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A survey of automation practices in the food industry ☆

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Abstract

Over the last few years, the food manufacturing industry has experienced unprecedented growth and became one of the major forces in the US economy. Some recently published surveys [N.A. Aly, A survey on the use of computer-integrated manufacturing in food processing companies, Food Technol. 43 (3) (1989) pp. 82–87; R.H. Caro, W.E. Morgan, Trends in process control and instrumentation, Food Technol. 43 (7) (1991) 62–66] indicate that the food industry has been rather slow to adopt new automation technologies, yet considering utilizing such technologies in the near future. A nationwide scientific survey of US food manufacturers was conducted to better determine the current state of automation in the food industry. The survey also included system integrators and equipment suppliers that sell goods and services to US food manufacturers. It has been determined that although there has been a significant increase in food process automation over the last decade, the current level of automation is extremely variable. Larger manufacturing plants are generally better automated and have less desire for future technological evolution. Equipment suppliers and system integrators are more advanced in the field of food process automation, but this advancement is seldom used due to food industry's low demand for advanced technologies. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Automation; Survey; Food manufacturing; Equipment supplier; System integrator

1. Introduction

In 1995, the food manufacturing sector accounted for 14% of the total US manufacturing output. In that same year, the processed food market represented $372 billion in value added. Clearly, the food manufacturing industry represents a dominant force in the US economy. Yet, as pointed out by Caro and Morgan (1991), the food industry has been slow to embrace manufacturing automation technology owing to the difficulty in justifying the capital expenditure required. This view was supported by a survey of California food manufacturers (Aly, 1989) who found that cost was the main obstacle in adopting computer-integrated manufacturing (CIM) systems. Many segments of the food industry operate under seasonal schedules and at low profit margins. These constraints reinforce the need to cost justify any capital expenditure in manufacturing equipment.

Other manufacturing sectors, such as the petroleum and chemical industries, have employed computer automation to improve productivity. However, the food industry must deal with constraints not present in other industrial sectors. These constraints include the use of perishable raw materials of variable composition, the technical difficulty and expense of sensing food properties online, and the availability of technically skilled employees. Despite these obstacles, Aly (1989) found that more than half of surveyed respondents had implemented CIM in some form. Furthermore, two thirds of respondents who did not use CIM technologies were considering utilizing such technologies within the near future.

Over the last decade, the food industry has experienced unprecedented growth primarily from mergers and acquisitions. Such activities place pressure on food manufacturers to become more flexible and to consolidate human and material resources. Results of recently published surveys (Morris, 1997; Ferrante, 1999) indicate that food companies are generally looking toward automation to facilitate greater manufacturing flexibility and less down time through better maintenance. We recently conducted a nationwide scientific survey of US food manufacturers to better determine the current state

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of automation in the food industry. Our survey also included system integrators and equipment suppliers that sell goods and services to US food manufacturers.

2. Survey objectives

The objectives of this survey were to:

- determine the current level of automation within the food industry;
- estimate what technologies the industry will attempt to adopt in the future;
- correlate current and anticipated automation technologies with the industry size;
- determine what portion of food companies rely on systems integrators and equipment manufacturers for primary automation services.

3. Methodology

The population pool of potential companies to be surveyed originated from a database maintained by the Department of Food Science at Purdue University. This database contained the names of individuals who have been involved with the research, outreach and educational activities of the Food Science Department over the past 15 years. From this database, 96 food manufacturing companies, food equipment suppliers and system integrators were found to operate or sell products and services to the food industry in the US. Individuals within these companies that are responsible for factory automation issues were first contacted by telephone. The purpose and methods of the survey were explained and the individuals were queried whether or not they would agree to participate. Of the initial 96 companies contacted by telephone, 50 agreed to participate in the survey. The remaining 46 companies either refused to take part in the survey or the appropriate personnel with the knowledge required to answer the survey questions were unavailable.

As a result, a total of 50 surveys were sent to 33 food-related businesses, including 20 food manufacturing companies, six food production equipment manufacturing companies, and seven system integrators responsible for food manufacturing automation. The total number of surveys exceeds the number of companies because the survey was designed to be plant-specific and in some instances was sent to more than one plant within one company. All surveyed companies were located in the US, with the exception of two companies located in Canada but doing business in the US. The survey was conducted as a blind study. Each respondent received a blank copy of the survey with a pre-stamped, self-addressed return envelope.

To estimate the reliability of the survey the internal consistency analysis was conducted using the Method of rational equivalence, namely, Cronbach's coefficient alpha form of Kuder–Richardson (Richardson & Kuder, 1939) formulas. This particular technique was chosen because most of the survey questions were presented in a non-dichotomous (multiple-choice) format (Gall, Borg, & Joyce, 1996).

During the analysis, all survey questions were coded positive and negative. Then, the survey was divided into two equal parts and the total scores of each respondent for each half of the survey were correlated. Multiple correlation tests allowed calculating the overall survey reliability. This value demonstrates the probability of acquiring the same information from the same make-up of respondents if the survey were to be conducted again (Kubiszyn & Borich, 1996).

4. Survey results

4.1. General information

Out of 37 surveys sent to food manufacturers, 17 (49%) were returned. Of six surveys sent to equipment suppliers all six (100%) were returned. Of seven surveys sent to system integrator companies four (55%) were returned.

