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Review

Trends in food packaging and manufacturing systems and technology

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In today's world of global markets and stiff competition in every product along with increasing consumer demand, it becomes imperative for companies to explore ways to improve their productivity in terms of maintaining safety, using sustainable packaging materials, implementing flexible and standardized technology, and adopting proven management principles. In this paper, we look into the state-of-the-art in the food processing and packaging industry in the light of recent advancements in the fields of (i) smart packaging and materials including the application of nanoscience and technology, (ii) automation and control technology, standards, and their application scenarios, and finally (iii) production management principles and their improvements for the food industry. A comprehensive review on the above and related areas is presented in appropriate order. From the survey of literature, it is clear that although researchers have focused on individual aspects of the processing, packaging, and manufacturing, there is need for a more holistic approach to system analysis while understanding the scope of the entire operations. We conclude that it is imperative to investigate why the practical implementations of these advancements seem to lag behind research in the field.

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Introduction

In today's world of global markets and stiff competition in every product, it becomes necessary for companies to explore ways to improve their productivity in terms of maintaining safety, using sustainable materials in packaging, implementing flexible and standardized technology, and adopting proven management principles (Cheruvu, Kapa, & Mahalik, 2008). Towards this end, companies have been striving to improve the efficiencies of their operations through improvements in the processes. Reducing wastes and shortening lead times becomes all the more imperative in the food industry due to the perishable nature of the product. Moreover, recent advances in technology such as Radio Frequency Identification (RFID) and nanomaterials afford companies greater opportunities to streamline the processing, packaging, and manufacturing schemes (Nambiar, 2009).

Visualizing the above, this paper presents a comprehensive review of processing, packaging and manufacturing aspects of food industry. There are a lot of similarities between the food processing and packaging industry and the traditional manufacturing industry. Hence, manufacturing concepts like lean principles, production systems and mass customization principles can easily be applied to the food industry as well. Even though researchers have focused on applying these techniques to the food industry, there seems to be a gap between research and its implementation in the industry. Arora and Kempkes (2008) make a case for continued collaboration between academic and industry in order to bridge the yawning gap between research in the field of food processing technologies and its implementation in the industry. In this work, we look into the trends as well as the state-of-the-art in food processing and packaging industry with emphasis on the materials, machines and methods used in the industry that provide companies with a competitive edge in the marketplace. The paper has three parts. In the first part we present the essence of the smart packaging and show how the associated materials play major role in this respect. The next section deals with the trends in automation and control schemes along with usage of latest technology. The final section reviews the proven principles of productivity-oriented management strategies and the relevant work of the researchers in relation to food industry.

Processing and packaging

Processing and packaging are the two important phases of operations in the food industry. Processing also includes preprocessing and cleaning which sometimes is referred to as post harvesting processes. The final phase is the packaging stage. A great deal of automation strategies are constantly being utilized in every phase of processing and packaging. Traditional processing principles are based on thermal processing where the combination of temperature and time plays a significant role in eliminating the desired number of microorganisms from the food product without compromising its quality. Optimization of thermal techniques (e.g. aseptic processing and ohmic and air impingement heating) is a measure of effectiveness and efficiency. Non-thermal processing methods such as PEF (Pulsed Electric Field), UV (Ultraviolet), and Ozone yield products with more 'fresh-like' flavor than those produced by traditional thermal processes due to fewer chemical and physical changes although they are not completely effective in reducing the activity of bacterial spores (Dunne & Kluter, 2001). Since there is an abundance of literature dealing with the above scientific techniques and methods, we prefer to concentrate on trends in packaging and materials.

Materials

Papers and clothes are flexible, lightweight, less waste-to-discard packaging materials. Glass and metals have been used for high-value products and are corrosion resistant and stronger, respectively. Polymers (plastics) exhibit many desirable features like transparency, softness, heat seal ability and good strength to weight ratio (Bohlmann, 2006). Further, their extensive uses in packaging (approximate annual world production-200 MT; average per capita consumption-100 kg) are due to low cost and efficient mechanical properties such as tear and tensile strength as well as good barrier to oxygen and thermal seal ability. The most commonly used plastics in packaging industry are based on petro chemical products such as polyethylene terephthalate (PET), poly vinyl chloride (PVC), polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyamide. However, they cause adverse effect (neither totally recyclable nor biodegradable) to the environment causing risk to human health or ecosystems. Moreover, consumption of fossil fuels (over 99% of plastics are of fossil fuel origin), environmental pollution (White Pollution), landfill depletion (high volume to weight ratio), the high energy use in the manufacturing process, and the diffusion of polymers and the additives into food materials are some of the serious issues faced by the present packaging industry and hence in recent times, there has been a shift towards increased usage of biodegradable materials. The Sustainable Packaging Alliance (SPA) in 2002 in Australia, for example, has already taken steps in formulating integrated, multi-dimensional ways to research and development for packaging applications. The SPA focuses on various factors including effectiveness, efficiency, recyclability, and safety. These mean that for sustainability the packaging systems are to be designed to use energy and materials efficiently in interaction with interrelated support systems like transportation, handling and storage throughout the product cycle. In order to minimize the material degradation and the use of upgrading additives, packaging materials are to be cycled constantly either through natural or technical systems.

