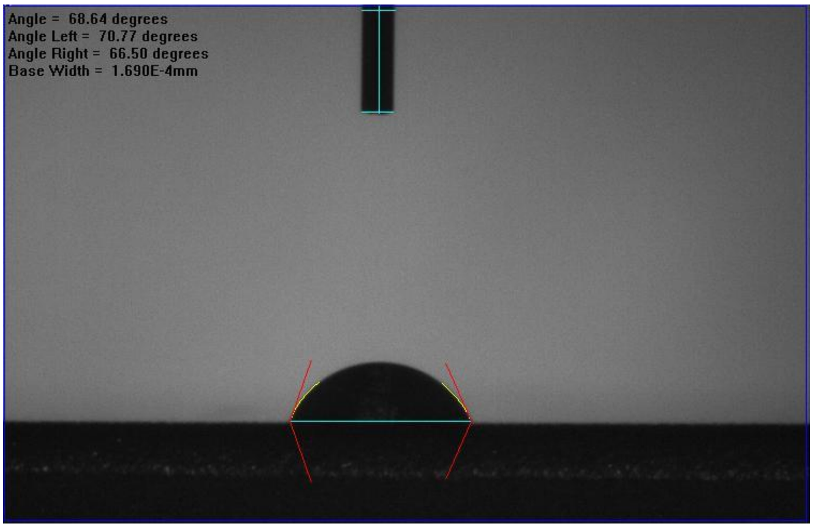


Figure. 4.30 Contact angle of the surface with water

Figure 4.30 and 4.31 show the contact angle of the existing surface. The contact angle is 68.64° and 64.35° with water and 35.80° and 38.18° with cooking oil.

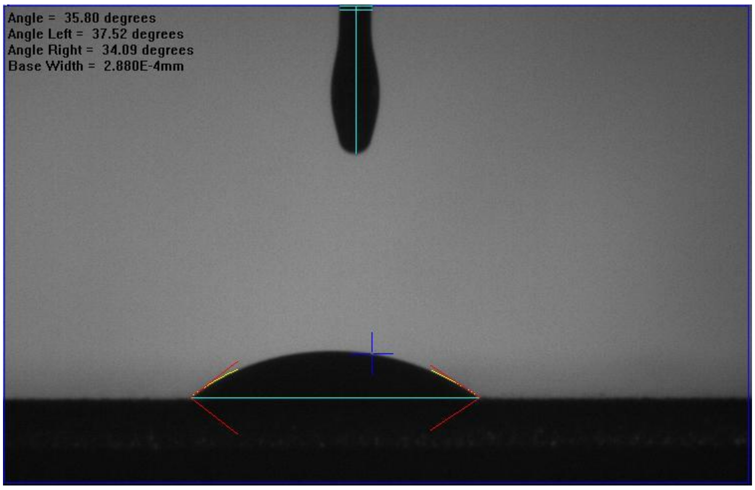


Figure 4.31 Contact angles with cooking oil

4.10 Production models

In the real world manufacturing problems are heavily influenced by various uncertain factors, and in order to improve the efficiency of such systems, different optimisation techniques are used. The production model is based on the production facility layout, which is the source of the data on the spatial distribution of the elements of the production system and the schedule data with the relevant data categories. The schedule is also a source from which the data on the sequence of execution of each operation is taken for each machine or workstation or the sequence of execution of the operations is specified for each workpiece [91][92]. Manufacturers have been using simulation to support decision making for the design and production. However, with the advancement of technologies using modelling and simulation (M&S) is one of the main steps in advanced manufacturing. In this case study we used the sample metal part which is the same surface texture as is being used by the company now.

The existing surface texture parameters and roughness readings were taken in the laboratory. These readings were used in the simulation model and compared with the proposed micro textured surfaces. It has been observed that a smoother surface will reduce the stickiness of flavour to the surface and hence it will reduce the frequency of cleaning and ultimately will save resources and time [64][71].

4.10.1 Production line model A

In this first model we inserted the real production data to show the production output of the manufacturing facility. The data input is the plant maximum capacity. The down time and the output production is shown in figure 4.32. The total plant capacity is as follows:

One production machine	6600 packs / hour
Ten production machines	66000 packs / hour
Twenty-four hours production without downtime	1,584,000 packs per day

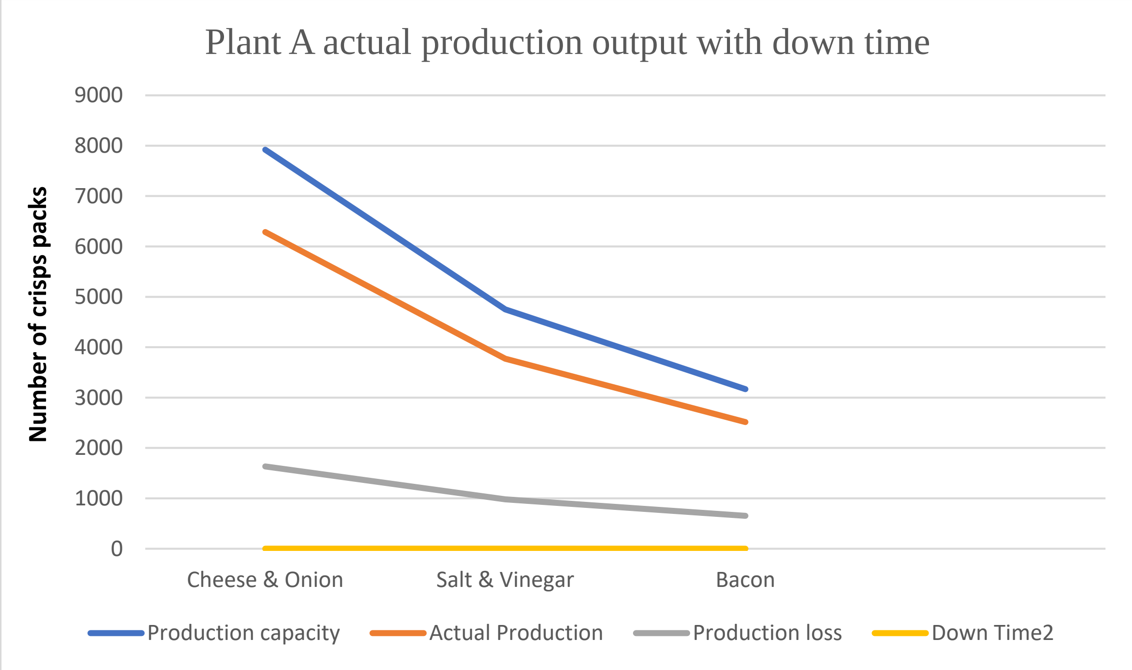


Figure 4.32 Average actual production output with down time

Figure 4.32shows the actual production output of the plant against the plant full capacity with down time. One year's data was gathered and it showed an average down time of 20.625 %; therefore, the plant's actual production was down by 20.625 % of its maximum capacity.

Furthermore, the 45.11 % down time is due to the surface texture used in the metal conveyor, production machines and parts. Therefore, our research is based on sustainable production enhancement through smart surfaces with self-cleaning facility, i.e. oleophobic surface.

4.10.2 Production line model B

In this section we will explain the model with the proposed surface texture and its outcome and impact on the plant's performance. Model B is figure 4.33 which shows the production with the proposed surface. This graph shows the overall down time of the plant will be reduced by 22.41 % and in production changeover the down time will be reduced by 49.67 %. In figure 4.34 the grey colour is production loss, the red is actual production and the blue is plant capacity.

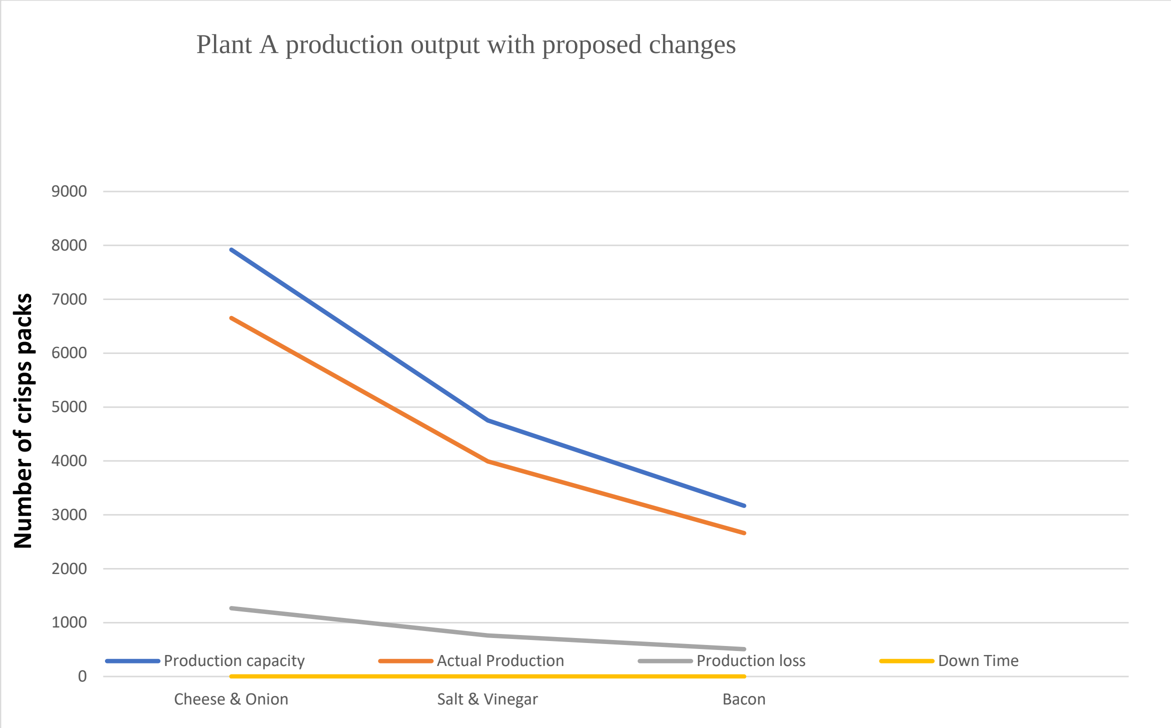


Figure 4.33 Production output with proposed surface

4.11 Possible outcomes from the proposed surface

In a previous section (4.10.1) the plant capacity has been specified and Figure 4.33 was drawn showing with the actual production data. The impact of the proposed surface and process improvements are laid out in the next chapter, section 5.10. This output was applied in section 4.10.2 and a graph was drawn to compare the existing production output of the plant with the proposed output of the plant. The total down time of the plant was reduced by 22.41 % and in production changeover the down time will be reduced by 49.67 %. This will reduce the complexity in production changeover and will make the production changeover much smoother and more sustainable. These calculations are just the comparison of existing surface with contact angle of 35.80° and 38.18° with cooking oil which is far low compare to 150°. These calculations are based on assumptions if use surface having contact angle of >150° where particles on surface roll off and not stick to the surface .

Chapter 5 Improving Plant Efficiency Through the Process Mapping and Optimization

5.1 Introduction

There is always scope for improvement in manufacturing processes. It is very rare that a manufacturing plant will run at 100% efficiency so the optimization process is a never ending activity. Most companies aim to maximise productivity and reduce their cost of operation. Manufacturing engineers have a strong interest in productivity improvement through various ways which includes line balancing, time and motion study, process improvement, layout improvement, human simulation for production line and automation. Developing ergonomics in early stage of production system human simulation is increasingly recognised as an essential step towards achieving healthy and sustainable production system. In our case study, as we discussed earlier, we set out to minimise the complexity in production changeover to enhance productivity and remove or minimise the cleaning and setup time during production changeover in a food manufacturing company. Cleaning is a critical and regular part of food manufacturing. It needs huge commitment to invest in the plant without having confirmation that the proposed changes will be helpful or not so there is also a high risk involved. With traditional approaches, high standards are becoming increasingly difficult or almost impossible to meet the desired goals. Therefore, a virtual production line can be the solution to check whether the production changeover can be done more smoothly and sustainably. The virtual factory concept has been implemented by leading manufacturing companies. For example, Ford Motor Company improves its assembly line performance by evaluating and optimising the designs using a virtual factory system. Similarly, Volvo group validates changes by having them virtually tested before any major changes are done in the real world. The virtual production line of food manufacturing offers several possibilities to improve and optimise the production system [64][71][81][82][155].

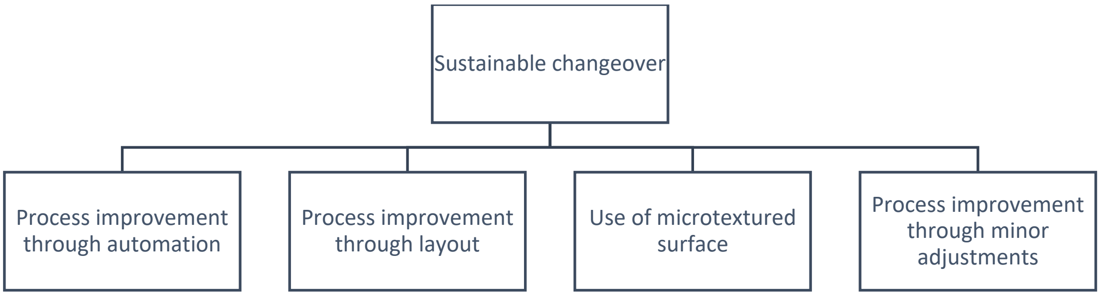


Figure 5.1 Sustainable changeover features (SCF)

Compared to the real production processes, the biggest advantage of a virtual production line is that in a virtual environment we operate only with the data and not with the physical resources, materials, energy, labour and investment of an actual factory. The production process in a virtual environment can be performed in any number of experiments and under various conditions and before the planned production processes are performed in reality. The analysis of the production process's parameters is carried out based on the results of virtual production and, on the basis of those results, the optimisation of the production line is carried out. During the literature review, it has been observed that virtual factories have been developed to find the outcome of the proposed changes but there was nothing found on production changeover simulation. Our case study investigates complexity reduction in production changeover and how to make it sustainable. It includes introducing automation in some parts of the operational set up, automatic cleaning tools (i.e. pneumatic tools for cleaning), process modification and some minor changes to the production line. These data are the input into the virtual production line for production changeover. The implementation of a virtual food production line will be facilitated by data collected from the actual production line that allows inputting the generating data using the same formats as those used in the real production line. In a similar way, data is input for the proposed changes to find the difference between the actual and the recommended [86].

5.2 Process automation

Increasing production automation is one of the proposals to reduce the complexity of changeover. During the site observations it was found that there are many places where automatic machines can be introduced to improve efficiency. Increasing automation in production changeover will result in improving production output along with man power and waste reduction.

For rapid changeover, automation can play a part in the improvement of the existing setup. Automation can be introduced wherever it is possible to improve production changeover, for example, for the cleaning of the conveyor. An automatic wipe can be fixed in position on the conveyor so that it can be wiped clean.

5.2.1 Plant automation scenarios

It has been widely acknowledged that improvements in manufacturing operations need detailed study and understanding of the production system with the consistent interlinked elements and flows. Without having knowledge of the production operation, recommendations for improvements cannot be made. Therefore, a general understanding of the manufacturing system as a combination of production factors, including production processes, production changeover and unproductive activities are necessary [84].

During our study of the production process of plant A, it has been observed that there is the possibility of improvement where the soft belt conveyor is operating. These could be in three places where automatic cleaning brushes can be fixed. These are as follows:

- Conveyor from the oven to storage conveyor
- Storage conveyor
- From storage to oil drums

In these three areas improvements are possible with small changes. These could be through small adjustments to the conveyor. For example, if a soft fabric cleaning brush is fixed to the rotating axis of the soft fabric conveyor, then the brush will wipe off any debris sticking to the soft belt conveyor. This brush should not be cleaning all the time. Instead, it should be liftable with a hand lever. When the cleaning process is started, it can be pulled down and when the conveyor rotates it will wipe off any debris from the conveyor belt. After few rotations of the belt it will be completely clean (Figure 5.2).

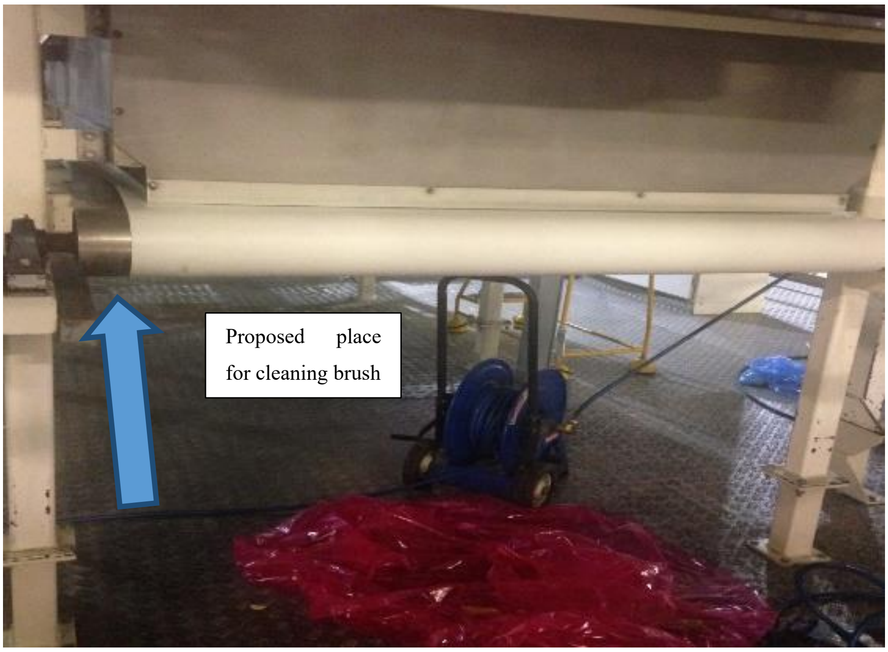


Figure 5.2 Storage conveyor rear end

Figure 5.3 shows the soft conveyor belt which transport crisps to the vibrating metal conveyor. This white soft belt conveyor is moving all the time during the production process. There is room for improvement for the cleaning of this belt. If air pressure is introduced to the edges of the belt conveyor where axis of rotation take place, air can be applied to remove particles from the edges and corners of the belt and also it will make it dry after cleaning with a brush and wet wipes.

Figure 5.3 Soft conveyor belt with flavour material on it

There are few cleaning automation options. Figure 5.4 shows that air pressure can be applied to the soft conveyor whenever cleaning is required. Both of these applications can applied at all three locations and it will ultimately reduce the cleaning time of the soft conveyor. It will increase sustainability in terms of a smaller number of chemical wipes used. So it will reduce labour hours, production time and resources.