The makeup of respondents demonstrated that the survey penetrated wide sampling of the population of food manufacturers. The results show that the majority of food manufacturers surveyed (76%) are producing human food products, 18% are making animal food and 6% are producing food ingredients. The production volume for most of the respondents (59%) is within the range of 100,000–1,000,000 tons per year. Majority of the respondents (76%) have more than 75% of their processes covered by federal regulations, 65% have USDA regulated processes, and 71% have FDA regulated processes. Majority of participants (59%) are using continuous type of processes versus 41% that are using batch type.

The results for the equipment suppliers show that all respondents manufacture equipment for both human and animal food production, 67% also manufacture equipment for production of food ingredients and the pharmaceutical industries. All of surveyed system integrator companies work with food processors, 75% also integrate pharmaceutical manufacturing and other manufacturing areas.

4.2. Survey reliability

The internal consistency analysis using the Method of rational equivalence method showed 81% of survey reliability. This value means that if the same survey was to be conducted again among the same make-up of respondents, the probability of getting the exact same information is 81%. According to Gall et al. (1996), the survey with a reliability coefficient of 65% and more is generally considered valid.

4.3. Level of automation

In this section, it was intended to determine the current and envisioned level of automation in the food manufacturing plant and the technological advancement of the equipment offered by equipment suppliers and system integrator companies.

Among the food manufacturers that returned surveys with usable information (all sections completed), the current level of automation in the plant was distributed as shown in Fig. 1. More than half (59%) of the food manufacturers indicated that their plant was mostly automated.

As for the level of automation that food manufacturers envision for the next five years (Fig. 2), 41% desire to implement full automation of their facility, and 18% would still expect to have only a limited number of operations automated. In six cases (35%) there was no desire for further automation indicated for the next five years.

In reference to equipment suppliers, the majority (83%) can offer fully automated equipment, and only 17% have equipment that is only somewhat automated. The latter group of respondents would like to have most of their equipment components automated within the next five years.

4.4. Level of automation among different operations

In this section, it was intended to check for the uniformity of plant automation. The level of automation across different food manufacturing operations is illustrated in Fig. 3. The majority of respondents have automated processing (94%) and packaging (82%) operations. Less than half of participants have automation in other steps of the manufacturing process. Most of participants (58%) showed that the level of automation varies widely among different operations and only 24% of respondents showed almost no variability in automation level.

Most of the equipment suppliers who responded (67%) showed that the level of automation varies widely among different kinds of manufactured equipment and the rest of the respondents (33%) showed almost no variability in automation level.

4.5. Microprocessor-based systems

In this section, the use of microprocessor-based technology, motivation factors for its use and obstacles to its implementation were analyzed. The majority of food manufacturing companies that responded (59%) are extensively using microprocessor-based technologies in their control systems. About 29% have some of their production lines controlled by microprocessors, and 12% have a small number of operations under microprocessor supervision and control.

In ranking the obstacles to implementation of microprocessor-based technologies among food manufacturers, the major obstacles seem to be cost (70%

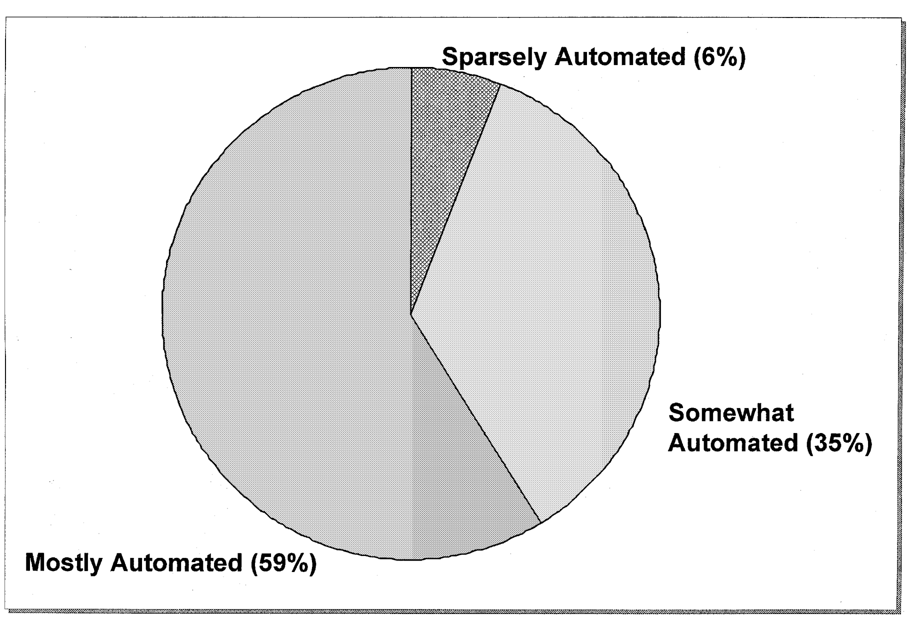

Fig. 1. Current level of automation (food manufacturers).