Biodegradable material for packaging

There is an increasing demand for identifying biodegradable packaging materials and finding innovative methods to make plastic degradable. Biodegradation is the process by which carbon-containing chemical compounds are decomposed in the presence of enzymes secreted by living organisms. The use of bioplastic is to replicate the life cycle of biomass by conserving the fossil fuels, carbon dioxide and water production. There are three requirements for the fast degradation process *viz*. temperature, humidity and type of microbes. The global market for biodegradable polymers exceeds 114 million pounds and is expected to rise at an average annual growth rate (AAGR) of 12.6% to 206 million pounds in 2010 (Aruas, Harte, & Selke, 2003; Schlechter, 2005).

Acceptable bioplastics are listed below (Chandra & Rustgi, 1998; Griffin & Turner, 1978; James, Fitzpatrick, Lewis, & Sonneveld, 2005; Jamshiddi, Hyon, & Ikada, 1988; Park, Lim, Shin, & Choi, 2001; Plastics Task Force, 2008).

- Cellulose: cellulose is isolated from its crystalline state in microfibrils by chemical extraction. It is fusible and soluble in hydrogen bond-breaking solvents such as N-methylmorpholine-N-oxide. Because of its infusibility and insolubility to others, its derivatives can also be used to make it more processable. This property is exploited for packaging applications.
- Starch: starch normally consists of a mixture of 20–30% amylose and 70–80% amylopectin. Biodegradation of starch-based polymers is due to enzymatic attack at the glycosidic linkages between the sugar groups, leading to a reduction in chain length and splitting out of lower molecular weight sugar units. As regards to its application in biodegradable plastics it is either physically mixed with its native granules or melted and blended on a molecular level with the appropriate polymer.
- Poly-beta-hydroxyalkanoates (PHB): PHB, a member of poly hydroxyl alkanoates, degrades under the presence of various microorganisms which upon contact with the polymer secrete enzymes that break the polymer into smaller parts. The three most unique properties of PHB are (i) 100% resistance to water, (ii) 100% biodegradability, (iii) thermoplastic process ability.
- Polylactide Acid (PLA) plastics: PLA is emerging as one of the most attractive packing material because of its excellent biodegradability, process ability, and biocompatibility. PLA, a thermoplastic, is processed by injection molding, blow molding, thermoforming, and extrusion. Its degradation is dependent on time, temperature, low-molecular weight impurities, and catalyst concentration. PLA films have better ultraviolet light barrier properties

than low density polyethylene (LDPE). It has lower melting and glass transition temperatures. PLA is mainly composed of lactic acid (2-hydroxy prop ionic acid) and contains pendent methyl group on the alpha carbon atom which gives rise to a specific structures. This in turn increases the molecular weight and when sufficiently high it becomes insoluble in water.

Smart packaging

A package can be made smart through its functional attributes that add benefits to the food and hence the consumers. It is essentially an integrating method that deals with mechanical, chemical, electrical and/or electronically-driven functions that enhance the usability or effectiveness of the food products in a proven way. Some of the aspects of smart packaging are time-temperature food quality labels, usage of self-heating or self-cooling containers with electronic displays indicating use-by dates and information regarding the nutritional qualities and origin of the product in numerous languages. Here are some examples—(i) self-cooling beer using zeolite-technology makes it possible to drink cool beer anywhere, (ii) self-heating coffee container based on the CaO exothermic reaction is becoming available, (iii) packaging using electronics technology and Li battery power sources that enhances the branding citation in a crowded consumer product category is an influencing feature. Another consideration that works for smart packaging is based on changing some characteristics of the materials coated inside the package (Goddard, Kemp, & Lane, 1997). Above and all, a conventional package can be made smart by an RFID (Radio Frequency Identification) tag. The functionality is electronic and the major beneficiaries are the stakeholders along the entire supply chain.

Application of nanocomposites

Recent studies have shown that at smaller dimensions, materials can be controlled at a greater extent (Tonnie, 2007). Research on application of nanocomposite (scale of 1–100 nm) materials (also called nanomaterials) in packaging is exponentially increasing. The use of nanocomposite materials improves the mechanical and oxidation stability and also the barrier properties. Nanocomposite materials are composed of nanoscale structure that enhances the macroscopic properties of food products. Barrier properties play a vital role in packaging by gaining access into the food products by light, moisture or gases. Other benefit of the use of nanomaterials is that they inhibit the growth of spoilage, thus increasing the shelf life (Tonnie, 2007) and quality. The common nanocomposites used in the food packaging industry are (i) Polymer clay nanoclay (ii) Silica nanocomposites of nanosilver. The effects of nanoclay in polymers are increased stiffness, strength, nucleating agent in foams, smaller cell size, higher cell density, and flame retardant. Nanosilver is composed of de-ionized water with silver in suspension which has excellent antibacterial properties. Silver nanoparticles interact well with other particles as they have large surface area relative to volume which increases their antibacterial efficiency as a result of which they are extensively used in the food packaging industry (Tonnie, 2007). Nanotechnology methods play significant role in producing these composites: (i) Durethan—a transparent plastic film containing nanoparticles of clay that block oxygen, moisture and carbon dioxide from entering into the food particles and also make plastic more durable and heat-resistant (Tonnie, 2007), (ii) embedded nano crystals which create a molecular barrier that helps to prevent the escape of oxygen, (iii) antimicrobial—Kodak is currently using anti-microbial packaging and it has also introduced active packaging which absorbs oxygen thereby preventing food from getting spoilt (Harrow, 2005), (iv) electronic tongue—Researchers at University of Connecticut are developing nanoparticle films with embedded sensors in packaging in order to detect pathogens. The technology will be able to detect and alert the consumers if the food is contaminated by triggering a color change in the packaging (Selke, 2008), (iv) nanotech bioswitch—research is being carried out to develop intelligent packaging in which a bioswitch made using nanotechnology triggers the release of preservatives if the food begins to spoil. By 2011, clay nanocomposites are projected to increase their market share to 44%. Between 2005 and 2011, other market share gainers include metal, metal oxide nanocomposites and ceramic nanocomposites which are projected to attain market shares of 20% and 11.5%, respectively. Carbon nanotube composites are expected to lose market share, down to 7.5%. (McWilliams, 2006). However, since nanocomposites have been introduced only in recent times, its potential detrimental long-term effects (if any) remain to be seen and this may be one of the reasons for the lack of its widespread acceptance.