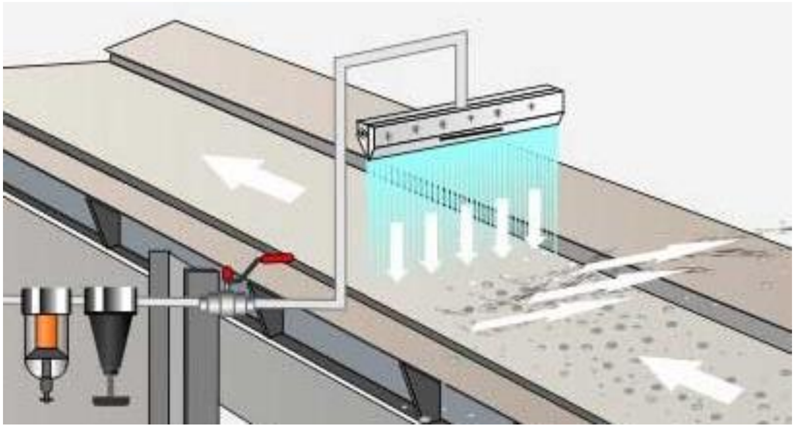


Figure 5.4 Air pressure applied to the surface [154]

At the moment, the company is using only manual tools to clean the whole production line. It is recommended that pneumatic cleaning tools can help and can work better than manual ones for cleaning. It will be quicker and can reach to the edges and corners for the parts and production machines. Figure 5.5 shows a current situation where it is not easy to clean using manual tools. Pneumatic cleaning brushes can ease of the work load and can help the cleaning process more robust.

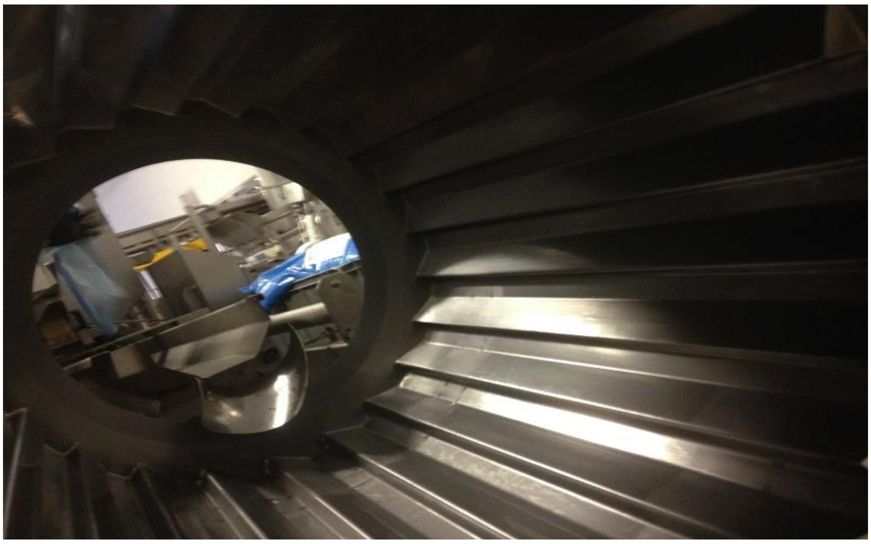


Figure 5.5 Improvement through automation

5.2.2 Steam water wash

During previous chapters it has been mentioned that there are 10 production machines and each machine has fourteen feeders, Fourteen large buckets and fourteen small buckets. These are comparatively small parts and can be placed in a large-scale dishwasher where they can be cleaned with steam and water. By using a microtextured superhydrophobic surface the frequency of the cleaning will be reduced and using large dishwasher will also be useful. These are forty-two parts, along with a few other parts, can be washed and cleaned in a large dishwasher rather than by manual cleaning which will save a substantial amount of time and energy. Figure 5.6 shows these parts on the production machine.

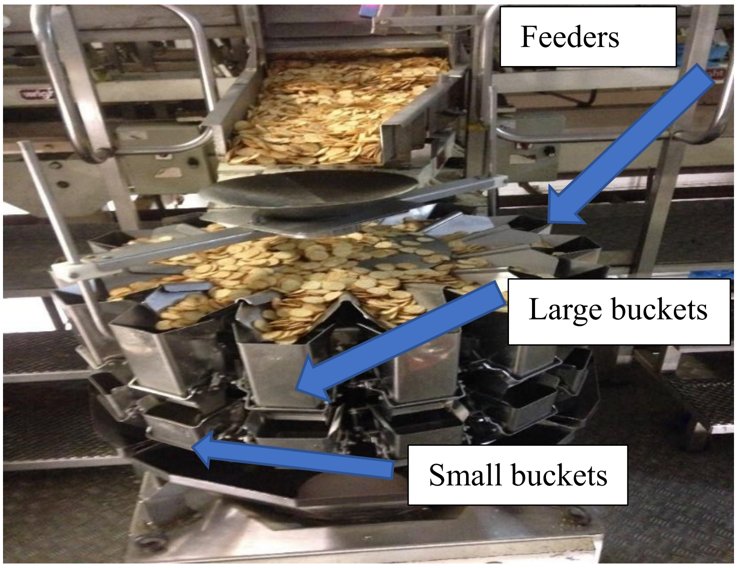


Figure 5.6 Production machine with its parts

5.3 Virtual production line

There is a growing recognition that current manufacturing companies must be agile and capable of operating profitability in a competitive environment of continuously changing customer demands. VPLs (virtual production line) are increasingly becoming a common idea for survival in the agile environment. The term ‘virtual production line’ has been defined in multiple ways in the manufacturing research and application domains including as a high-fidelity simulation, a virtual factory, a virtual reality representation and a simulation facility [64]. The virtual production line in food manufacturing offers several possibilities to improve and optimise the production system. Besides determining how the operations are performed on a time axis, the other most important possibilities are that it identifies the probable utilisation of production capacity in relation to various production parameters with less frequent cleaning breaks. The virtual food company is based on special features of the production process. The most important part of a real production system that is used in a virtual production line is the data about the real production processes. The virtual food company needs input data to run. In the virtual factory actual production data is used along with production changeover breaks. These includes stopping the line, disassembling parts from the production line, cleaning of the production line and then restoring the parts to the production line. Figure 5.7 shows the sustainable production changeover cycle.

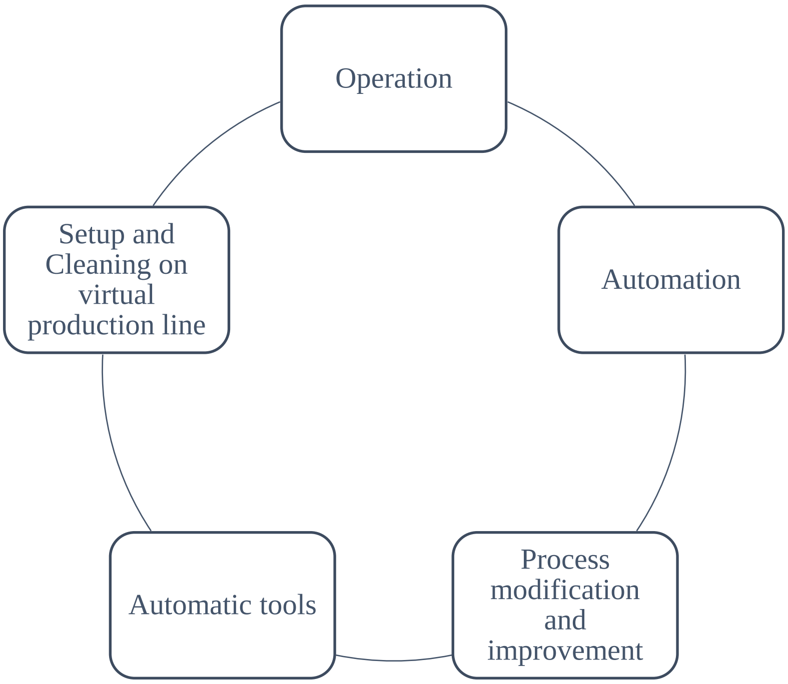


Figure 5.7 Sustainable production changeover cycle

The virtual food manufacturing line, with the input data which is the reading of the surface roughness of the micro textured surface, is compared with the existing surface and the difference in section 6.7. Both readings has been used as input data and results are been compared in the graphs. This is one of the proposed recommendations to improve production changeover and make it sustainable.

5.4 Development of the model

The virtual physical system is built on the basis of actual data from a real production line and has all the essential features of the actual production system. The most relevant data collection about a production system is the data about the real production system and downtime has been extracted from the data. In total down time we have select only downtime related to cleaning and setup.

5.5 Existing model parameters and its characteristics

The existing sample model has been studied and measurements have been taken with using some advanced equipment polytech topmop micro view. Visits have been made to the Polytec Institute and the equipment shown in Figure 5.8 has been used to measure the characteristics of the existing surface.

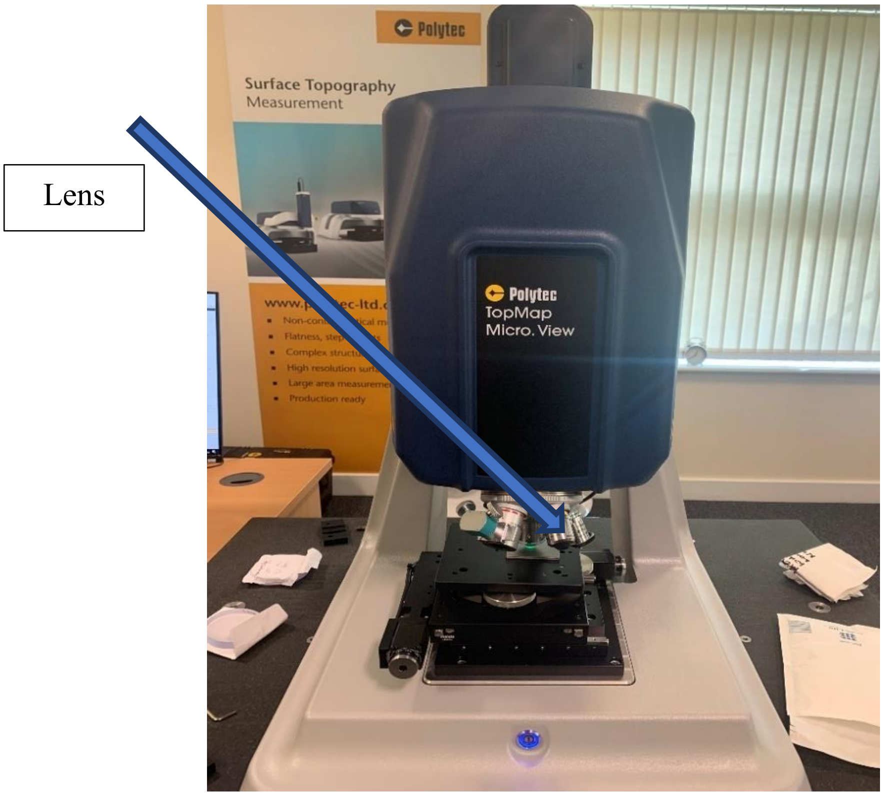


Figure 5.8 Polytech top mop micro view

The equipment shown in Figure 5.8 has many lenses to measure the characteristics of the surface which include 10 x zoom, 25 x zoom and 50 x zoom.

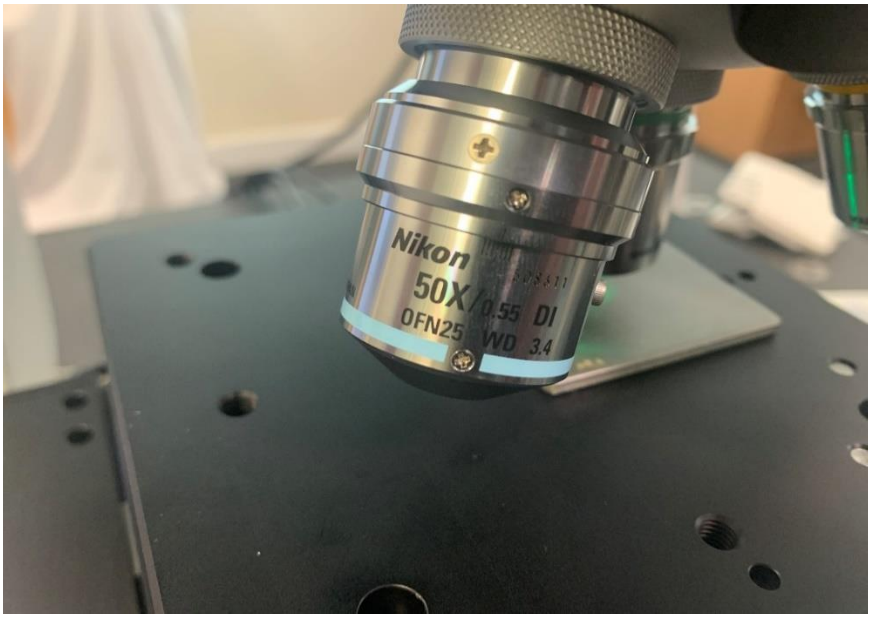


Figure 5.9 50 X lens

The lens shown in Figure 5.9 was used to measure the sample characteristics and its functional parameters which gave very accurate readings. Figure 5.10 shows an example of a reading with an image of the surface [92]. Figure 5.8 shows the Polytech instrument used to obtain the surface roughness readings and Figure 5.9 shows the 50X lens used to take measurements.

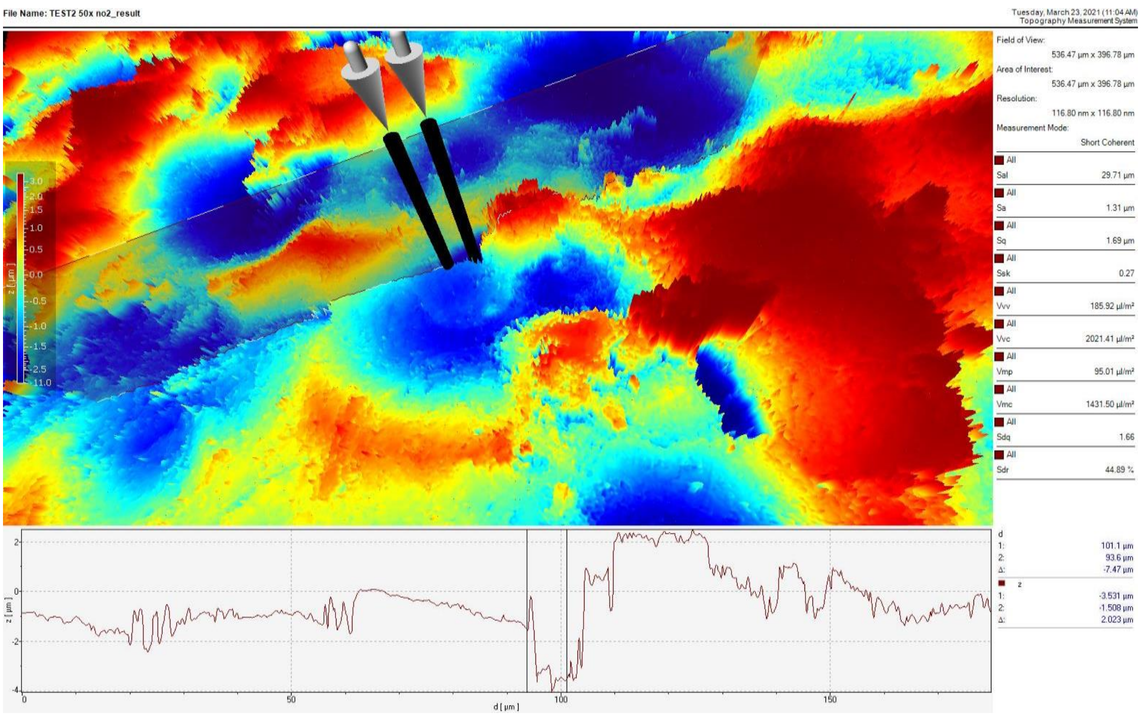


Figure 5.10 Surface roughness parameters of the sample surface

These are the surface roughness readings from Figure 5.10:

Vvv (Void volume dale)185.92 $\mu\iota/m^2$

Vvc (Core void volume) 2021.41 $\mu\iota/m^2$

Vmp (Peak material volume) 95.01 $\mu\iota/m^2$

Vmc (Core material volume) 1431.50 $\mu\iota/m^2$

Figure 5.11 shows the functional parameters of the surface.

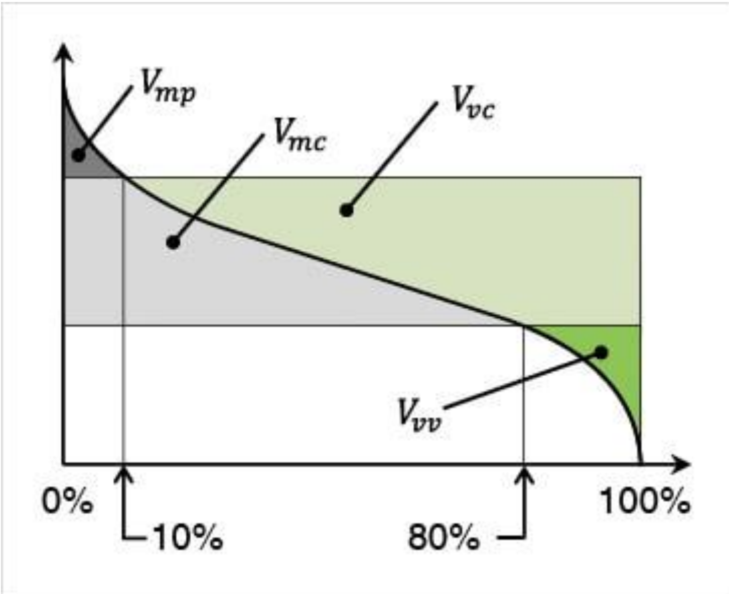


Figure 5.11 Functional parameters plot [102]

5.6 Surface functional parameters

From the experimental data section 4.9.1 we found that the surface of the sample is not smooth and the contact angle of the surface is >150°; therefore, the flavour particles stick to the surface during production and do not roll off the surface. These data has been explained in section 4.9.1. Figure 4.27 and 4.28 show the contact angle of the existing surface. The contact angle is 68.64° and 64.35° with water and 35.80° and 38.18° with cooking oil. It is proposed that the surface texture should be more than > 150°. The example in Figure 5.12 shows that a superhydrophobic surface can have an angle of more than > 150°. The fabrication of superhydrophobic surfaces is discussed in the next section [101][108].

