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MEASURING PLANT COMPLEXITY IN FOOD SUPPLY CHAIN

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Abstract

Food supply chain differs from all other supply chains in a lot of ways and it is characterized by a high complexity. Firstly due to the peculiarities of the products it deals with: usually foodstuffs are affected by short shelf life and long production lead time due to the biological growing process of cultivations and/or the breeding of animals. Some foodstuffs are characterized by long production lead time also in the industrial step, as in the case with wine fermentation or cheese and ham maturing.

Traceability, food safety, quality and sustainability are important challenges in food supply chain. Recording automatically and in real time relevant processes and products information, MES fulfils these aspects since much more information becomes available for managers, supporting quality control of work in progress, production scheduling, and maintenance planning and so on.

Difficulty in integrating MES with other information systems, large initial investment, long programming time, waste of time in order to relearn new processes, all are some aspects which reduce manufacturers' motivation in implementing MES solutions. There is a connection between working environment and MES implementation opportunity: the more complex the environment is, the more recommendable the MES implementation is. Four main factors influence MES implementation in practice: process, product, order and resource.

Even if lots of studies were carried out about complexity and lot of complexity factor have been pointed out. Despite that, any tool to measure complexity taking into consideration all the aspects has been developed.

In this thesis, a literary review has been done in order to find all the complexity factors which can affect a food industry; than the framework proposed by Azzi *et al.* (2011) to measure plant complexity has been implemented in a quantitative way.

The result is a useful tool which can allow managers and/or consultant to evaluate the complexity of the environment in order to have a better idea on difficulties, time, costs and risks of MES implementation.

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MISURAZIONE DELLA COMPLESSITA' DI UNO STABILIMENTO NEL SETTORE ALIMENTARE

1. Introduzione

Le catene di fornitura del settore alimentare si differenziano per molti aspetti dalle catene di fornitura di altro tipo e sono caratterizzate da un'alta complessità dovuta al particolare tipo di prodotto trattato. Limitata conservazione dei prodotti e lunghi tempi di produzione dovuti alle caratteristiche biologiche degli stessi, come ad esempio la maturazione degli ortaggi, sono due importanti caratteristiche.

La tracciabilità del prodotto, la sicurezza, la qualità e la sostenibilità sono tematiche molto rilevanti nel settore alimentare. Per affrontarle può essere di grande aiuto rilevare in tempo reale e memorizzare i dati sui prodotti e sui processi in atto. L'implementazione di un sistema MES (Maufacturing Execution System) permette al manager di avere a disposizione informazioni in tempo reale su ciò che sta accadendo nel sistema produttivo, supportando il controllo sulla qualità, i work in progress, la manutenzione eccetera.

L'implementazione del MES e la sua integrazione con gli altri sistemi informatici possono trovare alcune difficoltà come lunghi tempi di implementazione, alto investimento iniziale, necessità degli operatori di imparare nuovi processi, eccetera. Pur ottenendo maggiori benefici, l'implementazione di un sistema MES diventa tanto più problematica quanto più complesso è l'ambiente in cui deve essere applicato. Azzi *et al.* (2011) hanno ideato un modello concettuale che mette in relazione la difficoltà di implementazione con la complessità del sistema. Quest'ultima è valutata secondo quattro aspetti principali: processi, prodotti, ordini e risorse.

1.1. Scopo della tesi

Lo scopo della tesi è lo sviluppo in termini quantitativi del modello concettuale sviluppato da Azzi *et al.* (2011). La prima parte della tesi, dal paragrafo II al V, prevede l'analisi dei quattro aspetti di complessità citati sopra; successivamente, sarà proposto un nuovo modello quantitativo per misurare la complessità. In fine sono tratte le conclusioni e proposti alcuni possibili studi futuri.

2. Complessità dei processi

Le varie problematiche sulla sicurezza dei cibi susseguitesi negli ultimi anni, come ad esempio febbre suina, Escherichia Coli o diossina, hanno aumentato l'attenzione generale sulla qualità dei prodotti alimentari. Di conseguenza le aziende di settore hanno adottato, volontariamente o per obbligo legislativo, alcuni standard per la qualità e la sanità. La complessità dei processi influisce direttamente sui sistemi di controllo della qualità (Fig. 6).

Uno dei fattori che aumenta la complessità dei processi è sicuramente la natura delle materie prime. Disponibilità limitata ad alcuni periodi dell'anno ed eterogeneità sono tipiche caratteristiche dei prodotti alimentari. L'eterogeneità dei prodotti può essere sia di tipo geometrico sia dovuta a caratteristiche chimiche. La stagionalità della disponibilità è un problema quando si processano prodotti con durata limitata, soggetti a scadenza. In questo caso forniture da altre parti del mondo o particolari tecniche di immagazzinamento (es. congelamento) sono necessarie.

Oltre ai problemi caratteristici a quasi tutti i processi produttivi (set-up, limiti tecnici …) i processi del settore alimentare richiedono solitamente grande attenzione per il controllo della temperatura e la pulizia.

Tutti gli elementi di complessità dei processi sono riassunti nella tabella Table 2.

3. Complessità dei prodotti

Diversi aspetti distinguono i prodotti alimentari dai prodotti tradizionali, tali diversità spesso ne aumentano la complessità di gestione.

La deperibilità dei prodotti costringe a ricorrere a tecniche di produzione e gestione adeguate come l'aumento della frequenza delle spedizioni o il congelamento. Queste scelte complicano in oltre anche la logistica del settore alimentare per le problematiche riguardanti la necessità di non interrompere la catena del freddo dal processo al consumo di un prodotto.

La maggiore attenzione alla salute e alle proprietà degli alimenti da parte dei consumatori, ha aumentato la richiesta da parte dei clienti di prodotti che si adattino il più possibile alle loro specifiche esigenze. La natura dei prodotti alimentari e i tipi di processi cui sono sottoposti limitano però la possibilità di applicare tecniche di mass customisation costringendo le aziende ad aumentare la varietà interna aumentando la complessità.

La dipendenza dai fattori ambientali e climatici è un'altra peculiarità dei prodotti alimentari.

Tutti gli elementi di complessità dei processi sono riassunti nella tabella Table 3.

4. Complessità degli ordini

Il numero e la varietà degli ordini sono sicuramente cause di complessità, tali aspetti possono essere correlati al numero di clienti/punti di consegna dell'azienda.

Un fattore che aumenta considerevolmente la complessità è il disallineamento tra produzione e domanda dei clienti. I prodotti agricoli sono disponibili sono in alcuni periodi mentre i clienti li richiedono durante l'intero arco dell'anno. Effetto Forrester lungo la catena di fornitura e produzione a lotti anziché in linea con la domanda contribuiscono a tale disallineamento. Esiste anche uno sfasamento tra domanda e offerta a livello settimanale poiché la produzione si concentra nei cinque giorni lavorativi mentre i consumi sono più frequenti nel fine settimana causando dei problemi con prodotti deperibili.

La domanda inoltre è spesso variabile e legata ad aspetti poco prevedibili e gestibili dall'azienda come promozioni nei negozi, eventi climatici o casi di sicurezza alimentare.

Tutti gli elementi di complessità degli ordini sono riassunti nella tabella Table 4.

5. Complessità delle risorse

Il valore di una risorsa e la capacità di svolgere una certa attività sono correlati al contesto ambientale in cui la risorsa è utilizzata per svolgere una certa attività. L'incertezza dell'ambiente in cui si opera causa ambiguità riguardo alle risorse necessarie per l'azienda al fine di sviluppare e mantenere un vantaggio competitivo.

La variabilità e la stagionalità della domanda nel settore alimentare spingono spesso le aziende a ricorrere all'impiego di operatori, anche stagionali, anziché a macchinari automatici poiché questa scelta permette maggiore flessibilità e minor investimento economico.

Tuttavia anche i macchinari automatici hanno una certa rilevanza nel settore alimentare come dimostrato nell'indagine di Ilyukhin *et al.* (2001). Ben il 59% delle aziende intervistate è per la maggior parte automatizzate e ben il 41% mira ad aumentare il livello di automazione fino alla completa automazione dei processi. Tipicamente l'automazione è impiegata nella fase centrale e finale (Packaging) del processo produttivo, mentre raramente è utilizzata per il trattamento delle materie prime. Questo è dovuto alla natura delle materie prime nel settore alimentare, eterogeneità di forma, colore e dimensione rendono, infatti, complessa la gestione automatizzata dei prodotti.

Tutti gli elementi di complessità delle risorse sono riassunti nella tabella Table 5.

6. Nuovo Framework

6.1. Indagine sulla complessità degli stabilimenti

Al fine di valutare quanto gli aspetti di complessità ricavati dalla letteratura siano realmente influenti per le industrie alimentari, è stata condotta un'indagine tra alcune aziende del settore. Gli intervistati hanno dovuto valutare quanto i vari fattori influiscano sulla complessità dello stabilimento. Il questionario è stato somministrato a direttori di stabilimento in quanto hanno un'idea globale dello stabilimento, non focalizzata su una sola particolare funzione.

Dall'indagine risulta che il numero di set-up e il tempo di set-up sono i due fattori più critici, anche la stagionalità e l'eterogeneità delle materie prime sono un aspetto molto rilevante ma in questo caso le valutazioni sono meno omogenee, si può quindi presumere che sia un aspetto legato al tipo di prodotto che l'azienda produce.

6.2. Un nuovo strumento per misurare la complessità degli stabilimenti.

Il nuovo framework è stato realizzato sulla base di quello proposto da Azzi *et al.* (2011), rielaborandolo in modo quantitativo. Il framework è realizzato con Microsoft Excel® al fine di aumentarne la facilità di utilizzo per gli utenti fornendolo in una piattaforma molto diffusa.

Tutti i fattori di complessità ricavati dalla letteratura, sono tenuti in considerazione e sono raggruppati secondo i quattro aspetti principali: processi, prodotti, ordini e risorse.

Le domande sono di tre tipi: binarie, in cui l'utente deve dire se un fattore di complessità è presente o meno; a scelta multipla, la risposta va selezionata tra diverse alternative; numeriche, deve essere inserito un valore numerico, in questo caso poi la complessità è valutata con la formula (31).

La complessità è calcolata per ciascuno dei quattro aspetti come la media pesata dei valori di ogni singolo fattore. Il peso è dato dal risultato dell'indagine statistica. Il risultato è poi visualizzato anche in un diagramma a radar composto di quattro assi relativi ai quattro aspetti principali.

Il framework è presente come allegato digitale nel CD.

7. Conclusioni

Lo scopo della tesi è di migliorare il framework proposto da Azzi *et al.* (2011) in modo quantitativo. Per fare ciò è stata condotta una ricerca su quali aspetti influiscano sulla complessità di uno stabilimento del settore alimentare e sono stati studiati alcuni modelli matematici per misurare la capacità, presenti nella letteratura accademica.

E' stata poi condotta un'indagine statistica al fine di comprendere quanto gli aspetti ricavati dalla letteratura realmente influiscano nella pratica. E' risultato che numero e tempi di set-up, disponibilità stagionale ed eterogeneità delle materie prime sono i fattori più critici secondo i direttori di stabilimento. Alcune diversità si possono riscontrare in relazione al tipo di prodotto fornito dall'azienda.

E' stato infine implementato un framework che consideri tutti gli aspetti di complessità riscontrati nella letteratura, considerando anche la rispettiva importanza nella pratica quotidiana.

Ulteriori miglioramenti devono essere applicati al modello, l'indagine va allargata ad un maggior numero di aziende al fine di avere risultati maggiormente affidabili, e i modelli di assegnazione del livello di complessità alle varie risposte vanno rifiniti con l'applicazione a casi studio e casi reali.

CHAPTER 1. INTRODUCTION

1. Food supply chain and MES.

Food supply chain differs from all other supply chains in a lot of ways and it is characterized by a high complexity. Firstly due to the peculiarities of the products it deals with: usually foodstuffs are affected by short shelf life and long production lead time due to the biological growing process of cultivations and/or the breeding of animals. Some food stuffs are also characterized by long production lead time in the industrial stage, as in the case with wine fermentation or cheese and ham maturing.

Traceability, food safety, quality and sustainability are important challenges in food supply chains. Recording automatically and in real time relevant processes and products information is essential in coping with these challenges. The use of Manufacturing Execution System (MES) supports these aspects since much more information becomes in real-time available for managers, supporting quality control of work in progress, production scheduling, and maintenance planning and so on.

Difficulty in integrating MES with other information systems, large initial investment, long programming time, waste of time in order to learn new processes, are all aspects which reduce manufacturers' motivation in implementing MES solutions. There is a connection between working environment and MES implementation opportunity: the more complex the environment is, the more recommendable the MES implementation is. Anyway, MES performances are hard to assess in advance, a tool that predict the implementation difficulties is desirable. Azzi et al (2011) have identified four main factors, which influence MES implementation in practice: process, product, order and resource. According to them, the more complex these aspects are, the more critical the implementation of a MES system will be. They proposed a methodological framework that correlates complexity of the environment and the difficulties on MES implementation.

2. Aim of the Thesis

Starting from the conceptual framework for MES implementation developed by Azzi *et al.* (2011), the issues that affect the complexity of the 4 main factors will be analysed. The aim of this work is to further develop and quantify the conceptual framework in order to measure the complexity of a plant in the food supply chain and understand which factors most affects MES implementation in each case.

The thesis focuses on food-processing industries, since it is, among all the stages of the food supply chain, the one in which the use of MES systems is more common and interesting. Usually this stage is affected by a greater use of machines and implementation of processes (also automated) which can be managed by MES.

3. Structure of the thesis

In the next chapter a deeper overview of the food supply chain and MES systems is given in order to better understand the subsequent chapters in which the central topic of the thesis is analysed.

Each chapter from III to VI analyses one of the different aspects pointed out by Azzi *et al.* (2011). A review of the academic literature has been done in order to get that information; some mathematical models to measure complexity are presented as well. The data are grouped in line with the four main aspects: chapter III discusses process complexity, chapter IV looks into product complexity, chapter V considers order complexity and in chapter VI resource complexity is examined.

On chapter VII a new framework to measure the complexity of a plant will be presented. It is based both on the conceptual framework presented by Azzi *at al.* (2011) and the complexity factors pointed out in previous chapters. In order to evaluate the relevance of all the factors a survey among different food plants has been performed; the results of the survey and the questionnaire structure are discussed in chapter VII as well. Finally, in chapter VIII conclusions are drawn and directions for further research and improvement are discussed.

CHAPTER 2. BACKGROUND

1. Food Supply Chain

Food supply chain differs from all other supply chains in a lot of ways and it is characterized by a high complexity. Firstly due to the peculiarities of the products it deals with: usually foodstuffs are affected by short shelf life and long production lead time due to the biological growing process of cultivations and/or the breeding of animals. Some food stuffs are also characterized by long production lead time in the industrial stage, as in the case with wine fermentation or cheese and ham maturing. Other aspects influence food supply chains and they will be pointed out in later chapters.

1.1. Members of the Food Supply Chain

Yanes-Estévez *et al.* (2010) stated that a typical FSC is composed of four different members: Agriculture, Agrifood Industry, Distribution and, in the last step, Consumers. Other scholars agree with this pattern even if everyone names those players in different ways, e.g. Qin (2011) indicated the first three different stages as Production, Process and Marketing respectively. In order to be more general in the consideration of cultures, animals and fish supply chains in this thesis the names of the main members are changed in: Primary producers, Food-processing industries, Distributors and ,as before, Customers in the end (Figure 1).

Primary producers are at the first stage of the chain, they can be for example breeders, farmers or fishermen. Their most important characteristics are that they are usually affected by long production times due to the biological growing process in which the yield, quality and amount are strongly dependent on the environmental events.

Food-processing industries transform Primary producers' output producing finished foodstuffs as we usually find them in supermarkets. The types of processes done in this stage are the most varied (mixing, cooking, freezing, maturing, etc.) and the enterprises can be small-sized, medium-sized or an international food group; the issues which can affect each specific plant will be consequently really different. However, some common points can be identified. Most of these industries perform automated processes, manage products with relatively short shelf life and are subjected to mass distribution rules.

Distributors are usually wholesalers or large retailing chains and they deliver the end products of food industries to either retail shops or final customers. In the last decades market concentration occurred in food supply chains; retailers have decreased in number but they have increased sales volume hence their market power (Hingley *et al.*2006). As a consequence of the increased market share they usually gain power also in the upstream side of the supply chain.

Customers are the last link in the chain and by buying products they pay all the members of the chain who contributed to provide the right product in the right place, at the right time and for the right price.