Safety and the use of biosensors

Food industry uses biosensors for the detection of various biological species. A self-contained biosensor can continuously detect antibodies without any reagent added. The indicator organisms are microorganisms which detect the presence of pathogens, or harmful toxins during production, processing, storage, and distribution. Conductance and bioluminescence are two distinct methods mostly employed while designing the biosensors. The conductivity of the medium changes if microorganisms metabolize the substrate (e.g. carbohydrates) into intermediates (e.g. lactic acid) (Mello & Kubota, 2002). Bioluminescence is the measurement of light emitted from a chemical reaction. In this scenario, the reaction is by biological enzymatically catalyzed reaction—luciferase system. Other biosensors are enzyme sensors and immunosensors. Enzyme sensors fall into various classes, including those that are potentiometric, amperometric, electrochemical, optoelectric, calorimetric, and piezoelectric. The biosensor is reported to be able to detect penicillin in milk as it flows from trucks to dairy processing unit. Immunosensors that detect the binding between antibody and antigen have been developed for pathogens but still require long reaction times, multi-step processing, and/or resulted in false positives (Prusak-Sochaczewski & Luong, 1990).

Manufacturing systems

Food production and manufacturing is the cornerstone of all processing and packaging automation activities. The manufacturing system includes machineries, control and data acquisition methods.

Machineries and systems

Usage of food processing machines results in improved producer's ROI (Return on Investment) through innovative designs. Further, most of the machines are microprocessor-controlled, multi-outlet, and easily adaptable to changing production requirements with simple tooling changes. Although the list of machines used in food processing is quite exhaustive, most systems typically include cartoning machines, wrapping machines, labelers, shrink machines, box sealing machines, case and tray forming machines, capping machines, cooling and drying machines, feeding and placing machines, inspection and detecting machines, palletizing and depalletizing machines, pickers (robotic systems), and importantly the cleaning and sterilizing machine. Fig. 1 shows the percentage of food industry that typically integrate the number of packaging machines in their production lines. The types of machines typically the food processors use are listed below (Mahalik, 2003; Mahalik & Yen, 2008).

With increased regulations regarding food safety and quality, food irradiation assumes growing significance. It becomes imperative for irradiation equipment manufacturers to design the equipment to facilitate seamless integration into the existing network of complex machinery found in processing industries. Durante (2002) identifies the basic requirements that food processing industries will expect from irradiation equipment manufacturers which will enable these manufacturers to design their equipment to cater to the needs of their customers.

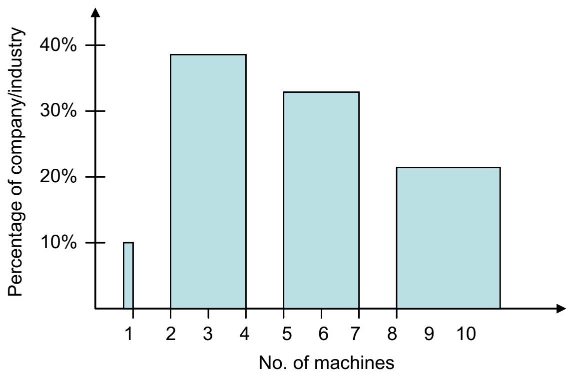

Fig. 1. No. of machines in a packaging line (source: www.OMAC.org).

The use of robots in food industry started a decade ago and is still 2% of its total population. Rising labor costs, health and safety issues, and the fact that most food is processed at temperatures not safe to work lead to the application of robots. Robotic cells are used in delicate pick-and-place operations. The processed food can be soft, fragile or sticky and may get contaminated when touched. They are mainly used for single products such as biscuits and chocolates. They integrate machine vision for accurate tracking of product as well as orientation by recognizing shape, size, and color and can detect undercooked food, damaged packets and make sure it is not taken to the packing stage. Future robots may be capable of making lasagna or filling sandwiches and packing them. The issues are handling and moving food quickly and effectively without damaging it.