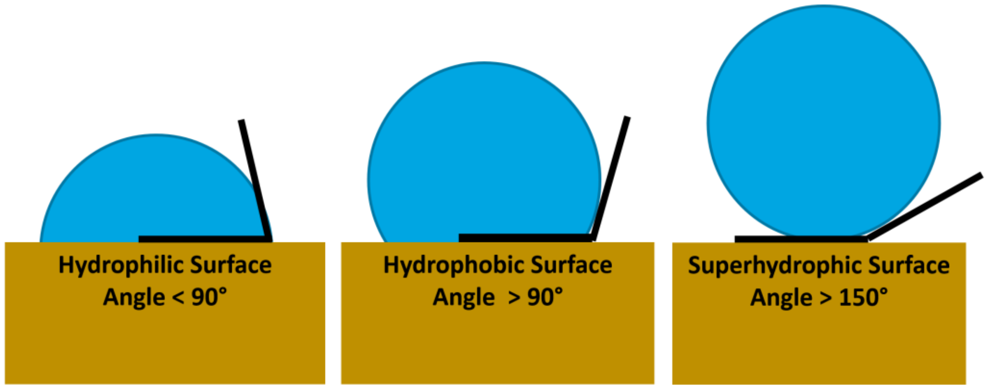


Figure 5.12 Water repellent surface with different angles

5.7 Development of a functional surface

The existing surface has a lower contact angle and therefore it is proposed to improve the contact angle to have a self-cleaning capability. There are different methods which have been found to create hydrophobic /oleophobic surface. Chemical and physical methods have been reported to alter rough surfaces using low-surface-energy coatings like molecular assembly processes, chemical vapor deposition, the sol–gel method, and the breath-figure technique (BFT) among others For these we need to modify the chemistry of the surface with various methods[109]. Superhydrophobicity-based strategies are definitely attractive and viable for fabricating self-cleaning surfaces. This is due to the fact that it traps air between the solid–liquid inter-faces of the superhydrophobic surfaces and reduces the probability of bacterial adhesion to the surface.

These methods include sol-gel dip coating, self-assembly, electrochemical, and chemical physical vapor deposition onto the surface. The surface roughness of the system can be made through the sol–gel technique by transforming the reacting molecules into functional materials. The sol–gel process is a useful and commercially viable technique. In this process, the monomeric small molecules are initially transformed into colloidal suspension (sol) which finally integrates into a network structure (gel) of specific morphology[109].

Figure 5.13 shows a traditional wetting model. This model can be used to estimate the contact angle of a rough surface where air pockets exist providing a theoretical approach for the design of a functional surface with wettability The surface with this is shown in Figure 5.13[97] [98].

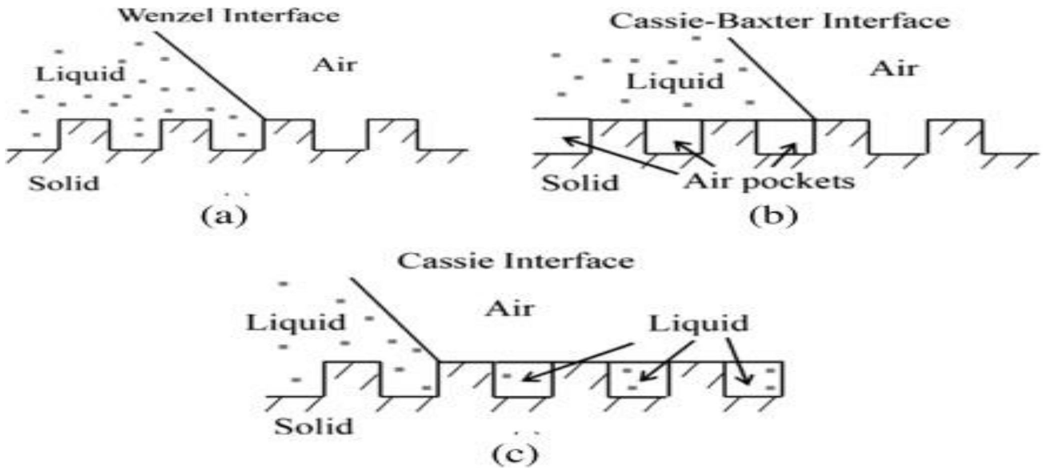


Figure 5.13 Air pockets on the surface [103]

Different coating methods are available to create the water-repellent surfaces, including an artist's spray gun to coat hard substrates such as glass and steel. Water or oil drops can bounce instead of making the surface oily. Ding et al. explained that superhydrophobic surfaces with Zno nanostructure can be obtained by electro spinning [95][96][99][107].

Self-assembly is another simple and inexpensive method to prepare micro and nano dual scale superhydrophobic surfaces with a self-cleaning and oleophobic surface.

Based on the proposed model it is possible for the surface to get the required result of self-cleaning and a surface can be made by controlling the microstructure to promote free, spontaneous movement of a liquid oil droplet on the surface, allowing it to extract contaminants from the surface with its superhydrophobic/oleophobic capability. The principal goal to achieve this self-cleaning is to make sure the droplet of oil or flavour particles flow or roll off the surface without any resistance. Surface modification requires limited material consumption, proves to be the most effective and widely used method to create a surface unique wetting behaviour [105][106][111].

5.8 Characteristics of the functional surface

As discussed, fabrication of self-cleaning surfaces requires strong water/oil repellence which can be obtained by fabricating a rough surface from low surface energy materials or can be modified with treatment to make it microtextured. The advancement in ultra-precision machining technology enables to generate microtextured self-cleaning surfaces [29].

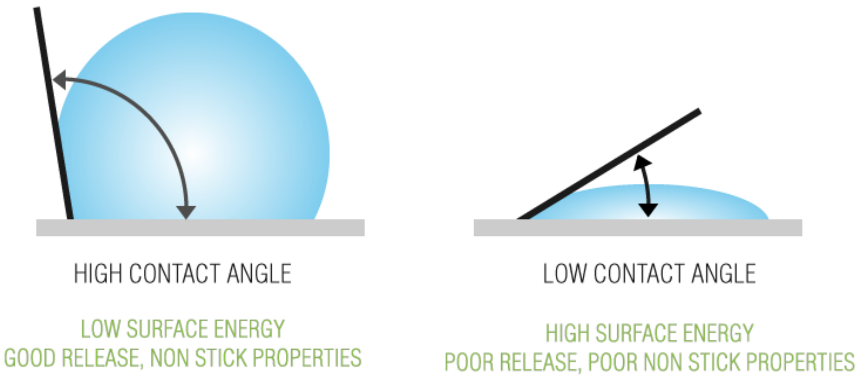


Figure 5.14 Proposed contact angle on proposed surface with low surface energy [100]

The proposed surface must have the low surface energy and high contact angle. This will make the surface hydrophobic / oleophobic. This type of surface will improve the plant performance and reduce the complexity of the production changeover which is the principal goal of the project. Figure 5.14 shows if the contact angle is high then it will have low surface energy and it will be superhydrophobic / oleophobic surface and will repel flavour particles.

5.9 Optimization analysis

A systematic quality study has been carried out at the plant to find the bottleneck of the production changeover complexity with the aim of to reduce the production changeover complexity by increasing the control of the production changeover. The most time consuming activities in the production changeover were identified and considered for improvement. In order to solve changeover complexity, minor changes to the production line are proposed. These changes include small amendments to the existing procedures, minor changes to the part design to improve the dismounting and mounting. It includes suitable tools for cleaning. It also includes the introduction of automation where possible. These changes include surface texture change of the production machines and metal conveyors. The recommendations will make the production changeover less complex and more sustainable [83][110].

5.10 Model validation

As discussed earlier that two experiments have been carried out, one with water and one with cooking oil. Our case study is related to a food company, therefore, we will consider the contact angle of the cooking oil. The cooking oil contact angle is 38.18° and 35.8°. Here we will take the average of both readings which is 36.99°. This means that the surface is not hydrophobic/oleophobic. Therefore, the flavour debris stuck to the surface and required regular cleaning during production. We assume that by using the low surface energy with a high contact angle of 150° and over, a hydrophobic/oleophobic micro textured surface will improve the surface by 75.34% compared to the existing one. This will reduce the cleaning time of the surface by 75.34% which can be utilised in production.

Table 4.3 shows the cleaning downtime and changeover time. With this frequency (75.34% reduction in cleaning time) it is expected that the cleaning time will reduce by 75.34% of the total cleaning down time. This time is on a daily basis and deep cleaning is other than these figures. This is on the daily basis and it will be 59.51 minutes on this basis and will be utilised in production which can produce over 65 thousand packs more. This production enhancement is through using smart surfaces only.

Deep cleaning figures are as follows and deep cleaning takes place once every three weeks. The time consumed during deep cleaning is listed in details in Table 5.1. The total time consumed in deep cleaning is 22 hours and 47 minutes. It takes roughly 7 to 8 hours when three members of staff are working on deep cleaning. Similarly, 75.34% of the time will be saved on production machines, oil drum cleaning, flavour mixer cleaning and conveyors cleaning.

From automation on the main fabric storage conveyor belt can save 80 % of the time and on the belt conveyor can also save 80% of the time. It is explained in Chapter 4 (section 4.4) where the automation can be fixed on the soft belt conveyor and two others. Introducing suitable tools for cleaning and with process modification, which is explained in Chapter 4, it is estimated that down time in changeover is expected to be reduced by 24 % approximately.

Table 5.1 Time consumed in deep cleaning

Production machines dissembling, cleaning and assembling	660 minutes
Cleaning of conveyors	324 minutes
Flavour mixer cleaning and setup	188 minutes
Oil drum cleaning and setup	135 minutes
Storage conveyor cleaning	60 minutes

Table 4.3 shows total down time due to production changeover and in cleaning we will be able to save 75.34% of the down time and with the changeover we will be able to save 24 % of the time with the help of automation and process modification and minor changes to the parts.

Cleaning Breaks	23.23 % of plant total down time(see table 4.3)
Changeover	16.50 % of total production changeover (table 4.3)
Overall changeover downtime is	45.11 % of the plant total down time (table 4.3).

Overall the total down time can be reduced by 22.41 % of the plant down time and in production changeover the time can be reduced by 49.67%. These calculations has been calculated with the assumptions of 75.34% improvement in the proposed surface with improved contact angle.

5.11 Summary

Textured surfaces with self-cleaning properties can be used in many applications to remove contamination by high contact angle which maintains cleanliness automatically.

Textured surfaces provide air pocket formation. Air pockets inside grooves underneath the flavour debris reduces the contact area between the flavour debris and the surface resulting in self-cleaning. Low energy surface with higher contact angles are responsible for the self-cleaning and superhydrophobic properties in nature and, similarly with fabricated surfaces having similar properties. A large amount of research on superhydrophobic self-cleaning is bio-inspired and has been successfully carried out on a small scale in the laboratory. The self-cleaning surface usually possesses others functions due to its unique structure and chemistry. The self-cleaning surfaces with multifunctionality may provide additional benefits and properties including anti-icing, anti-fogging, oil and water-repellent surfaces. The recommended surface texture for the metal conveyor, production machines, flavour mixer and oil mixer are one aspect of the production changeover complexity reduction. The other aspect of the complexity reduction in production changeover can be overcome with the proposed process mapping and process optimisation. These include the introduction of automation for the belt conveyor, suitable tools for cleaning and some process improvements to improve the plant productivity. These will make the production changeover less complex and more sustainable overall.

Chapter 6 Application Case Study: Results, Analysis and Discussion

6.1 Introduction

In this chapter we will discuss our case study which is related to one of the Europe's biggest biscuits and crisps manufacture called Uni Biscuits and, in the market, we know them as MCVITE'S. The company is producing various varieties of biscuits and crisps. Our case study is related to the crisps manufacturing production line which is called plant A. There are various flavours crisps produced. It has been discussed that company has a major issue with market demand as it fluctuates frequently. In the past, we could see a steady volume increase after the release of the product and then have quite a long stable phase but the product volume climbs faster then goes down more quickly due to new products in the market. The company has to meet customer needs and therefore needs to make changes in their plans frequently. To meet the demand of the customers changes in the production line are required frequently. These changes are related to shifting of production from one flavour to another depending on market demand. These flavours are salt and vinegar, cheese and onion and bacon. Each flavour has different requirements and demand from the market [78] which results in stopping the production line, then cleaning and starting to produce another flavour.

Figure 6.1 Crisps variants on Plant A

It also includes production changeover along with all production line cleaning. Full production changeover is a complicated process and it consumes substantial amounts of time and resources. Cleaning of the surfaces is also mandatory due to flavour change and food hygiene. The main objectives of the project are to reduce the complexity of the production changeover and design and make recommendations for a sustainable production changeover process. Further details are explained in later sections in this chapter.

6.2 Case study at McVitie's Ltd

In this section we will talk about the case study which relates to a crisps manufacturing plant. The plant is running 24/7 and is manufacturing three flavours of crisps. There is one production line which is called plant A. On the plant there is one main conveyor which transport crisps from the oven and it moves to storage conveyor. From storage conveyor crisps through another conveyor which is connected to three oil drums. In the following station these oil drums are connected to flavour mixer where flavour is sprinkle on crisps. These three flavour mixers are connected with three conveyors which transports crisps to the ten production machines. The flow of crisps towards the production machines can be controlled and depending on which flavour crisp and its requirements. There are different types of conveyors: one type is soft fabric conveyor and other is metal conveyor with vibration. The main conveyor which transport crisps from oven is soft (Figure 6.2).

Figure 6.2 Soft conveyor belt transporting crisps from oven

This conveyor transports crisps from oven to the storage conveyor where a part of the conveyor is soft, and another part is a soft fabric conveyor. From the storage conveyor the crisps are transported to the next step (Figure 6.3).

Figure 6.3. Storage conveyor with crisps

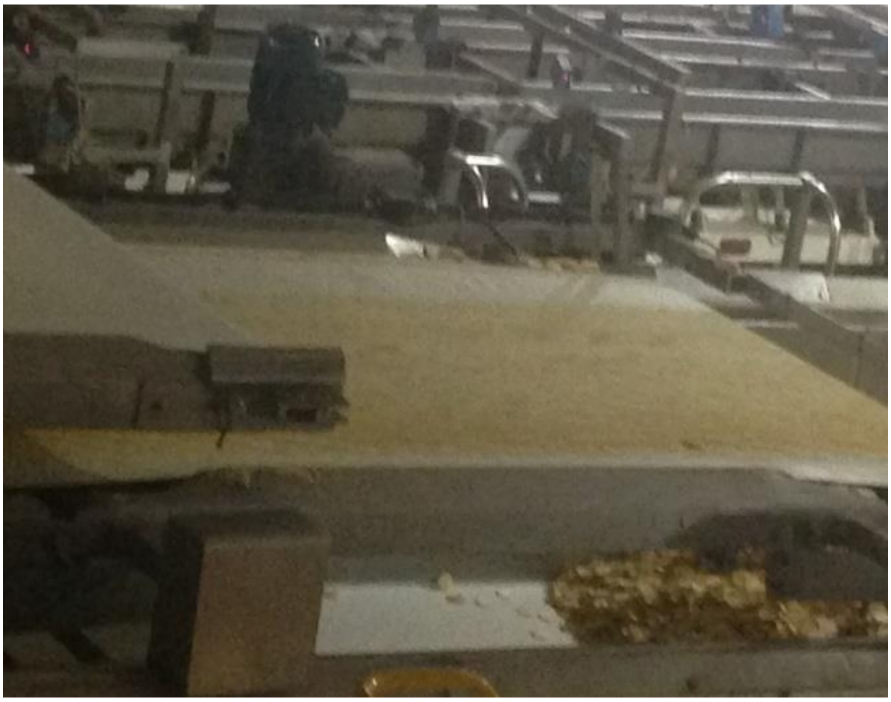


Figure 6.4 Storage conveyors without crisps before cleaning

After the storage conveyor, the crisps move through various conveyors to the three different conveyors. Figure 6.5 shows transportation towards the oil drums from the storage conveyor.

Figure 6.5 Conveyor belt from storage conveyor to oil drums

Figure 6.6 Vibrating metal conveyor towards oil drums

These are divided into three because the plant manufactures three flavours of snack. Each of the conveyors transports crisps to the oil drum where the snacks are sprayed with oil using oil drums (Figure 6.7).

Figure 6.7 Oil drum

In the oil drum the lower part is inside the oil drum which sprinkles oil on the crisps. This makes the crisps oily and when the crisps are oily the flavour is sprinkled on the crisps which sticks because of the oil.

Figure 6.8 Oil sprinkle part inside the oil drum

Figure 6.8 shows the flavour drum where flavour is deposited on the crisps before being transported further through three conveyors to production machines. These three conveyors are each dedicated to a flavour and so their use depends on the market demand. If the demand for one flavour is high, then two conveyors can run one flavour and the other conveyor runs the second required flavour. If only one flavour needs to be produced, then all three oil drums, flavour drums and conveyors run the same flavour. These three conveyors are linked to the ten production machines.

Figure 6.9 Production line plant A

There are ten machines which transport crisps to the packing machine below these machines (Figure 6.9). These machines run day and night 24/7. These machines produced different size crisps packs which included the following.

- 25 grams
- 35 grams
- 50 grams
- 125 grams

There are also large packs but they are not among the main products of the company and are only produced when there is specific demand for them. These include the following sizes:

- 150 grams
- 175 grams
- 350 grams

As mentioned before the plant operates 24/7 and each machine produce 110 packs per minute and all ten machines can produce 1100 packs per minute and 66,000 packs in one hour.

Similarly, if whole plant is running 24/7 without any problem and with full capacity then it can produce 1.584 million packs in 24 hours. In practical it is not possible due to several factors and these factors are mentioned in table 4.2.

6.3 Problem descriptions

Various visits have been made to understand the production system of the plant and find where the problem is. Various discussion took place with the plant manager and online production staff. During visits many problems were observed and will be discussed one by one. Due to food hygiene, it is required that many places need regular cleaning. These include various areas and parts of conveyors to the production machines i.e. conveyors, soft conveyors, metal conveyors, storage conveyors, conveyors before production machines and ten machines. There are various types of cleaning and the most common is regular cleaning which takes place every 4 hours. These are mostly related to the production machines. Production machines are complicated to clean due to various parts.

To find the severity of the problems we need to describe the process involved during the cleaning and setting of the production machines. This also includes stopping some part of the production line which needs to be cleaned, disassembling of the production machine (example shown in Figure 6.10), cleaning of each part and re-assembling of the machine. All these processes are explained below in detail which will help to understand the importance and severity of the problem.

Figure 6.10 Production machine

The machine shown in Figure 6.10 produces 110 packs per minute and this needs cleaning every 4 hours due to food hygiene. Each of these parts needs to be removed from the machine.

6.3.1 Cleaning process of production machine

Each machine is cleaned after 4 hours on average. For the machine which needs cleaning the conveyor is stopped where it receives crisps and this feed is diverted to other machines (Figure 6.11). Then all snacks are removed from the machine and collected in blue bin bags. There are different parts which needs to be removed one by one.