Obviously there can be some differences between real supply chains and the one proposed in Fig.1: usually there are other actors playing a role in the Food Supply chain (e.g. Transporters), as in other supply chains, and sometimes some actor is skipped, e.g. Primary producers may send products directly to customers. Those aspects are not taken into consideration because they are not relevant for the following analysis, which will focus on Food-processing Industries stage.

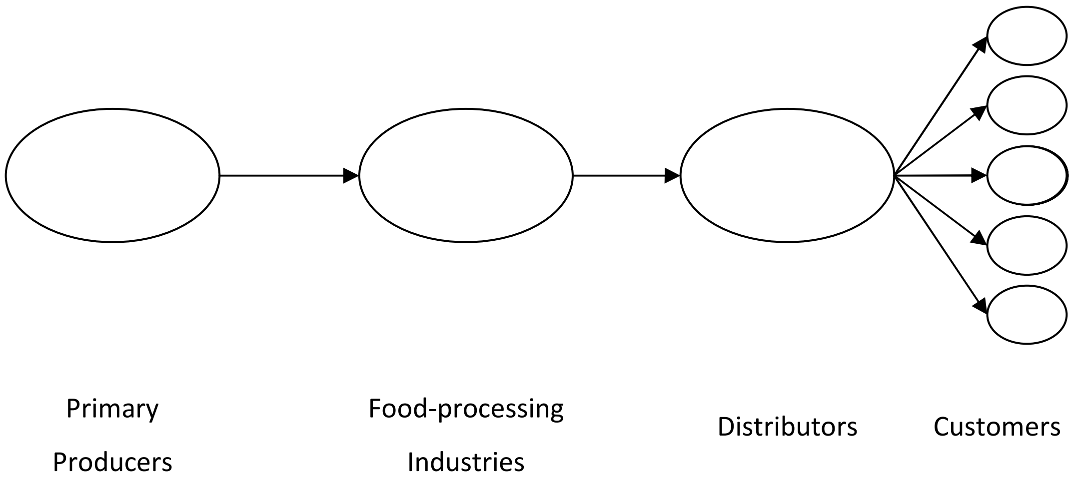


Figure 1. Representation of a food supply chain

1.2. Relations among Members of the Food Supply Chain

During the last 20 years there have been a lot of changes in FSC environment which have affected relationships among FSC Members. Customers are more self assured and are making new demands on products and services and, consequently, on suppliers. This requires very radical changes, the clearest of which is the transformation of production-driven supply chains into market-driven supply chains: this implies that members of FSC must cooperate more than they did in the past and share information about the customers' needs in quality and quantity.

Also a greater attention on food health aspects and the new laws and standards on food safety and traceability (e.g. EC 178/20002 and ISO 9000:2000) led towards more structured relationships. For instance, a lot of retailers shifted during the last years from spot markets towards contractual arrangements which have helped to secure a higher quality of products and processes, guaranteeing safety standards and products traceability (Fischer *et al.* 2009). For instance new EU regulations make large retailers liable for the quality and identity preservation of the food they sell, long term contracts ease Dealers to manage this matter. The most significant differences between the new more structured relationships and the old volatile ones are summarized in Table 1.

Spot market	**Long-term agreement**
Many alternatives	Few alternatives, at least one.
Every negotiation is a new one and none can benefit from past performance	A deal is a part of a long relationship and this relationship is part of a network context
Maximizing the potential of competition	Maximizing the potential of cooperation
Free competition	Joint development
Renewal and effectiveness by change of partner, choosing the most efficient at any time	Renewal and effectiveness by collaboration and team effects, combining resources and knowledge
Buying products	Buying also capabilities
Price orientation: to achieve the cheapest price for a well specified products	Cost and Value orientation: to achieve lower total cost of supply and develop new value

Table 1. Characteristic of Transaction-oriented and Relation oriented approach (Axelsson and Wynstra, 2002).

Market concentration has increased the supply chain power of retailers who command an increasingly higher volume of sales compared to food-processing industries and primary producers. Although retailers shift the power within food market channel to their advantage, they are starting to acknowledge the importance of suppliers in gaining retail market share for the reasons mentioned above.

Lots of scholars, such as Harvey *et al*. (2011), Qin (2011), and Wilson (1996), pointed out that different kinds of contracts exist among the different players of the supply chain.

The slow growth in the overall food market and a greater attention on food safety and traceability are causing manufacturers and retailers to seek product flow strategies that create greater efficiency and economy as a means of increasing their margins and that make processes/products information management easier. Thus firms have shifted from spot market to some kind of contractual arrangements.

Asymmetrical information, moral hazard, adverse selection, free riding, incomplete contracts, uncertainty, specific investments, etc. are some of the issues of agri-food sector, and they result in food safety problem and price fluctuation. Cooperation among different companies permits to restrain those issues. Two kind of cooperation can be identified: horizontal and vertical one.

Horizontal cooperation exists among companies of the same stage, mainly at the level of primary producers, and tackles with free riding; typical examples of horizontal agreements are cooperative, joint ventures and collective trademark.

Vertical cooperation embraces firms at different stages of the chain and copes primarily with holdups; relational contracts, strategic alliances and joint ventures are the most popular vertical cooperative frameworks.

Of course different types of vertical and horizontal cooperation exist, with related differences in commodities characteristics.

Among vertical cooperation, the simplest agreement is a marketing contract in which producer and buyer negotiate prices and quantities before production begins but no information about production process is arranged and the producer can manage the process as it prefers. This kind of agreement is possible when shelf life is long enough not to be an important issue, like in crop production. A more tightly coordinated agreement is production contract; with this type of contract production specifications are defined as well, so less freedom is granted to the producer on the process management. Even if producers lose part of their authority, this agreement become necessary in order to manage food traceability and safety; typical cases of application of these contracts are livestock markets. Vertical integration is the strongest form of vertical coordination: a leading firm owns and manages more production stages coordinating more suppliers in order to guarantee the regularity and quality of products; usually the leading company tends to rely on a stable network of suppliers. Egg and broiler markets are the most important fields of employment.

An emblematic case of horizontal agreement is cooperative; a large number of participants join the cooperative with the same rights and duties, aiming to achieve scale and scope economy. Well-built cooperation structure guarantees quality, reduces contractual hazard and prevents free riders.

Obviously different kinds of contract exist across commodities, regions and company sizes. However all of these agreements tend to improve coordination and collaboration between firms, according to Palmer (1994) and Wilson (1996) relationships which enable players to synergize their strengths in order to supply and develop the market in a better way have the following benefits:

- Improve the stability of prices/returns
- Provide better financial returns
- Improve each actor’s ability to supply what the market requires
- Provide economies of scale and marketing support
- Reduce transaction costs
- Minimize distribution and inventory costs
- Long-term innovation
- Improve quality
- Improve service; and
- Maximize market opportunities.

2. MES, Manufacturing Execution System

In order to carry on the agreements aforesaid successfully, a lot of information must be managed and shared among different companies and within each plant requiring suitable software and frameworks. As mentioned above, a lot of attention is paid to food safety and traceability, improving needs of process control. One of the more important software tools for process management is a Manufacturing Execution System (MES).

2.1. MES definition and functionalities

The Manufacturing Execution System Association (MESA) defines MES as (MESA 1997a):

> ”Manufacturing Execution Systems (MES) deliver information that enables the optimization of production activities from order launch to finished goods. Using current and accurate data, MES guides, initiates, responds to, and reports on plant activities as they occur. The resulting rapid response to changing conditions, coupled with a focus on reducing non value-added activities, drives effective plant operations and processes. MES improves the return on operational assets as well as on-time delivery, inventory turns, gross margin, and cash flow performance. MES provides mission-critical information about production activities across the enterprise and supply chain via bi-directional communications.”

MES interfaces with the automation and control systems and the Enterprise Resource Planning system (ERP), developing the physical and logical links between the true business model and the manufacturing real time details (Soplop *et al.* 2009).

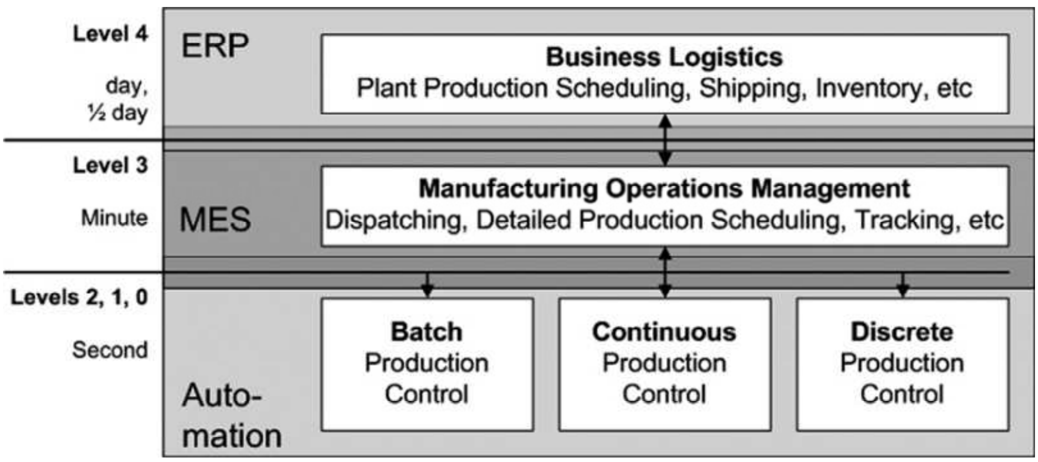


Figure 2. MES positioning in the Computer Integrated Manufacturing context (Saenz de Ugarte et al., 2009)

The 11 principal functions identified by MESA (MESA, 1997b) that a MES must have are listed below and summarized in Figure 3:

1. Operations/Detailed Scheduling: sequencing and timing activities for optimised plant performance based on finite capacities of resources.
2. Process Management: directing the flow of work into the plant based on planned and actual production activities.
3. Document Control: managing and distributing information on products, processes, designs or orders, as well as gathering certification statement of work and conditions.
4. Data Collection/acquisition: monitoring, gathering and organising data about the processes, materials and operations from people, machines or controls.
5. Labour Management: tracking and directing the use of personnel during a shift based on qualifications, work patterns and business needs.
6. Quality Management: recording, tracking and analysing product and process characteristics against engineering ideals.
7. Dispatching Production Units: giving the command to send materials or orders to certain parts of the plant to begin a process or step.
8. Maintenance Management: planning and executing appropriate activities to keep equipment and other capital assets in the plant performing to the goal.
9. Product Tracking and Genealogy: monitoring the progress of units, batches or lots of output to create a full history of the product.
10. Performance Analysis: comparing measured results in the plant with goals and metrics set by the corporation, customers or regulatory bodies.
11. Resource Allocation and Status: guiding what people, machines, tools and materials should do, and tracking what they are currently doing or have just done.

MES can perform a lot of tasks, some closely related to the process, e.g. scheduling and quality control, some others crossing more functions and business departments, e.g. resource and maintenance management. This inter-functionality has made MES an intermediary between the various departments of the company (Fig. 2) linking the management level with the shop floor. For example it executes and controls on the shop floor production orders which emanate from ERP.

According to Saenz de Ugarte *et al*. (2009) processes are the privileged form of action for modern companies because they generate the added value. MES helps to focus on processes since the objective of its concept is the optimization of the manufacturing processes and resources.

The greatest feature of MES is that it processes and analyses data in real time allowing to make optimal, or at least better, decisions because it relies on accurate and real time data instead of on old and aggregate ones. Indicators such as the use of materials, the productivity and the machine breakdown can be calculated in real time. Thanks to the linkage with other company systems, also financial indicators can be calculated.

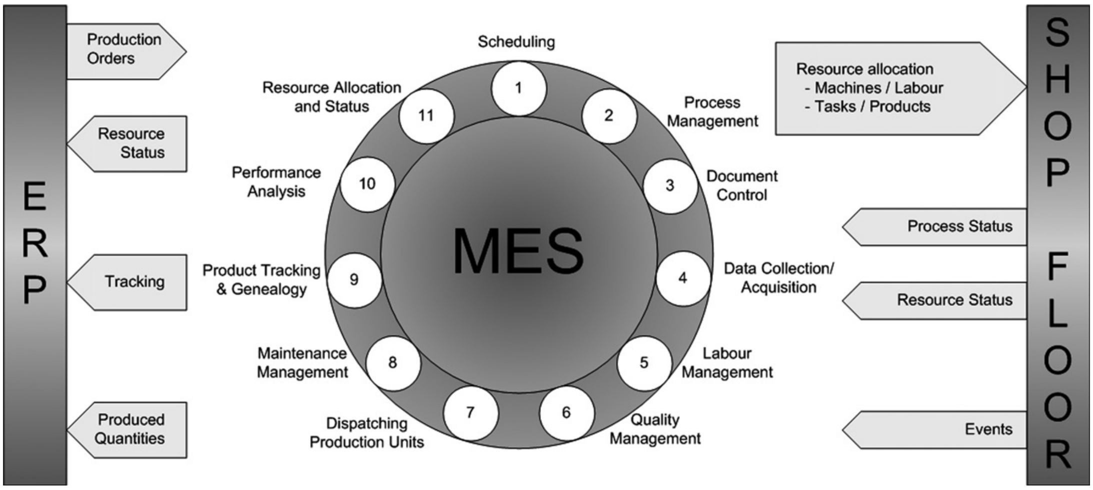


Figure 3. MES functionalities (Saenz de Ugarte et al., 2009).

With these data at hand, piloting dashboards to evaluate indicators can be created and kept up to date, and then used by managers to take decisions.

MES is also an important tool for continuous improvement theory implementation (Fig. 4) in so far as it provides to alarm, present and format the data wished by the user who has to take decisions.

A survey (Fraser 2004) demonstrates that firms measuring and linking operations and financial indicators perform at their best and using automated real time data collection on the shop floor they improve in quality, throughput, customer service, conformity, assets utilization and inventory. Furthermore, MES implementation is an opportunity to rethink processes, recognising and then seizing all the chances to improve internally (e.g. reducing costs) or in the marketplace (e.g. rising sales) as suggested by the 'continuous improvement', or *kaizen*, theory.

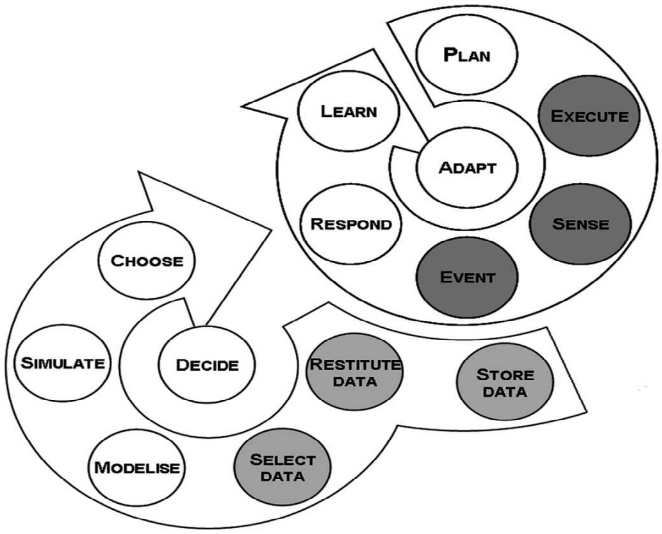


Figure 4. Adaptive intelligent manufacturing system. In grey: covered by current MES (Saenz de Ugarte et al., 2009)

2.1.1. MES in Food Supply Chains

MES functionalities fit perfectly with FSC firms needs and MES can solve a lot of Food Industries issues.

MES is a perfect tool to implement product traceability which is one of the top priorities for Food markets due to legislations and customer attentions. Using MES coupled with other systems, such as RFID, the manufacturer can know in real-time at which stage the items associated with the tags are within the supply chain (Perry 2008).

This is not the only advantage of MES and its link with the Food supply chain is deeper. According with Akkerman *et al*. (2010) food safety, quality and sustainability are three important challenges in food supply chain. Recording automatically and in real time relevant processes and products information, MES supports these aspects since much more information becomes available for managers, supporting quality control of work in progress, production scheduling, and maintenance planning and so on.

Hence MES is an important tool to increase productivity, by reducing waste and production losses, and to improve product quality and safety, by controlling the process and realising food traceability according to the current legislation.

2.2. MES implementation

In spite of the great advantages of MES utilisation, a certain resistance to its implementation is often encountered. Difficulty in integrating MES with other information systems, large initial investments, long programming time, waste of time in order to learn new processes, are some of the aspects that reduce manufacturers' motivation in implementing MES solutions.