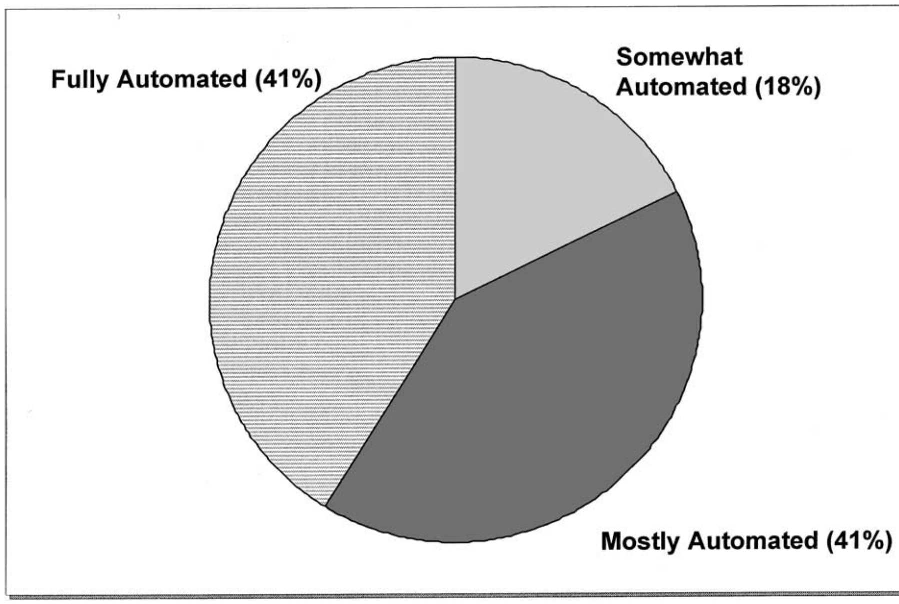

Fig. 2. Envisioned level of automation (food manufacturers).

of respondents), management commitment (59% of respondents), time (48% of respondents), and poor technical skills of support staff (47% of respondents). Only 18% of respondents find control system compliance with existing hardware and software standards to be an obstacle for implementation of microprocessor-based technologies.

Various motivational factors for implementation of microprocessor-based control systems are shown in Fig. 4. The top three motivational factors are improvement of product quality (100%), decrease in production cost (94%) and access to process information (76%). The lowest motivational factor for implementation of microprocessor-based technologies indicated by 33% of respondents was improvement of personnel safety.

Only 33% of equipment suppliers that responded use microprocessor-based systems to control all parts of their equipment, the other 33% use it to control most operations performed by their equipment. About 17% of equipment suppliers seldom use microprocessor-based systems for process control and data acquisition.

Among the different obstacles for implementation of microprocessor-based systems, equipment suppliers named the following as major obstacles: technical skills of support staff (50%), cost (33%), management commitment (17%), and technical skills of the customer (17%). The top motivational factor for using micro-

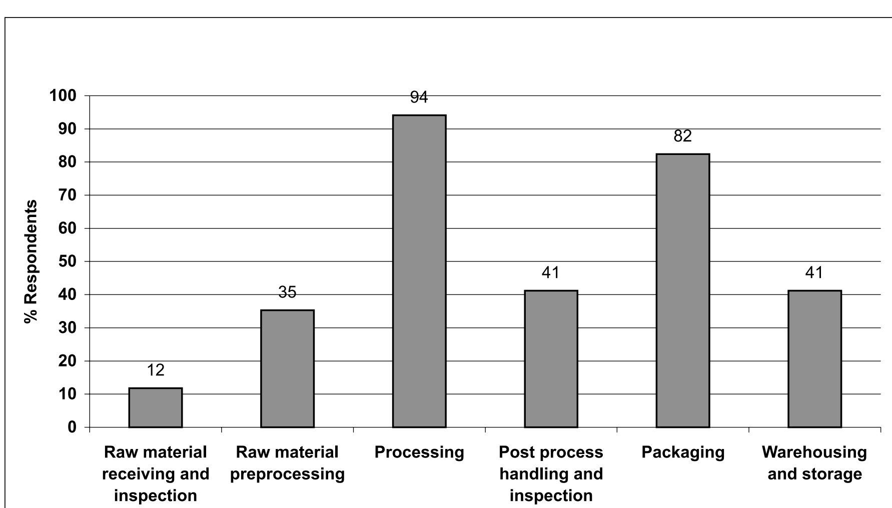

Fig. 3. Level of automation in different stages of manufacturing (food manufacturers).