Figure 6.11.Production machine feeder

Figure 6.12 Top feeder of the machine

Top radial feeder (Figure 6.13). One on each machine. It needs to be removed and cleaned with cleaning wipes and other tools.

Figure 6.13 Top cover above lower feeders

The lower cover above the feeder needs to be removed and cleaned.

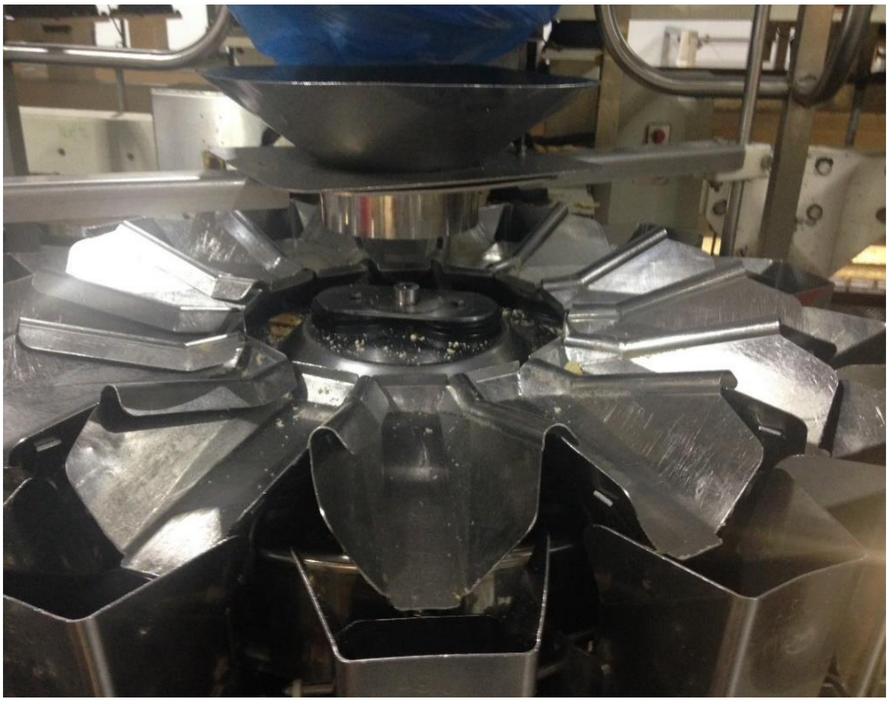


Figure 6.14 Fourteen feeders to feed crisps
to the large buckets

Feeders need to be removed from the machine (Figure 6.14). There are fourteen feeders which need to be wiped and cleaned (Figure 6.15).

Figure 6.15 Feeder with flavour and crisps particles

Figure 6.16 Buckets of production machine

The upper are large buckets (Figure 6.16). There are fourteen on each machine. The lower ones are small buckets. So, the total is twenty-eight buckets (parts) which need to be removed from the machine and each of them cleaned.

Figure 6.17 Inner view of large bucket

Figure 6.17 shows inside the bucket. We can see that a large amount of material is stuck to the surface. Sometimes the material is hard depending on the weather and the flavour. In the picture the material is salt and vinegar which is the hardest one and takes large amount of time to clean as compared with others.

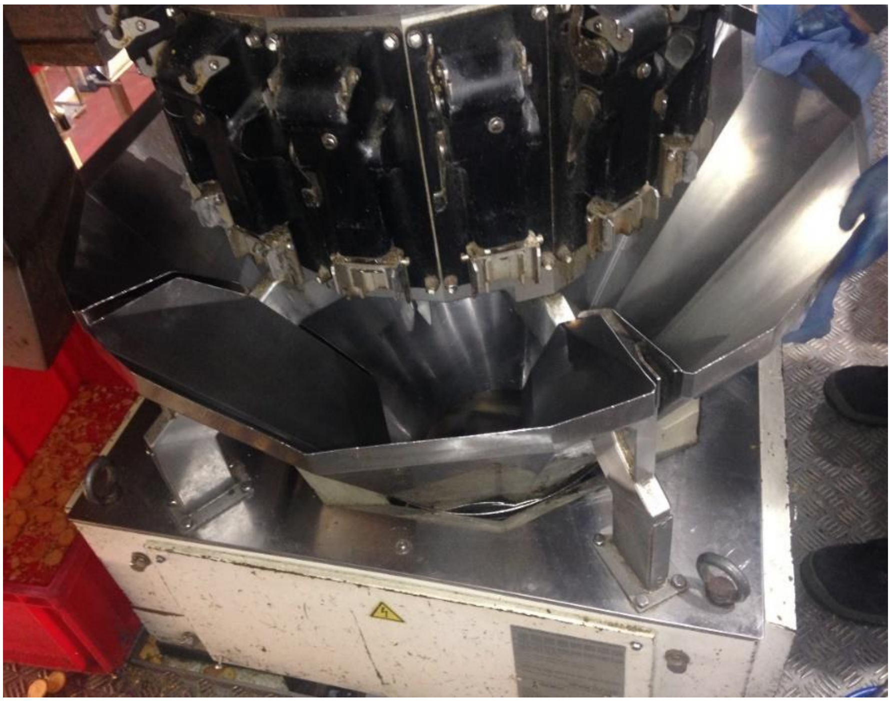


Figure 6.18 Lower parts of the production machines

The removal of the flask below small buckets has to take place. It needs to be disassembled first then there is another flask which is lower than the one shown in Figure 6.18.

Figure 6.19 Lower flask of production machine

This flask also needs to be removed from the machine and needs to be wiped and cleaned properly (Figure 6.19).

Figure 6.20 Buckets mounting location

After removing these parts, all of them need to be cleaned and wiped with different equipment. These include air hose pipes, soft rubber spatulas, wet wipes, dry wipes, metal spatulas to remove the hard bits. After cleaning all these parts they need to be assembled back in the machine for the next production run. Table 6.1 shows the parts cleaning and assembly timetable.

Table. 6.1 Production machine dismounting and cleaning activities

Serial No	**Description**	**Time consumed**
1	The top radial feeder removal	50 seconds
2	Top radial feeder cleaning	45 seconds
3	Lower cover above feeder	48 seconds
4	Lower cover above feeder cleaning	46 seconds
5	Dispenser feeder removal (14 feeders)	3 minutes 30 seconds
6	Dispenser feeder cleaning (14 feeders)	4 minutes and 20 seconds
7	Large buckets removal (14 buckets)	55 seconds / bucket, total time is 12 minutes and 50 seconds
8	Cleaning of each bucket depends on material stick to the bucket (14 large buckets)	Average 1 minute 50 seconds = 25 minutes and 40 seconds
9	Small buckets removal (14 buckets)	50 seconds / bucket, total 11 minutes, and 40 seconds
10	Cleaning of each small bucket depends on material stick to the bucket	Average is 50 seconds / each bucket, Total is 11 minutes and 40 seconds
11	Removal of flask below the small buckets	45 seconds
12	Cleaning of flask below the small buckets	50 seconds
13	Removal of lower plastic flask	20 seconds
14	Cleaning of lower plastic flask	45 seconds

The total time consumed in disassembling and cleaning is one hour fourteen minutes and thirty-nine seconds for each machine.

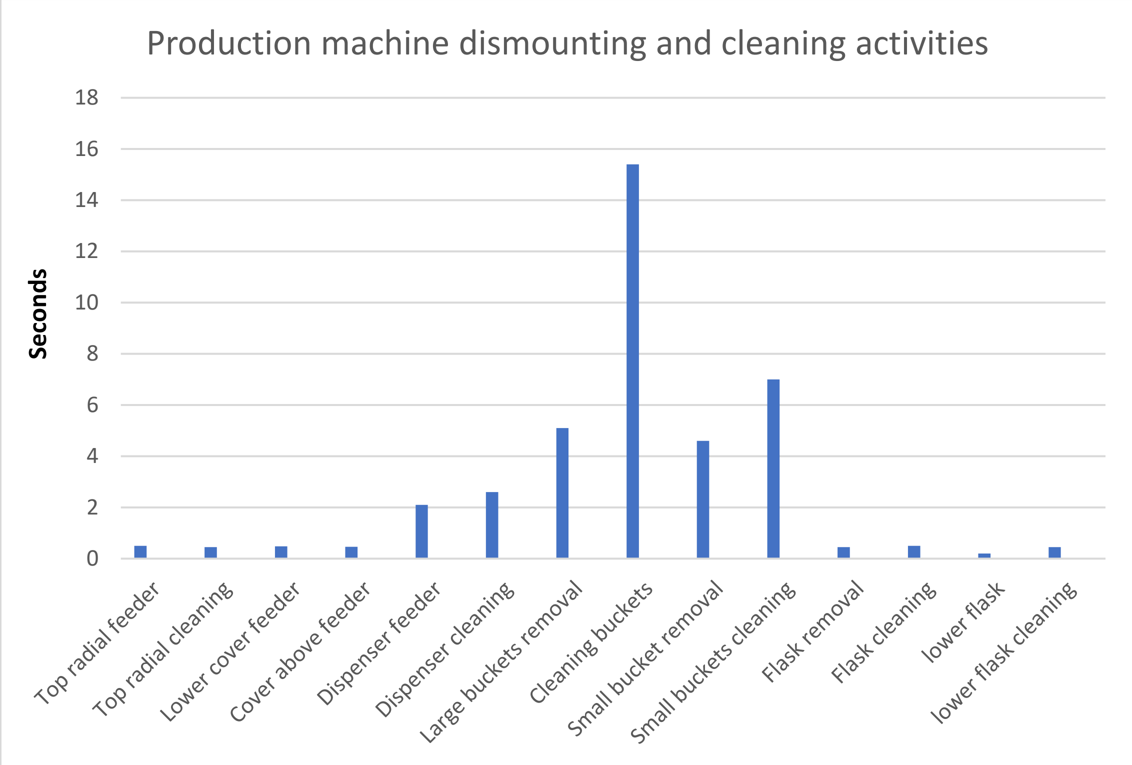


Figure 6.21 Production machine disassembling and cleaning activities

Table 6.2 Mounting of parts on production machine

S. No	**Description**	**Time consumed**
1	Fixing of lower plastic flask	45 seconds
2	Fixing of flask below the small buckets	45 seconds
3	Mounting of small fourteen buckets	2 minutes 20 seconds
4	Mounting of large fourteen buckets	2 minutes 20 seconds
5	Mouthing of fourteen feeders	2 minutes 20 seconds
6	Fixing of top above feeder	30 seconds
7	Fixing of top	25 seconds
8	Air blow to the machine and below machine	25 seconds

Table 6.2 shows the steps when the machines parts are cleaned and then mounted back onto the machine for production. The assembling takes nine minutes and fifty seconds.

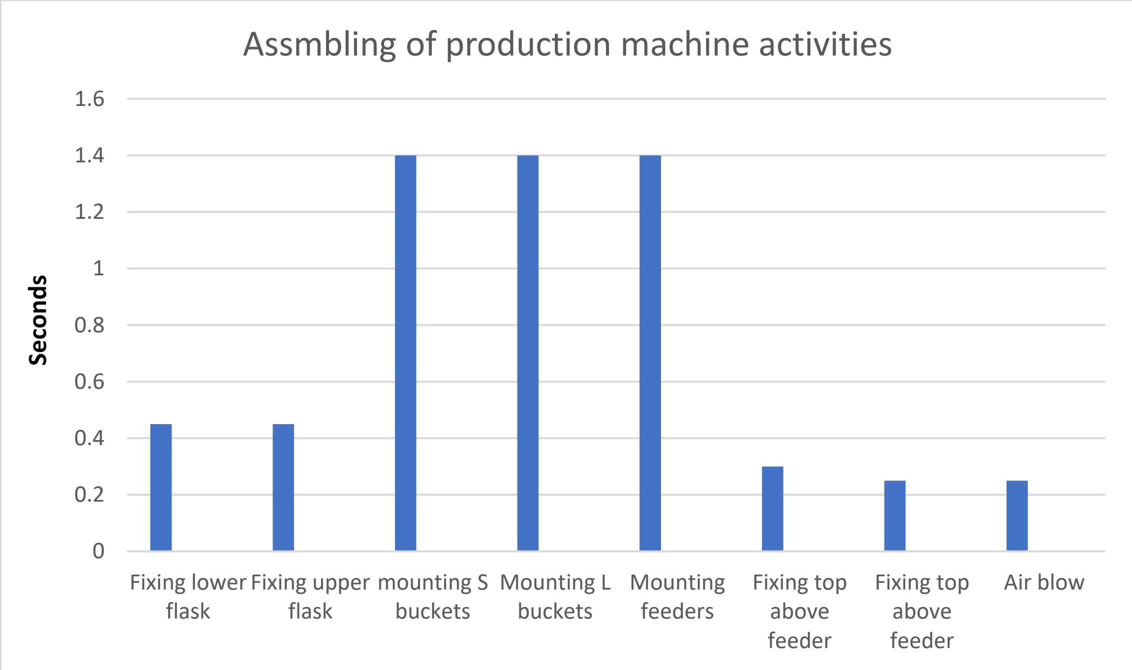


Figure 6.22 Assembling of production machine activities

The time consumed for the full cleaning of one production machine is one hour sixteen minutes and fifty-nine seconds. This time is the average time to clean one production machine and there are ten production machines which have to be cleaned one by one. So, the total time consumed to clean all ten production machines is thirteen hours fifty seven minutes and fifty seconds.

6.3.2 Cleaning of storage conveyor

The cleaning of storage takes a considerable amount of time, but it depends on the type of cleaning. One is partial cleaning which takes place every four hours and one is deep cleaning. Here in this section the deep cleaning steps are studied. Crisps coming from the main conveyor are stored on the storage conveyor from where they are transported to the next process. There are many steps to clean the storage conveyor (Figure 6.23).

Figure 6.23 Upper storage conveyor

Figure 6.23 shows the upper side of the storage conveyor and Figure 6.24 shows the lower side. The upper one is like a belt and moving continuously which can be seen in white. The lower one is metal works with vibration.

Figure 6.24 Lower portion of storage conveyor
with flavour particles

Firstly, all snacks are transported from the storage conveyor through the blue conveyor to the next process and when cleaning needs to be done the remaining snacks have to be removed first after stopping the production line. Once all crisps have been taken from the storage conveyor and collected in blue bin bags which is waste, one of the staff members removes the material from the hard metal conveyor with a spatula. There are some places which are hard to reach and clean. Figure 6.25 shows how the cleaning process takes place.

Figure 6.25 Inside of storage conveyor

Figure 6.25 shows that one of the staff members goes inside to clean and this is a hard posture for cleaning. All material has been removed from both the soft and hard conveyors with different equipment which includes hard and soft spatulas, wet wipes, dry wipes, and air hose to clean the remaining bits from the edges and corners.

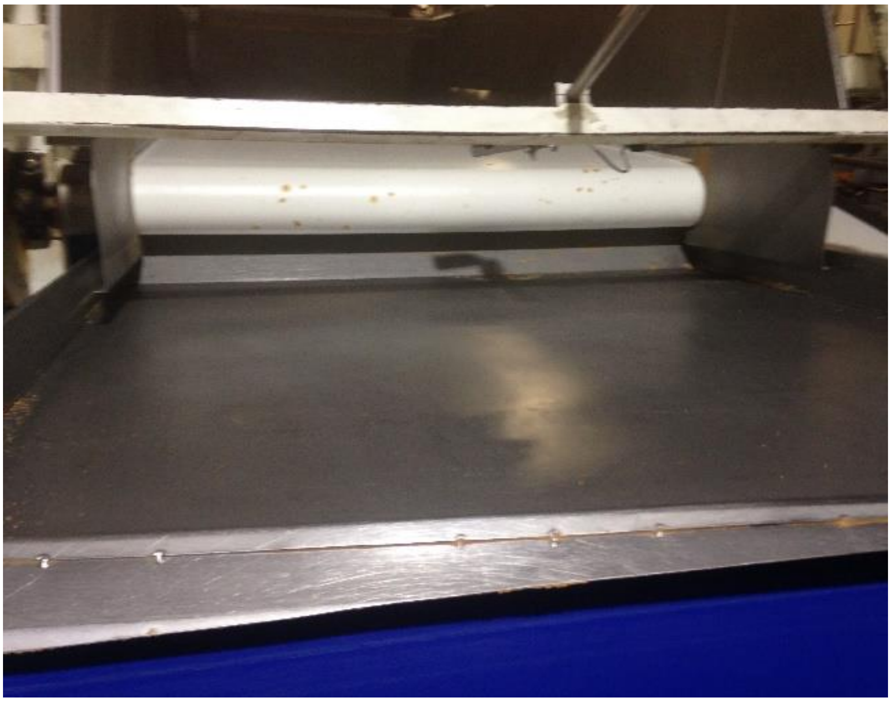


Figure 6.26 Storage conveyor front side after cleaning

Figure 6.27 Upper side of storage soft conveyor after cleaning

Figures 6.26 and 6.27 show the storage conveyor after cleaning. The whole cleaning time for the storage conveyor is approximately 60 minutes.

6.3.4 Cleaning of conveyors

There are many conveyors and all need to be cleaned regularly. As explained before, some of them need to be cleaned partially every four hours and one requires periodic deep cleaning when everything needs to be stopped and cleaned. First, the main conveyor which transport crisps from the oven is stopped and cleaned. This is a soft fabric belt conveyor and is cleaned easily compared to the metal ones (Figure 6.28).

Figure 6.28 Soft conveyor belt transporting crisps from oven to storage conveyor

Figure 6.28 shows the conveyor belt which transports the crisps from the oven to the storage conveyor. This needs to be cleaned with a metal spatula carefully so it does not damage the surface. Once the material has been removed, it has to be wiped using wet wipes and dry wipes to make it fully clean without any particles. This takes approximately 40 minutes.

6.3.4.1 Cleaning of metal conveyors before oil drums

The next step is the cleaning of the metal vibrating conveyor which transports the crisps from storage conveyor to the oil drums (Figure 6.29). Material sticks to the surface but the quanitity of the material is not as high compared to the material sticking to the surface after oil spray. The process of cleaning is the same and the material has to be removed using both metal and soft spatulas. Once it has been removed then it is wiped with wet wipes and dry wipes. Air is also blown onto it to remove the small particles from the edges and corners on the conveyor.