A conventional way to evaluate investments by financial criteria (e.g. Return On Investment) is unsuitable to make a decision about MES because intangible benefits aren't taken into consideration. Agility, flexibility, customers satisfactions, new market opportunities are some of the intangibles, but really important, benefits that MES implementation can enable and they must be considered in the evaluation of MES investment.

Liang and Li (2006) propose a decisional methodology for MES applications which goes beyond classical financial indicators including intangible benefits as well. They state that an *as is – to be* analysis should be done including benefits, opportunities, costs and risks (BORC). The model they propose includes not only costs and tangible benefits but also an aim to evaluate other aspects like opportunities and risks. Benefits are time, costs, service, capacity and quality; opportunities consider increased market share, fast ROI/payback period and agile manufacturing; costs include cost of software, implementation, training, maintenance and upgrade; risks consist of time delay, budget overrun and technology (flexibility, ease to use, reliability and compatibility).

Azzi *et al.* (2011) establish a connection between the production environment and MES implementation opportunity, the more complex the environment is, the more recommendable the MES implementation is.

They pointed out 4 main factors that influence MES implementation in practice and create a conceptual framework to guide managers in their decision of investing on MES (Figure5). Processes, Products, Orders and Resources are the 4 main factors which, according to Azzi *et al.*, affect MES implementation, the more complex one of this aspects is, the more critical the MES implementation will be. In the presence of a critical environment (even for only one aspect) a complete implementation of MES system at the whole firm/supply chain is not suggested if successful results and payback are desired in a short – medium term.

A fifth factor should be considered, it is the Profit Margin; obviously, the higher it is the wider the area of the framework in which MES is strongly recommended will be.

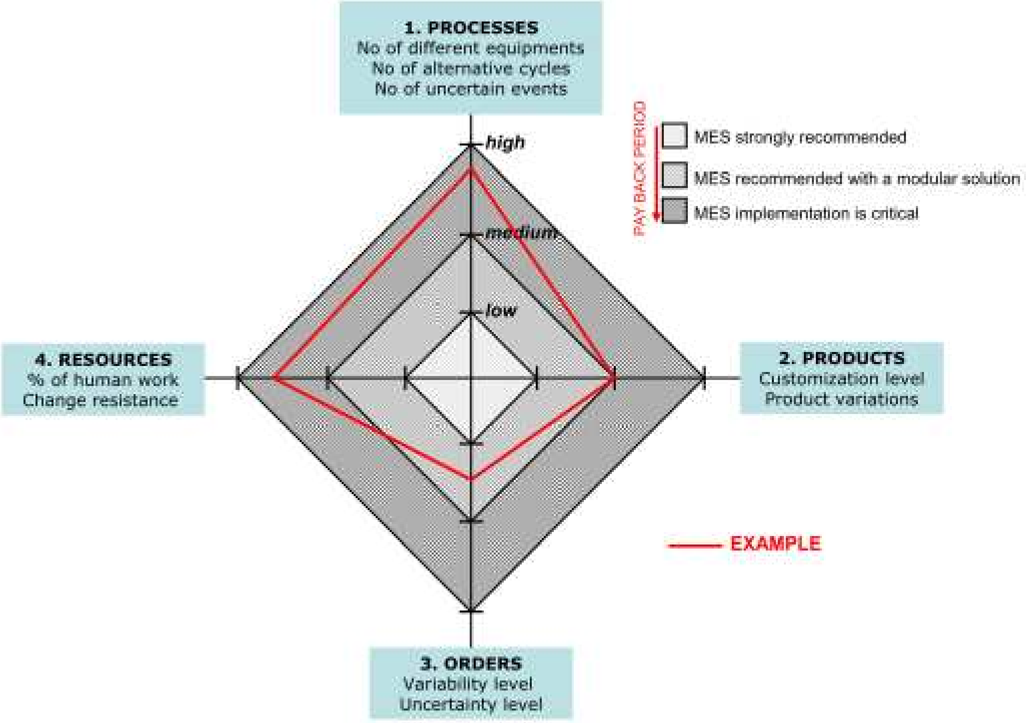


Figure 5. Conceptual framework for MES implementation (Azzi et al., 2011)

CHAPTER 3. PROCESS COMPLEXITY

The variability and uncertainty of processes are two aspects that surely affect MES utilisation because in that environment a greater flexibility is required for the system. Also the number of processes is important since the more processes there are, the more information must be processed by MES in order to establish a connection to the real shop floor. Hence MES takes more time for computation, operating less in real time and consequently in a less useful way.

Unfortunately Food Industries processes are characterised by variability, uncertainty and variety, so MES implementation becomes often complicated. Even if it becomes complicated, it is useful since MES allow managing all the large amount of information needed to control the processes.

In section 1 the causes of process complexity are pointed out while some frameworks to measure that complexity are explained in section 2.

1. Process complexity aspects

Contamination has occurred on foodstuffs during the last few years, for example BSE (Bovine Spongiform Encephalopathy), CSF (Classical Swine Fever), dioxin or Escherichia Coli on cucumbers. Also lifestyle changes have made customers more critical on Food safety and quality (Van der Spiegel *et al.* 2003, 2004). Consequently Food Industries have become more careful about products and process quality. Quality Assurance (QA) systems such as GMP (Good Manufacturing Practice), HACCP (Hazards Analysis Critical Control Points) and ISO have been implemented spontaneously or by legislation. For these reasons *sector legislation* is really relevant for food companies.

Production quality and quality management are influenced by contextual factors such as the complexity of supply chain, organisation, production process and product assortment (Fig. 6).

The analysis of process complexity will follow the logical stream of processes: from raw materials to final products. Sources of the subsequent paragraphs are Van der Spiegel *et al.* (2004) and Wurdemann *et al.* (2011).

Raw materials are affected by two main problems: temporary availability and variability.

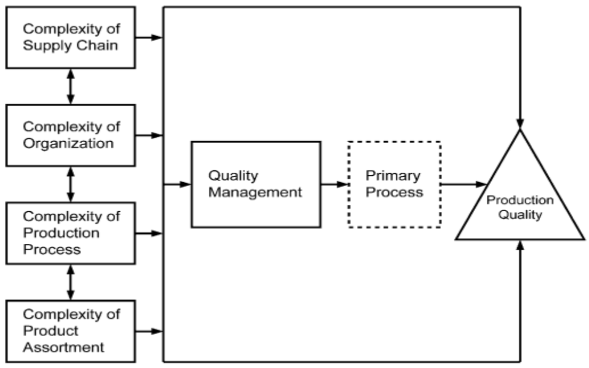


Figure 6. The conceptual model of food quality systems (Van der Spiegel *et al.*, 2003).

The availability of lots of raw materials is related to natural aspects (for instance ripening and harvest periods), therefore raw materials are purchasable only in some well-defined periods of the year while finished products are requested all year long. This aspect is much more problematic when coupled with the restricted shelf life of products, since buying a huge amount of raw materials in order to satisfy the annual demand is not possible. To buy products from other countries with different timing and to store the items under specific conditions (i.e. deep-freezing) in order to extend their shelf life are examples of solutions to this problem adopted by food-industries. However, both of them represent an additional issue to be managed that increases the complexity of processes.

The *heterogeneity of raw materials* can concern both internal (i.e. chemical composition) and external aspects: food products may be very diverse and display a wide range of variety in size, texture, weight, susceptibility to damage, etc. Some aspects which affect the variability of products are small-scale production, cultivating/breeding differences, seasonal variables and harvesting time. An illustrative case of chemical variability is milk production: milk drawn from a cow is different from milk drawn from another one but the final product must be the same in any case because customers expect that a specific brand of milk has always the same taste. Internal variability can be minimised by special demands on specifications or by mixing several batches of products. External variability becomes a problem when automation is implemented because, if product characteristics are out of the equipment's range, machines cannot process the product. To overcome this kind of problem, more sophisticated, and therefore more expensive, equipment is needed; many times companies prefer to employ human workers who are flexible instead of investing in technology (Wurdemann *et al.* 2011).

Process execution and management are affected by a lot of issues as well. Some aspects are the same as in other sectors: *different production lines*, *set-ups*, *differences among processes* and *technical constraints* are typical issues of process management and they cause problems to food industries as well. Common *technical constraints* on food processes concern temperature level and cleaning; sterilization is often required, and it extends set-ups time. In order to control all the process parameters in each step, controlling points are required, the grater their number, the more information has to be processed by MES. Hence MES takes more time for computation becoming less real time and consequently less useful.

Usually food products, thereby food processes, are low value added; this means that a lot of effort in order to optimise processes and reduce wastes must be done. Improving control systems, so increase the *number of critical control points*, finding out and reducing complexity causes help to achieve this goal (Frizelle and Woodcock 1994).

The process complexity factors pointed out in this chapter are summarised in Table2. These factors have been used to develop the survey and the framework presented in the chapter VII.

Process complexity factors
Sector legislation
Heterogeneity of raw materials
Number of processes
Number of process steps
Number of set up
Set up times
Specificity of process
Number of different equipments
Technical constraints
Number of critical control points

Table 2. Process complexity factors.

2. Process complexity measurement

As stated above, a lot of issues affect process complexity and finding out a unique way to measure it seems to be difficult. A lot of scholars have studied production processes and have proposed many models to measure their complexity, focusing on different aspects. An example is explained below.

2.1. A measure for process commonality

The following model was developed by Jiao and Tseng (2000). Commonality among processes is the aspect analysed by them. The process commonality index incorporates such factors as process flexibility, lot sizing and scheduling into one analytical measurement.

2.1.1. Process commonality index

The process commonality of a product family is characterized by the mean utilization of manufacturing capabilities for producing all the internally made parts and end products in the family. The initial formulation of process commonality index, $CI^{(P)}$, is:

$$CI_1^{(P)} = \frac{\sum_{p=1}^{n_p} \sum_{j=1}^{n_d} \lambda_{pj}}{n_p} \qquad 1 \le CI_1^{(P)} \le \beta_1 \qquad (1)$$

Where p indicates the processes and j the internally made items; λ_{pj} is a binary variable indicating if the part item j is produced at process p or not, this variable allows to consider the situation that one process could produce more than one distinct part item and similar component parts could share one process; β_1 is the maximal degree of commonality, $\beta_1=n_d>=1$.

However equation (1) doesn't give a complete view of process commonality since an important aspect as lot sizing is not taken into consideration. The set-up time (cost) required is a key factor in order to determine the appropriate economic lot size. Management should schedule the production so that the total set up time is minimized. In the analysis of process commonality the production sequence which minimise the total set up time is considered. The commonality index so becomes:

$$CI_2^{(P)} = \sum_{p=1}^{n_p} \left(\frac{\sum_{j=1}^{n_d} \lambda_{pj} \sum_{j^*=1}^{n_{pd}^*} SET_{pj^*}^* \sum_{j^*=1}^{n_{pd}^*} D_j^*}{n_p \sum_{j^*=1}^{n_{pd}^*} \left(D_j^* \, SET_{pj^*}^*\right)} \right) \qquad 1 \le CI_2^{(P)} \le \beta_2 \qquad (2)$$

Where n_{pd} indicates the total number of part items produced by process p when production is scheduled in the sequence that minimizes the total set up time; $SET^*_{pj^*}$ denotes the set up time of part item j^* on process p according to the sequence of the minimum total set up time; D_{j^*} is the demand of part item j^*.

In order to have a complete representation of a real manufacturing system another aspect must be considered: the sequencing flexibility. It concerns the different penalties, in term of set up time (cost), for changing between any two operations. If the set up time required for all the operations were the same, this flexibility would be maximum. The commonality index so becomes:

$$CI^{(P)} = \sum_{p=1}^{n_p} \left[\frac{\sum_{j=1}^{n_d} \lambda_{pj} \sum_{j^*=1}^{n_{pd}^*} SET_{pj^*}^* \sum_{j^*=1}^{n_{pd}^*} D_j^*}{n_p \sum_{j^*=1}^{n_{pd}^*} \left(D_j^* \, SET_{pj^*}^* \right)} \left(1 - \frac{n_{pd}}{\sum_{j=1}^{n_{pd}} SET_{pj}} \sqrt{\frac{\sum_{j=1}^{n_{pd}} \left(SET_{pj} - \overline{SET_p} \right)^2}{n_{pd} - 1}} \right) \right] \quad (3)$$

$$1 \leq CI^{(P)} \leq \beta$$

Where SET_{pj} represents the set up time for a part item *j* at process *p*; SET_p denotes the average set up times of the set of jobs that can be produced at process *p*; n_{pd} is the total number of part items required by a product family to be produced by process *p*.

2.1.2. Interpreting the model

The process commonality index analyses the commonality among different processes taking into consideration process steps, lot sizing and set up times. $CI^{(P)}$ has managerial implication both on a strategic and on an operational level. It can be used to evaluate the impact of product family designs on existing process capabilities, thereby facilitating a systematic approach to maintaining the economy of scale in processes. It is also a criterion for the value analysis of a firm's product planning and strategy and it an important lever with which to assist process re-engineering as well.

Process complexity is obviously related to process commonality since the greater the commonality is, the fewer the processes to make the same number of items are, and consequently fewer processes have to be managed and controlled by MES.

Furthermore, this mathematical model defines the relevance of aspects such as number and specificity of the processes, and number and time (cost) of the set ups on the evaluation of the complexity of a process. It suggests that all these elements must be taken into consideration on the framework development.

CHAPTER 4. PRODUCT COMPLEXITY

MES implementations are also affected by products characteristics. Differences among products, due to customisation, imply to manage different end products in different way, in terms of process, inventory, traceability, etc. MES must control all this aspects. The more end products there are and the more aspects of them must be handled, the more flexibility and computational capability is required to MES system.

Food products are characterised by heterogeneity, customisation, technical constraints and legislation duties.

In section 1 the causes of products complexity are pointed out while a framework to measure complexity is explained in section 2.

1. Product complexity aspects

Food products are characterised by specific aspects which differentiate them from others and make them complicated to process and to manage, variety of products required by market is also a troublesome point for food industries.

McIntosh *et al.* (2010) listed as many as 13 key factors which distinguish food products from others.

1) Chemical change: often during food processes chemical changes occur to products, they always happen by cooking and fermentation. Most of the times those changes are irreversible.
2) Food product decay: almost all food products have a limited shelf life, it can be shorter or longer but the foodstuff will experience chemical change through decay anyway. Texture, smell and taste can change and commodity can become toxic as well. Package, controlled processing/storage, drying and other strategies allow delaying decay.
3) Maturing cycles/delay: in some cases a maturing cycle is required to produce the end product. This period can last form few months (e.g. ham) to several years (e.g. whisky).
4) Mixing products and assembly products: mixing ingredients can be both in finely divided and liquid form. The mixing processes are more automatable than traditional

assembly ones since orientation and positioning specifications are not required and not even precedent relationships must be observed.

5) Recycling/recovery: taking in account the previous points, once the process starts, the original ingredients cannot usually be recovered.
6) Cleaning/purging: food companies are affected by needs of cleaning more than others, especially considering hygiene and cross contamination which can cause allergies issues. Although special cleaning techniques are used, this problem is still relevant for companies since extends changeover time.
7) Packaging: packaging must preserve food products in special environment and the process must be done in microbiologically clean environments.
8) Simplifying product design for mass customisation: usually the list of ingredients is extensive and cannot be reduced or changed since taste and texture are highly important for customers' choices and it can vary even for small changes on raw materials types or amounts. The order of process activities is often inflexible as well.
9) Access: access of operators to process is often forbidden or not desirable for hygiene (e.g. process occurs in sterilised environment), operators safety (e.g. process occurs at high temperature) or other reasons (e.g. process occurs in only one multi step device).
10) Delicate: foodstuffs are generally more delicate than mechanical products so special handling system must be used.
11) Legal provisions: provisions as sell-by date or production location are required by law.
12) Economies of scale: in some case economy of scale can be reached so set up and production variety is reduced.
13) Distribution: many foodstuffs required particular distribution constraints. For instance cold chain cannot be interrupted during frozen products delivery while vegetables need to be transported as soon as possible.

All of this factors increase products complexity, their consequence for food industries worth to be more deeply analysed.

Food products are perishable and have a *limited shelf life*; product proprieties can change very fast by physiological processes and microbiological combinations, which can result in deterioration (Van der Spiegel *et al.* 2004). Management and production aspects are both necessary in order to face this situation. Higher delivery frequency, which allows supplying the desired product quality making products shelf life for customers longer, is an example of management solution while methods such as drying or heating are cases of production strategies to prolong products duration.

