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Integration of Agents' Technology in Manufacturing

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Acronyms

AGV Automated Guided Vehicle. 12
AI Artificial Intelligence. 28
AR Augmented Reality. 7

CPPS Cyber Physical Production System. 18
CPS Cyber Physical System. 7, 13, 21

DPWS Device Profile for Web Services. 21

ERP Enterprise resource planning. 22

GPU Graphics Processing Unit. 14

ICT Information & Communication Technologies. 9
IoS Internet of Services. 7
IoT Internet of Things. 7, 9
IT Information Technology. 10

JADE Java Agent DEvelopment framework. 18, 37

MAS Multi-Agent System. 8, 15–19, 24, 25, 28, 39
MES Manufacturing Execution System. 19
ML Machine Learning. 19

NPD New Product Development. 9

OEE Overall Equipment Effectiveness. 12
OEM Original Equipment Manufacturers. 10

PLC Programmable logic controller. 21, 37

PLM Product lifecycle management. 22
PSO Particle Swarm Optimization. 16
PSS Product Service System. 10

RD Research & Development. 9
RFID Radio-frequency identification. 8, 18
RL Reinforcement Learning. 18

SM Smart Manufacturing. 7
SQL Structured Query Language. 22
SWOT Strength Weakness Opportunities Threats. 8, 24, 28, 39

TRL Technology Readiness Level. 17

UI User Interface. 9

VR Virtual Reality. 7

WSANs Wireless sensor and Actuator Network. 21

Summary

The advent of Smart manufacturing and the exposure to a new generation of technological enablers have revolutionized the way how manufacturing process are carried out. Cyber-Physical Production Systems (CPPS) are introduced as main actors of this manufacturing shift. They are characterized for having high levels of communication and integration and for computational capabilities that led them to a certain level of autonomy. Despite the high expectations and vision of CPPS, it still remains an exploratory topic and several issues have to be clarified i.e. methodologies for its design and implementation. Multi-Agent Systems (MAS), have been widely used by software engineers to solve traditional computing problems e.g. banking transactions. Because of their high levels of distribution and autonomous capabilities, MAS have been considered by the the research community as a good solution to design and implement CPPS.

This work first introduces a collection of requirements and characteristics of smart manufacturing. Afterwards, we surveyed various research applications, to understand what is the current state of the art and where it has been applied. With this ideas we formulate a SWOT analysis, that allow us to identify pros and cons of the implementation of agents in industry. In a next step, we use this knowledge to make an industrial expert evaluation (questionnaire), to understand the vision that industries have about the application of agents and emerging technologies in industry. In the last chapter of this report we provide main conclusions and future work ideas.

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Chapter 1

Introduction

1.1 Smart manufacturing

Smart manufacturing SM is a technology-driven method that monitors the manufacturing process using Internet-connected equipment. The aim of SM is to discover possibilities for automating processes and to enhance manufacturing performance via data analytics.

Distributed manufacturing intelligence on the factory floor may minimize setup times through planned or reactive control, as well as machine failures, by combining maintenance with machine data acquisition and status information monitoring.

Artificial intelligence, multi-agent technologies, service-based infrastructures, and cloud computing are enabling new levels of interoperability, integration, and seamless data exchange. These are necessary conditions for the transfer to the new system.

The emergence of modular, adaptable, and reconfigurable manufacturing systems has sparked new breakthroughs in distributed intelligence, such as holonic manufacturing environments and manufacturing systems that automatically adapt to unforeseen changes.

1.2 Emerging technologies in smart manufacturing

The advances in information, computation and communication technologies has helped shape the new manufacturing evolution. Sameer Mittal et al[1] has classified these enabling technologies into various technological clusters. A similar technological clustering is listed below,

- Visual technologies (Virtual Reality, Augmented Reality, Hologram)
- Data Analytics (Big Data, Machine learning, Modeling and Simulation)
- Cyber Physical System & digital twin
- Internet of Things/Internet of Services
- Cloud manufacturing (cloud, Edge and Fog computing)
- advance manufacturing (Flexible Manufacturing System, Reconfigurable Manufacturing System, Computer Integrated Manufacturing, Additive manufacturing)
- Cyber security (Federated learning)

- Smart products/parts (reusable & resilient parts, smart sensors, RFID)

These technologies combined with the legacy systems in place has led to a smarter and more efficient manufacturing system.