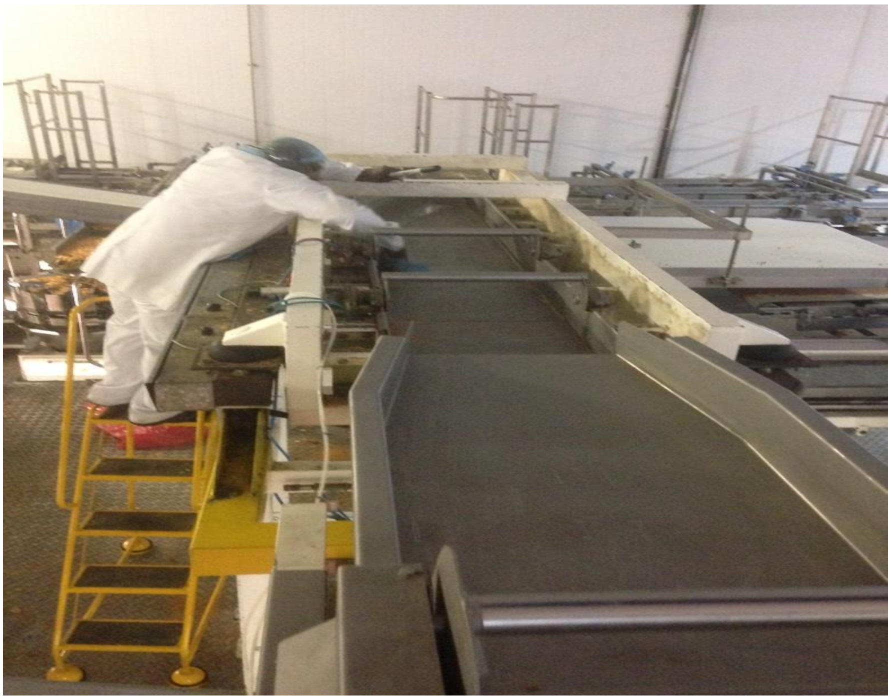


Figure 6.29 Metal vibrating conveyor

Figure 6.30 shows the equipment used to remove material from the surface of the conveyor.

Figure 6.30 Tools for cleaning

The total time consumed to clean this conveyor is one hour six minutes.

6.3.5 Cleaning of oil drum

First, the old drum needs to be pulled out from the production line and its parts have to be removed one by one. Once the parts have been removed then oil needs to be wiped out from the drum inside and from outside wherever the oil is found.

Figure 6.31 Oil drum

Figure 6.31 shows the oil drum. There are many parts which need to be removed from the drum and before cleaning.

Figure 6.32 Oil sprinkle pipe inside oil drum

Figure 6.32 shows the part that goes inside the oil drum for sprinkling oil on the crisps. The drum itself is rotating and the oil pipe is static and sprinkles oil on the crisps all over. This results in the inside being full of oil and particles from crisps are stuck inside the drum. The oil drum is designed from inside with some layers where the crisp particles stick with oil to the surface and that needs to be removed and cleaned. The whole process of the oil drum dismounting, cleaning from inside and outside and the refitting of parts takes a large amount of time. Once everything has been cleaned inside and outside then the oil drum is cleaned with steam also. Steam is passed all over the inside to make it completely clean. This is due to the food hygiene requirements to make sure that it is cleaned to a high standard. The breakdown of each activity and time consumed in each activity is described in Chapter 4 in detail. The total time consumed to carry out all these activities takes two hours and ten seconds, approximately. The same equipment that is used here is also used to clean the oil drum.

6.3.6 Cleaning of flavour mixer drum

This is the next step of after cleaning the oil drum. Cleaning the flavour mixer drum is complicated and time consuming. The same procedures are also used for cleaning the flavour mixer drum. First, it needs to be taken off the production line. Once it has been taken off then parts need to be removed from the mixer drum (Figure 6.33).

Figure 6.33 Flavour mixer drum on the production line

Figure 6.33 shows the flavour mixer drums and in Figure 6.34 we can see flavour is coming out of the flavour tank through a pipe and then moves to the drum where it is added to the crisps. The drum is rotating during production and flavour is added to the crisps.

Figure 6.34 Flavour being added to the crisps

The upper parts of the flavour tunnel, the lower flavour tunnel, the pipe for the flavour, the tray below the flavour which transports crisps to the flavour mixer drum have been disconnected from the line one by one. Then debris and particles are removed from each part, wiped with wet wipes and then dried up with dry. Taking these parts off the line, cleaning and mounting them back onto the line is a time consuming activity.

Figure 6.35 Manual removal of crisps from flavour mixer

Figure 6.35 shows a staff member removing crisps from the flavour mixer drum. These crisps are waste and are collected in blue bin bags. We can also see that flavour material is stuck to the outside of the drum which also needs to be wiped and cleaned.

Figure 6.36(a) Flavour mixer drain to bin bag. (b) outside side of flavour mixer with flavour depoist on the surface

After cleaning the drum there are other parts which need cleaning including the flavour tank. The flavour tank needs to be opened to clean it. First the flavour is drained from the flavour tank. Figure 6.37 shows the flavour being drained from the flavour tank and collected in red bags. This flavour is waste. Once the flavour tank is empty then the tanks need to be opened for cleaning inside. When all the cleaning is done from inside and outside steam is used inside the flavour drum. This is due to food hygiene and it is to make sure that the oil drum is completely clean. The steam process is only carried out during deep cleaning.

Figure 6.37 Disassembling of flavour tank

Figure 6.38 Shafts from flavour tank

Figure 6.38 shows the two shafts and the pipe for the flavour which are disassembled and taken away to wash with water. The distance to the washing place is about 150 meters from the machine, and it takes 3 minutes to reach there; the cleaning time is 6 minutes to clean both shafts and pipe and 3 minutes to come back to the working station.

The breakdown of all these activities are mentioned in Chapter 4 and total time consumed to disassemble, clean and then assembled the oil drum takes three hours seven minutes forty-three seconds

6.3.7 Cleaning of conveyors between flavour mixer and production machines

There are three conveyors from the oil mixer to the production lines and these are further divided into 10 to transport crisps to the 10 production machines. Figures 6.39 and 6.40 show the conveyors with the material on the surface. These need to be removed and cleaned. The length of each conveyor is approximately 10 metres and the width of each conveyor is approximately .5 metres.

Figure 6.39 Metal vibrating conveyors before cleaning

The same tools are used for cleaning. i.e. soft rubber spatula, metal spatula, wet wipes, dry wipes and an air hose to blow particles from the edges and corners of the conveyor. When the conveyors are cleaned air is blown onto the conveyors to remove any particles left in the edges and corners. The time consumed on each conveyor is one hour forty-eight minutes. The total time consumed to clean all three conveyors is five hours twenty-four minutes. This includes cleaning the feeder and doors to the all 10 production machines.

Figure 6.40 Metal vibrating conveyors before cleaning

There are three conveyors which transport crisps and each of them needs to be cleaned. When partial cleaning is required then its every four hours and takes less time but when full cleaning is required it needs a large amount of time. Some of the areas are easy to clean and some are hard to clean. If the surface is smooth, then it takes less time to clean but edges and corners are hard to clean and need more labour hours.

Figure 6.41 Metal vibrating conveyors cleaning before production machines

Figure 6.42 Thick material stuck to a metal conveyor

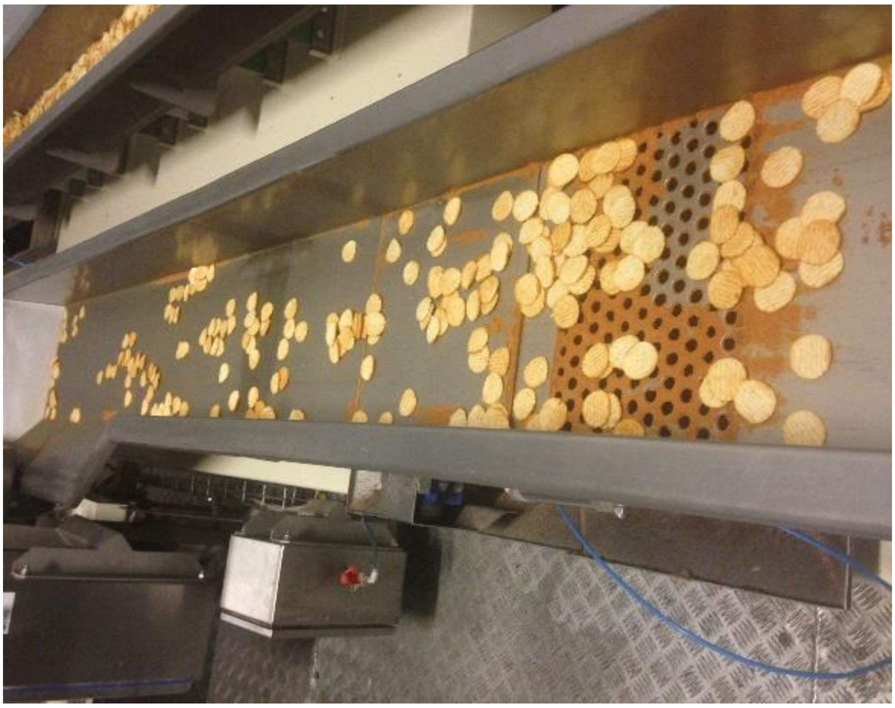


Figure 6.43 Cleaning a metal conveyor

Figure 6.44 Metal part after flavour drum

6.4 Total changeover time

The total time consumed on the cleaning is not limited to these procedures but they are the main cleaning areas which are mandatory to clean. So, if we add up the above cleaning time, the total time consumed on the cleaning is shown in Figure 6.45.

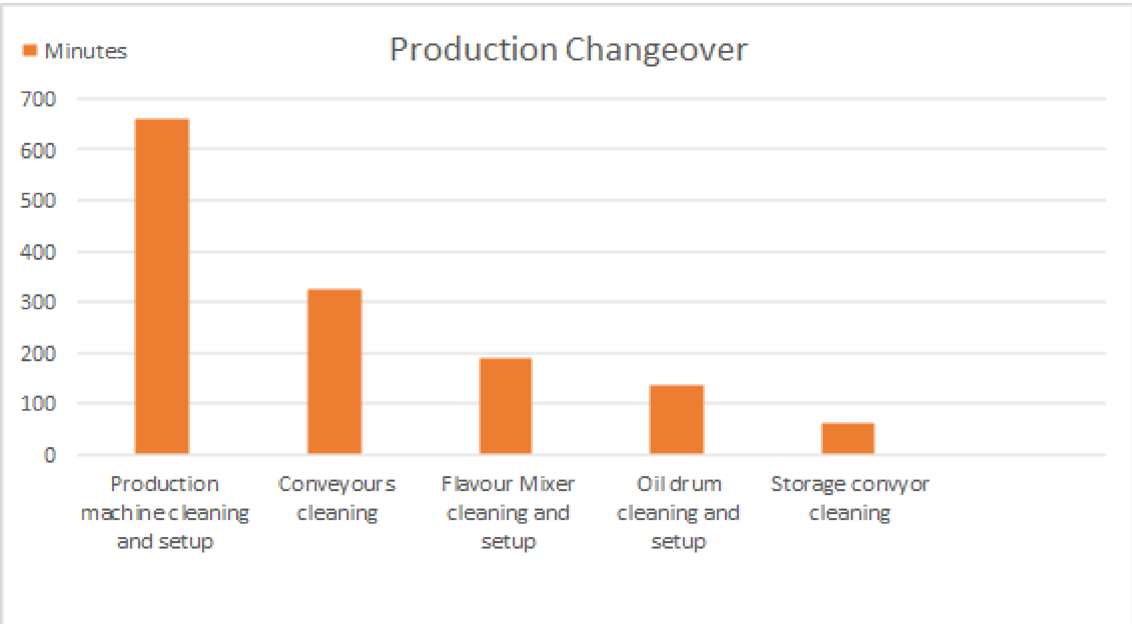


Figure 6.45 Production changeover

6.5 Objectives and scopes

The objective of the project is to understand the whole manufacturing process, compare the production with plant optimum capacity, try to find out where the root cause is of losses in production. After carrying out a deep study of the manufacturing process different down times have been noted. Production line cleaning has been divided into five sections:

- Dis-assembling, cleaning and then assembling of ten production machines
- Cleaning of storage conveyor
- Cleaning of all conveyors
- Dismounting of oil drum, cleaning of oil drum and mounting of oil drum
- Dismounting of flavour mixer, cleaning of flavour mixer and mounting of flavour mixer

Storage conveyor has been mentioned separate as it takes sustainable amount of time and different from other conveyors. All these have been explained with each step and the time consumed to carry out each activity has been recorded. The purpose of the study is to minimise the down time of the plant and to have maximum utilisation of the plant. This has been done through introducing a micro textured surface which has a self-cleaning capability. The micro textured surface has the capability to repel the debris of the flavour and is smoother than the existing surfaces. It reduces the frequency of cleaning. Automation has been introduced to reduce the complexity of the production changeover which also helps to reduce the time consumed in some parts of the cleaning process, particularly with the storage conveyor [122][123].

6.6 Data utilisation

Data analysis plays a vital role in sustainable manufacturing / sustainable changeover and helps to take decisions accordingly. Productivity can be enhanced by exercising economy at all levels of the production facility. Therefore, controlling the quantity of resource inputs as well as by increasing outputs with the same or reduced levels of inputs helps productivity. During this study of the manufacturing plant various data have been collected. These data are related to daily production activities and various types of down time. These down times have already been explained in Chapter 4. Setup time is one of the vital parameters used in any manufacturing industry and is a form of necessary inputs to every machine or work station. Setup is a collection of sequence dependent changeover activities which are carried out before starting the production of a product, so productive time for a machine can be increased by reducing setup time. There is little awareness about the quantitative techniques that can be used to calculate the requirements of having shorter changeovers. There is even less understanding on the part of concerned persons about the impact and the importance of shorter and sustainable production changeover. Quantitively set up time for every machine has been recorded. The production data has been collected for one year and, similarly, so has down time [72][73].

6.7 Technical aspects

In this study, we are mostly working with using smart surfaces to make production changeover sustainable. So, in this section we will discuss the technical aspects of the surface texture which we proposed for use in the plant. Superhydrophobic surfaces have many applications across a wide range of areas. These include anti corrosion, anti-icing and self-cleaning as well. It is well known that hydrophobicity of a surface is governed by the surface chemistry and surface roughness. Low surface energy is associated with micro and nano roughness and this can create surface superhydrophobic surfaces. Self-cleaning surfaces can also be formed by fabricating the micro/nanostructures necessary to change the surface wettability. Figure 6.46 (a) is the picture of sample surface and (b) is its surface measurements.

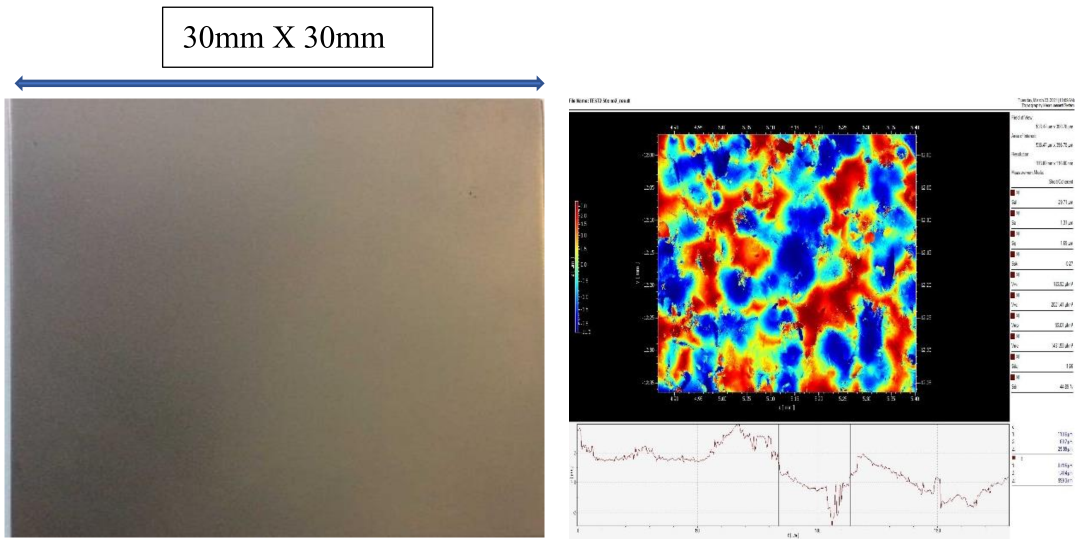


Figure 6.46 (a) Metal sample (b) Sample parameters measurements

The degree of wettability is usually expressed as the contact angle formed at the three-phase boundary (solid/liquid/vapor) between the surfaces of the liquid droplets and the solid surface. Self-cleaning surfaces are broadly divided into two major categories, i.e. superhydrophilic and superhydrophobic. Ultra-fast laser include texturing provides extremely high processing accuracy and almost no thermal damage due to the fast processes. Figure 4.47 shows different view of sample surface.

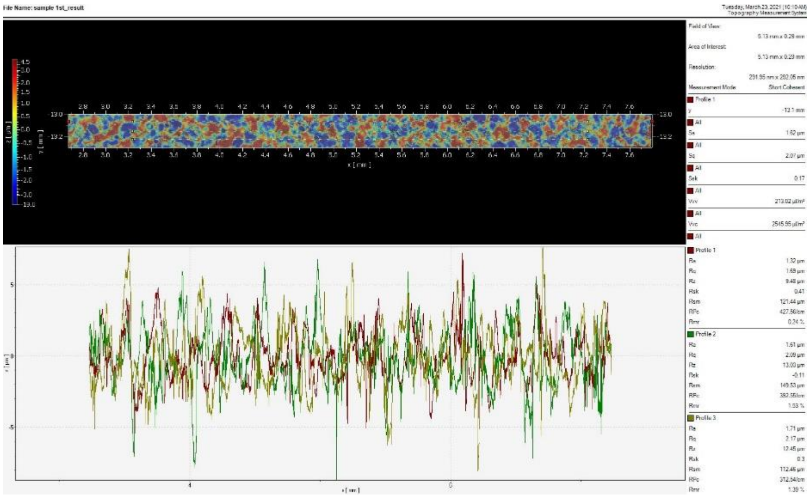


Figure 6.47 Different view of sample surface

It produces micro/nano structures of different shapes and sizes and is environmentally friendly in terms of not polluting the environment. It is one of the best methods to create self-cleaning surfaces with micro textured features. A micro textured surface has many unique properties which can change the surface wettability to produce a superhydrophobic self-cleaning surface. During the experiment we only studied the surface of the sample and its roughness and proposed microtextured surface with high contact angle. We didn't consider the energy requirements of running the laser and this has been proposed to be consider in future work.