Withal some solutions can affect both management and production aspects, freezing is one case. To freeze certainly make shelf life of foods longer, but once a foodstuff is frozen it must be kept in this state until the consumption; then *storage condition*, transportation and other links of the chain are involved in order to manage it. Shipping temperature-controlled goods carries a whole host of risks: improper loading techniques, extended exposure to ambient temperatures, improper delivery protocol, delays, and lack of control in the cold chain (Kuzeljevich 2010).

According to Li (2010) food logistics are very complicated since many units are included from the beginning of farm produce cultivation, raw material transportation, food processing and production to being shipped to distribution centres. Logistics process is influenced in various degrees by each section, so structuring a reasonable food cold chain logistics management system should be passed through the whole process. Implementation of vertical integration management and cooperation such as joint ventures and alliances are required in order to improve a good and profitable cold chain. Besides refrigerated vehicles, cold storage, IT systems and other resources are prerequisites to implement it.

Cold chain management is nowadays a relevant issue, since the cold storage rate of perishable food in developed nation, such as America, England, is reach to 100% from the points of the whole cold chain system (Li 2010); moreover goodness of cold chain is strictly linked to food quality and healthy.

Food cold chain management system is a long-term process and requires from the hardware facilities, management measures, rules and regulations and many other aspects to proceed in order to build a healthy, rational system.

Packaging is also a tool to protect foodstuffs from deterioration, according to lots of scholars (e.g. Robertson 1990, Olsson and Györei 2002) packaging is not a merely protection of the good it contain, but rather its design influence the efficiency of the entire value chain in term of functions, features, information and cost. Olsson *et al.* (2004) state than even if economies of scale are still looked for, customers are more involved in packaging decisions and environmental concerns are more focused as well.

They pointed out packaging characteristics for food manufacturers:

1) Provides satisfactions of customer requirements
2) Real end-user benefit
3) Performs well in filling machines
4) Provides cost effective handling and delivery (e.g. maximise pallet utilisation)
5) Comprises as few units as possible
6) Ideally there is some form of unity between different solutions
7) Provides protection through the supply chain
8) Minimises environmental impact
9) Differentiates products from competitors' ones
10) Promotes the brand; and
11) Makes possible a price and quality according to customer needs.

Actually packaging is one of the most popular forms of mass customisation on food products. Mass customisation demands the involvement of customers in the design of the product prior to manufacture, concerning to sensory and functional performance (Boland 2006).

Boland (2006) recognises three drivers for mass customisation on food industries; they are:

1) Validation of 'I' as an individual in an increasingly crowded and apparently uniform world
2) Individual taste and experiential preferences; and
3) Individual health needs.

Firsts two elements are related to sensory aspects while the last one affects safety need of the customer, thus it is more important to the individual since it affect a lower layer in Maslow' hierarchy of needs.

Customers are becoming more aware on food healthy and properties, they *concern on food safety* and look for products that best fit with their needs and ask for tailored products with specific features. In order to face to this change, agriculture is shifting from a push system driven by the producer's ability to generate commodities to a pull system driven by customers' needs and wishes (German and Watzke 2004). So that, recognise the correct *level of customisation required* has become an important issue for food companies.

In traditional food production system, economies of scale want to be achieved by industries so that cost throughout the supply chain can be reduced, in this way biological difference among raw materials is an issues and companies look for how to reduce it. In pull demand system differences among products generate value since they might satisfy customers' needs; producers can take advantage of this diversity since biological variation can be associated with specific health values (Figure 7).

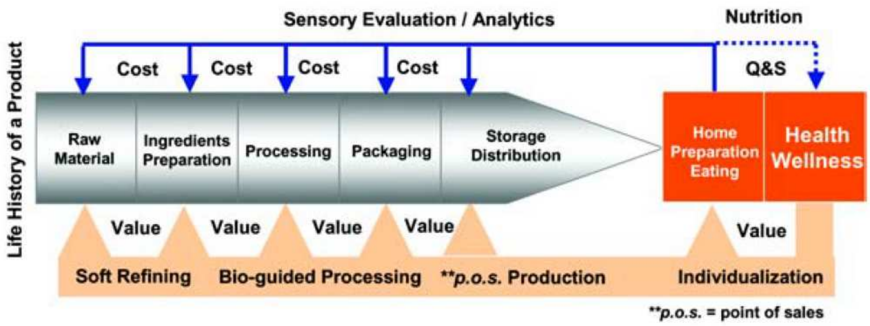


Figure 7. Overview of food-process chain from agricultural raw materials to the final perceived sensation and health effects of products (German and Watzke, 2004).

Change, in developed countries, in customers' behaviour and their tendency to purchase foods in order to obtain quality and emotional benefits is confirmed by Barrena and Sanchez (2012). Three kinds of products were pointed out by them: experience products, search products and credence products. This classification is based on the predominant characteristics of the product among the three possible cues a product can convey: experience cues, search cues or credence cues. Experience cues can only be observed and verified after consuming the product (e.g. taste), search cues are visible before purchase and enable the consumer to judge the quality of the product (e.g. texture of fruits) while credence cues are hidden and cannot be observed or verified by consumers at any time, not even after the consumption.

They state that foods generate an emotional reaction in consumers that appears to increase in complexity of number of credence characteristics featured by the product. Decision-making processes of customers no longer rely solely on their product knowledge. The evidence shows that they are also depend increasingly on customers' self-knowledge, which acquires a more significant role when the purchase decision involves one of the growing numbers of credence goods in the marketplaces of all developed countries. Customer choice process depends on the kind of products she/he is buying so advertising campaigns and product positioning should be adapt to the type of product that the company produce; labelling plays an important role to conveying information about product quality and other features, especially in the case of food products with strong health and environmental improvement associations.

In spite of being really useful, mass customisation found a lot of constraints in order to be applied by food industries. Food products distinguish factors reduce possibility of mass customisation application; chemical changes, legal requirement and maturing cycles, for example, are items that cannot be changed.

According to McIntosh *et al.* (2010), mixing instead of component assembly, irreversible and time dependant chemical changes limit the extent of potential mass customisation implementation. Moreover, being food products chosen for sensory and emotional aspects (Barrena and Sanchez 2010) rather than for functionality aspects, design for modularity solutions such as changes of some ingredients are not always acceptable by customers.

The increase demand for tailored food products force industries to increase products variety and at the same time mass customisation is difficult to be implemented for the reasons explained before. Those factors entail that food industries must raise the number of raw materials and processes thus increasing complexity in order to increase products assortment. The larger the variety of raw materials is, the more the aspects that have to be considered during production processes will be, in order to obtain the desired production quality (Van der Spiegel *et al.* 2003).

Product variety has negative impact on plant complexity. According to Fujimoto *et al.* (2003) process complexity and equipment cost increase because of required flexibility in handling components, or subassemblies, of different shape or configurations; additional working station and floor space can be needed to process new parts. High inventory, feeding complexity, excessive capital investment, low utilisation of facilities and complexity in line scheduling and balancing are some of the negative impacts of product variety. Product variety is due to the *number of products* and the *differences among different products*.

A further aspect which affects products complexity is the *reliance on environmental events*. Local or worldwide food diseases, such as BSE or CSF, imply a reduction of the demand of related products but also a change in the production systems due to new *ad hoc* norms dictated by authorities. Also distortions on the process environment, such as temperature or humidity level, impact on finish products quality. Climate is important for some food industries as well; according to climate, quality and quantity of raw material can vary.

An example is given by Everingham *et al.* (2002) referring to sugarcane supply chain; in this sector dealing with climatic variability is important to obtain a profitable and sustainable production because stability of income from year to year affects the risk of farming and milling operations. Climate forecast tools are used in risk management to take decisions; benefits of coupling climate forecast tools and management strategies are improvement on farm profitability by better use of resources; improved planning for wet weather harvest disruption and early season sugar supply and better scheduling of milling operations leading to more effective use of resources, and enhanced industry competitiveness through more effective forward selling of sugar based on enhanced knowledge of amount of sugar supply and improved efficiency of sugar shipments.

The product complexity factors pointed out in this chapter are summarised in Table 3. These factors have been used to develop the survey and the framework presented in the chapter VII.

Product complexity factors
Limited shelf life
Sector legislation
Specific storage condition
Customer concerns on food safety
Customisation level required
Number of products
Differences among different products
Reliance on environmental events

Table 3. Product complexity factors

2. Product complexity measurement

Lots of issues affect product complexity and find out a unique way to measure is not easy at all. A lot of scholars studied products matter and proposed many models to measure their complexity, however most of them focus on product commonality since it is an important aspect to apply mass customisation. An example of measurement is explained below.

2.1. A measure for products commonality

The following model is developed by Jiao and Tseng (2000). Commonality among products is calculated referring to the bills of materials (BOM) of products. Different food products are identified by different recipes, so recipes can be associated at BOM of other type of products. As matter of fact a recipe lists the type and the amount of raw material needed to produce a specific final product, just as a BOM.

2.1.1. Product commonality index

To count the number of repetition of items among products could be an idea to valuate commonality, but in the analysis of whether or not a product family is adequately designed it is not enough. More dimensions, such as the cost or price of each component part, the volume of the final product, and the quantity per operation should be taken in consideration.

The initial formulation for component part commonality index, $CI_1^{(C)}$, is:

$$CI_1^{(C)} = \frac{\sum_{j=1}^{d}\left(P_j \sum_{i=1}^{m} \varphi_{ij}\right)}{\sum_{j=1}^{d} P_j} \qquad 1 \leq CI_1^{(C)} \leq \alpha_1 \tag{4}$$

Where *j* indicates the distinct component parts, and *i* indicates the various end products. P_j is the price to buy the j^{th} purchased part or the cost to produce the j^{th} internal made part while φ_{ij} represent the number of immediate parents for each distinct component part d_j so that $\Sigma_i\varphi_{ij}$ is the total number of repetition of the j^{th} part among all the m products. $\alpha_1=\Sigma_j\Sigma_i\varphi_{ij}>=1$ is the maximal degree of commonality.

Another dimension that $CI^{(C)}$ should take into account is the quantity of component parts for each operation (parent–child relationship) that has been specified in the BOM-like product structures. Let *Qij* denote the quantity of distinct component part *dj* required by the product *i*, then the $CI_1^{(C)}$ of equation (4) can be further refined as follows:

$$CI_2^{(C)} = \frac{\sum_{j=1}^{d}\left(P_j \sum_{i=1}^{m} \varphi_{ij} \sum_{i=1}^{m} Q_{ij}\right)}{\sum_{j=1}^{d}\left(P_j \sum_{i=1}^{m} Q_{ij}\right)} \qquad 1 \leq CI_2^{(C)} \leq \alpha_2 \tag{5}$$

Where $\alpha_2=\Sigma_j\Sigma_i\varphi_{ij}>=1$ is the maximal degree of commonality.

Since multiple end products are involved with $CI^{(C)}$ for a product family, end product volume must also be considered. Let Vi denote the volume of end product i in the family. We can rewrite equation (5) as:

$$CI^{(C)} = \frac{\sum_{j=1}^{d}\left(P_j \sum_{i=1}^{m} \varphi_{ij} \sum_{i=1}^{m}\left(V_i * Q_{ij}\right)\right)}{\sum_{j=1}^{d}\left(P_j \sum_{i=1}^{m}\left(V_i * Q_{ij}\right)\right)} \qquad 1 \leq CI^{(C)} \leq \alpha \tag{6}$$

Where $\alpha=\Sigma_j\Sigma_i\varphi_{ij}>=1$ is the maximal degree of commonality.

The quantity of distinct component parts d_j applied to one particular product i can be calculated by multiplying quantity per operation q through the levels of the product BOM, Q_{ij} can hence be calculated by equation (7):

$$Q_{ij} = \sum_{h=1}^{n_h}\left(\prod_{k=0}^{n_k} q_{hk}\right) \tag{7}$$

Where h represents one particular path from the item d_j to the end item node through the levels of the BOM for a particular end product in the family (the path includes node d_j and excludes the end item node, and is identified in the same way as finding immediate parent nodes for d_j in a product i), n_h denotes the total number of such paths for d_j within product i, n_k denotes the total number of parent nodes on path h, k is the index of the nodes on path h, where k = 1, 2, . . ., n_k represents parent nodes and k = 0 represents the node dj itself, and q_{hk} represents the quantity per operation (either manufacturing or assembly) of node k required by its immediate parent node along path h.

Using equation (7) in to calculate Q_{ij} in equation (6) the final equation of component part commonality index will be:

$$CI^{(C)} = \frac{\sum_{j=1}^{d}\left\{P_j \sum_{i=1}^{m} \varphi_{ij} \sum_{i=1}^{m}\left[V_i \sum_{h=1}^{n_h}\left(\prod_{k=0}^{n_k} q_{hk}\right)_{ij}\right]\right\}}{\sum_{j=1}^{d}\left\{P_j \sum_{i=1}^{m}\left[V_i \sum_{h=1}^{n_h}\left(\prod_{k=0}^{n_k} q_{hk}\right)_{ij}\right]\right\}} \qquad 1 \leq CI^{(C)} \leq \alpha \tag{8}$$

2.1.2. Interpreting the model

The component part commonality index $CI^{(C)}$ valuate the degree to which common part costs have been distributed across all products in a product family. Implications of parts cost, part utilisation, and end product volume on $CI^{(C)}$ are discussed below.

Cost of parts and part utilisation are correlate, the commonality is more sensitive to the cost of a common part than a less common part. While the large cost of a common part increases $CI^{(c)}$, the large cost of uncommon part has a negative effect on $CI^{(c)}$, since a larger cost of a part increases the weight of that part on the calculation of $CI^{(C)}$. That means that is better focus standardisation strategies on more expansive items (Figure 8).

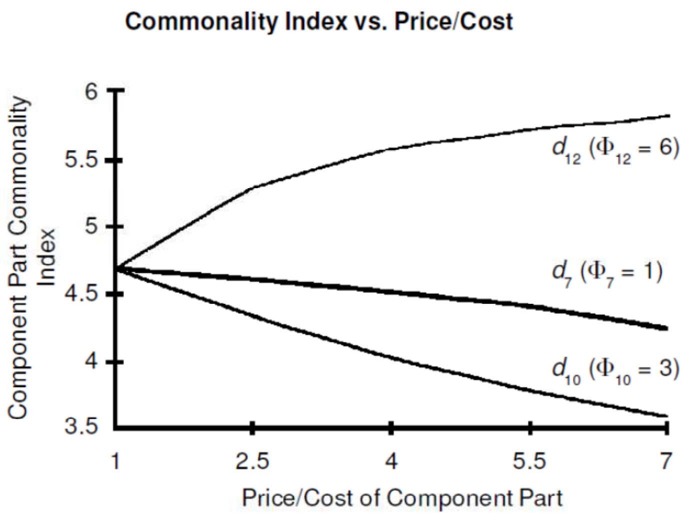


Figure 8. Changes of component part commonality index with respect to part cost (Jiao and Tseng, 2000).

A high level of quantity per operation increases commonality, so rises the $CI^{(c)}$, only if that part is a common one; otherwise the $CI^{(c)}$ deceases. Therefore common parts should be used as many as possible wherever possible (Figure 9). According to equation (8) the weight of each part is in direct ratio to their utilisation. Increasing the utilisation of an uncommon part, it becomes more influent on $CI^{(C)}$ calculation, thus $CI^{(C)}$ decreases.

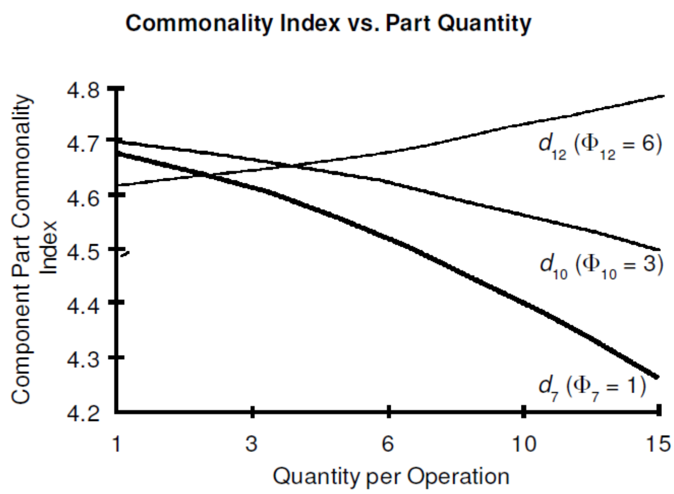


Figure 9. Changes of component part commonality index according to quantity per operation (Jiao and Tseng, 2000).