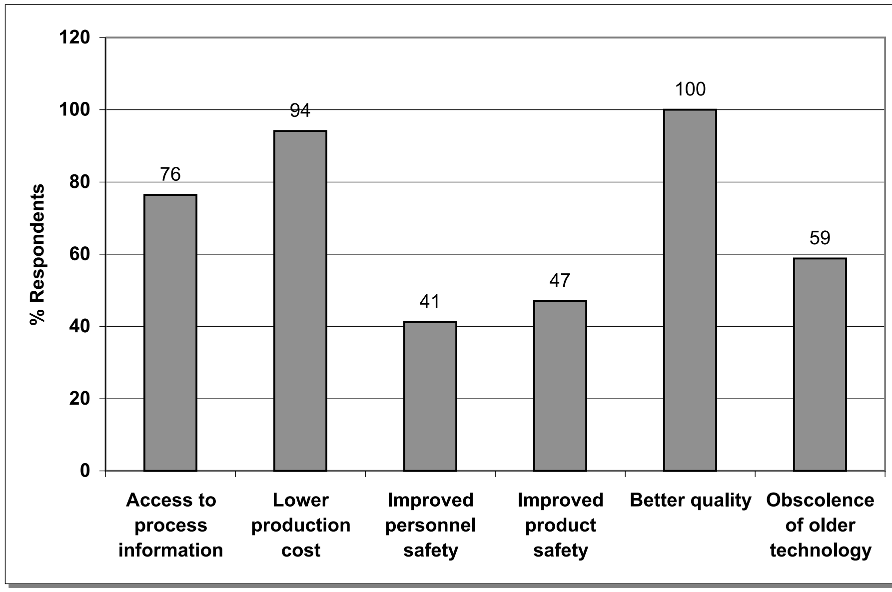

Fig. 4. Motivational factors for implementation of microprocessor-based technology (food manufacturers).

processor technology is product quality improvement indicated as by all of the equipment supplier companies. Decrease in production cost was considered the smallest motivational factor (33%).

4.6. Computer-integrated food manufacturing

In this section it was intended to probe for the current level of using computer integration in various parts of food manufacturing process. In response to which areas computer integrated technology is used, majority of food manufacturing companies (94%) indicated the computer-aided manufacturing. Distribution management and computer-aided design are each integrated in 47% of cases. Electronic HACCP programs are used among 24% of respondents. Results are shown in Fig. 5.

4.7. Process controller

This section was designed to determine the types of industrial controllers currently used in food manufacturing, and the prevalence of a certain type of controller among food manufacturers, equipment suppliers and system integrator companies.

All of the food manufacturers who responded (100%) use programmable logic controllers (PLC), 35% use personal computers (PC), and 24% use distributed control systems (DCS) for process control. About 88% of all participants in this group mentioned PLC as the prevalent type of industrial control system hardware. Personal computers and DCS were reported as the prevalent type of controllers among 6% of all respondents.

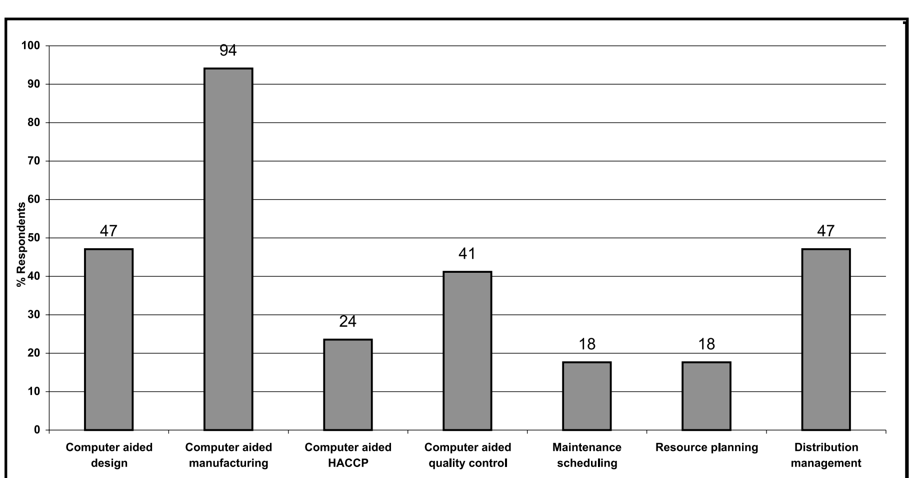

Fig. 5. The use of computer-integrated technology in food manufacturing.

All equipment suppliers who responded to the survey use PLCs for process control. Half of them also use personal computers, and only a third (33%) use DCS. All the respondents mentioned PLC as a prevalent type of controller.

All system integrator companies who responded indicated that they use personal computers for process control, 75% of them also use PLC systems, and 50% of them also use DCS. A quarter of all respondents in this group showed no prevalence in the type of controller, and the rest (75%) selected PLC as the prevalent controller hardware. Most of the system integrators (75%) use between one and five different controller brands, the rest of them use five to ten different brands in their work. The top factors for choosing a particular controller brand were the level of security built in the system (indicated by 75% of respondents), and control system parts' quality (also 75%). Control system cost, vendor's experience and clientele, availability for future system expansion and available training were other factors that had a relatively high influence on choosing a particular control system brand.

4.8. Software

This section was intended to determine what software is the most frequently used in processing environment. The result of the survey demonstrate that the Windows NT® operating system is used by 65% of the food manufacturers in their processing environment (process control, data acquisition or system configuration). Windows 95/98 is used for the same purposes by 29% of respondents. DOS® is used by 12% of participants. Unix-compatible operating systems are used by 6% of participants.

The Windows NT operating system is used by most of the equipment suppliers (83%). Windows 95/98® is used by 67% of respondents, and 33% of equipment supplier companies still use DOS® system for control system configuration and data acquisition. None of the respondents is using Unix-compatible operating systems for this purpose.

The Windows NT® operating system is used among all of the system integrators for control system configuration and data acquisition, Windows 95/98® is also used among 75% of respondents for the same purpose. Half of surveyed system integrators also use DOS®.