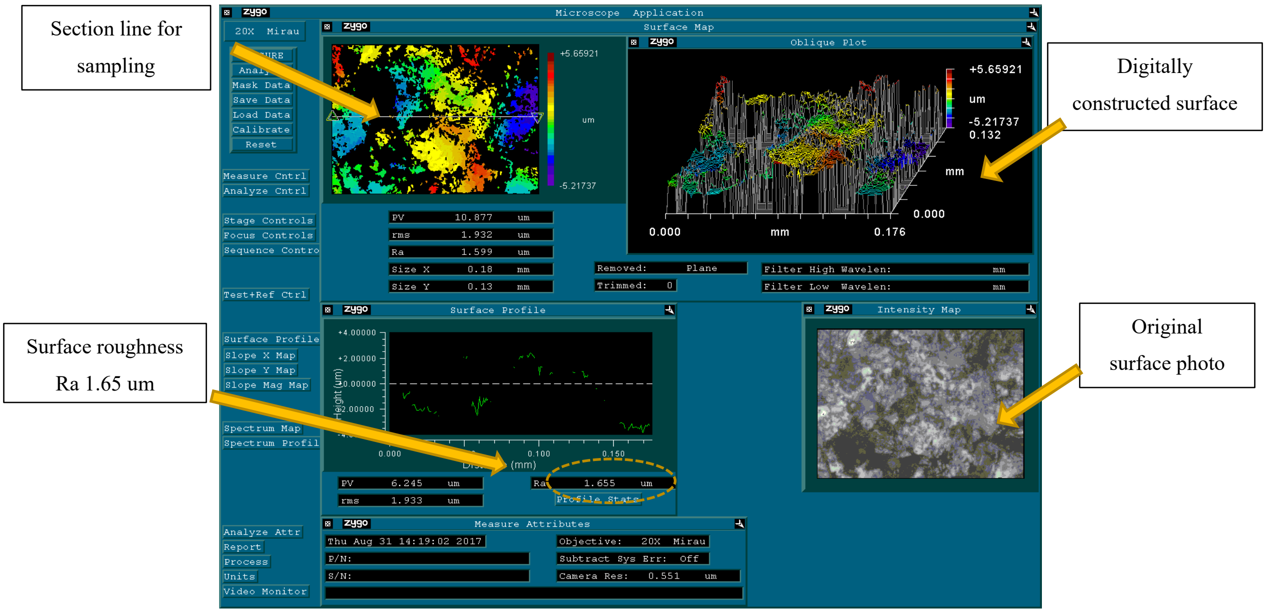


Figure 6.48 Surface roughness is 1.65 um of the existing Metal sample used in the company

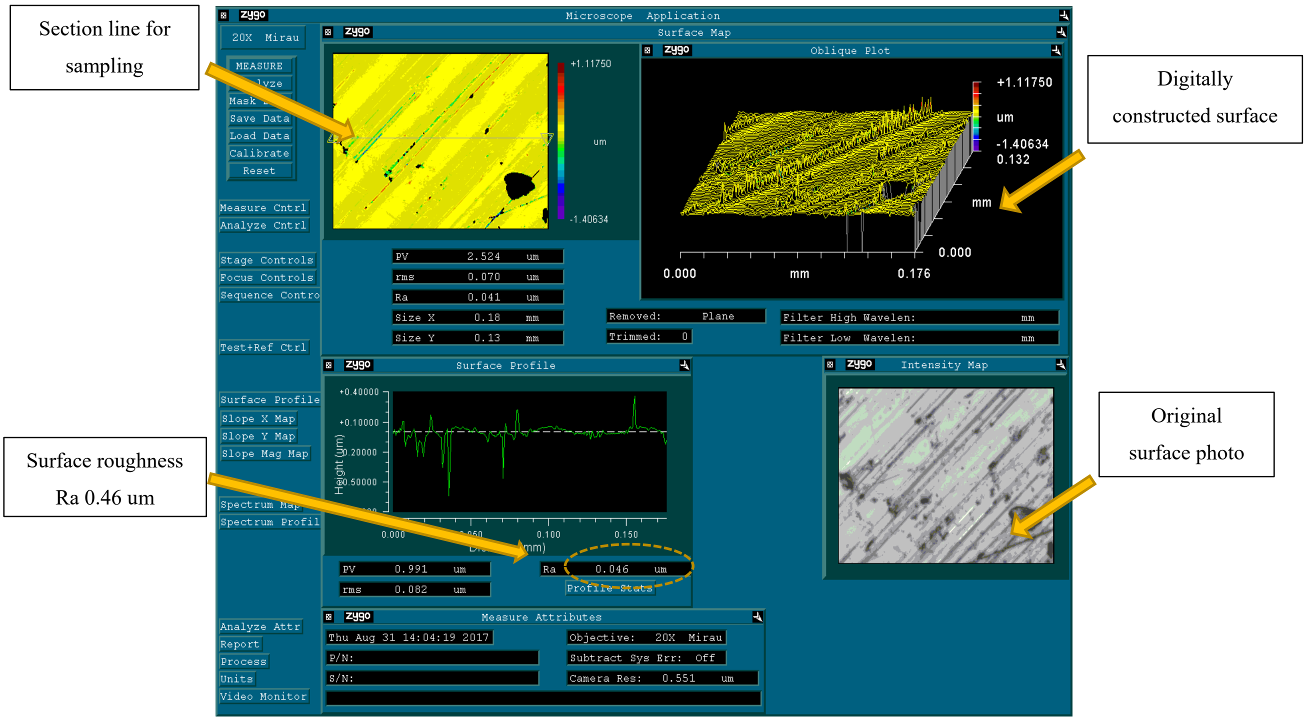


Figure 6.49 Smooth surface roughness 0.046um

Figures 6.48 and 6.49 show the sample which is being used at the plant at the moment has a surface roughness of 1.65um, but the surface roughness of the micro textured surface is 0.046um. which shows how much difference there is between the two surfaces' roughness. The self-cleaning mechanism of a superhydrophilic surface requires that a water droplet absorbs onto the concave surface of the micro nano structure by spreading out instantly on the surface to form a film of water on the solid liquid interface surface. The water film will prevent toxins from direct contact with the conveyor surface. The self-cleaning effect occurs because debris of the flavour will remove itself. The flavour particles will be removed because the water droplets are pushed away from the conveyor surface by quickly sliding away [76][77]. A microtextured self-cleaning capable surface could be used on the conveyor on a trial basis and it could improve the cleaning process as compared to the existing one. A micro textured surface with self-cleaning capability is one aspect of our case study. The dynamics of the machine tools have a major influence on productivity. The design must be considering the interaction between the processes and the structure in the virtual environment so that a well-designed machine and tools can be achieved during the design phase [79].

One more aspect is the proposed changes in the production changeover to make it sustainable. These are mentioned in previous chapters in detail. They include: the introduction of automation in different areas of the production line for better cleaning; The use of better tools to reduce the cleaning time and process improvement through minor changes in the production line. There is a risk involved in using the trial basis to introduce automatic tools for better and quicker cleaning. The risk can be to the failure of trail but they can be introduced in this way to use them one by one to see the outcome on the plant. There are many recommendations made which can be introduced to the plant A for better changeover and these are discussed in the process improvement sections.

6.8 Problem descriptions

Set up activities are a vital part of the production lead time of any product and so affect overall product cost and plant performance. The ability to perform changeover quickly from one product to another product is a key step towards the achievement of maximising plant performance. During research it was observed that most of the literature assumed the conventional methods of SMED. Although it is still widely used and very useful, we aimed to introduce new ways to improve the production changeover in terms of sustainability. Therefore, we worked on smart surfaces which have already been discussed in previous sections and chapters. It has been observed that lengthy down time is related to the set-up time during production changeover and cleaning of the production line. The cleaning of the production line is manual and only manual tools have been used which consumes more time and resources. The small narrow flavour feeder has flavour particles stuck to the surface and with the shown plastic spatula it is hard to clean the corners and edges of the surface, particularly where the metal joint is (Figure 6.50).

Figure 6.50 Tools used to clean narrow size flavour feeder

Similarly, for the flavour mixer tank which is not easily accessible with these tools, it takes more time to clean than other places. Automatic tools have been suggested to improve the process of changeover in section 5.2.

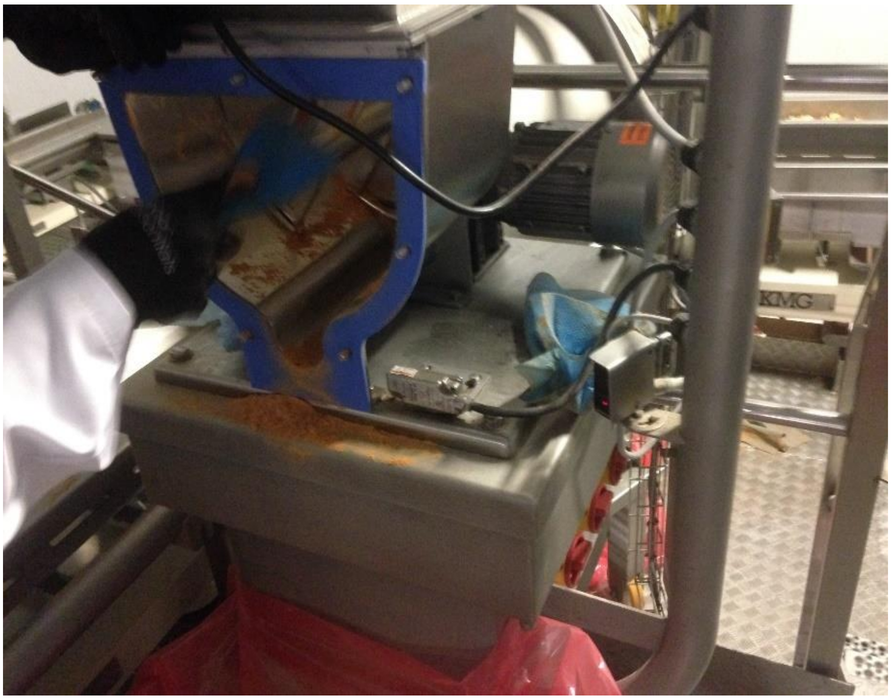


Figure 6.51 Tools used to clean flavour tank manually

Another example is shown in Figure 6.51 and 6.52. There are many areas where improvement can be made, and these are discussed in the process improvement sections in previous chapters in detail.

Figure 6.52 Member of staff cleaning flavour mixer drum

In this project we recommend the automation of the plant to reduce the time consumed in cleaning. These automations include automatic tools for cleaning to reduce time and effort. Some of the recommendations are for minor adjustments to the production line which are explained in previous chapters in the process improvement sections. As discussed before, the metal surfaces used on the conveyors, production machines and other parts are not hydrophobic surfaces and, therefore, debris sticks to it due to the surfaces of the conveyors not being smooth and not having self-cleaning capability. As a result, more frequent cleaning is required due to flavour sticking to the production line surface [74][75][80].

6.9 Summary

In this chapter, the approach to the problem of the case study has been described in detail including actual data collection from the plant. In the data processing we found that most of the down time is related to the cleaning and setup time which is over 45% of the total down time. Different processes and procedures have been discussed. These are the cleaning and set up processes for oil mixer drums, storage conveyor, soft belt conveyor, flavour mixer drums, flavour mixer drum parts, flavour mixer tank and its cleaning, disassembling all parts from both flavour mixer and oil drum and then set up of all parts back to the production line for the next production run. The most time consuming one is the production machine disassembling, cleaning, and assembling which is complicated and time consuming due to there being many parts in the machine.

Technical aspects of the existing metal parts have been discussed and it was found that, if the surface is not smooth and does not have the capability to repel the flavour debris from the surface, frequent cleaning of the metal parts is required which is the main waste of the production line. A micro textured surface has been compared with the existing surface and the roughness difference between them is shown with the help of surface measurements pictures. Some recommendations for automation have been made in previous chapters to make minor changes in the production line to improve the cleaning process of the soft belt conveyor and with the proper tools.

Chapter 7 Conclusions and Recommendations for Future Work

7.1 Conclusions

The use of demand for improving operational efficiency is a topic that has received considerable attention in recent years. Production changeover is one of the issues causing production loss and waste of time and resources. Changeover costs (and times) are central to numerous manufacturing operations. Production changeover is a complex process in food manufacturing due to the demands of food hygiene. Therefore, frequent cleaning is required during production and due to the variety of products it makes the system more complex. The aim of the project is to introduce a holistic approach to make the production changeover robust, reduce the complexity of the production changeover, and make it sustainable. There are several research papers in which production changeover is discussed but mostly about the conventional way like SMED. Similarly there is literature available on sustainability but production changeover has not been addressed. We identify how a sustainable approach can be applied to the production changeover to make the changeover sustainable which is explained in previous chapters.

Extensive studies have been carried out to understand the production changeover process at McVitie's. Over one-year's data has been gathered and filtered to find the most problematic issue in the production changeover. Many recommendations have been made to improve the production changeover. The proposed methodology entails the use of a super hydrophobic surface to reduce the roughness of the metal conveyor and introduce automation to clean the soft storage conveyor belt.

The objective of the research presented here is to identify an effective instructional design of the production changeover to make the manufacturing system more robust. To achieve the objective we introduce the superhydrophobic surface which has a self-cleaning capability and with a high contact angle for the production machines and their parts and a metal storage conveyor. There are also recommendations made for automation.

7.2 Knowledge contributions

An extensive literature review has been carried out during the whole dissertation and it has been observed that there is a knowledge gap in production changeover theories and research. Most of the literature has been about traditional production changeover procedures, for example, single minute exchange die. New approaches have been introduced and microtextured surfaces with superhydrophobic/self-cleaning surfaces have been recommended for use to improve production changeover.

The gap has been addressed and the following work carried out.

- Surface functionality is an important issue in the characterisation of high precision machined surfaces. The characterisation parameters for high precision machined surfaces should match the surface functionality. The surface functionality is discussed in detail in previous chapters. Active control of surface functionality is of significance for the achievement of a precision product with the desired performance of self-cleaning.

- A new approach has been introduced in production changeover with proposed changes which is different from traditional methods.

- A production model has been made with the existing production output and proposed changes and the difference is shown and calculated. It increases the production output and reduces the production changeover time. Complexity has been reduced in the production changeover.

- Design and proposed automation of the conveyor belt processes are recommended to reduce complexity in production changeover. This reduces the cleaning time of the conveyor belt by 80% and makes the changeover sustainable.

These are the improvements to the existing production changeover process:

- Downtime of the manufacturing plant is reduced by 22.41 % overall and down time is reduced by 49.67% in production changeover.

- Overall production changeover complexity has been reduced dramatically and this gives the manufacturer flexibility to produce many products on the same production line and the ability to do changeovers more smoothly.

These approaches not only enable multifunctionality but also provide the ability to deliver more variety of products while using fewer resources, these are enabling manufacturers to make sustainable production changeovers. Ultimately, these improvements will increase the plant productivity and profit.

7.3 Recommendations for future work

Even though much understanding of the complexities has been gained, there are still issues that need to be resolved in order to remove the complexity in production changeover completely. The use of engineered surfaces has improved its industrial importance and expanded to new areas that take benefit of a greater knowledge of the phenomena occurring on the engineered surfaces. The potential of engineered surfaces must face the complexity in their functional and other properties. From the engineering perspective more work needs to be done on smart surfaces to extend their durability and self-cleaning capability. Advanced technologies and instruments used for texturing surfaces have been reviewed. Some technologies are used currently in industry but not in food manufacturing. These can be improved by further development and experiments.

Further development in the fabrication process will make these smart surfaces more cost effective, flexible, sustainable, durable and reliable to use in food manufacturing and pharmaceutical companies where the chances of contamination are higher than in other industries. These surfaces can be mechanically weak and can stop functioning in long production runs or with high work load. We hope that this work will help other researchers to carry out further research for the benefit of food manufacturing and pharmaceutical companies. One of the aspect needs to be considered in future work is energy requirements of running the laser while producing surface.

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Appendices

Appendix I List of Publications Arising from the Research

1. Khalid Mustafa, K. Cheng. An investigation on production changeover time reduction in supply chain-oriented manufacturing plant and sustainability to improve the plant performance, Annual Cambridge Manufacturing Symposium, 11th Sept 2014, pp 564-575.

2. Khalid Mustafa, K. Cheng. Managing complexity in manufacturing changeover: A sustainable manufacturing-oriented approach and the application case study. Proceedings of the 2016 Manufacturing Science and Engineering Conference (MSEC), 2016-8744.

3. Khalid Mustafa, K. Cheng, improving production changeover and the optimisation: A simulation based virtual process approach and its application perspective. Procedia Manufacturing, Proceedings of 27th international conference FAIM 2017, Modena, Italy.

4. Khalid Mustafa, K. Cheng. The design and analysis of micro textured surfaces for self-cleaning and reducing production changeover complexity in food industry. 6th international conference on nano manufacturing (nanoMan2018), London, UK, 4-6 July 2018.

5. Khalid Mustafa, K. Cheng. Efficient production changeability in food packaging through smart surfaces, 6th International conference on Sustainable Design and Manufacturing (SDM 2019), Budapest, Hungary, KES international.

Appendix II Summary of Facilities in the Research

Zygo	1. White light interferometer Zygo NewView 5000
Polytech	Table-top optical surface profiler TopMop Micro.View® is an easy to use and compact optical profiler. Combine exceptional performance and affordability with this powerful metrology solution. An extended 100 mm Z measurement range with CST Continuous Scanning Technology allows complex topographies to be measured at nm resolution. This convenient table-top setup features integrated electronics, with the smart focus finder simplifying and speeding up the measurement procedure. Unit 8, The cobalt centre, Coventry, CV3 4PE, UK.
McVitie's Factory	Manufacturing facility
Experimental technique centre Brunel	FTA 1000B First Ten Angstroms

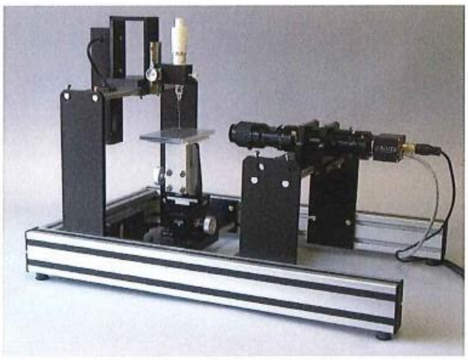
Appendix III Contact Angle Measurement instruments FTA 1000B.