Family commonality is closer to the within-product commonality index of a high volume produced product than a low volume one. That means that a volume increase in a high within-product commonality should increase the overall commonality of a product family (Figure 10). An high within-product commonality product is composed by common parts, so increasing the volume of this products, the volume of common parts are increased as well, so they become more common within the product family. If a low within-product commonality product has its volume increased, its parts become more used. Being these parts few common, their volume increment made the commonality index lower since their weight become higher and consequently the weight of common parts become lower.

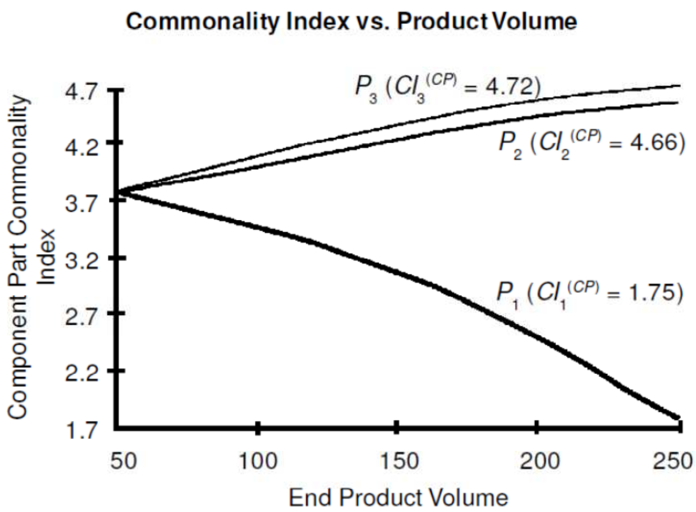


Figure 10. Changes of component part commonality index with respect to product volume (Jiao and Tseng, 2000).

Product complexity is related to product commonality since the greater the commonality is, the fewer the number of end and raw products and the issues of customisation are; consequently fewer data have to be managed and controlled by MES.

Furthermore, this mathematical model defines the relevance of aspects such as number of products and the differences among on the evaluation of the complexity of a process. It suggests that all these elements must be taken into consideration on the framework development. Other aspects pointed out on section 1 are not considered in this model because it is not focused on food industries but they will taken into consideration on the framework development anyway.

CHAPTER 5. ORDER COMPLEXITY

MES implementation is affected by orders characteristics. Differences among products, due to customisation and market segmentation, imply the management of the orders of different end products in different way, in terms of demand, inventory, delivery etc. MES must provide the control of all these aspects. Uncertainty is another issue which affects MES systems.

Food orders are related to unpredictable climate events, and during the last few decades food industries are moving towards some sort of market segmentation.

In the following section the causes of orders complexity are pointed out.

1. Order complexity aspects

The number of orders is surely something that has an impact on the overall complexity since the more orders there are, the more data must be calculated by MES and the less real-time the results provided by the system will be. Wauters *et al.* have demonstrated how the average calculation time increases according to the number of orders (Fig. 11).

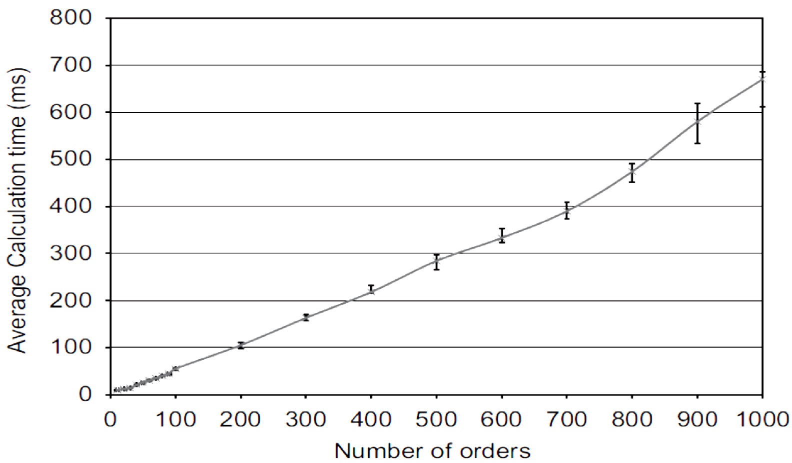


Figure 11. Average calculation time in function of the number of orders (Wauters *et al.,* 2011).

The average process time grows linearly because orders are scheduled in series one after another. Figure 11 shows the average calculation time for the first scheduling solution. MES aims to optimise it so that more iterations are required; according to Wauters *et al.* in order to generate an optimised solution for a set of 30 orders, MES would take approximately 10 seconds. Actually this duration depends on the termination condition which usually is the follow: stop when the number of consecutive loops (iterations) without significant improvement (>$x_{min\%}$) exceeds a limit (L_{max}); this condition works since the improvement, provided by a further iteration, decreases with the number of iterations already done (Fig. 12).

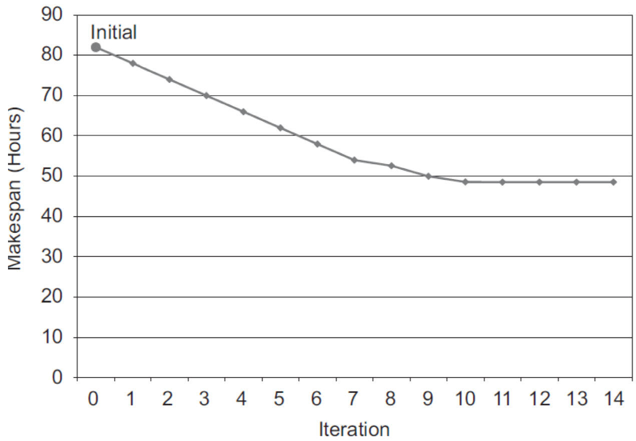


Figure 12. Optimization progress starting from an initial schedule (Wauters *et al.* 2011).

The number of orders can be coupled with the *number of customers/delivery points* of the firms, since it is plausible that the more customers/delivery points it has, the more different the orders the company receives will be.

Order complexity is affected also by a *misalignment between the agricultural production time and the consumer demand*. According to Van der Spiegel *et al.* (2004) and Taylor and Fearne (2009), the consumer demand is disconnected from agricultural production; end products are required throughout the whole year while food products are characterised by seasonal availability and long lead time of production. Other causes of this misalignment were pointed out by Taylor and Faerne (2009): for instance, the well-known Forrester effect surely contributes to the disconnection between market demand and food industry production.

However, those above are not the only causes; process companies want to reach targets of equipments efficiency which can require batch production and a higher inventory level since production is not in line with the customer demand.

Demand and production are misaligned also within weekly time windows; consumers' habits imply that the demand level is higher during the weekend (Taylor and Faerne 2009), and firms should process those orders in advance if they works five days per week. This problem is more relevant with fresh products affected by short shelf life since to face this inconvenience companies usually overproduce during the week to fulfil the weekend demand.

The complexity of orders is not affected by misalignment only; the variability of demand increases such complexity as well. Seasonality, unseasonable weather, and promotional policies are some causes of the variability of demand levels (Taylor and Faerne 2009).

Environmental events affect customers' decision and the production process as well, as stated in the previous chapter. Considering climatic aspects and weather forecasts helps to enhance strategies for marketing plans and demand management (Everingham *et al.* 2002).

Nowadays customers are more aware of the relationship between diet and health (Van der Spiegel 2004), and also such aspects such as animal welfare and environmental respect are taken into consideration by customers more often than in the past (Barrena and Sanchez 2012).

Those elements make consumers' choice more complex since more credence aspects are evaluated and a higher level of abstraction is required. Barrena and Sanchez (2012) have developed a research on the process of customer's choice for food products. They pointed out how food induces an emotional reaction in consumers that increases in complexity with the number of credence characteristics featured by the product. In figure 13 an example of their results is shown; it is quite emblematic how many attributes influence the purchase choice even for a simple product like rice.

Identifying and understanding the process by which the of consumers' personality aspects influence their purchase decisions can help marketers to improve their strategic positioning (Barrena and Sanchez 2012). This explains why *customisation* and *market segmentation* are so relevant for food markets nowadays. Furthermore to meet customers' needs is becoming increasingly important for food companies since lots of them are shifting their production from foodservices towards retail products (Higgins 2010) which required a greater customisation.

Van Kampen *et al.* (2012) defined an order as a demanded amount of a product by a customer at a moment in time. This definition allows stressing the difference between the customisation of products and orders. Product customisation concerns the possibility of a customer to choose the product feature which better fit which her/his needs; order customisation also concern about the chance of a customer to choose the amount of the desired product and when she/he want to receive it. An example helps to better understand this difference: if a company produce 10 different models for a product, the consumer can choose among them and it can be considered a good product customisation. Anyway, if the product can be shipped only in a minimum lot of 20 pieces and by boat, the order customisation is not enough for the customer if she/he would like to receive only 3 pieces and in a short time.

Furthermore, also the relevance of product variety is different between product and order customisation and affect more the order complexity. In some cases customisation occur only on the last part of the process, typically on packaging stage for food companies (Boland 2006); in these cases the differences on producing different models of a product are reduced. Thus, product complexity can be reduced since the differences among different products are reduced, but the order complexity does not change since from the order point or view these products are still completely different for the customers.

During the last few years the food sector is moving from spot market and push system to a more structured system with long-term relations among companies. In such an environment it is easier to share information, and that is an important way to reduce order complexity. The production of a joint long-term forecast by farmers, processors and retailers for a period of time determined by the growth cycle of a certain product would be an important step toward helping to link production to consumer demand (Taylor and Fearne 2009).

The consumers' final demand must to be accounted for since from primary production when there are limited possibilities of adjusting product attributes at intermediate steps (Aramayan and Kuiper 2009).

The importance of cooperation among different actors of the chain in order to better fit with the market and achieve greater profits is pointed out also by Folkerts and Koehorst (1998). They state that individual companies in the agribusiness and food industries cannot achieve their desired market position solely through their own efforts; they have to cooperate more effectively as an integrated supply chain. The vertical coordination of chain strategies and activities allows improving accuracy, speed and flexibility in responding to the market the consumers' demands.

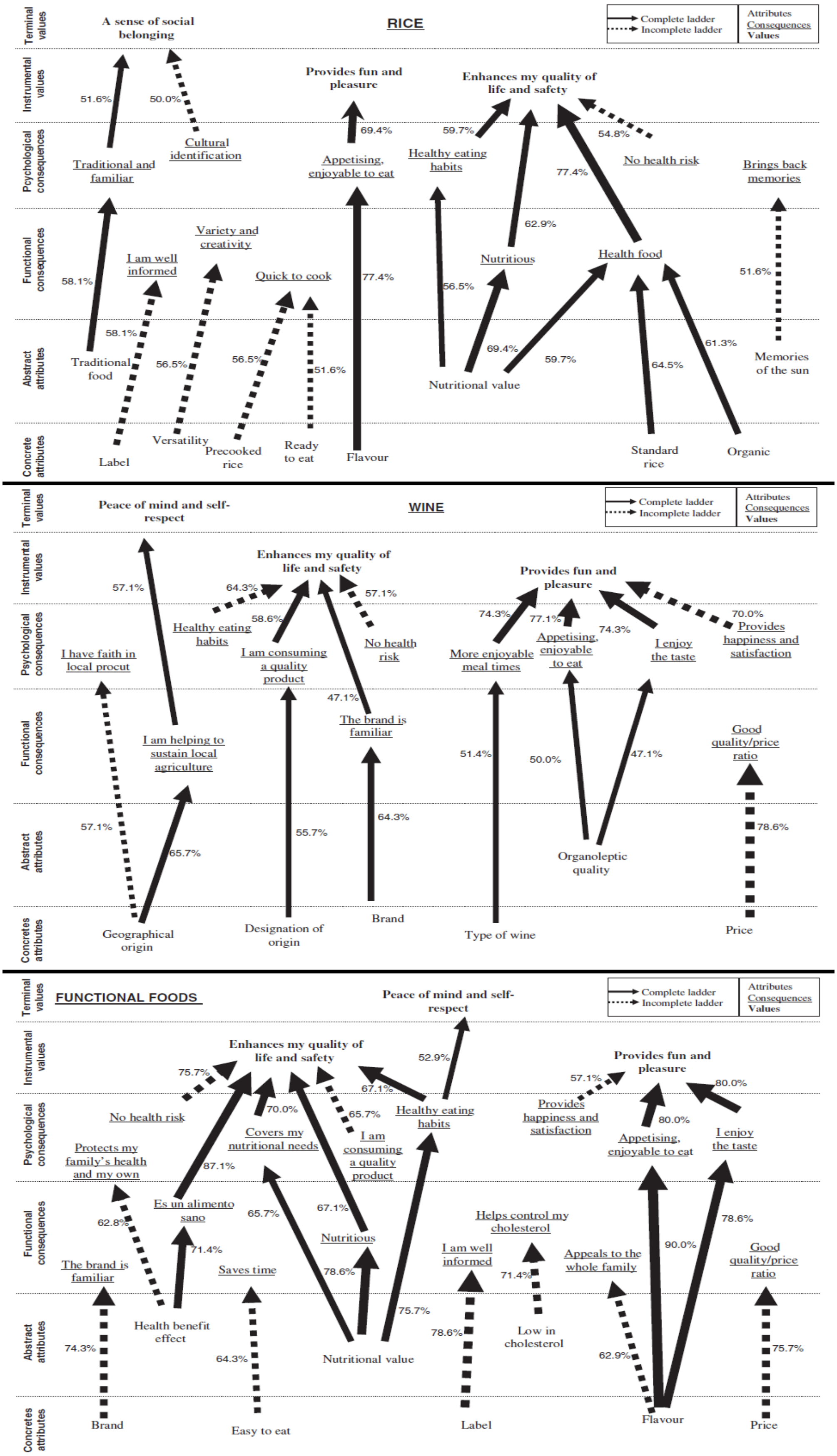


Figure 13. Hierarchical Value Map for different type of products (Barrena and Sanchez, 2012).

The order complexity factors pointed out in this chapter are summarised in Table 4. These factors have been used to develop the survey and the framework presented in the chapter VII.

Order complexity factors
Number of customers/deliver points
Misalignment between agricultural production time and consumer demand
Reliance on environmental events
Customisation level required
Market segmentation

Table 4. Order complexity factors.

CHAPTER 6. RESOURCE COMPLEXITY

Resource characteristics can make MES implementation more complicated. Two types of resources are used by companies: human workers and machines. The variability of human resource and their resistance to changes level increase the risk for MES system failure. Unskilled workers and high turnover have the similar negative effects on MES implementation. MES can be integrated with machines for control and manage them in order to optimise their utilisation.

In the first section the causes of resources complexity are discussed while in the second section a framework to measure the static complexity will be analysed.

1. Resource complexity aspects

From a resource-based perspective (RBP) value is created only when the firm's resources are evaluated, manipulated and deployed appropriately within the firm's environmental context (Hitt *et al.* 2007). All the firms aim to attain sustainable competitive advantage; in order to achieve it, a company must be able to consistently deliver greater customer value or create comparable value at a lower cost, or do both, as compared to its competitors. From RBP, in order to get a sustainable competitive advantage, a firm must be able to access valuable, rare, and inimitable or non-substitutable resources and gainfully use those resources in value-creating activities (Sanyal and Sett 2011). According to Sanyal and Sett (2011) the value of a resource, or capability to perform an activity, is specific to its environmental context; indeed environmental uncertainty creates ambiguity about the resources (including capabilities) strategically needed to develop and maintain competitive advantage.

Also the *amount of resources* needed to fulfil the market is uncertain because of the variability of the end products demand. The variable demand of end products is confirmed by the research of Akkerman and van Donk (2009) in which variable demand for end products is one of the characteristics more encountered in the case study. In order to face demand variability and seasonality companies resort to human workers, especially *temporary workers* (Azzi et al. 2011), since this solution is more flexible and economical than automatic devices.

The *relevance of human workers* on food companies results is confirmed by the Granarolo case study (2011); Having faced bankruptcy in the late 1990s, Granarolo recovered market share and competitiveness through the close involvement of its employees. Granarolo's managers aimed at increasing the trust of employees and investors in order to re-launch the company. Employees were closely involved in defining and implementing a new set of corporate values. Senior and middle managers led the definition of company's values; the focus of those values is on personal growth, ethics, creativity, customer satisfaction, positive internal climate, quality of life, participation and team spirit.

A system of voluntary groups of employees, called "group of change" and "Archimede groups", have been established in order to discuss common problems in the workplace and share ideas and solutions. Each new managerial process is evaluated with a measurement centred on reputation drivers as customer satisfaction and the quality of internal climate.