4.9. Uninterruptible power supply

Uninterruptible power supply modules are an essential component of a robust and reliable control system. This section was designed to probe for the use of such devices in food manufacturing plants. The majority (88%) of food manufacturers use uninterruptible power supplies for back-up power for their control systems. All equipment supplier and system integrator companies provide uninterruptible power supplies for control system components.

4.10. Control system failures

In this section, it was intended to check for the annual number of identifiable control system failures, hoping to later correlate the responses to the results of the other sections of this survey. The participants were also asked to identify the most frequent reason for control system mishaps.

The results of the survey show that the majority of food manufacturing companies (76%) experience less than 10 identifiable control system hardware failures, 18% experience 10–30 of such failures, and 6% experience more than 30 identifiable control system hardware failures, annually. Most of the food manufacturers who responded (47%) experience less than five identifiable control system software failures, 42% have 5–30 of such failures, and 6% experience more than 30 identifiable control system software failures, annually.

As shown in Fig. 6, the majority of food manufacturers (53%) named control system hardware as a prevalent reason for control system failures. Power failures stand second in the list with 29% of these companies. Control system software causes most failures among 12% of respondents.

The majority of equipment suppliers surveyed experience less than five identifiable control system hardware failures (50%), and less than five identifiable control system software failures (67%) per year. None of them have more than 30 identifiable control system failures annually. The most frequent reason given for control system failures is shown in Fig. 7. The top two reasons are control system hardware failures (33%) and operator error (33%).

Control system hardware malfunction is the most frequent reason for control system failures among 50% of the system integrators. The other half named operating system to be the main reason for control system failures.

4.11. Sensors

All of the food manufacturers that participated in the survey use a wide variety of sensors for measuring physical characteristics of the product, such as temperature, pressure, etc. For the analytical measurements, about 29% of these companies use refractive index sensors, 59% use densimeters, 35% use viscometers, and 41% use pH electrodes. About 18% of food manufacturers showed a desire for digital sensors. About 17% of these companies also anticipated the use of new methods

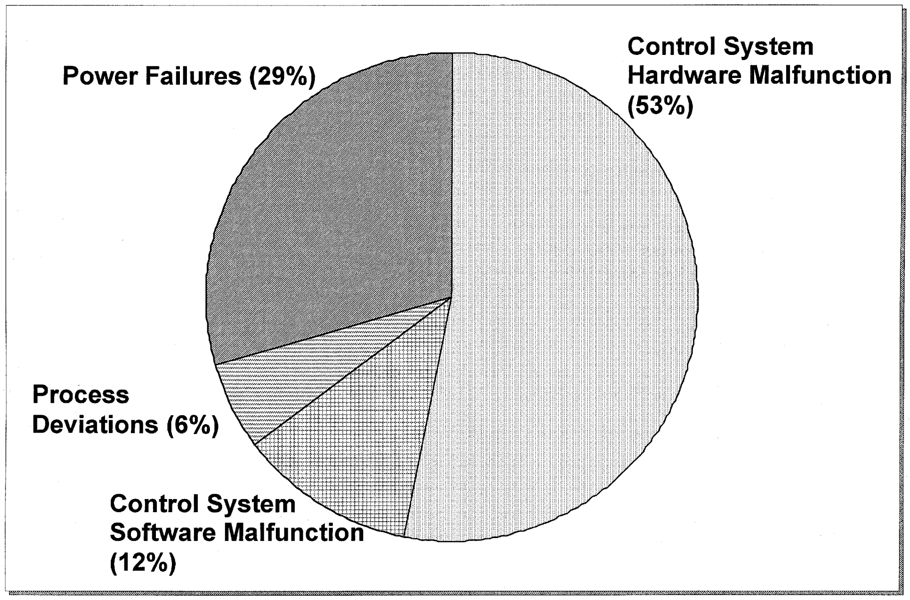

Fig. 6. Main reasons for control system failures (food manufacturers).

of measurement, such as in-line spectroscopy, within the next five years.

4.12. Communications

Considering the wide spectrum of communication technologies available on today's market, all of the different standards were organized into three groups: pneumatic, analog and digital. Please note that digital signal technology is not a communication with a 'discrete' device (e.g., a switch) but a method of transferring portions of data within a control system in a digital format. In this section, it was also intended to gather information on the use of fiber-optic lines for communications within a plant.

On average among food manufacturers, analog signal transmission technology is used in 72% of the cases, digital technology is used in 17% of the cases, and pneumatic transmissions are used in 11% of the cases. More than half of the participants (53%) use fiber-optic