Automation and control systems

Operational efficiency is vital in all types of manufacturing organizations. In the food industry more automation reduces the increasing challenge in employing workers which in turn axiomatically encourages turnover. Even the factory floor automation strategy is no more isolated, i.e., it extends to the rest of the supply chain. Nevertheless, human-centered automation will allow food manufacturers and distributors to achieve a consistent pattern of growth and return on equity through advanced manufacturing. Equipment reliability, flexibility, and efficiency must be well-considered, because the batch process (difference recipes for each food product manufactured) often impacts start-up curves and downtime. Fewer equipment service calls and faster machine changeovers create a direct benefit as long as the technology solutions are implemented to measure and drive ongoing levels of productivity (Cutler, 2009).

Non-traditional fieldbus technology-based automation solution

Modern food industry operation entails sophisticated automation and control architecture. By applying the proven success of modern control technology to most of its operations including food preservation, manufacturing, packaging, and handling, the productivity of food plants can be significantly improved. ARC, one of the world's big consultants propose the use of fieldbus in hybrid industries namely, food and beverage and pharmaceutical, particularly in the areas of validation, regulatory compliance, and integration of batch procedural operations with continuous processes. Current automation systems are predominantly based on either PC (personal computer) or PLCs (Programmable Logic Controllers). In these scenarios several processing modules are implemented with fixed functionality inheriting vendor-specific interconnection methods. The system has a central processing unit that communicates with all the sensors, actuators, switches, valves, drives, etc. in a point-to-point configuration. However, the architecture needs to be flexible in terms of extendibility, scalability and configurability to enable features to be developed, added, modified or removed independently (Moon, Lee, Taniguchi, Miyamoto, & Kimura, 2001). In particular, the automation system should facilitate a great deal of online modification including I/O interfacings, instrumentation hardware, diagnostics, prognostics, data collection and operator interfaces. In this respect, Distributed Control System (DCS) is found to be flexible over the whole operating range. In fact, more and more food industries are inclining towards DCS implementation. DCS can also accommodate standardized wireless connectivity for more automation. In a nutshell, DCS interconnects devices with a single serial link that primarily provides 4-layers of automation services. The bottom component layer still has a room for PC and PLCs. For example, LonWorks, a DCS system, called fieldbus, from Echelon Inc, can be interfaced with the PLCs by using standardized interfaces. Interface layer is similar to MAC (media access control) sub-layer of the link layer service. Process layer includes application layer features. Final application layer is somehow different from those traditional models in that it accommodates the features of *function blocks* along with the *object variables* for the transfer of data. Although a dedicated DCS system for food industry does not exist yet to the best of our knowledge, the available fieldbus standards are sufficiently adequate. Fieldbus, a technology that can be used to implement DCS, is still under development. Fieldbus can be classified based on topology, processing power, service type, and speed (Fig. 2). The leading fieldbuses with their characteristics can be found in Chandra and Rustgi (1998). Some of the industries that are shifting their control strategies into fieldbus-based solutions are listed below.

- Foundation Fieldbus (FF) is a full-digitalized serial two-way-communication system, used in local networks (LAN) in process and supervisory level. FF has been successful in food and beverage industry. Delta V system employs fieldbus technology that interconnects measurement and control equipment adhering to the stringent codes of the FF (Food Engineering, 2009). Carlton and United Breweries, Australia's leading beer brewer and one of the top five brewers in the world, producing more than half the beer consumed in Australia, requires tight process control mechanisms due to the complexities involved in beer production. The company embarked on a $17 Million plan to replace the filtration room with fieldbus-based control system that uses Fisher-Rosemount PlantWeb® architecture.
- Profibus is an automation technology covering the entire spectrum of requirements for industrial automation as well as in the areas of production and process automation. Profibus allows the fast transfer of time-critical application information at speeds of up to 12 Mbaub. Drinks bottler in Germany selected Profibus-DP technology to control its blow-molding machines. In addition, Roberts PolyPro adopted this fieldbus for a new high speed French fry scoop maker that can run at 1,800 ft/min.
- McDonald's is using LonWork's power-line networking technology to provide communication and data exchange between various pieces of kitchen equipment in its restaurants to manage energy use. McDonald's is encouraging its kitchen-equipment manufacturers to include Echelon's power-line technology in new equipment for its restaurants. The communication occurs over existing power lines. The i.LON module collects data from kitchen equipment and generates reports (QSR Web, 2007).
- Eurosicma's new packing machine and feeder system uses CAN (Controller Area Network) technology. It has been designed for the pillow-pack packaging of sweets, sugar-coated sweets and small pastilles. This is a completely electronic machine that uses industrial PC, brushless motor and CAN. With a capacity of 1,000 packing units per minute, the machine, throughout the process, has a size-changing flexibility, handling up to 25% packing unit length variation.
- The Müller dairy in Germany operates nine filling systems for curd milk and yogurt products at Leppersdorf. These can be used to fill 267,000 units every hour. Opening and closing of valves, activating pumps, measuring temperatures and monitoring pressures and flow volumes are controlled by the INTERBUS fieldbus system. The control system planning for the plant is based on the high level of automation and rationalization. The automation equipment in all production areas is connected to the