According to Jabbour and Santos (2008) human workers are a key factor to gain a sustainable organisation. A sustainable organisation is a company that takes into consideration economical social and environmental criteria in its operations. The importance of sustainability has increased during the last few years, since more attention is given to such issues as environmental degradation, the marginalisation of significant social groups and the search for innovation in public and private sectors that are concerned with these dilemmas. Those issues affect food companies as well.

According to Eisenstat (1996) human resource function has a central role in organisations and can stimulate the inclusion of issues concerning sustainability in the scope of the various relationships that take place inside a company and with external organisation.

Modern human resource management presents two important challenges: the first concern attracting, retaining and developing the talents needed for the survival of a company in globalisation and search for innovation; the second refers to planning a form of human resource management which meets the objectives linked to the economic, social and environmental sustainability (Boudreau and Ramstad 2005).

Jabbour and Santos (2008) state that human resource is a key factor to improve environmental management performance, which is an important aspect for several food companies. According to the relevance of human resources, *labour legislation* is an important issue for food companies.

According to the relevance of human resource, MES implementation must face with it. Human resources are variable and unpredictable; unlike the automatic equipment, the human workers are not subordinate to mathematical models, at least not with the same precision. This makes their control and management more complex for a software as a MES.

Even if human resources are really important, other kind of resources are used by food companies in order to produce the end products. Machines and automatic equipment in particular, are very common in food industries.

A typical issue about resources is flexibility; a considerable amount of literature can be found about this topic. Koste and Malhotra (1999) made a research in this field summarising lots of previous studies by several scholars. According to Koste and Malhotra (1999) the following definitions of flexibility can be given.

Labour flexibility is the number and heterogeneity (variety) of tasks/operations a worker can execute without incurring high transition penalties or large changes in performance outcomes. Labour flexibility has a really important role in most production processes and affects the overall performance. Process design and managerial polices as cross-training and reward structures can affect labour flexibility reducing transition penalties and motivating employees to be more consistent in work methods.

Machine flexibility is the number and heterogeneity (variety) of operations a machine can execute without incurring high transition penalties or large changes in performance. Transition penalties can be machine changeover time, set up cost, lost production time or scraps due to changeover.

During the last decade, an unprecedented growth primarily among mergers and acquisitions has occurred in food industries; such activities have put more pressure on food manufactures to become more flexible and to consolidate human and material resources. According to Ferrante (1999) food companies are looking toward *automation* to promote greater flexibility and less down time through better maintenance.

A survey on automation practices was carried on by Ilyukhin *et al.* (2001).

The first important result is the confirmation of the widespread utilisation of automations in food industries; in fact, in the majority of the companies, 59%, plants are mostly automated while only in a small 6% they are sparsely automated; the remaining 35% is in a hybrid situation (Fig. 14).

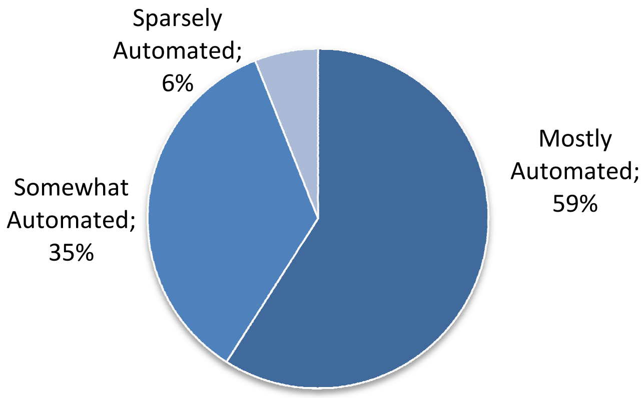


Figure 14. Current level of automation (Ilyukhin *et al.,* 2001).

It seems also that the use of automation systems is bound to grow in the next few years since the 41% of the interviewed companies would like to implement fully automated systems on their facilities over the next five years (Fig. 15). This trend is confirmed by a more recent survey (Higgins 2010), more than the 25% of the respondents said that management is budgeting more funds for capital spending and automation upgrades.

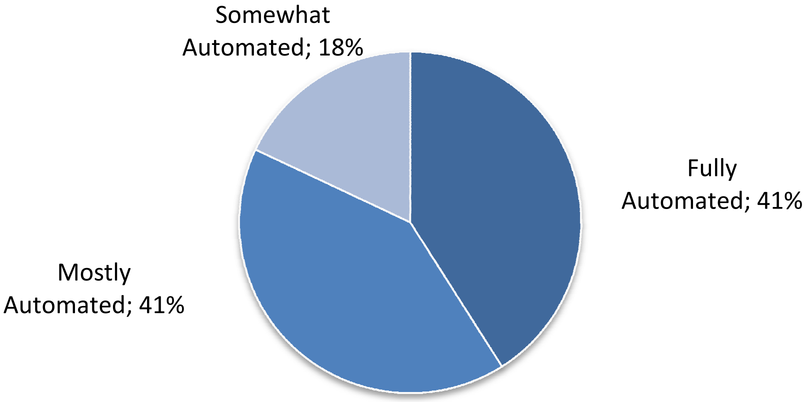


Figure 15. Envisioned level of automation (Ilyukhin *et al.,* 2001).

The survey shows that automation is not uniformly implemented across all the operational range; processing and packaging are the most automated operations, respectively in 94% and 82% of the cases (Fig. 16).

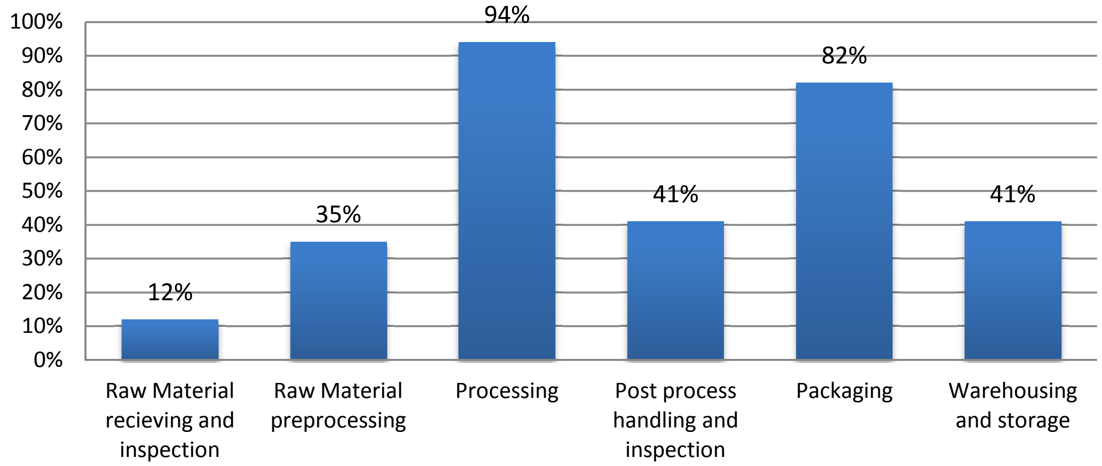


Figure 16. Level of automation in different stages of manufacturing (Ilyukhin *et al.,* 2001).

The less automated operations are those which manage raw materials. This is not surprising since in this part of the process automation is difficult due to the heterogeneity in shape, size and texture of raw food material.

Differences on the implementation of automation systems within food companies are related also to the production volumes. Plants with higher production levels are generally more and better automated than those with lower production volumes. According to the survey, only 25% of the small companies are mostly automated, while within larger plants, the percentage of mostly automated companies reaches 67%.

In spite of these data, the will of automation is stronger on small companies. 75% of the small companies would like to improve their automation level by one step and the left-over 25% would like to increase their automation level by two steps. Within large companies, only 50% want to improve automation by one step and the remaining half of the firms are not interested in automation improvements. Hence, differences in automation levels are not due solely to companies' inclination but to time and cost constraints which are stricter for small plants.

Other issues affect the implementation of automation in food industries as well. According to Wurdermann *et al.* (2011), in order to apply automation and robotics to the food industry, challenges have to be met. One issue is that food products are very diverse and display a wide range in size, texture, weight, susceptibility to damage, color and shape; hence, machines must be flexible in order to handle heterogeneous products. Furthermore, technology aimed at the food sector needs to be cleanable, lightweight, fast to cope with production rates and operate at typically low temperatures. When a complete automation is not possible, or economically convenient, different types of resource are used at the same time; in this case there is *uncertainty about the combination of resource* which performs the best results.

The resource complexity factors pointed out in this chapter are summarised in Table 5. These factors have been used to develop the survey and the framework presented in the chapter VII.

Resource complexity factors
Uncertainty about amount of resources needed
Use of temporary employees
Influence of human workers on end product quality
Labour legislation
Complexity of production equipment
Degree of automation
Uncertainty about combination of resources needed

Table 5. Resource complexity factors.

2. Complexity measurement

As stated above a lot of factors affect resource complexity, but, in spite of its importance aspect for plant management, there is a lack of studies on this topic. No important tools, which focus only on resource, are present in literature so this could be an interesting field for further researches by scholars.

In the following section a framework to measure the static complexity of a plant is explained, this measurement takes a broad view of the plant since it takes into consideration process, product and resource characteristics.

2.1. A measure for static complexity

The following model has been developed by Deshmukh *et al.* (1998). According to this study, in spite of being often used to classify manufacturing planning and control problems, computational and algorithmic complexity don't capture all the aspects of manufacturing system complexity.

The manufacturing environment consists of physical systems in which a series of sequential decisions need to be made in order to produce finished parts. The sequence and nature of these decisions are not only dependent on the system capabilities but also on the products being manufactured in the system. Hence, any measure of system complexity should be dependent on both system and product information (Deshmukh *et al.* 1998).

According to Deshmukh *et al.* (1998), static complexity can be viewed as a function of the structure of the system, the connective patterns, the variety of components, and the strength of their interactions.

2.1.1. Static complexity index

The structure of a manufacturing system is defined by the part flow in the system; the part flow in a manufacturing system is governed by the type of material handling devices being used and by the machine complexity. The variety of sub-systems is determined by the different types of resources and part types in the system. Thus static complexity can be considered as the evaluation of the information needed to describe the system and its components.

Static complexity can be viewed as a result of the following factors:

1) More than one part type being produced in a single production run.
2) Each part type requiring multiple operations.
3) Each operation, for a given part type, having multiple machine or processor options.
4) The set of operations needed to produce a given part type may or may not have precedence constraints.

A static complexity measurement must consider all these factors and their effects; furthermore, it has to satisfy the following conditions:

1) Static complexity should increase with the number of parts, number of machines and operations required in order to produce the part mix.
2) Static complexity should increase with an increase in sequence flexibility of the parts in the production batch.
3) Static complexity should increase as the sharing of resources among parts increases.
4) If the original part mix is split in two or more groups, the complexity of processing should remain constant.

Let $P = (P_1,\dots,P_n)$ be a part mix of n parts and let $Q = (q_1,\dots,q_n)$ be the quantity that has to be produced for each of n parts.

The mix ratio Ψ is calculated for each of n parts as in formula 9:

$$\Psi_i = \frac{q_i}{\sum_{i=1}^{n} q_i} \tag{9}$$

A binary variable, Φ_{ikl}, describes which machines and operations are required by each part; Φ_{ikl} is equal to 1 if part l requires operation i on machine k, Φ_{ikl} is equal to 0 otherwise. Hence, for each part it is possible to write the follow matrix.

$$\Phi_l = \begin{bmatrix} \Phi_{11l} & \cdots & \Phi_{1rl} \\ \vdots & \ddots & \vdots \\ \Phi_{m1l} & \cdots & \Phi_{mrl} \end{bmatrix} \tag{10}$$

Where r represents the total number of machines associated with a given part mix, and m represents the total of operations associated with the given part mix.

The set of processing times, in integer units, is defined as:

$$\Pi = \{\pi_{ijkl}, \forall i \in (1, \dots, m), \forall j \in (1, \dots, m), \forall k \in (1, \dots, r), \forall l \in (1, \dots, n)\} \tag{11}$$

There are two indexes, i and j, for the parts, and this allows considering precedence constraints: if operation i has to precede operation j, π_{ijkl} indicates the processing time of operation i while π_{jikl} is equal to 0; if there aren't any precedence constraints, π_{ijkl} indicates the processing time of operation i while π_{jikl} indicates the processing time of operation j. If Φ_{ikl} is equal to 0, then π_{ijkl} is also equal to 0 for any j.

The Π matrix represents the processing time requirements for a given part, and also the precedence relationships among operations.

Defined

$$\Lambda_{ijkl} = min(1, \pi_{ijkl}) \tag{12}$$

And

$$\hat{\Lambda}_{ijk} = \sum_{l=1}^{n} \Lambda_{ijkl} \tag{13}$$

The value of $\hat{\Lambda}_{ijk}$ represents the number of times a particular operation sequence ($i \rightarrow j$) on machine k is required over all parts. This is a measure of interaction among parts. It measures the similarity of sequences and the sharing of machines for these sequences.

Now, let

$$\hat{\pi}_{ijkl} = \pi_{ijkl} * \Psi_l * \hat{\Lambda}_{ijk} \tag{14}$$

And

$$\hat{\Pi} = \{\hat{\pi}_{ijkl}, \forall i \in (1, \dots, m), \forall j \in (1, \dots, m), \forall k \in (1, \dots, r), \forall l \in (1, \dots, n)\} \tag{15}$$

The set $\hat{\Pi}$ contains the weighted processing times for all the parts. The weight is calculated by the mix ratio of parts and the interaction measure.

Let the normalised processing requirements be defined as:

$$\tilde{\pi}_{ijkl} = \frac{\hat{\pi}_{ijkl}}{\sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{k=1}^{r}\sum_{l=1}^{n}\hat{\pi}_{ijkl}} \tag{16}$$

So $\sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{k=1}^{r}\sum_{l=1}^{n}\tilde{\pi}_{ijkl} = 1$

Defined the set of normalised times as:

$$\tilde{\Pi} = \{\tilde{\pi}_{ijkl}, \forall i \in (1, \dots, m), \forall j \in (1, \dots, m), \forall k \in (1, \dots, r), \forall l \in (1, \dots, n)\} \tag{17}$$

The static complexity H_P for a part mix P is defined as:

$$H_P = -C \sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{k=1}^{r}\sum_{l=1}^{n} \tilde{\pi}_{ijkl} * \log \tilde{\pi}_{ijkl} \tag{18}$$

Where, C is a positive constant corresponding to the unit of measure.

All the information used in this representation can be gathered from the production order and the process plan for individual parts.

Deshmukh *et al.* assume C = 1 and the logarithm to be taken with base 2. Therefore, in accordance with standard notations, the units of H_P are *bits*. Deshmukh *et al.* also define $\log_2 0 = 0$. The measure presented in this paper only considers the interactions between machines or processors and parts to determine the structure of the system. Some auxiliary interactions, such as cutting tools, fixturing devices, material handling devices, and NC part programs can also be included in the static complexity measure by adding dimensions to the Π matrix. The static complexity measure does not consider the effect of multiple part precedence requirements which are encountered in assembly/disassembly operations. The measure presented in this paper is therefore limited to machining or forming operations, where there is no aggregation/disaggregation of parts as they are processed in the system. In addition, the effects of setup times at each processor are not explicitly modelled in this framework. The setup times can be considered as a part of the processing times, if they are sequence independent. However, if the setup times are sequence dependent, then the processing matrix Π needs to be augmented by including two more dimensions for the setup time representation, similarly to the processing time representation in the P matrix.

2.1.2. *Interpreting the model*

This measurement has some interesting characteristics which are significant in the manufacturing environment. Effects on the static complexity index of changes of similarity in processing requirements, system size and products design, and their practical consequences are discussed below.

Dissimilarity between processing requirements is defined as the deviation of elements of $\hat{\Pi}$ matrix from the average value. Two causes can vary $\hat{\Pi}$ elements: the changes in products or processes required to manufacture a given set of products (e.g. the installation of new equipments and process redesign) and changes in customers' demand which alters the part mix ratio.

Let σ_P be the measure of dissimilarity

$$\sigma_P = \frac{\sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{k=1}^{r}\sum_{l=1}^{n}\left(\hat{\pi}_{ijkl} - \bar{\hat{\pi}}\right)^2}{\bar{\hat{\pi}}} \tag{19}$$

Therefore the similarity is $1/\sigma_P$.