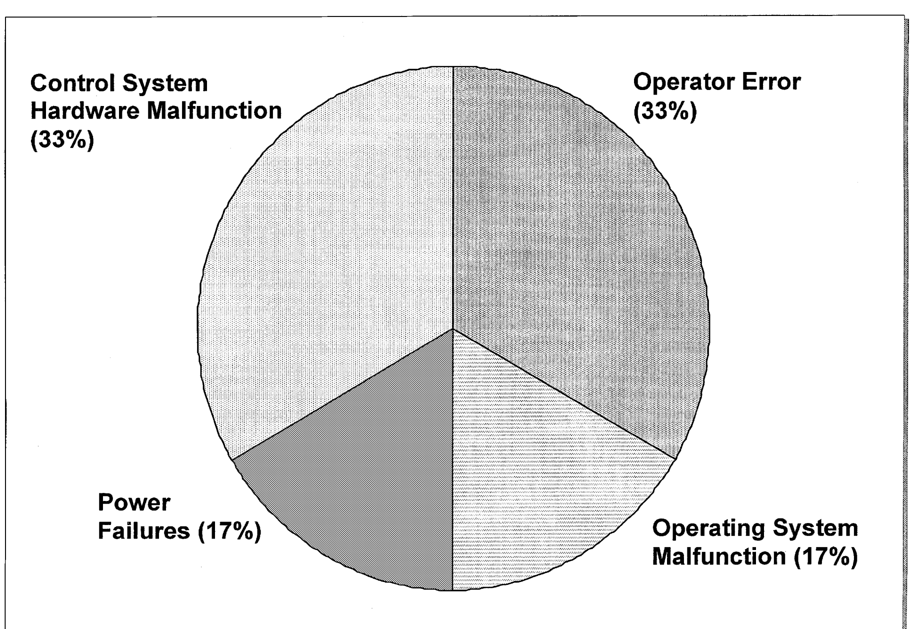

Fig. 7. Main reasons for control system failures (equipment suppliers).

technology for in-factory communications. Most of the food manufacturers (89%) indicated reliability as a major reason for using the fiber-optics.

Among the equipment supplier companies, analog technology is used on average in 45% cases, digital technology in 36% of cases and pneumatics in 19% of cases. About 17% of the equipment suppliers use fiber-optic technology in their equipment. All of them indicated reliability as a major motivation factor for using fiber-optics for signal transmission.

System integrator companies that responded indicated a large prevalence (66%) in using digital technology for signal transmission. Analog communications are used on average in 31% of cases, and pneumatics is used only in 3% of cases. About 75% of respondents in this group use fiber-optic technology in their systems. The prevalent reason for its use is reliability.

4.13. Control strategies

This section was intended to collect information on the use of different control techniques in food manufacturing, and newer methods available from equipment suppliers and system integrator companies.

The majority of food manufacturers (88%) use proportional-integral-derivative (PID) algorithms to control their processes. About 12% of respondents in this group also use Fuzzy Logic techniques and 6% use predictive process control. The majority of respondents (65%) use auto-tuning methods to tune their control loops.

All of the equipment suppliers indicated that they use PID algorithms to control their equipment. About 17% also use Fuzzy Logic techniques. Only a third of participants in this group (33%) use autotuning methods to tune their control loops. All of the system integrator companies use PID algorithms for process control. Half of them also use Fuzzy Logic techniques.

4.14. Third party control systems

Today, many food manufacturing companies work directly with equipment suppliers and system integrators to establish plant automation. In this section, it was intended to probe for the number of food manufacturing companies that use services provided by a third-party company (i.e., equipment supplier, system integrator, consulting company). It was also intended to know the factors that have the most influence in choosing a particular third-party company. Considering that equipment suppliers may also work with a third-party company (e.g., system integrator), it was also intended to check for the number of suppliers that had established such relationships and motivational factors for doing so.

The majority of food manufacturers who responded to the survey (76%) work with specific system integrator companies to implement process automation. Among the factors for choosing a particular system integrator, the top two factors are integrator's control system reliability (indicated as major influence by 54% of participants) and level of technical support and assistance (54%). The two factors that follow are the integrator's experience and clientele (38%) and control system parts quality (31%). The factor that has the lowest influence on choosing a particular system integrator is availability for future training (15%). The majority of food manufacturers (65%) use between one and five vendors to provide components for their control system equipment.

The majority of equipment supplier companies (67%) work with system integrators to provide control system components for their equipment. The top factor for choosing a particular system integrator is the integrator's experience and clientele (chosen by 75% of respondents as a major influence). Among other important factors were level of security built in the system (50%), control system parts quality (50%) and system compliance with required specifications for the process (50%).

4.15. Technical support and training program

Technical support and training are an integral part of the control system service and should be provided by a third-party company, which supplied the control system equipment. In this section, it was intended to determine the level of satisfaction with a training program and technical support among those food-related businesses that use the services of a third-party firm.

Most of the food manufacturers (53%) ranked technical support of their system integrator or control system vendor as good. About 12% considered it excellent, and 35% ranked it satisfactory. As for the level of satisfaction with system integrator's or equipment vendor's training program, 47% of the food manufacturers ranked it satisfactory, 29% considered it good, and 24% thought that it was poor.

About a half of the equipment suppliers surveyed found technical support of their system integrator or control system vendor as excellent. About 25% considered it satisfactory, and other 25% ranked it poor.

In the case of working with a system integrator company, 75% of the equipment suppliers established combined training program. All of those who did not have such program in place would like to establish one within the next five years.

About 75% of all system integrators ranked the technical support of control system manufacturer as good, and 25% ranked it satisfactory. Half of respondents ranked the available training from control system manufacturers as good, the other half found it satisfactory.

5. Discussion

5.1. Food manufacturers

Some correlation between the age of the plants and the level of automation was expected, however, no correlation was found between these parameters. The level of automation varied widely among and within different age groups of plants and was correlated to the annual production.

The entire population of respondents in the 'Food Manufacturers' group was broken into three groups: food ingredient manufacturers (5.9% of total), animal food manufacturers (17.6% of total) and human food manufacturers (76.5% of total). The latter two groups were further divided on the basis of annual production volume, less than or equal to 100,000 tons per year, and more than 100,000 tons per year. The division is shown in Fig. 8.