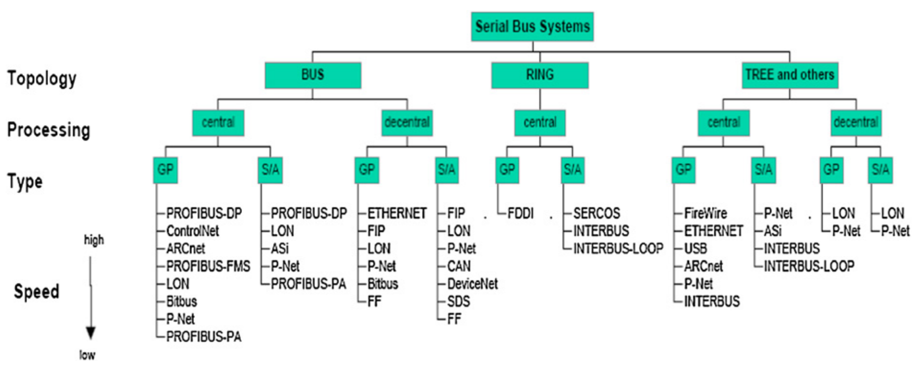

Fig. 2. Fieldbus classification (source and copyright (1992–2006): STEINHOFF Automation & Fieldbus-Systems; courtesy: STEINHOFF A).

peripherals using the INTERBUS system. The high level of availability of the machines and systems is largely due to this technology. The data received *via* the INTERBUS modules is analyzed and transferred by the process control system. The process control system accesses these data interfaces for control, monitoring and visualization functions (Quade & De Vries, 1999). The drives, IP 54 and IP 67 are designed for the food and beverage industry. A control device is able to synchronize the drives by synchronizing the control cycle.

- Approximately, 800,000 liters of whole milk are received and processed for skim milk, cream and cheese at MD Food at Rødkærsbro in Denmark. The entire automation of the dairy has been implemented by means of control and supervision systems using P-NET.

System integration and standardization

OMAC Users Group (UG) is trying to derive common solutions for both technical and non-technical issues in the development, implementation, and commercialization of open, modular architecture control (OMAC) technology for food manufacturing. OMAC Packaging Working Group takes care of maximizing the business value of packaging machinery in terms of formulating automation guidelines. The central objective is to enhance flexibility, capability, and reduce integration costs. The guidelines for Packaging Automation version 3.1 document the original guidelines and are periodically being updated. There are five packaging sub-groups and their dedicated activities are as follows.

- PackSoft: Guidelines for machinery programming languages.
- PackConnect: Define control architecture platforms and connectivity.
- PackAdvantage: Identify the benefits of connect & pack guidelines.
- PackML: Naming convention communications.
- PackLearn: Educational and training needs of the industry.

In-line inspection methods

In order to ensure compliance with the National Competition Policy, the Commonwealth Government in Europe is undertaking comprehensive examination of the legislation of the Imported Food Control Act Review (IFCAR). Part of it also includes food safety and inspection. Further, Part-11 of FDA 21 CFR (Federal Drug Administration) contains a catalogue of requirements, which applies to the areas of pharmacy as well as the food, beverage, tobacco and luxury food industries. Since food safety issue is becoming rigorous in the industry, it has been mandatory to have implemented the automated in-line food inspection system. Contaminants such as plastics, glass, metal, bone, rubber, stone etc. must be inspected and removed. In this respect, non-destructive methods are preferred. Besides safety issues, non-destructive methods also evaluate food quality. Jun *et al.* (2008) proposes a new non-destructive testing procedure to evaluate the bacterial contamination on the surface of stainless steel food processing equipment. Chen and Patel (2008) analyze the effects of the drying process on the quality of food and propose a model to predict the changes in the physical and biological properties of the food product. X-ray inspection has an advantage as it can detect hidden defects or contaminations without any destruction. An X-ray image is generated by different X-radiation absorption. The absorption differences are due to variations in density or thickness of the object. For example, X-rays that are elastically or inelastically scattered from a sample provide valuable information about the molecular structure, density and atomic number of the product. Bull, Zwiggelaar, and Speller (1997) in their paper show that since the field of view of the source and detector can be defined, by selecting the incident and scatter angles, it is possible to examine the properties of a small volume element of the sample, rather than the integrated information more commonly obtained from a transmission image. X-ray technology also embeds artificial neural network methods and tools that provide sophisticated shape recognition capability. The important features to be looked at the online X-ray system are the compatibility to variable conveyor speeds, power requirements, HMI (Human Machine Interface) compatibility, and interfacing standards, graphs and color coded algorithm, system diagnostics, plug and play features. Hyperspectral imaging is another successful method. The use of hyperspectral technique for the in-line inspection of poultry, fruits, vegetables, and specialty crops not only increases the quality and safety of food products but also increases productivity and throughput. This imaging spectroscopy system includes special detector system consisting of CCD (Charged Coupled Devices) devices to gather reflected radiation that can record up to 100s of spectral channels simultaneously over the range from 400 to 2500 nm. When few channels are used it is called multispectral imaging systemwhich is usually used for high-speed applications. Although, machine vision technology has been a standard approach, hyperspectral imaging would offer the additional benefit of analyzing the chemical composition of food products thereby significantly increasing production yields. By employing high-throughput chemometrics, food products can be analyzed for disease conditions, ripeness, tenderness, grading, or contamination (Headwall Photonics, 2009). Researchers are developing techniques with regard to processing, visualization, and analysis of hyperspectral data by focusing on the development of calibration methods, procedures for extracting information, and related information products. Simultaneously, machine vision method is gaining popularity in the food industry. In this respect the dual-band spectral imaging system are good. Such system has a two-port camera system that consist of two identical monochrome CCD cameras, an optical system, and two narrow bandpass filters. The system can be designed by the use of off-the-shelf products. For more detail design and construction the reader is referred to Park, Kise, Lawrence, Windham, and Yoon (2008).