First Ten Ångstroms

December, 2009

FTA1000B Manual Drop Shape Analyzer
Model B 23A 110

- **High Performance at low cost**
- **Small bench-top footprint**
- **Manual drop formation, 2cc micrometer syringe**
- **Manual drop touch-off, 50mm Z precision movement**
- **Drop size, 0.5-40µl**
- **Rack-and-pinion XYZ manual specimen stage**
- **6x zoom microscope lens**
- **GigE Camera, 60fps at 640x480 full resolution**
- **Fta32 Software for video acquisition and full data analysis**
- **High quality mechanical construction**



Part No.	
B	B frame and Fta32 software. Site-wide license
B 2	Specimen stage, XYZ manual rack-and-pinion movement
B 03	Camera, Gigabit Ethernet, 60fps at 640x480, 1/3" sensor
B 00A	Microscope, 6x zoom, 7mm-1mm FOV
B 000 1	Backlight, 25mm blue LED, best image resolution
B 000 01	Dispenser, 2ml micrometer syringe, 50mm Z movement
B 000 000	Dual core microprocessor optional, but recommended

For more information contact sales@firsttenangstroms.com

465 Dinwiddie Street • Portsmouth, Virginia 23704 • 1.757.393.1584 Fax: 1.757.393.3708
http://www.firsttenangstroms.com

Contact Angle Water Readings

Contact Angle (deg)	68.64
Contact Angle Left (deg)	70.77
Contact Angle Right (deg)	66.50
Base Tilt Angle (deg)	0.00
Base (mm)	1.690E-4
Base Area (mm2)	2.243E-8
Height (mm)	5.200E-5
Tip Width (mm)	3.078E-5
Wetted Tip Width (mm)	2.932E-5
Sessile Volume (ul)	7.034E-13
Sessile Surface Area (mm2)	3.126E-8
Contrast (cts)	128
Sharpness (cts)	69
Black Peak (cts)	12
White Peak (cts)	140
Edge Threshold (cts)	65
Base Left X (mm)	0.000
Base Right X (mm)	0.000
Base Y (mm)	0.000

Contact Angle Water Reading B

Contact Angle (deg)	64.35
Contact Angle Left (deg)	63.66
Contact Angle Right (deg)	65.03
Base Tilt Angle (deg)	0.00
Base (mm)	2.290E-4
Base Area (mm2)	4.119E-8
Height (mm)	6.600E-5
Sessile Volume (ul)	1.575E-12
Sessile Surface Area (mm2)	5.578E-8
Contrast (cts)	130
Sharpness (cts)	67
Black Peak (cts)	10
White Peak (cts)	140
Edge Threshold (cts)	64
Base Left X (mm)	0.000
Base Right X (mm)	0.000
Base Y (mm)	0.000

Contact Angle Cooking Oil Readings A

Contact Angle (deg)	35.80
Contact Angle Left (deg)	37.52
Contact Angle Right (deg)	34.09
Base Tilt Angle (deg)	0.00
Base (mm)	2.880E-4
Base Area (mm2)	6.514E-8
Height (mm)	4.300E-5
Tip Width (mm)	3.228E-5
Wetted Tip Width (mm)	3.228E-5
Sessile Volume (ul)	1.589E-12
Sessile Surface Area (mm2)	7.315E-8
Contrast (cts)	137
Sharpness (cts)	76
Black Peak (cts)	8
White Peak (cts)	145
Edge Threshold (cts)	65
Base Left X (mm)	0.000
Base Right X (mm)	0.000
Base Y (mm)	0.000

Contact Angle Cooking Oil Readings B

Contact Angle (deg)	38.18
Contact Angle Left (deg)	38.27
Contact Angle Right (deg)	38.09
Base Tilt Angle (deg)	0.00
Base (mm)	3.480E-4
Base Area (mm2)	9.511E-8
Height (mm)	5.300E-5
Tip Width (mm)	2.342E-5
Wetted Tip Width (mm)	2.342E-5
Sessile Volume (ul)	2.819E-12
Sessile Surface Area (mm2)	1.025E-7
Contrast (cts)	136
Sharpness (cts)	75
Black Peak (cts)	9
White Peak (cts)	145
Edge Threshold (cts)	65
Base Left X (mm)	0.000
Base Right X (mm)	0.001
Base Y (mm)	0.000

Appendix IV Polytech table-top optical surface profiler and specifications

TopMap Micro.View®
Table-top optical surface profiler

TopMap Micro.View® is an easy to use and compact optical profiler. Combine exceptional performance and affordability with this powerful metrology solution.
An extended 100 mm Z-measurement range with CST Continuous Scanning Technology allows complex topographies to be measured at nm resolution. This convenient table-top setup features integrated electronics, with the smart focus finder simplifying and speeding up the measurement procedure.

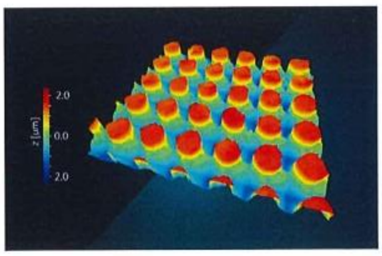
Small footprint with expanded capability

Benefit from the optional ECT Environmental Compensation Technology, securing reliable and accurate measurement results even in noisy and challenging production environments. Micro.View® is the cost-effective quality control instrument for inspecting precision engineered surfaces in the field of manufacturing and research.

!

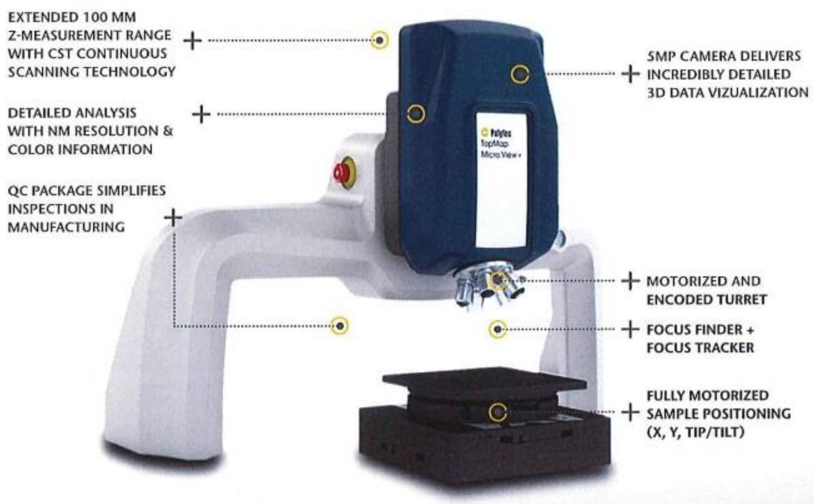
Highligths

- Measure surface finish in a compact setup with nm resolution
- 100 mm Z-measurement range with CST Continuous Scanning Technology
- Cost-effective quality control solution



4

TopMap Micro.View®+
Next generation optical surface profiler



TopMap Micro.View®+ is the next generation optical surface profiler. Designed for modularity, this comprehensive workstation allows for customized and application-specific configurations. The Micro.View®+ delivers the most detailed analysis of surface roughness, texture and microstructure topography. Combine 3D data with color information for amazing vizualizations and extended analysis like detailed documentation of defects. The high-resolution 5 MP camera delivers incredibly detailed 3D data vizualization of engineered surfaces.

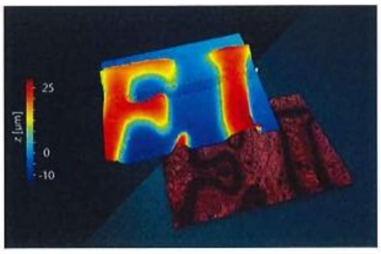
Automation enabled and production-ready

The encoded and motorized turret secures a seamless transition between objectives. Micro.View®+ also features the latest Focus Finder plus Focus Tracker, keeping the surface in focus at all circumstances. The fully motorized sample positioning stages allow for stitching and automation.

!

Highligths

- High-end white-light interferometer with nm resolution
- With Focus Finder and Focus Tracker ready for automation
- Motorized X, Y, Z, tip/tilt and turret save repositioning



5

TopMap Micro.View®
Table-top optical surface profiler

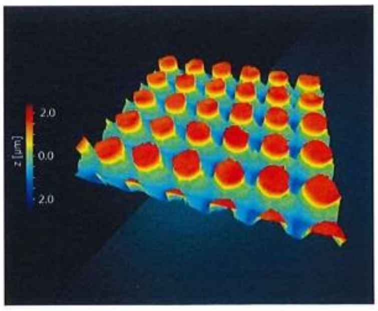
TopMap Micro.View® is an easy to use and compact optical profiler. Combine exceptional performance and affordability with this powerful metrology solution. An extended 100 mm Z measurement range with CST Continuous Scanning Technology allows complex topographies to be measured at nm resolution.This conventient table-top setup features integrated electronics, with the smart focus finder simplifying and speeding up the measurement procedure.

Small footprint with expanded capability

Benefit from the optional ECT Environmental Compensation Technology, securing reliable and accurate measurement results even in noisy and challenging production environments. Micro.View® is the cost-effective quality control instrument for inspecting precision engineered surfaces in the field of manufacturing and research.

Highlights

- Measure surface finish in a compact setup
- Non-contact measurement of 3D topography, roughness and texture
- 100 mm Z measurement range with CST Continuous Scanning Technology
- Excellent lateral resolution



Quality inspection of surface details.

8

TopMap Micro.View®+
Next generation optical surface profiler

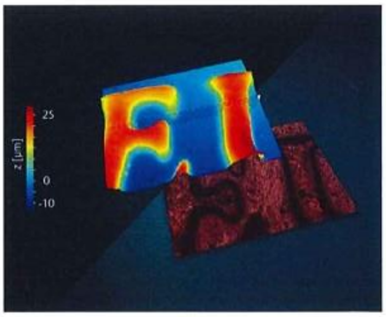
TopMap Micro.View®+ is the next generation optical surface profiler. Designed for modularity, this comprehensive workstation allows for customized and application-specific configurations. The Micro.View®+ delivers the most detailed analysis of surface roughness, texture and microstructure topography. Combine 3D data with color information for amazing vizualizations and extended analysis like detailed documentation of defects. The high-resolution 5 MP camera delivers incredibly detailed 3D data visualization of engineered surfaces.

Automation enabled and production-ready

The encoded and motorized turret secures a seamless transition between objectives. Micro.View®+ also features the latest Focus Finder plus Focus Tracker, keeping the surface in focus at all circumstances. The fully motorized sample positioning stages allow for stitching and automation.

Highlights

- High-end white-light interferometer with nm resolution
- 100 mm Z measurement range with CST Continuous Scanning Technology
- With Focus Finder and Focus Tracker ready for automation
- Motorized X, Y, Z, tip/tilt and turret save repositioning
- Color information mode for extended analysis and documentation of defects



Detailed analysis with nm resolution and color information.

9

Appendix V Example of Daily production report used in dissertation

24 hour Review of Performance - Cheddars

Saftey Issues	
Quality Issues	
Packaging issues	
Labour issues	
Other	

CP24	**A**	**Plant**
Total kg	22104	
Efficiency	64.41%	
Run Time	17.92	
Waste	1.08%	

SKU	Product	Cases
27631	Mini Cheddars Cheese & Onion7pk 25x7x25g	4608
1017201	MINI CHEDDARS CHEESE & ONION 210 X25G	120
27800	Mini Cheddars BBQ 7pk 25x7x25g	240
70818	Mini Cheddars Big Bag Saucy BBQ 30x50g	160

Waste	Early Shift	Late Shift	Night Shift	Total
Mixing Room	0	0	0	0
Laminator	0	0	40	40
Oven	0	0	33	33
Packing Hall	0	0	166	166
Staff Shop	0	0	0	0
Total	0	0	239	239

Downtime		Waste Justification
Early Shift	**RPM: 45 -** Packing Hall Breaks - **20/20/20/20mins**. Cleaning Breaks - **30/30mins** - Cleaning break was extended after a gate on the wrights was found to be producing metal filings - **30mins** - resolved. Change of shells - **15mins**. A02 - Vacuum vanes damaged - resolved. Former missing teflon tape and loose - resolved. Plenum plates - 2 screws missing - resolved. A3 - off all shift. A4 - Teflon tape missing - resolved. New Teflon tape has been applied to all formers. **Total Downtime: 185mins** **Total Waste: 90kg**	Mixing Lam 20 Oven 10 P/hall 60 Run Rate 10.08kg/hr
Late shift		
Night shift	45 rpm. Cleaning breaks **30/30 mins. Last biscuit (cheese & onion) in oven at 0215hrs. Process ready at 0325 hrs First biscuit BBQ through oven at 0345 hrs. Total time off 90 mins. Reason for delay, waiting for mixes. Packing hall. Last biscuit packed off at 0300 hrs. Storeveyor ready at 0330 hrs Packing hall ready at 0410 hrs first biscuit packed off at 0415hrs. Total time off 120 mins. Started getting lumps of ammonia on the laminator outfeed, instructed bulk to sieve the ammonia before using, monitoring. Total downtime = 180 mins**	Mixing Lam 20 kgs Oven 23 kgs P/hall 106 kgs **Run Rate 16.5kgs/hr**

CP29	**C**	**Plant**
Total kg	32246	
Efficiency	95.26%	
Run Time	23.5	
Waste	0.39%	

SKU	Product	Cases
11555	Mini Cheddars Original Multi Pk 25x7x25g	2136
11556	Mini Cheddars Original 12Pack 18x12x25g	1416
36564	Mini Cheddars Big Bag Original 30x50g	5760
1017200	ORIGINAL MINI CHEDDARS LAYERSIDE 210X25G	1260

Waste	Early Shift	Late Shift	Night Shift	Total
Mixing Room	0	0	0	0
Laminator	0	0	40	40
Oven	29	0	20	49
Packing Hall	0	0	37	37
Staff Shop	0	0	0	0
Total	29	0	97	126

Downtime		Waste Justification
Early Shift	**RPM: 60 -** Oscilating scrap return web stop running. Unit would move from side to side however the web was not running - Caused a pile up - no waste generated howere **15mins**. Salter Unit blown down - 4 x 3mins **(12mins)**. **Total Downtime: 27mins** **Total Waste: 99kg**	Mixing Lam 40 Oven 39 P/hall 20 Run Rate 8.57kg/hr
Late shift		
Night shift	60 rpm, cleaning salter 4 mins.	Mixing Lam 10 kgs Oven 10 kgs P/hall 27 kgs/hr **Run Rate 3.91 kgs/hr**

CP32		**Plant**
Total kg	Output	
Efficiency	0.00%	
Run Time	0	
Waste		

SKU	Product	Cases

Waste	Early Shift	Late Shift	Night Shift	Total
Mixing Room	0	0	0	0
Laminator	0	0	0	0
Oven	0	0	0	0
Packing Hall	0	0	0	0
Staff Shop	0	0	0	0
Total	0	0	0	0

Downtime		Waste Justification
Early Shift		Mixing Lam Oven P/hall Run Rate
Late shift		Mixing Lam Oven P/hall Run Rate
Night shift		Mixing Lam Oven P/hall Run Rate

SHIFT REPORT - CP24

Date	30-Mar-16	Week	13	Line	CP24	Cheddars

Production input - Please Complete GREY Cells ONLY

24hr Line KPIs	Actual Line Performance (kg)	Line Standard (kg)	Efficiency/ Gain/ Loss (kg)
Output	22104	34318	64.4%
Waste	239	663	424
TOS	65	273	208

Waste in kg	Early Shift	Late Shift	Night Shift	Total
Mixing Room				0
Laminator			40	40
Oven			33	33
Packing Hall			166	166
Staff Shop				0
Total	0	0	239	239

Early Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	**TOS %**	No of Mixes	Format	Run Time	Manned Time	**Shift Performance**
1017201	MINI CHEDDARS CHEESE & ONION 210 X25G	3.00	30.00	90	3	5.25	473	0.36	26	Handy	8.92	1	33.1%
27631	Mini Cheddars Cheese & Onion7pk 25x7x25g	98.00	24.00	2352	98	4.38	10302	0.36		Tube		11	65.5%
			-			0.00	0						
			-			0.00	0						
			-			0.00	0						
			-			0.00	0						
						Total	10774	39			8.92	12	

Late Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	**TOS %**	No of Mixes	Format	Run Time	Manned Time	**Shift Performance**
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	0	0			0	0	

Night shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	**TOS %**	No of Mixes	Format	Run Time	Manned Time	**Shift Performance**
27631	Mini Cheddars Cheese & Onion7pk 25x7x25g	94.00	24.00	2256	94	4.38	9881	0.23	17	Tube	9	12	57.6%
1017201	MINI CHEDDARS CHEESE & ONION 210 X25G	1.00	30.00	30	1	5.25	158	0.23		Handy			
27800	Mini Cheddars BBQ 7pk 25x7x25g	10.00	24.00	240	10	4.38	1051	0.23		Tube			
70818	Mini Cheddars Big Bag Saucy BBQ 30x50g	2.00	80.00	160	2	1.50	240	0.23		Handy			
			0.00			0.00	0						
			0.00			0.00	0						
						Total	11330	26			9	12	

End of Period Pallet Count			
Product Code	Product Description	Number of Cases	Weight (kg)
		Total	0

Performance

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
1428	1428	3.0	14	0.7	3
1430	15730	3.0	309	1.2	123
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	17158		323		126

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	0		0		0

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
1430	17160	3.0	296	1.2	118
1428	0	3.0	5	0.7	1
1430	0	3.0	32	2.6	27
1785	0	3.0	7	0.7	2
0	0	0.0	0	0.0	0
	17160		340		148

SAP Report

Date 30-Mar-16
Week 13
Line CP24-Cheddars

		Input					Output			Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product Code	Best Before Date	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit Waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP24	am	1	8.92	1001091	Handy	26	1017201		90	1001091	0	1012680	0	1014452	0	0	0	1014441	2
CP24	am	11	0	1001091	Tube	0	27631		2352	1001091	0	1012680	0	1014452	0	0	0	1014441	37
CP24	am	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
CP24	am	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
CP24	am	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
				0		0	0		0	0	0	0	0	0	0	0	0	0	0
											0		0		0				39

		Input					Output			Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product Code	Best Before Date	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit Waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP24	pm	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
CP24	pm	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
CP24	pm	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
CP24	pm	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
CP24	pm	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
CP24	pm	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
											0		0		0				0

		Input					Output			Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product Code	Best Before Date	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit Waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP24	nts	12	9	1001091	Tube	17	27631		2256	1001091	0	1012680	35	1014452	29	145	208	1014441	23
CP24	nts	0	0	1001091	Handy	0	1017201		30	1001091	0	1012680	1	1014452	0	2	3	1014441	0
CP24	nts	0	0	1001091	Tube	0	27800		240	1001091	0	1012680	4	1001641	3	15	22	1012817	2
CP24	nts	0	0	1001091	Handy	0	70818		160	1001091	0	1012680	1	1001641	1	4	5	1001634	1
CP24	nts	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
CP24	nts	0	0	0		0	0		0	0	0	0	0	0	0	0	0	0	0
											0		40		33				26
		24	17.92			43			5128		0		40		33	166	239		65