Analysis of the current automation level showed that the plants with smaller production level per year ($\leqslant 100,000$ tons) reported that they are generally less automated than those with higher product volumes ($>100,000$ tons). This applies to both human and animal food manufacturers. For small plants, 25% of respondents indicated that the plant was mostly automated. For large plants, the percentage of mostly automated manufacturers was 67%.

This trend also applies to the use of microprocessor technology. Only 25% of respondents in small production volume group were mostly using microprocessor devices for process control. In the higher production volume category, 72.7% use mostly microprocessor-based systems. This suggests that larger plants are taking advantage of the benefits of microprocessor based technology.

None of the plants with smaller production volume (both human and animal food) use digital sensors. On the other hand, 44% of respondents with high annual production volume use some digital sensors for their process control. At the same time, none of the plants with higher production volumes still use pneumatic sensors, whereas in the group of smaller plants they are used in 25% of the cases.

Only 7.5% of smaller plants use digital communications within their control systems. The results for the category with higher production volumes show that 22.7% of respondents in this group use digital communications. None of the smaller production plants use fiber-optics for data transfer. About 11% of the larger production plants use fiber-optics for plant communications.

However, it appears that plants with smaller annual production volume have stronger desire for automation. About 75% of respondents in this group wanted to increase their automation level by one step (e.g., 'somewhat automated to mostly automated'), and 25% of respondents wanted a two-step automation increase (i.e., 'somewhat automated to fully automated'). In the group with higher production volumes ($> 100,000$ tons), only 50% wanted a one-step change in the automation level, and the rest of respondents did not want to increase their automation at all.

In considering the obstacles for implementation of new automation technologies it appears that the two biggest obstacles for plants with smaller production volume are time and cost. However, for larger plants, two biggest obstacles are cost and management commitment.

Regardless of age, most plants (94%) indicated that they have completely automated food processing. At the same time, it was found that most of the larger production scale plants (95%) have automated packaging,

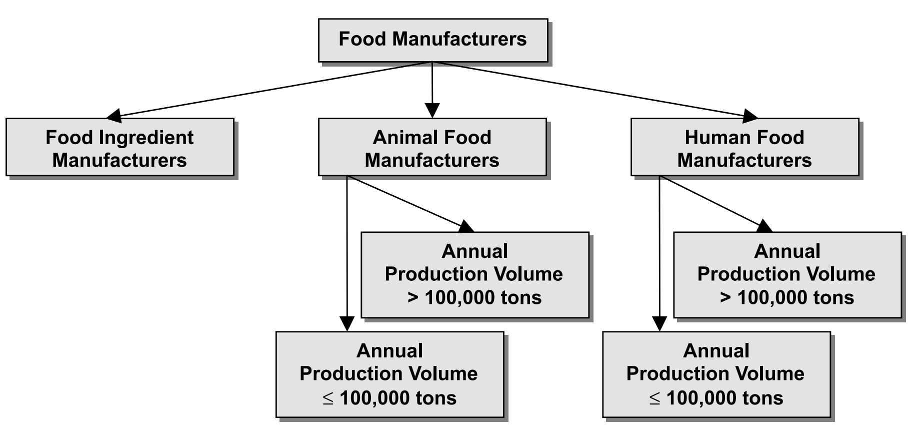

Fig. 8. Food manufacturers group division.

whereas only 50% of smaller scale plants have automated packaging lines.

Results of the survey show that the prevalent type of controller for food manufacturing plants is a PLC (found in 88% of surveys). PLC prevalence (63.4%) was also shown by Morris (1997) in his survey of food manufacturing companies. There was only one plant in this survey that had production level of more than 1,000,000 tons per year, and it is controlled by a DCS.

It was also found that plants with larger annual production level ($>100,000$ tons) use more advanced technologies for process control algorithms. Such methods as predictive control and fuzzy logic were only found in a few cases of plants with higher production levels. Although Caro and Morgan (1991) predicted almost 10 years ago that the use of fuzzy logic and neural networks has a big potential for the food industry, the results of the survey show that the industry is still being relatively slow to adopt these control strategies (fuzzy logic is used in only 12% of the cases).

As mentioned earlier, hardware and power failures were the two primary reasons for control system mishaps. It was also found that in one case, where power failures were the biggest reason, that uninterruptible power supply modules were not used to back-up the power for the control system equipment.

Over the last decade, the food manufacturers have made significant progress in applying computer technologies to all stages of the manufacturing process. Compared to the data gathered by Aly (1989), the use of computer-integrated manufacturing has increased from 41.9% to 94%. An even more significant increase was found in the use of computer-aided design of manufacturing processes. It increased from 6.5% in 1989 to 47% in 1999. The use of CIM technology in maintenance scheduling increased from 6.5% to 18%. The use of computer technology in the distribution management stayed about the same (45.2% in 1989 and 47% in 1999).

This survey found that 24% of respondents use CIM technology for HACCP. Ferrante (1999) in "Food Engineering's 1999 Food Manufacturing Trends Survey" indicated the use of CIM technology in HACCP programs has the highest priority among the food manufacturers for the next five years. This survey indicates that trend is starting to evolve.