Anti-microbial coating-based material handling

Conveyor belt-based material handling (food products) is inevitable in food manufacturing. Stainless steel products work well under this constraints. However, bacteria can situate and form in small joints and hinges of the conveyor belts. During operation the belt develops a bacterial biofilm (listeria, salmonella, and staphylococcus) forming tough layer on the surface requiring cleaning for removal. The conventional methods that are employed for the removal of these biofilm are: temperature, chemicals, and physical scrubbing. The above methods have side effects because of chemical usage and downtime. In order to fulfill USDA (United State Department of Agriculture) and the FDA requirements researchers are continually developing means to prevent development of biofilm. Conveyor belt with a blue habilene coating can improve the release properties of stickiness. The modified polyolefine can also be useful. Such types of coated belts are gaining popularity in bakery, biscuit, dairy, meat, fish and poultry processing plants. The coating contains anti-microbial additive that prevents the growth of spoilage microorganisms on belt surfaces (Twomey, Truemper, & Murphy, 2006).

Trends in productivity oriented management systems

Larger industries are vulnerable to volatile management strategy. Advanced management principles such as lean principles, packaging execution systems (PES), supply chain management, mass customization, etc., have a significant role to play in the food industry. Execution of these principles can yield significant rewards in terms of reducing costs and increasing the overall efficiency of the system. The following section deals with the attributes as regards to improvements in production management strategies.

Lean principles

An article published by Arc Advisory Group (2007) states that the food and beverage industries are facing increased regulations from FDA (2009) and USDA (2009) vis-a-vis quality control and traceability. The compliance to these regulations which in many cases result in increased costs necessitates process improvements in other areas to reduce costs. The same article and another by Weinekotter (2009) report that in many cases, the packaging machinery remains severely under-utilized. This may be attributed to shorter production runs and frequent changeovers. Thus, it becomes imperative to develop more efficient production techniques and increase the overall equipment effectiveness (OEE) in order for companies to be cost effective. Lean principles pioneered by Womack and Jones (1996) have been applied to numerous industries to yield drastic improvements in efficiencies and reductions in costs. The five lean principles highlighted by Womack and Jones (1996) all of which have the same underlying central concept of *doing more and more with less and less* include, (i) identify value of product/service to customer, (ii) identify value-stream using Value-Stream Mapping, (iii) ensure continuous flow, (iv) ensure customers pull value using *kanban* systems, and (v) continuously strive for perfection through *kaizen*. The activities in any organization can be divided into three main categories *viz*. value-added activities that contribute to the usefulness of the product/service, necessary non-value-added activities that can be eliminated albeit through significant improvements, and non-necessary non-value-added activities that can be eliminate immediately with little or no effort. Eliminating wastes (muda) and reducing lead times assumes even greater significance in the food processing industry especially due to the perishable nature of the products. There has been increased focus (H. T. L Consultants, 2009; Langhauser, 2008; MATCON, 2009) on implementing lean principles in the food processing industry with the aim of staying competitive. Schwartz (2005) highlights the importance of using a demand-driven production management system for faster throughputs, reduced inventories and increased profits. Ranalio (2009) explains how the food processing industry can reap benefits by implementing lean principles and proposes an organization-wide strategy to help companies get started on their lean journey. Heymans (2009) identifies some of the biggest issues behind the yawning gap between lean implementations in manufacturing and food industries. These include lack of leadership, vision, employee involvement among others. The author also elaborates on how each of the lean techniques like continuous improvement (kaizen), total productive maintenance (TPM), continuous flow and setup reduction can be applied to the food industry. Concepts like Just in Time (JIT) and make-to-order (MTO) help in reducing inventory levels to the bare minimum. However, these are applicable under conditions of steady demands and low varieties. In a high-variety environment like food industry, a certain level of inventory is often desirable. However, given the perishable nature of the goods, it becomes imperative to effective handle the available inventory. The concept of Available To Promise (ATP) is often used to integrate aggregate production planning with day-to-day activities in the organization thus enabling better management of the customer order de-coupling point. Christou and Ponis (2008) propose a new ATP scheduling model for the food and beverage industry that integrates seamlessly with existing Enterprise Resource Planning (ERP) software.

Reusing and recycling packaging materials can help companies not only reduce costs but also improve its *green-image*. Tsiliyannis (2005) presents a quantitative model that analyzes packaging flow performance with special emphasis on reuse and recycling. Cross (2009) explains how a food processing company in Ohio achieved significant improvements through value-stream mapping, a principle that helps to clearly distinguish between value-added activities and non-value-added activities: the company found that only eight of its 105 steps added value. Melvin and Baglee (2008) apply value-stream mapping technique to a dairy company that produces yogurt and its derivatives. The process helped identify wastes in the process which upon elimination can result in a 20% reduction in the CO2 emissions. Hero Baby Food (2009) implemented lean principles at their baby food processing plant in Spain by identifying their bottleneck operations and streamlining their processes.