The static complexity in the processing of a part mix is the minimum when the similarity (dissimilarity) among the processing requirements is the minimum (maximum); the static complexity associated with a system is the maximum when the similarity (dissimilarity) in the processing requirements is the maximum (minimum). A theoretical limit of complexity exists for each kind of manufacturing technology. In a system with only one machine which can process only one part, the complexity is *log1=0*; the limit of static complexity of a transfer line with *r* machines, in which each machine processes one single operation, is equal to *log r*; for a FMS capable of handling *n* parts and processing a maximum of *m* operations each on *r* machines with flexible routings, the upper limit of complexity is $log\ m^2rn$; a job shop system is a between the two cases. Consequently: $(H_p)_{transfer\ line} <= (H_p)_{job\ shop} <= (H_p)_{FMS}$.

What stated above seems to raise group technology theory, since grouping products based on process similarity increases static complexity. It should be noted that grouping techniques decompose the entire part set into smaller sets of parts, thus decreasing the complexity.

The number of parts, machines and operations associated with the part mix influences the size of the normalised processing matrix $\widetilde{\Pi}$. The addition or removal of each element corresponds to a change in the size of $\widetilde{\Pi}$ matrix; the smaller the system is, the higher the effect of increasing the number of parts, operations or machines, will be.

Independent dimension of $\widetilde{\Pi}$ have sub-synergetic influence on H_p.

Products design influences static complexity since it affects the elements of $\widetilde{\Pi}$ matrix. Changes on raw materials, products designs or process improvements are typical in a manufacturing environment, and therefore designers, who usually have limited resources, should focus on improving those changes which have the best impact, that means choosing the modification which most reduces the complexity.

The elements of the $\widetilde{\Pi}$ matrix have sub-synergetic effect on H_p.

Static complexity increases as the number of machines, the variety of components in the system and their interaction increase. Static complexity is worth increasing only if that allows improving the overall performance of the system.

The model emphasizes how all process, product and resource characteristics contribute to complexity. All these aspects must be considered and focusing in only one of them do not give the right idea of the plant complexity. In the proposed framework all the three aspects are examined and, according to Azzi *et al.* (2011), also resources are studied in order to obtain a more complete complexity measurement.

Furthermore this model state that different production environments have different complexity ($(H_p)_{transfer\ line} <= (H_p)_{job\ shop} <= (H_p)_{FMS}$); this aspect must be taken into consideration, for this reason the type of production process is asked in the survey.

CHAPTER 7. A NEW FRAMEWORK TO MEASURE PLANT COMPLEXITY

None of the measurements proposed in the previous chapters takes into consideration all the complexity factors of a food plant that have been singled out by the literature; the aim of the thesis is to develop a measurement system which looks at all the aspects of a food plant.

Starting from the conceptual framework developed by Azzi *et al.* (2011), a new approach to measure plant complexity in food supply chains is here proposed by the author.

First, in order to evaluate the importance of the different complexity factors for the real firms, a survey was carried out.

1. Survey on plant complexity

Objectives, structure and results of the survey are discussed below.

1.1. Survey objectives

Once the complexity factors have been identified in the literature, the question is to understand how influential these factors actually are for the food industries. In order to get this kind of information, several companies were asked to answer a questionnaire. This questionnaire allows making a survey on the real importance of the theoretical factors on the everyday practice.

The results of the survey have been used to develop the framework to measure the complexity of a plant, which is presented in the second part of this chapter.

The questionnaires have been handed out to the plants managers of food companies since they are supposed to have a complete view on all the aspects of the plant and not just on very few aspects such as production, marketing, human resource, etc.

1.2. Survey structure

Malhotra and Grover (1998) have stated that there are three characteristics which are typical of survey research and differentiate it from other kinds of survey. First, information is gathered by a sample, so the findings must be generalized from the sample to the entire population. Second, information is collected by asking questions in some structured way. Last but not least, a survey research is commonly a quantitative method, which asks for information in order to define or describe variables, or to investigate the relationship between variables.

The last point reveals the two possible goals of a survey research, which Kerlinger (1986) has classified as exploratory and explanatory.

The objective of an exploratory research is to become more familiar with a topic; in this case theoretical models are not needed. An exploratory survey is useful to determine, for example, the benefits that may be associated with the adoption of MRP systems. This kind of research can also aim to describe the distribution of a phenomenon in a population.

In contrast, the objective of an explanatory research is finding the existence of causal relationships between variables. Theory-based constructs on how and why variables should be related with each other are needed. A typical goal of an explanatory research is finding if there is a positive relationship between the implementation of MRP systems and the improvement in materials management.

The survey carried out for this Master thesis can be labeled as an exploratory research, since its goal is to understand the importance of each factor of complexity; no relationship between them is sought so no theoretical model is required.

In order to make the questionnaire more user friendly, the questions have been grouped in five clusters.

In the first group some general information about the plant is collected, like the country where the plant is situated, the type of products and the number of employees. A request of information about the type of production processes and the type of fulfillment strategies completes the first part of the questionnaire. These information allow to group the answered questionnaire by different type of characteristics and identified possible differences on complexity feels among different type of plants.

The other four parts concern the four aspects of complexity pointed out by Azzi *et al.* (2011): process, product, order and resource. In each section of the questionnaire, the respondent has to indicate how each of the factors picked out in the previous chapters affects the complexity.

A scale from 1 to 5 has been established in order to measure the importance of each factor according to the manager, with the following scale values: 1 = Unimportant, 2 = Slightly important, 3 = Important, 4 = Very important and 5 = Critical.

According to Meric and Wagner (2006), whether that verbal descriptions are used only at end points or at every scale point, it may affect the distribution of the collected data either way. The good practice is to assign a label or number to each rating scale; in the mentioned questionnaire, the meaning of each values of the rating system is explained in each section and the values corresponding to the boxes which have to be ticked are shown at the top of each column.

The full questionnaire is attached in appendix A.

1.3. Survey results

The sample is constituted by three food companies which made different type of products. The first is a brewery, the second is a confectionary industry and the third is a feed raw producer. In order to obtain more reliable results a larger sample would be needed.

Grouping the respondents by the type of product, the relevance of each problem in the different sectors can be identified. The same grouping can be done by the type of production strategies or other dimensions. This aspect can be interesting for the framework implementation because it can make the tool customisable, an opportunity that will be deeply analysed in the next section.

In spite of the limited sample size, some useful information can be drawn from the survey in any case.

Number of set-ups and set-up time seem the two most critical issues since their influence on process complexity is considered to be really problematic by managers. The average rate of the answers to this question is 4.3333; the standard deviation is one of the lowest, only 0.5773; that means that this problem is perceived in similar ways by all the companies.

The seasonal availability and heterogeneity of raw materials are also quite relevant. The rate is 4 in both the questions; the standard deviation is 1.7321, and that means that this issue is perceived in different ways by companies. It is probably linked to the type of raw material being used, so it can be related to the end products that the company realizes.

All the aspects are classified as at least "slightly important" for the companies; the value 1 has been used only in six of the total ninety-three answers, just a bit more than the six percent.

The results of the survey are summarized in Table 6.

Question	Average	St.Dev.
Process		
Number of different processes	2.6667	1.1547
Technical constraints of processes	3	1
Specificity of process	3.6667	1.5275
Differences among different processes	3	1
Number of process steps	2.3333	0.5773
Number of critical control points	2.3333	1.5275
Number of set ups	4.3333	0.5773
Time for set ups	4.3333	0.5773
Seasonal availability of raw materials	4	1.7321
Heterogeneity of raw materials	4	1.7321
Number of different equipment	2.3333	0.5773
Sector legislation	2.6667	2.0817
Product		
Limited shelf-life	3.6667	0.5773
Customization level required	2.6667	0.5773
Specific storage conditions	3.6667	1.5275
Differences among different products	3.6667	0.5773
Sector legislations	3.3333	2.0817
Reliance on environmental/climate events	3	1
Customer concerns on food safety	3.6667	2.3094
Order		
Number of costumers/deliver points	3	1
Customization level required	3	1
Market segmentation	3	1
Reliance on environmental/climate events	3	1
Misalignment between agricultural production time and consumer demand	2.6667	2.0817
Resource		
Influence of human workers on end product quality	3.3333	1.1547
Use of temporary employees	2.3333	0.5773
Complexity of production equipment	2.6667	0.5773
Uncertainty about volume of resources needed	2.3333	0.5773
Uncertainty about combination of resources needed	2.3333	0.5773
Labour legislation	2.3333	1.5275
Degree of automation	3	1

Table 6. Survey results.

2. A new framework to measure plant complexity

In this section a new framework to measure plant complexity is shown; some information on the theoretical background and on the possible field of utilisation is also presented.

2.1. Framework for plant complexity measurement

The main idea is further improve the theoretical framework proposed by Azzi *et al.* (2011) changing it from a qualitative to a quantitative tool.

The new framework has been developed using Microsoft Excel® in order to make it as user-friendly as possible; according to Thiriez (2004) the better user acceptance of a MS Excel® tool is caused by the availability of MS Excel® on most computers and by the fact that the user can see, at least partially, how the model works, which makes her/him feel closer to the model and less reluctant to actually use it.

Every complexity factor found in the literature, and explained in the previous chapters, is taken into consideration; they are grouped by four main aspects: process, product, order and resource. The complexity factors of process, product, order and resource are summarised respectively on tables 2, 3, 4 and 5.

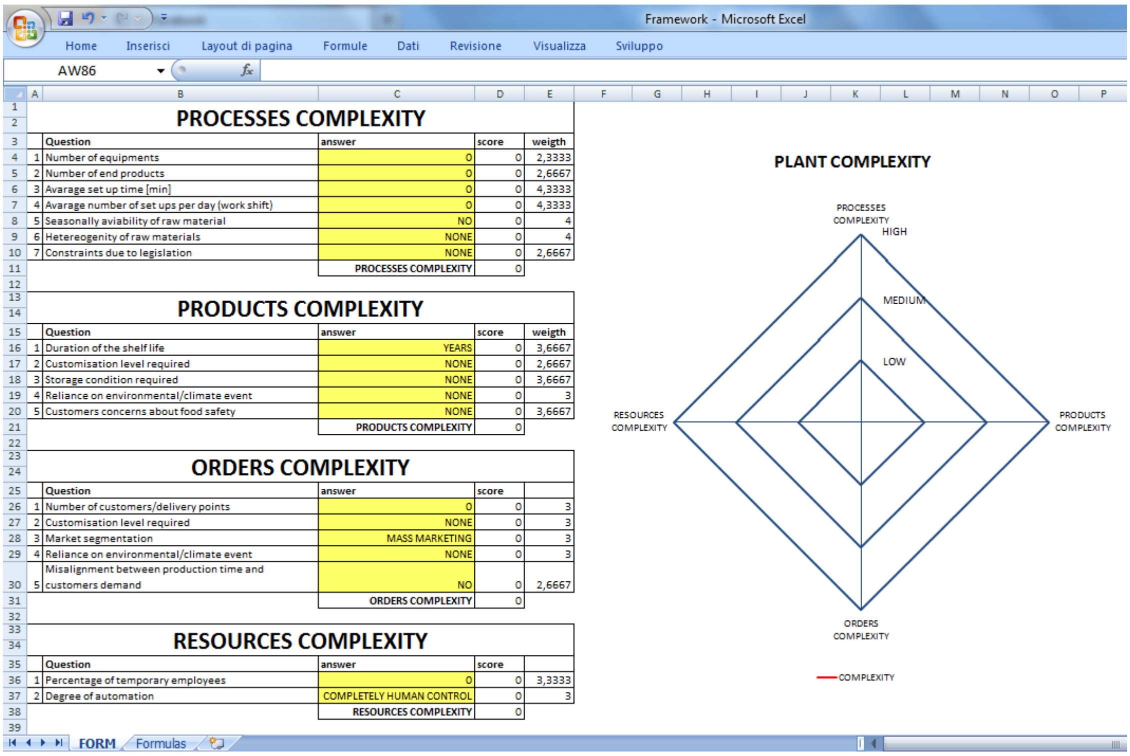
The research has revealed that some overlaps among the 4 dimension exist, and the boundaries are not always clear and easily definable. This is due to some interconnections between the dimensions, for example: processes are linked to the types of product done and resources affect the way how a process is performed and are chosen according to the kind of product they have to process. Process, product, order and resource are not independent, but they are four different aspects of the same company and they must to be coherent to obtain good results. Despite that, the factors of complexity identified in the previous chapters are specific for the four main aspects. Therefore independent measure of complexity can be calculated for each one of the four aspects.

The framework is composed by 2 sheets. In the first one, named “FORM” (Fig. 18), there is the form which has to be filled by the users and a radar diagram which sums up the results. In the second one, named “Formulas” (Fig. 19), there are the possible answers to the questions of the first sheet and the formulas to calculate complexity according to users’ answers.

In chapters III, IV and VI, some models to measure complexity have been analysed, none of them gives a complete view of the problem and none of them is specific for the food supply chain context. Therefore a new model is proposed for this framework; considering all the factors it gives a complete idea of the complexity.

There are three different kinds of questions in the form: yes/no questions, multiple choice, or numerical. Hence, three different models have been developed to manage each different type.

Yes/no questions are evaluated with a binary criterion: the value is 1 if the complexity element is present (the user chooses the alternative “YES”), otherwise 0. An example is the element “seasonality availability” within the “process complexity” group: complexity due to seasonality availability is 1 if there is seasonality availability, otherwise 0.



PROCESSES COMPLEXITY

	Question	answer	score	weigth
1	Number of equipments	0	0	2,3333
2	Number of end products	0	0	2,6667
3	Avarage set up time [min]	0	0	4,3333
4	Avarage number of set ups per day (work shift)	0	0	4,3333
5	Seasonally aviability of raw material	NO	0	4
6	Hetereogenity of raw materials	NONE	0	4
7	Constraints due to legislation	NONE	0	2,6667
		PROCESSES COMPLEXITY	0	

PRODUCTS COMPLEXITY

	Question	answer	score	weigth
1	Duration of the shelf life	YEARS	0	3,6667
2	Customisation level required	NONE	0	2,6667
3	Storage condition required	NONE	0	3,6667
4	Reliance on environmental/climate event	NONE	0	3
5	Customers concerns about food safety	NONE	0	3,6667
		PRODUCTS COMPLEXITY	0	

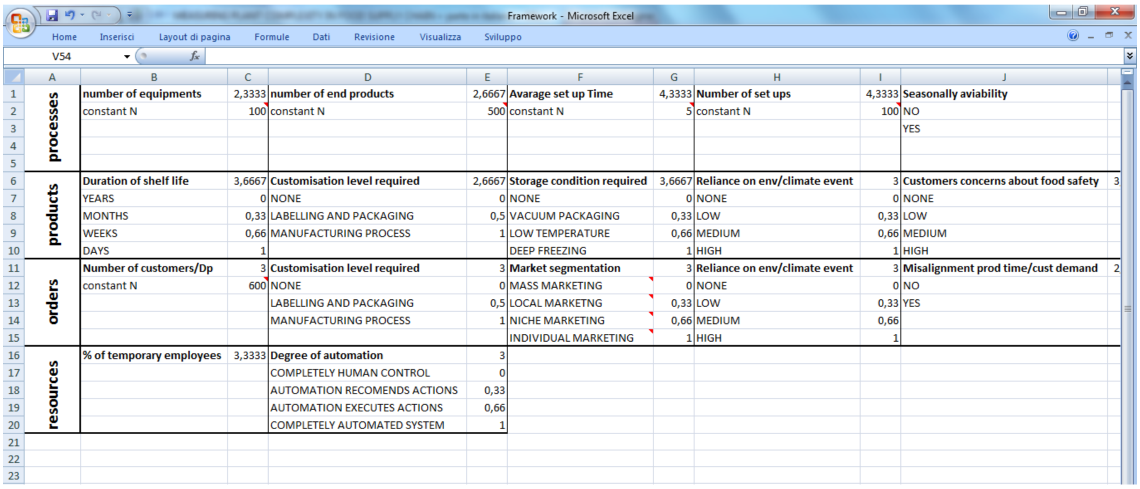
ORDERS COMPLEXITY

	Question	answer	score	
1	Number of customers/delivery points	0	0	3
2	Customisation level required	NONE	0	3
3	Market segmentation	MASS MARKETING	0	3
4	Reliance on environmental/climate event	NONE	0	3
5	Misalignment between production time and customers demand	NO	0	2,6667
		ORDERS COMPLEXITY	0	

RESOURCES COMPLEXITY

	Question	answer	score	
1	Percentage of temporary employees	0	0	3,3333
2	Degree of automation	COMPLETELY HUMAN CONTROL	0	3
		RESOURCES COMPLEXITY	0	

Figure 17. Screenshot of the sheet “FORM” of the framework.