1.3 MAS in smart manufacturing

One of the emerging technology, which has not been widely used in current manufacturing industries but has a very high potential to develop a more autonomous and efficient system especially in complex manufacturing process is agent-based computation. Agent based technologies has attracted considerable interest in the research community due to its ability to tackle highly distributed and re-configurable control systems. These can help in developing a much dynamic and flexible manufacturing solutions.

Agents, in simple terms are ”cognitive entity with autonomous and social abilities”. There is very little consensus in properly defining an agent. A commonly accepted definition for an agent is that it's “an encapsulated computational system that is situated in some environment and that is capable of flexible, autonomous action in that environment in order to meet its design objectives [2]”.

Despite the lack of consensus in a proper definition of an agent, it is widely accepted that certain properties of the agents are desirable to be considered as an agent. these properties include,

- Autonomy - ability to have control on its own behaviours
- Reactivity - ability to receive inputs and react to environment to achieve its objective
- Pro-Activeness - Ability to initiate and adopt to achieve its objective
- Social Ability - Ability to collaborate with other agents in achieving inter-dependent tasks

These Agents could be inhabited in a physical environment (ex. thermostat) or software/virtual environment (ex. software daemons). An agent by itself is limited to its information, computing ability & environmental perspectives and is not able to solve a complex problems. In order to tackle these large and unpredictable problems, the agents collaborate with each other to solve the problem. Such systems are called as Multi-Agent System (MAS) where each agents solves its particular problems using its abilities but also collaborates with other agents to solve interdependent problems.

This deliverable is divided into 4 sections. First section tries to explain the current requirements of smart manufacturing, followed by the various applications of agents in manufacturing in second section. Considering the first and second section, the Pros and Cons on integrating the agent technologies is explained in the third section using a SWOT analysis table. The SWOT table is then validated through an industrial expert evaluation in the last section.

Chapter 2

Requirements of Smart Manufacturing

The shift in the market needs has always impacted the manufacturing industry and defined new challenges and requirements to be satisfied by the manufacturing industry. Increased competition from emerging markets and mass customization demands has pushed manufacturers to better utilize the new technologies in Information & Communication Technologies (ICT). This has laid the foundation for the new manufacturing paradigm called "smart manufacturing". These market needs have posed new requirements in smart manufacturing. A brief overview of the new requirements are mentioned below.

2.1 Integration

The process of integrating several businesses into a single industry, while still segmenting into separate departments to produce a completed product is referred to as manufacturing integration. Additionally, a very precise machining firm and a sheet metal company, as well as an injection moulding business, work together to create an electrical device.

A holistic approach to manufacturing integration looks at the product as a whole, rather than looking at it as an island. It is accomplished by becoming fully involved in the whole product engineering process, and also by taking part in UI development. Each component may be produced to satisfy its tolerance requirements by utilising the product's specification sheet. Compiling the components guarantees that the final product will function correctly when it is produced, eliminating any issues that may occur if the process is omitted[3].

The design of an IoT system should incorporate low-power communication technologies while also developing a standard way to communicate data amongst devices that are part of the network[4].

An important element of sustained competitive advantage is integrating with the other functional areas and suppliers.

A wide range of applications are available. For example, integration in problem-solving and coordination, integration in New Product Development (NPD), manufacturing and supply integration, manufacturing and marketing integration, integration in Research & Development (RD), and other types of integration are available[3].

2.2 Virtualization

Virtualization is an old concept, but not very well known. It has been in existence since the beginning of mainframe computers. It allows a business to utilise a big computer, with several programmes and operating systems, all on one device.

Virtualization is an industry-standard technology that is well recognised and often utilised. The machine will not have one database, it will have a database on each computer. If you have a single physical server, you may put all the virtual machines on that hardware and get access to the entire capacity and performance of the server. Businesses will use applications, and virtualization offers massive advantages for IT[5].