The results of the above comparison show that there has been a big breakthrough in the food industry in use of computer technologies during the last 10 years. Most of the food manufacturers (94%) have adopted electronic record keeping systems for creating and logging the records of their processes but only less than a half of them back-up their systems for these records.

Morris (1997) in his research showed that 58% of food manufacturers have "scattered islands of control", and only 2.7% of surveyed plants have integrated the manufacturing process from top to bottom. It seems that the situation has not yet changed. Although all food manufacturers had some level of automation in their production facilities, the implementation of top-to-bottom integration principle in the food industry is still relatively low.

5.2. Equipment suppliers

It was found that among those equipment suppliers that do not have all parts of their equipment automated using microprocessors, the major obstacle for the implementation of modern technologies is the cost. However, for the group that has some to none microprocessor-controlled equipment, another major obstacle (with the same rating as cost) is the lack of skilled personnel.

Another interesting trend was found during the analysis of motivational factors for implementation of microprocessor technology. It was for the group that had most parts of their equipment automated using microprocessors, the decrease in production costs using their equipment is the lowest motivation factor (indicated by 25% of respondents). The highest motivation factor was increase in the quality of products manufactured on supplied equipment.

As expected, group that had most parts of their equipment automated using microprocessors uses more PC-based control systems (75%) than group that had some to none microprocessor devices in their equipment (25%). However, it was also found for the group that uses more PC-based control that the number of control system hardware and software failures per year is higher (three cases of more than 10 control system failures annually) than for the group that uses less PC control (one case annually).

An interesting trend was also found in use of fiber-optic technology. The results of the survey demonstrate that the group with more microprocessor-based equipment uses some fiber-optic communications (2% of plant signal transmission), whereas the group with little to no microprocessor-based systems does not use fiber-optics at all. This may imply that the group with more microprocessor-based equipment has higher exposure to the modern technologies available in the field of process control.

The majority of equipment suppliers work with system integrator companies to provide control for the manufactured equipment. Analysis of the factors that influence the decision of choosing a particular system integrator company revealed that the major factors for the group with less microprocessor-based systems was the cost of the control system provided by the integrator, integrator's experience and clientele and system compliance to process specifications. However, for the group with more use of microprocessors, control system cost is the lowest motivational factor in choosing an integrator company. The major factors for this group were the integrator's experience, clientele, technical support, assistance, and level of security built into the control system. This implies that the factor of system cost is perhaps the imaginary hurdle for the equipment suppliers that do not use microprocessor systems. The results for the group with higher use of microprocessor technology in their equipment demonstrate that once these technologies are applied, cost tends to be a minor factor for further application of microprocessors. Yet, technical assistance and support become very important.

The results for the equipment suppliers suggest that although these companies are generally more experienced and have greater desire for using cutting edge technologies for process control, they seem to follow trends in food manufacturing industry in slowly adopting new means and methods of process control. One example of such tendency is the use of different communication standards. Although equipment suppliers have twice as high use of digital transmission as food manufacturers, they still use significant amount of pneumatic communications. This could be driven by the food industry's demands for cheaper and less automated equipment.

5.3. System integrators

System integrators appeared to have highest experience and desire for using advanced technologies for process control. They offer a variety of control hardware (PLC, PC, DCS) as well as control system software packages.

Although 50% of the system integrators offer fuzzy logic algorithms for process control, all of them still offer traditional PID strategies. This demonstrates high demand among food processing companies for traditional methods of process control and relatively low desire of experimenting with some of the new process control strategies.

Yet, another reason to believe that system integrators are generally more advanced in using cutting edge technologies is the use of digital technology in sensors and signal transmission. All of the respondents offer a wide variety of digital sensors. The prevalent type of signal transmission offered by these companies is also digital (66%).

The results of the survey suggest that although system integrators offer a wide spectrum of technologically advanced devices and standards, in many cases their efforts are diminished by the food manufacturing plants not willing to adopt most modern equipment and automation practices.

6. Conclusions

This survey has demonstrated the current situation with automation in the food industry. Given the current knowledge, the following conclusions can be drawn.

- There is a significant increase in the level of process automation compared to the data gathered 10 years ago. The results of the survey demonstrate that although the majority of food manufacturers did not show a very high degree of automation, it can be stated that all food manufacturers have automated their manufacturing processes to some extent.
- Most of the respondents in this survey use electronic record keeping devices. However, some of the food manufacturers did not have a back-up system for the process records.
- The level of automation within the food industry is extremely variable. Manufacturing plants with higher production volumes are generally better automated and have lesser desire for further technological evolution primarily because of the lack of management commitment. Perhaps, this is due to the fact that additional automation cannot be justified based on returns gained. Smaller plants have less automation and almost no use of modern technologies and digital standards but have a very high desire for technological progress.
- Equipment suppliers are more advanced in the field of process automation than food manufacturing companies. However, driven by the food industry's demands for average-level of automation, this technological advancement is seldom used in the manufactured equipment.
- System integrator companies are much more technologically advanced and offer a wide variety of newest automation technologies. Equipment suppliers and system integrators should combine their efforts to provide complete automation plans for the food industry. Two main parameters that should be taken into account are the cost of the offered equipment and services, and change of management philosophy of the food industry towards process automation.

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