Recent developments in packaging execution systems

Applying lean principles to food processing and packaging requires accurate information regarding packaging operations. Packaging Execution System (PES) (Arc Advisory Group, 2007) is a derivative of its parent, Manufacturing Execution System (MES) which is specifically geared towards intuitive goal. PES integrates packaging operations into the organization's overall operations management system thus providing a holistic view of the entire organization. Fig. 3 shows how different aspects of the industry fit together in the PES system and the corresponding tools that enable the integration of the organization's operations. Baliga (1998) explains how the MES system tailored to meet the requirements of packaging and assembly area thus improving traceability and efficiency. Packaging systems are seldom integrated with the existing MES. Cheng, Yang, Kuo, Feng, and Jeng (2000) develop an Equipment Manager system that can be integrated with the existing MES to control packaging machinery. The system also allows for a quantitative analysis of the equipment efficiencies. Ryvita of the British Foods Group (E. F. Scientist, 2008b) implemented a factory-wide information reporting system that enables them to track quality issues and compute OEEs for their equipment.

Improvements in production management

Planning, scheduling and control of the various processing activities can be daunting especially when one is aiming to achieve more with less. Efficient scheduling algorithms help in making competent use of the scarce resources and reducing wastes. Inventory management is of paramount importance in the food industry especially due to the consumable nature of products. Fujiwara, Soewandi, and Sedarage (1997) develop an ordering policy for better inventory management of products like fresh meat in supermarkets. Packaging is often viewed as a value-adding activity—its manufacturing process and design can have a significant bearing on the distribution logistics of the product. Chain, Chan, and Choy (2006) propose a systematic approach towards making improvements in packaging that will improve the distribution efficiency. Liu (2008), Liu and Tu (2008) and Liu, Chu, Chu, and Wang (2007) propose a polynomial time algorithm to solve the lot sizing problem in a system with bounded inventories and lost sales costs. Food production systems typically involve a processing stage and a packaging stage with a storage area in between. Akkerman and van Donk (2008) and Akkerman, van Donk, and Gaalman (2007) analyze the various sequence and dispatching rules for such a two-stage system with time, storage and capacity constraints. The authors conclude that increasing the intermediate storage space, albeit resulting in higher utilization rates for machinery, is detrimental due to the perishable nature of the food products. The authors suggest that the popular Shortest Processing Time (SPT) (Rajendran & Holthaus, 1999) dispatching rule yields favorable results in terms of all the constraints.

Food processing industries especially the canning lines can be modeled as a hybrid flexible flow-shop with setup times and lags between stages (allowing food to cool before canning). Ruiz, Serifoglu, and Urlings (2008) develop a mixed integer programming model for such a system and solve the model using popular heuristics like NEH heuristic (Nawaz, Enscore, & Ham, 1985) in scheduling literature. Computer simulation is a tool that facilitates better visualization of the interconnectedness of various processes in an organization while helping identify potential problems. Cicco, Gentili, and Santucci (2007) apply the

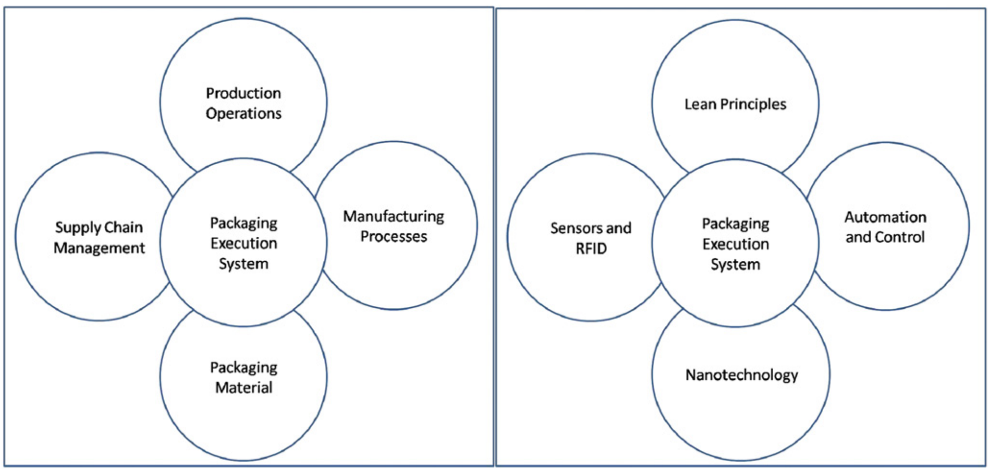

Fig. 3. PES framework and tools.

concepts of discrete event system simulation to analyze the manufacturing process of cheese. The authors develop a fuzzy logic-based model for the production process to incorporate the uncertainties and vagaries in the parameters involved.

Another concept often employed in traditional manufacturing industries is Theory of Constraints (TOC) first introduced by Goldratt (1984). This approach allows for a holistic view of the entire organization's activities thus facilitating performance measurements and continuous improvements. Spencer (2000) examines the application of this concept to a food processing company. The company successfully implemented TOC concepts like performance-based accounting system, line balancing, and drum-buffer-rope scheduling to yield improved operating conditions.