For smaller companies and those in sectors where process-related improvements are required, virtualization is quite helpful. To help conquer the obstacle of integrating virtual processes with the serial manufacturing of goods, such as the Demonstrations Fabrik Aachen GmbH and SmartFactory KL e.V. have been established to conduct demonstration and research. SCM experts agreed with our theory and said that we should use the end-to-end virtual engineering approach to identify the optimum operating point, and also said that releasing a new product might be expedited by using the technique[6]. The scale business would prove to be especially challenging for large Original Equipment Manufacturers (OEM) of cars, owing to their complicated supply networks and manual manufacturing processes. According to an additional expert, virtual prototype simulation software is critical to Industry 4.0, as it ”reduces the need for large-scale models from 1,000+ and more to a single prototype.” Even while the use of sophisticated simulation tools for production virtualization, particularly in small businesses, is at an early stage, according to the VDE Electrical, Electronic and Information Technology Electronics Association (VELEI) study, the use of these tools is nevertheless prevalent. The German factory system could not go much farther because the lack of uniform tooling and environments stopped the expansion of German manufacturing[7].

2.3 Service orientation

Aptitude and interest in anticipating, identifying, and meeting the needs of others, whether these needs have yet to be identified or not. People that are service-oriented are dedicated to meeting the needs of customers and being accessible to them. constantly exploring new methods to assist others[8].

With the move to higher-value manufacturing, service has become more essential. In the near future, it seems that service is going to become the main form of production and consumption. In this case, providing one complete solution to consumers via integrated services and physical goods is called a comprehensive solution through a single Product Service System (PSS). Additionally, the firms that supply PSS specialise in certain industries, and help each other as part of that relationship[9].

Many service-oriented manufacturing networks have developed between businesses that offer services as well as manufacturing services to one other. When looking at the business from an economic perspective, examine the reasons why the firm relies on outsourcing their business operations as an intermediary product to link various businesses. Even if a company operates inside various links in the manufacturing chain, profitability may vary. Explain the distinct added value of each step in the manufacturing chain using technical strength and industry knowledge. The service-oriented manufacturing business model, industry knowledge, and technological strength are explained by means of three components: business model, industry classification, and software.

2.4 Interoperability

The IEEE standard computer dictionary defines interoperability as "the ability of systems or components to exchange information and to use the information that has been exchanged" [10]. Different categories, approaches and perspectives of interoperability have been explained in previous years e.g. device, semantic, syntactic, technical interoperability etc. [11]. They describe data formats, ontological reasoning, technologies and even computation needed to achieve such level of communication exchange.

The challenge of interoperability appears in manufacturing because of the high need of integration and cooperation in the production processes at all levels of the factory due to the different actors involved (e.g. people, machines or organizational departments), and their role in supply chain process management. Therefore, achieving high levels of vertical and horizontal integration is majorly restricted in such scenarios. Interoperability should be anchored with high level of standardization. [12] Standardized protocols provide structured and reliable methods that makes easier the adaptation of certain technologies or in this case a communication exchange. With current high level of technological enablers, it is imperative to adopt common standards or in turn an adapter or transcriber for sorting heterogeneous environments or devices.

Following current interoperability requirements in smart manufacturing, several technological enablers have been adopted by academia and industrial practitioners. These provide the necessary infrastructure and autonomy for achieving such level of interoperability required. For example, multi agent systems, cloud based technologies and service oriented architectures have been highly applied in recent applications [13]. More recently, the use of fog computing has been also utilized as a way to enhance computation capabilities and security, by not managing the data outside the shop floor.

2.5 Reconfigurability

A reconfigurable manufacturing system as defined by Koren, Y. et al "is designed at the outset for the rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in market or in regulatory requirements" [14].

Within such definition, key characteristics for considering a system to be reconfigurable are [14]: Modularity which refers to the abstraction of the software and hardware components, integration capability related to the integration of the software and control module, customization related to modules with process oriented functions, convertibility that refers to the capacity of a system to be reused in a short time and diagnosability that relates the capacity of the modules to detect possible failures in the process.

In addition, the control of such reconfigurable systems should fulfill specific requirements i.e autonomous, distributed, open and scalable [15].