	A	B	C	D	E	F	G	H	I	J	
1	processes	number of equipments	2,3333	number of end products	2,6667	Avarage set up Time	4,3333	Number of set ups	4,3333	Seasonally aviability	
2		constant N	100	constant N	500	constant N	5	constant N	100	NO	
3										YES	
4											
5											
6	products	Duration of shelf life	3,6667	Customisation level required	2,6667	Storage condition required	3,6667	Reliance on env/climate event	3	Customers concerns about food safety	3
7		YEARS	0	NONE	0	NONE	0	NONE	0	NONE	
8		MONTHS	0,33	LABELLING AND PACKAGING	0,5	VACUUM PACKAGING	0,33	LOW	0,33	LOW	
9		WEEKS	0,66	MANUFACTURING PROCESS	1	LOW TEMPERATURE	0,66	MEDIUM	0,66	MEDIUM	
10		DAYS	1			DEEP FREEZING	1	HIGH	1	HIGH	
11	orders	Number of customers/Dp	3	Customisation level required	3	Market segmentation	3	Reliance on env/climate event	3	Misalignment prod time/cust demand	2
12		constant N	600	NONE	0	MASS MARKETING	0	NONE	0	NO	
13				LABELLING AND PACKAGING	0,5	LOCAL MARKETNG	0,33	LOW	0,33	YES	
14				MANUFACTURING PROCESS	1	NICHE MARKETING	0,66	MEDIUM	0,66		
15						INDIVIDUAL MARKETING	1	HIGH	1		
16	resources	% of temporary employees	3,3333	Degree of automation	3						
17				COMPLETELY HUMAN CONTROL	0						
18				AUTOMATION RECOMENDS ACTIONS	0,33						
19				AUTOMATION EXECUTES ACTIONS	0,66						
20				COMPLETELY AUTOMATED SYSTEM	1						
21											
22											
23											

Figure 18. Screenshot of the sheet “formulas” of the framework.

For multiple choice questions, the possible answers are listed on the sheet “Formulas” and a level of complexity, from 0 to 1, is associated to each possible answer. When the respondent fills the form she/he can choose among the alternatives by a drop-down menu; then the complexity value is transferred according to the values in the sheet “Formulas”. An example is the issue “Duration of shelf life”. For this topic four possible solutions are available: “years, months, weeks, days”, and the values of complexity are 0, 0.33, 0.66 and 1 respectively. The alternatives have been chosen according to the literature, and the relative rates have been fixed according to the assumption that complexity increases from the simplest situation (complexity index equal to 0) to the most complex one (complexity index equal to 1).

The complexity value for numerical questions is calculated by hypothesizing a direct relation between the answer given by the user and the complexity value. The relation is shown below:

$$C = \left(1 - e^{-n/N}\right) \tag{20}$$

Where C represents the value of complexity, n is the number written in the form by the user and N is a constant. The upper boundary of this formula is 1 and the lower is 0, so the results are comparable with the values of the others kinds of questions. According to the N constant, the slope of the curve described by the formula (20) varies (Fig. 19); when n is equals to N, the value of complexity is around 0.63. Therefore the choice of the N value is really important in order to obtain reliable results.

The values of *Ns* in the framework are chosen according to the expected range of answers; the expected ranges are based on both literature and case studies. It is possible to configure the tool for a specific kind of plants choosing the corrects values of *Ns*.

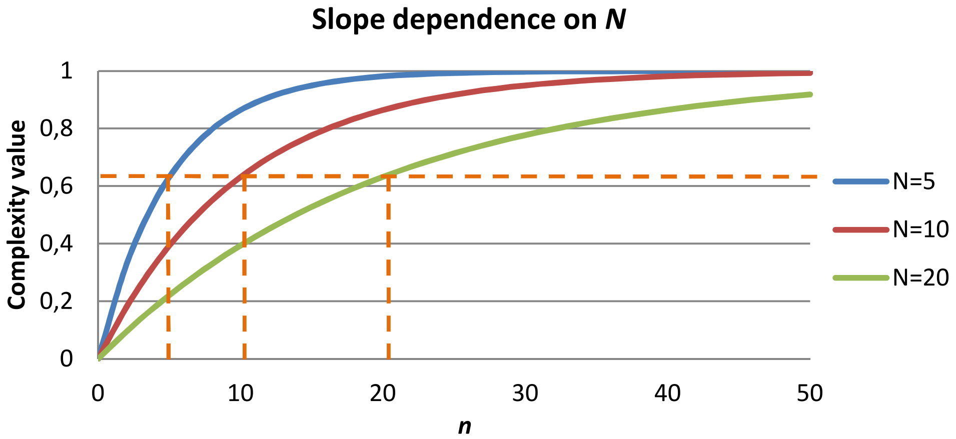


Figure 19. Slope dependence on *N*.

The overall complexity for each section is calculated by a weighted average among the values. The weights used indicate the importance of the complexity factors obtained by the survey. Thus, the contribution of each factor is related to the importance which that factor has for the companies.

A radar diagram similar to the one proposed by Azzi *et al.* (2011) gives a visual idea of the results. It is composed of 4 axes, one for each main aspect (product, process, order, and resource); the weighted average for any of them is calculated and shown in the correspondent axis of the radar diagram and a red line indicates the level of complexity of the analyzed case.

An example of a complexity calculation is shown below (Fig. 20).

The graphic interface of the form is shown as an attachment to the appendix B; the complete form is in attachment in the CD as framework.xlsx.

The framework is customizable since it can be adapted to the specific cases by changing the values of parameters in the “Formulas” sheet. The values of the alternatives and the relevance of each question can be adapted in order to fit better with a more detailed field of utilization, e.g. breweries, frozen food producers and so on.

Even if it has been developed for food industries, this framework can be configured in order to measure the complexity of a plant of other businesses just modifying the values on the sheet “Formulas”.

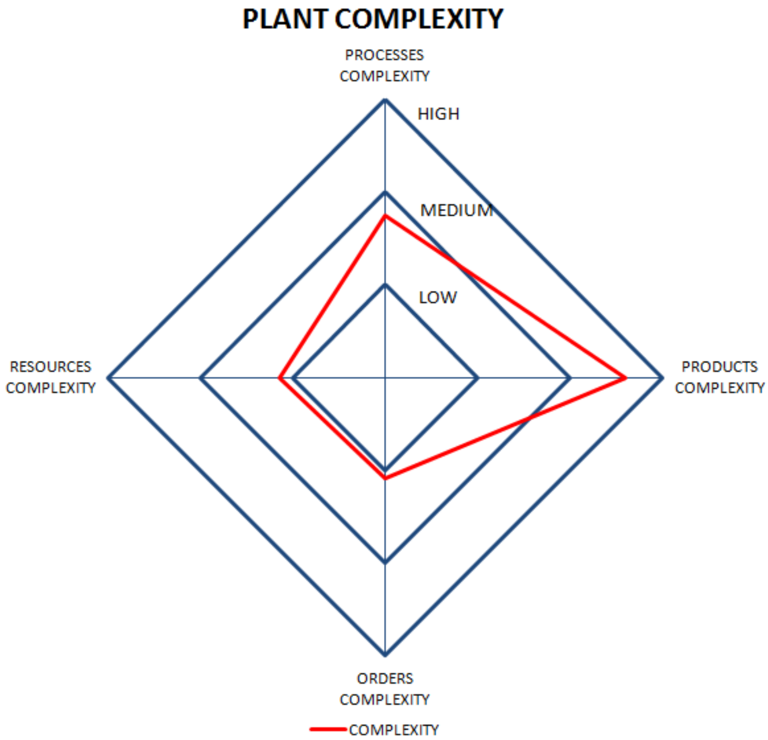


Figure 20. Example of complexity evaluation.

2.2. Field of utilisation

Two main applications are devised for the framework.

Managers can use it in order to evaluate how complex implement a MES system in their plants would be and which issues most affects the adoption of such a system. In order to do that, managers just have to fill the form with the characteristic values of the company. Once a manager knows how and why the implementation of the MES will be hard he can choose the best solution for the company by comparing costs and benefits.

This tool can be used by consultants as well. A consultant who is required to install a MES system into a customer's company can use the framework in order to evaluate how complex this implementation will be, and for which reasons, so that she/he can more precisely estimate the cost of the MES system implementation in every specific case and which is the best way to implement the MES, for example choosing between a systematic complete implementation and a focused implementation on the more critical point.

CHAPTER 8. CONCLUSIONS

1. Conclusions

Food supply chains, and food-manufacturing companies, are different from supply chains and companies which fulfil other kinds of products. The peculiarities of the products that they manage increase the level of complexity of the plants. Several factors can affect the complexity of a plant; and these are pointed out and discussed through chapter III to chapter VI.

The implementation of a Manufacturing Execution System (MES) allows to manage this situation but the more complex the environment is, the more problematic the implementation of a MES can eventually be, even if its benefits will be higher. Azzi *et al.* (2011) have presented a methodological framework which relates the difficulty of a MES implementation to the complexity of a plant in food supply chain. Four main aspects must be taken into consideration: process, product, order and resource.

The aim of the thesis was to further improve and quantify that framework in order to use it to measure the complexity of the plants. Some models to measure such complexity have been explained in chapters III, IV and VI. None of them cover all the complexity factors of a food-manufacturing plant, thus a new model has been proposed.

A survey has been carried in order to evaluate how each factor affects the plant complexity according to the real-world. The questionnaire asks plant's managers to evaluate how each factor affects the complexity and some useful information has been gathered: the number of set-ups, set-up time, seasonal availability and the heterogeneity of raw materials are the issues that most trouble managers. Differences among plants which produce different type of finish products have been identified according to the survey.

The proposed framework takes into consideration all the complexity factors pointed out by the academic literature and the results of the survey. It is based on the methodological framework developed by Azzi *et al.* (2011), and the results are summarised in a radar-diagram similar to the one they proposed.

The user of the framework has to answer questions on each of the complexity factors. Answers can be YES/NO, multiple choice or numerical. Not all the questions have the same relevance, which is why the answers are weighted according to the survey results.

According to the user's answers the complexity of the four main aspects is calculated automatically and shown both in the form and in the radar diagram. The radar-diagram gives to the user a visual idea about which of the main aspects can be more problematic for the implementation of the MES.

2. Further improvements

The proposed framework, before being used for its goals, needs to be tested in both case studies and real cases in order to improve it. The type of alternatives and their relative complexity values should be deeply analysed according to the real experience as well as to the literature. Thus, values on sheet "Formulas" can be refined in order to obtain a more accurate tool.

The relevance of each question could also be better evaluated extending the survey to a greater number of companies.

Besides presenting more trustworthy results, a broader sample also would allow to group information and results according to type of products and/or other types of information available from the survey (e.g. number of employees, type of production system, etc.). This give the chance to make the framework customisable: different set of values in the sheet "Formulas" can be chosen according to aspects such as the type of end products offered by a specific company or the type of production process etc. Customisation would be an important characteristic for that tool since different issues and needs exist among different users.

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APPENDIX A. SURVEY ON PLANT COMPLEXITY

Thank you for taking the time to complete this survey by Marco Perotto, Master student at the Technical University of Denmark. This survey should take less than 5 minutes of your time. Your answers will be completely anonymous and all the data will be used only for this survey.

The aim of this survey is to understand which factors influence the complexity of a specific production system in the food industry.

You are asked to rate a series of factors on a scale from 1 to 5 (1 means Unimportant, 5 means Critical).

The included factors are built upon a number of related research projects. The survey contains four groups of factors: Processes, Products, Resources and Orders.

Please, as you answer at all the questions save the file as PDF and send it back at s111713@student.dtu.dk, for any question about the questionnaire write me at the same email address.

Before starting please answer the following general questions

Country:

Type of products:

Number of employees: , of which work on the production floor

Type of the production process:
- ☐ Job shop
- ☐ Batch production
- ☐ Batch production controlled by bottleneck
- ☐ Production line

Type of fulfilment strategy:
- ☐ Mainly order driven
- ☐ Mainly forecast driven

PROCESSES

Evaluate how the following aspects affect the complexity of the processes in your plant, giving a score from 1 to 5 according to the following scale of values:

1 = Unimportant

2 = Slightly important

3 = Important

4 = Very important

5 = Critical

		1	2	3	4	5
PC1	Number of different processes	☐	☐	☐	☐	☐
PC2	Technical constraints of processes	☐	☐	☐	☐	☐
PC3	Specificity of process	☐	☐	☐	☐	☐
PC4	Differences among different processes	☐	☐	☐	☐	☐
PC5	Number of process steps	☐	☐	☐	☐	☐
PC6	Number of critical control points	☐	☐	☐	☐	☐
PC7	Number of set ups	☐	☐	☐	☐	☐
PC8	Time for set ups	☐	☐	☐	☐	☐
PC9	Seasonal availability of raw materials	☐	☐	☐	☐	☐
PC10	Heterogeneity of raw materials	☐	☐	☐	☐	☐
PC11	Number of different equipment	☐	☐	☐	☐	☐
PC12	Sector legislation	☐	☐	☐	☐	☐

PRODUCTS

Evaluate how the following aspects affect the complexity of the products in your plant, giving a score from 1 to 5 according to the following scale of values:

1 = Unimportant

2 = Slightly important

3 = Important

4 = Very important

5 = Critical

		1	2	3	4	5
PD1	Limited shelf-life	☐	☐	☐	☐	☐
PD2	Customization level required	☐	☐	☐	☐	☐
PD3	Specific storage conditions	☐	☐	☐	☐	☐
PD4	Differences among different products	☐	☐	☐	☐	☐
PD5	Sector legislations	☐	☐	☐	☐	☐
PD6	Reliance on environmental/climate events	☐	☐	☐	☐	☐
PD7	Customer concerns on food safety	☐	☐	☐	☐	☐

ORDERS

Evaluate how the following aspects affect the complexity of the orders in your plant, giving a score from 1 to 5 according to the following scale of values:

1 = Unimportant

2 = Slightly important

3 = Important

4 = Very important

5 = Critical

		1	2	3	4	5
OR1	Number of costumers/deliver points	☐	☐	☐	☐	☐
OR2	Customization level required	☐	☐	☐	☐	☐
OR3	Market segmentation	☐	☐	☐	☐	☐
OR4	Reliance on environmental/climate events	☐	☐	☐	☐	☐
OR5	Misalignment between agricultural production time and consumer demand	☐	☐	☐	☐	☐

RESOURCES

Evaluate how the following aspects affect the complexity of the resources in your plant, giving a score from 1 to 5 according to the following scale of values:

1 = Unimportant

2 = Slightly important

3 = Important

4 = Very important

5 = Critical

		1	2	3	4	5
RS1	Influence of human workers on end product quality	☐	☐	☐	☐	☐
RS2	Use of temporary employees	☐	☐	☐	☐	☐
RS3	Complexity of production equipment	☐	☐	☐	☐	☐
RS4	Uncertainty about volume of resources needed	☐	☐	☐	☐	☐
RS5	Uncertainty about combination of resources needed	☐	☐	☐	☐	☐
RS6	Labour legislation	☐	☐	☐	☐	☐
RS7	Degree of automation	☐	☐	☐	☐	☐

APPENDIX B. FRAMEWORK

PROCESSES COMPLEXITY

	Question	answer	score	weigth
1	Number of equipments	0	0	2,3333
2	Number of end products	0	0	2,6667
3	Avarage set up time [min]	0	0	4,3333
4	Avarage number of set ups per day (work shift)	0	0	4,3333
5	Seasonally aviability of raw material	NO	0	4
6	Hetereogenity of raw materials	NONE	0	4
7	Constraints due to legislation	NONE	0	2,6667
		PROCESSES COMPLEXITY	0	

PRODUCTS COMPLEXITY

	Question	answer	score	weigth
1	Duration of the shelf life	YEARS	0	3,6667
2	Customisation level required	NONE	0	2,6667
3	Storage condition required	NONE	0	3,6667
4	Reliance on environmental/climate event	NONE	0	3
5	Customers concerns about food safety	NONE	0	3,6667
		PRODUCTS COMPLEXITY	0	

ORDERS COMPLEXITY

	Question	answer	score	
1	Number of customers/delivery points	0	0	3
2	Customisation level required	NONE	0	3
3	Market segmentation	MASS MARKETING	0	3
4	Reliance on environmental/climate event	NONE	0	3
5	Misalignment between production time and customers demand	NO	0	2,6667
		ORDERS COMPLEXITY	0	

RESOURCES COMPLEXITY

	Question	answer	score	
1	Percentage of temporary employees	0	0	3,3333
2	Degree of automation	COMPLETELY HUMAN CONTROL	0	3
		RESOURCES COMPLEXITY	0