Supply chain management

An efficient supply chain management strategy right from procurement to distribution is indispensable in the food processing industry. Dabbene, Gay, and Sacco (2008a, 2008b) develop a mathematical framework to model the supply chain for a meat processing company. The model takes into account of the effects of handling procedures and time delays on the quality of the final product and generates an optimized solution that minimizes logistic costs and maximizes product quality. Bevilacqua, Ciarapica, and Giacchetta (2009) propose a framework for a computer-based system to improve the flow of information and material through the supply chain. The authors implement the system for a fourth-range vegetable industry which involves cleaning, cutting, mixing and bagging vegetables in Italy. The supply chain for this industry involves seed production, cultivation, processing and distribution. Traceability is heavily involved in supply chains. Traceability refers to the ability to keep track of the product as it moves along the supply chain. This provides numerous benefits such as improved quality, better process control and better use of raw materials. Bertolini, Bevilacqua, and Massini (2006) propose the use of the Failure Modes Effects and Criticality Analysis (FMECA) technique to quickly identify potential areas of failure their impact on the process or product in the traceability system. The authors apply this technique in an Italian pasta manufacturing company and propose organizational changes to better handle potential failures. RFID technology is becoming increasingly popular due to the advantages they offer. RFID tags differ from barcodes in that the information on RFID tags can be automatically read using sensors that can unobtrusively blend into the different systems. RFID tags (Connolly, 2007) help improve the efficiency of the supply chain and also helps ensure that only genuine products reach the customer. Perry (2008) discusses how RFID technology can help improve efficiencies at food and beverage process companies by improving the traceability of products and facilitating better quality control.

Mass customization

Since its inception in the 1980s, the concept of *mass customization* has seen mixed responses from both researchers and practitioners alike. Gilmore and Pine (1997) propose a strategy which classifies the extent of mass customization based on the involvement of customer and the variations in the product. Fig. 4 shows the four different ''faces'' of mass customization of which the true and complete form of mass customization is the *collaborative* face which necessitates a high involvement of the customer and also results in significant variations in the product. The *adaptive* approach is the one with least involvement from customer. However, the product may be modified or reconfigured by the customer independently to suit his/her needs. In the *transparent* approach, the company ''learns'' customer's preferences unbeknownst to the customer by collecting data about the customer's habits and preferences. Mass customization holds tremendous promise for the food processing and packaging industry. By employing mass customization principles, food processing and packaging companies can introduced tailored products catering to specific customer demands. A quick glance at the shopping aisles in the local grocery stores reveals an immense variety of choices available to the consumers. However, that being said, this is not to suggest that every company should jump on to the ''mass customization bandwagon'' immediately. It is imperative to have the necessary foundational understanding of the processes within the organization before embarking on this journey. It is evident that an attempt at satisfying all customers would not be an economically viable proposition. However, the objective should be to meet as many of the customer requirements as possible within the given constraints. Mass customization principles like modularity can help companies achieve this objective. Swedish company Tetra Pak (E. F. Scientist, 2008a) has designed customizable milk processing equipment that can be tailored to each customer's requirements of desired production rate and quality.

Implementation issues

As is evidenced from the aforementioned survey of the state of the art in the field of food processing and

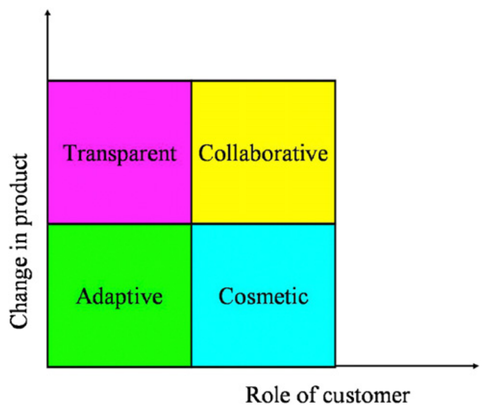

Fig. 4. Four faces of mass customization ([70]).

packaging, there seems to be a wide gap between research in the field and its practical implementations. Some of the issues related to the slow implementation of latest research findings may be attributed to the perishable nature of the products. In order to fully capitalize on the vagaries of agricultural yield, it becomes imperative to build in redundancies into the system in the form of excess capacity and labor. Moreover, due to the low profit margins, distributors are generally averse to taking risks. Many of the processing industries employ a large number of temporary unskilled low-wage workers in response to the seasonality of the market. This makes it difficult to find skilled labor who are adequately trained. Lastly, the food processing industry tends to be highly scattered with a multitude of customers and hence it becomes difficult for companies to implement some of these wide-reaching improvement techniques.

Conclusions

The food processing and packaging industry, albeit very similar to traditional manufacturing industries, poses very unique set of challenges. Companies in this area typically face stringent regulations in the light of their increased impact on the environment and the health of the consumers. The companies also have to deal with products with very limited shelf life and thus making it indispensable to strive to reduce lead times as much as possible. In this paper, we have looked into the state of the art in the food processing and packaging industry in the light of recent technological advancements in the fields of (i) packaging and materials including applications of nanoscience, (ii) automation and control technology and standards, and (iii)production management principles. A comprehensive review on the above and related fields was presented in order. From the aforementioned survey of literature, it is clear that although researchers have focused on individual aspects of the processing and packaging industry, there is need for a more holistic systems analysis of the entire operations. Moreover, it is imperative to investigate why the practical implementations of these advancements seem to lag behind research in the field. Some potential areas have been identified in the previous section. These and others need to be addressed so that the food processing and packaging industry can benefit from the latest research in this field.

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