SHIFT REPORT - CP29

Date	30-Mar-16	Week	13	Line	CP29	Cheddars

Production input - Please Complete GREY Cells ONLY

24hr Line KPIs	Actual Line Performance (kg)	Line Standard (kg)	Efficiency/ Gain/ Loss (kg)
Output	32246	33850	95.3%
Waste	126	580	454
TOS	129	384	254

Waste in kg	Early Shift	Late Shift	Night Shift	Total
Mixing Room				0
Laminator			40	40
Oven	29		20	49
Packing Hall			37	37
Staff Shop				0
Total	29	0	97	126

Early Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
11555	Mini Cheddars Original Multi Pk 25x7x25g	45.00	24.00	1080	45	4.38	4725	0.13	25	Multi	11.55	5	70.5%
11556	Mini Cheddars Original 12Pack 18x12x25g	24.00	24.00	576	24	5.40	3110	0.13		Multi		3	69.4%
36564	Mini Cheddars Big Bag Original 30x50g	35.00	80.00	2800	35	1.50	4200	1.69		Handy		2	140.6%
1017200	ORIGINAL MINI CHEDDARS LAYERSIDE 210X25G	20.00	30.00	600	20	5.25	3150	0.13		Handy		2	117.5%
			0.00			0.00	0						
			0.00			0.00	0						
						Total	15185	85			11.55	12	

Late Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
							Total	0	0			0	0

Night shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
11555	Mini Cheddars Original Multi Pk 25x7x25g	44.00	24.00	1056	44	4.38	4620	0.11	26	Multi	11.95	4	86.2%
11556	Mini Cheddars Original 12Pack 18x12x25g	35.00	24.00	840	35	5.40	4536	0.11		Multi		3	101.3%
36564	Mini Cheddars Big Bag Original 30x50g	37.00	80.00	2960	37	1.50	4440	0.68		Handy		3	99.1%
1017200	ORIGINAL MINI CHEDDARS LAYERSIDE 210X25G	22.00	30.00	660	22	5.25	3465	0.11		Handy		2	129.2%
			0.00			0.00	0						
			0.00			0.00	0						
						Total	17061	44			11.95	12	

End of Period Pallet Count			
Product Code	Product Description	Number of Cases	Weight (kg)
		Total	0

Performance

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
1340	6702	1.8	85	1.2	56
1493	4479	1.8	56	1.2	37
1493	2986	1.8	76	1.2	50
1340	2681	1.8	57	1.2	37
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	16849		273		181

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	0		0		0

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
1340	5362	1.8	83	1.2	55
1493	4479	1.8	82	1.2	54
1493	4479	1.8	80	1.2	53
1340	2681	1.8	62	1.2	41
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	17001		307		203

SAP Report

Date 30-Mar-16
Week 13
Line CP29-Cheddars

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product Code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit Waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP29	am	5	11.55	1001092	Multi	25	11555	1080	1001092	0	1012672	0	1001483	9	0	9	1001133	6
CP29	am	3	0	1001092	Multi	0	11556	576	1001092	0	1012672	0	1001483	6	0	6	1001642	4
CP29	am	2	0	1001092	Handy	0	36564	2800	1001092	0	1012672	0	1001483	8	0	8	1001393	71
CP29	am	2	0	1001092	Handy	0	1017200	600	1001092	0	1012672	0	1001483	6	0	6	1001642	4
CP29	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
				0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		29				85

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product Code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit Waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		0				0

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product Code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit Waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP29	nts	4	11.95	1001092	Multi	26	11555	1056	1001092	0	1012672	11	1001483	5	10	26	1001133	5
CP29	nts	3	0	1001092	Multi	0	11556	840	1001092	0	1012672	11	1001483	5	10	26	1001642	5
CP29	nts	3	0	1001092	Handy	0	36564	2960	1001092	0	1012672	10	1001483	5	10	25	1001393	30
CP29	nts	2	0	1001092	Handy	0	1017200	660	1001092	0	1012672	8	1001483	4	8	20	1001642	4
CP29	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		40		20				44
		24	23.5			51		10572		0		40		49	37	126		129

SHIFT REPORT - CP32

Date	25-Mar-16

Week	12

Line	CP32	Cheddars

Production input - Please Complete GREY Cells ONLY

24hr Line KPIs	Actual Line Performan	Line Standard (kg)	Efficiency/ Gain/ Loss (kg)
Output	0	0	
Waste	0	0	0
TOS	0	0	0

Waste in kg	Early Shift	Late Shift	Night Shift	Total
Mixing Room				0
Laminator				0
Oven				0
Packing Hall				0
Staff Shop				0
Total	0	0	0	0

Early Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	0	0			0	0	

Late Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	0	0			0	0	

Night shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	0	0			0	0	

End of Period Pallet Count			
Product Code	Product Description	Number of Cases	Weight (kg)
		Total	0

Performance

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	0		0		0

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	0		0		0

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	0		0		0

SAP Report

Date 25-Mar-16
Week 12
Line CP32-Cheddars

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product Code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated / Biscuit Waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP32	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
				0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		0				0

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated / Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		0				0

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated / Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		0				0

		0	0			0		0		0		0		0	0	0		0

24 hour Review of Performance - Cheddars

Saftey Issues	
Quality Issues	
Packaging issues	
Labour issues	
Other	

CP24 A Plant

Total kg	25681
Efficiency	69.10%
Run Time	19.26
Waste	0.73%

SKU	Product	Cases
27800	Mini Cheddars BBQ 7pk 25x7x25g	4704
70818	Mini Cheddars Big Bag Saucy BBQ 30x50g	3280
1017201	MINI CHEDDARS CHEESE & ONION 210 X25G	30

Waste	Early Shift	Late Shift	Night Shift	Total
Mixing Room	0	0	0	0
Laminator	0	0	20	20
Oven	30	0	20	50
Packing Hall	59	0	58	117
Staff Shop	0	0	0	0
Total	89	0	98	187

Downtime		Waste Justification
Early Shift	**RPM: 50** reduced to **48**. Packing Hall Breaks - **15mins**. Cleaning Breaks - **30/35/30mins**. Oiler disc loose - Gap put in and oiler disc tightened up - resolved - **28mins**. 1 bucket of ice added at 15:00 as temperature was 30.1 **Total Downtime: 138mins** **Total Waste: 119kg**	Mixing Lam Oven 40 P/hall 79 Run Rate 12.2kg/hr
Late shift		
Night shift	50 rpm. Cleaning breaks **30/30/30 mins**. **8 mins** clearing dough build up on sheeter rollers. **3 mins** wrap around. **15/15/15 mins** packing hall break due to issues with A6 Jaws jamming, A2 giving too many rejects, TNA slowed down. A3 locked off. A5 backseal issues. A6 & A5 both unresolved, Effectively 3.5 machines down hence reduced speed to 45 rpm. **Total downtime = 146 mins**	Mixing Lam 10 kgs Oven 10 kgs P/hall 38 kgs **Run Rate 6 kgs/hr**

CP29 C Plant

Total kg	33180
Efficiency	119.02%
Run Time	23.7
Waste	0.35%

SKU	Product	Cases
11555	Mini Cheddars Original Multi Pk 25x7x25g	2760
11556	Mini Cheddars Original 12Pack 18x12x25g	432
30037	Mini Ched. Original 6 for 5 pack 25x6x25g	1056
36564	Mini Cheddars Big Bag Original 30x50g	5360
1017200	ORIGINAL MINI CHEDDARS LAYERSIDE 210X25G	990

Waste	Early Shift	Late Shift	Night Shift	Total
Mixing Room	0	0	0	0
Laminator	0	0	49	49
Oven	8	0	20	28
Packing Hall	26	0	14	40
Staff Shop	0	0	0	0
Total	34	0	83	117

Downtime		Waste Justification
Early Shift	**RPM: 60 -** Salter unit blown down - 4 x 3min (12mins). 1 bucket of ice added at 15:00 as temperature was 30.3. **Total Downtime: 12mins** **Total Waste: 34kg**	Mixing Lam 10 Oven 8 P/hall 16 Run Rate 2.8kg/hr
Late shift		Mixing Lam 10 Oven 8 P/hall 16 Run Rate 2.8kg/hr
Night shift	60 rpm. Issues with D elevator jamming the cases, resolved. C12 DACs not rejecting overweoghts, resolved. C4 & C10 crossfeeders tripped out after ROFLO stop. Ongoing issues with C13 jaming cases in elevator, sensor issue which is proving difficult to resolve, ET on line. **5 mins** cleaning salter **Total downtime = 5 mins**	Mixing Lam 29 kgs Oven 20 kgs P/hall 24 kgs **Run Rate 6.13 kgs/hr**

CP32 Plant

Total kg	0
Efficiency	
Run Time	0
Waste	

SKU	Product	Cases

Waste	Early Shift	Late Shift	Night Shift	Total
Mixing Room	0	0	0	0
Laminator	0	0	0	0
Oven	0	0	0	0
Packing Hall	0	0	0	0
Staff Shop	0	0	0	0
Total	0	0	0	0

Downtime		Waste Justification
Early Shift		Mixing Lam Oven P/hall Run Rate
Late shift		Mixing Lam Oven P/hall Run Rate
Night shift	**Ran oven band with felt and brushes and flappers from 0130 hrs.**	Mixing Lam Oven P/hall Run Rate

SHIFT REPORT - CP24	Date	31-Mar-16	Week	13	Line	CP24	Cheddars

Production input - Please Complete GREY Cells ONLY

24hr Line KPIs	Actual Line Performance (kg)	Line Standard (kg)	Efficiency/ Gain/ Loss (kg)
Output	25681	37163	69.1%
Waste	187	770	583
TOS	74	570	496

Waste in kg	Early Shift	Late Shift	Night Shift	Total
Mixing Room				0
Laminator			20	20
Oven	30		20	50
Packing Hall	59		58	117
Staff Shop				0
Total	89	0	98	187

Early Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
27800	Mini Cheddars BBQ 7pk 25x7x25g	95.00	24.00	2280	95	4.38	9986	0.21	20	Tube	9.7	8	87.3%
70818	Mini Cheddars Big Bag Saucy BBQ 30x50g	22.00	80.00	1760	22	1.50	2640	0.61		Handy		4	37.0%
1017201	MINI CHEDDARS CHEESE & ONION 210 X25G	1.00	30.00	30	1	5.25	158	0.21		Handy			
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	12784	37			9.7	12	

Late Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	0	0			0	0	

Night shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
27800	Mini Cheddars BBQ 7pk 25x7x25g	101.00	24.00	2424	101	4.38	10617	0.19	20	Tube	9.56	8	92.8%
70818	Mini Cheddars Big Bag Saucy BBQ 30x50g	19.00	80.00	1520	19	1.50	2280	0.70		Handy		4	31.9%
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	12897	36			9.56	12	

End of Period Pallet Count			
Product Code	Product Description	Number of Cases	Weight (kg)
		Total	0

Performance

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
1430	11440	3.0	300	2.6	260
1785	7142	3.0	79	0.7	18
1428	0	3.0	5	0.7	1
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	18582		384		278

Potential Output kg	Output x hours	Std Waste %	Waste % x output	TOS % per sku	TOS % x output
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	0		0		0

Potential Output kg	Output x hours	Std Waste %	Waste % x output	TOS % per sku	TOS % x output
1430	11440	3.0	319	2.6	276
1785	7142	3.0	68	0.7	15
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	18582		387		291

SAP Report

Date	31-Mar-16
Week	13
Line	CP24-Cheddars

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP24	am	8	9.7	1001091	Tube	20	27800	2280	1001091	0	1012680	0	1001641	23	46	70	1012817	21
CP24	am	4	0	1001091	Handy	0	70818	1760	1001091	0	1012680	0	1001641	6	12	18	1001634	16
CP24	am	0	0	1001091	Handy	0	1017201	30	1001091	0	1012680	0	1014452	0	1	1	1014441	0
CP24	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP24	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
				0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		30				37

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP24	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP24	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP24	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP24	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP24	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP24	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		0				0

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP24	nts	8	9.56	1001091	Tube	20	27800	2424	1001091	0	1012680	16	1001641	16	48	81	1012817	20
CP24	nts	4	0	1001091	Handy	0	70818	1520	1001091	0	1012680	4	1001641	4	10	17	1001634	16
CP24	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP24	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP24	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP24	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		20		20				36
		24	19.26			40		8014		0		20		50	117	187		74

SHIFT REPORT - CP29

Date	31-Mar-16	Week	13	Line	CP29 Cheddars

Production input - Please Complete GREY Cells ONLY

24hr Line KPIs	Actual Line Performance (kg)	Line Standard (kg)	Efficiency/ Gain/ Loss (kg)
Output	33180	27878	119.0%
Waste	117	526	409
TOS	127	348	221

Waste in kg	Early Shift	Late Shift	Night Shift	Total
Mixing Room				0
Laminator			49	49
Oven	8		20	28
Packing Hall	26		14	40
Staff Shop				0
Total	34	0	83	117

Early Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	**TOS %**	No of Mixes	Format	Run Time	Manned Time	**Shift Performance**
11555	Mini Cheddars Original Multi Pk 25x7x25g	53.00	24.00	1272	53	4.38	5565	0.10	27	Multi	11.8	4	103.8%
11556	Mini Cheddars Original 12Pack 18x12x25g	18.00	24.00	432	18	5.40	2333	0.10		Multi		2	78.1%
36564	Mini Cheddars Big Bag Original 30x50g	33.00	80.00	2640	33	1.50	3960	1.33		Handy		3	88.4%
1017200	ORIGINAL MINI CHEDDARS LAYERSIDE 210X25G	21.00	30.00	630	20	5.25	3308	0.10		Handy		2	123.4%
30037	Mini Ched. Original 6 for 5 pack 25x6x25g	14.00	24.00	336	14	3.75	1260	0.10		Handy		1	
			0.00			0.00	0						
						Total	16425	65			11.8	12	

Late Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	**TOS %**	No of Mixes	Format	Run Time	Manned Time	**Shift Performance**
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	0	0			0	0	

Night shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	**TOS %**	No of Mixes	Format	Run Time	Manned Time	**Shift Performance**
11555	Mini Cheddars Original Multi Pk 25x7x25g	62.00	24.00	1488	62	4.38	6510	0.10	27	Multi	11.9	5	97.1%
30037	Mini Ched. Original 6 for 5 pack 25x6x25g	30.00	24.00	720	30	3.75	2700	0.10		Handy		3	
36564	Mini Cheddars Big Bag Original 30x50g	34.00	80.00	2720	34	1.50	4080	1.20		Handy		2	136.6%
1017200	ORIGINAL MINI CHEDDARS LAYERSIDE 210X25G	22.00	30.00	660	22	5.25	3465	0.10		Handy		2	129.2%
			0.00			0.00	0	0.10					
			0.00			0.00	0						
						Total	16755	62			11.9	12	

End of Period Pallet Count			
Product Code	Product Description	Number of Cases	Weight (kg)
		Total	0

Performance

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
1340	5362	1.8	100	1.2	66
1493	2986	1.8	42	1.2	28
1493	4479	1.8	71	1.2	47
1340	2681	1.8	60	1.2	39
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	15508		273		180

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	0		0		0

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
1340	6702	1.8	117	1.2	77
0	0	0.0	0	0.0	0
1493	2986	1.8	73	1.2	49
1340	2681	1.8	62	1.2	41
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	12369		253		167

SAP Report

Date 31-Mar-16
Week 13
Line CP29-Cheddars

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP29	am	4	11.8	1001092	Multi	27	11555	1272	1001092	0	1012672	0	1001483	3	9	12	1001133	6
CP29	am	2	0	1001092	Multi	0	11556	432	1001092	0	1012672	0	1001483	1	4	5	1001642	2
CP29	am	3	0	1001092	Handy	0	36564	2640	1001092	0	1012672	0	1001483	2	6	8	1001393	53
CP29	am	2	0	1001092	Handy	0	1017200	630	1001092	0	1012672	0	1001483	2	5	7	1001642	3
CP29	am	1	0	1001092	Handy	0	30037	336	1001092	0	1012672	0	1001483	1	2	3	1001133	1
				0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		8				65

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		0				0

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP29	nts	5	11.9	1001092	Multi	27	11555	1488	1001092	0	1012672	19	1001483	8	5	32	1001133	7
CP29	nts	3	0	1001092	Handy	0	30037	720	1001092	0	1012672	8	1001483	3	2	13	1001133	3
CP29	nts	2	0	1001092	Handy	0	36564	2720	1001092	0	1012672	12	1001483	5	3	20	1001393	49
CP29	nts	2	0	1001092	Handy	0	1017200	660	1001092	0	1012672	10	1001483	4	3	17	1001642	3
CP29	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP29	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		49		20				62

		24	23.7			54		10898		0		49		28	40	117		127

SHIFT REPORT - CP32

Date	25-Mar-16

Week	12

Line	CP32	Cheddars

Production input - Please Complete GREY Cells ONLY

24hr Line KPIs	Actual Line Performance (kg)	Line Standard (kg)	Efficiency/ Gain/ Loss (kg)
Output	0	0	
Waste	0	0	0
TOS	0	0	0

Waste in kg	Early Shift	Late Shift	Night Shift	Total
Mixing Room				0
Laminator				0
Oven				0
Packing Hall				0
Staff Shop				0
Total	0	0	0	0

Early Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	0	0			0	0	

Late Shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	0	0			0	0	

Night shift

Output								Losses	Inputs				
Product Code	Product Description	WMS Pallet Count	Cases Per Pallet	WMS Case Count	Physical Pallet Count	WMS Case Wt.	Total (kg)	TOS %	No of Mixes	Format	Run Time	Manned Time	Shift Performance
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
			0.00			0.00	0						
						Total	0	0			0	0	

End of Period Pallet Count			
Product Code	Product Description	Number of Cases	Weight (kg)
		Total	0

Performance

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	0		0		0

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	0		0		0

Potential Output kg	Output x Hours	Std Waste %	Waste % x Output	TOS % Per Sku	TOS % x Output
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
0	0	0.0	0	0.0	0
	0		0		0

SAP Report

Date 25-Mar-16
Week 12
Line CP32-Cheddars

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP32	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	am	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
				0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		0				0

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	pm	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		0				0

		Input					Output		Waste								TOS	
Plant	Shift	Man m/c time	Run Time	Dough Code	Format	No. of Mixes	Product code	Cases	Dough Code	Dough Waste	Uncoated/ Biscuit Code	Uncoated/ Biscuit waste	Coated/ Biscuit Code	Coated Bisc. Waste	Crumb	Total Waste	TOS Code	Actual TOS
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
CP32	nts	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
										0		0		0				0

		0	0			0		0		0		0		0	0	0		0