In terms of hardware and considering the manufacturing process to be carried out, reconfigurable systems can be related to machining system or machine tools (part of modular systems), reconfigurable fixturing systems i.e. hardware that is composed of different basic modules, reconfigurable assembly systems i.e. assembly machines can be changed to fulfill specifications of a product, reconfigurable material handling systems with the purpose of transporting material through the shop floor and finally higher levels of reconfigurability which are on the top of the shop floor [15].

In smart manufacturing the role of such reconfigurability results in high levels of re-usability of components, an increasing agility which is reflected in less time to system adaptation and the reduction of re-engineering effort. This level of reconfiguration is achieved by creating knowledge based systems e.g. ontologies or data models which provide the necessary expertise to support system changes and reconfiguration.

2.6 Safety and Security

Cyber security is used in the context of security practices related to the combination of offensive or defensive actions involving or relying upon information technology and/or operational technology. In this context, manufacturing systems can have vulnerabilities and those can occur at intersections (and intra-sections, referred to collectivelly as intersections) of cyber, physical, cyber-physical and human entities.

Because of the digitization required in the industry 4.0 context, these internet-based and interoperable manufacturing contexts, the cyber security threads represent one of the most significant challenges. The entire business model can be affected due to these vulnerabilities.

Cybersecurity accidents happen in different scales and areas, even from the lower levels of interoperable manufacturing management such as Overall Equipment Effectiveness (OEE) to cross-site attacks on different targets and types [16]. Although cybersecurity is perceived as a priority, the majority of companies have not been well prepared yet, which is further evidenced by the report in 2017 on McKinsey and Company [17] indicating that 75 percent of experts, but only 16 percent say their company is well prepared". One of the reasons that limit the ability to deal with the cybersecurity threads is that those threads associated with the scales and objectives have been evolved and adapted in different ways.

The workers are more concerned on safety and environmental risks in work space in which the cyber attacker may take over the control on manufacturing process or emission treatment and even manipulate endangering modifications on the user interface to cause human safety risks.

2.7 Modularity

Modularity can be defined as the ability of a system to easily and quickly decompose and/or combine with other system(s) to form different configuration. In Manufacturing, the concept of modularity is the ability to rapidly change to customer needs (i.e. product change) by having a system which can be flexibly adapted (by replacing or expanding individual modules). Its characteristics are not restricted to changes in the layout of the shop floor but also includes the ability to change the production capacity or integrate new functionalities.

Certain requirements of smart manufacturing is similar to Modularity for example, Composability (ability to be developed from sub-systems) or Convertibility (ability to extend the system functionality). A key requirement to enable modularity is the plug and produce [18] nature of the system/machines. Modularity can enable the ability to self-adapt, make the system scalable and composable, rapid integration and relocate the production line on time.

2.8 Decentralization

Decentralization can be defined as the ability of a group of systems to work independently towards a common goal. In manufacturing, system elements (workstations, machine tools, AGVs, products etc.) make autonomous decision in real time with focus on an overall organizational goal without a common control unit. The systems should perform the tasks autonomous (even during external interferences, specific exception and/or conflicting goals) and be designed to achieve global goals with local operating information. The Shift from a central to de-central control could be attributed to the effect of self-capabilities of CPSs. This may be achieved with the help of embedded computers interacting with sensors and actuators for an autonomous CPS. Emerging technologies like Internet of Things makes new data available at real time and aid in decentralized decision making [19]. Decentralization is a prime enabler of integration. A common synonym of decentralization used in manufacturing is Distribution (network of computers exchanging information for a specific goal).

2.9 Real-time capability

In simple terms, Real-time capability could be defined as the ability to respond in real time. In manufacturing, this response could be on changes in customer need, equipment conditions, quality defects etc. This could be achieved by analyzing the data generated from raw materials, equipments and finished goods. The systems and sub-systems (including product tracking) need to be monitored and controlled in real time to achieve this requirement. The system control could be using either diagnostic or reactive decision-making enabling the ability to recover from disturbances also in real time. The system should also be able to include humans and communicate with them in real time.

Virutalization, real-time visibility and Digital twinning could be considered as complementary characteristics to real-time capability as they tried to create a digital replica and visualize the real system. This could be used to derive insights in real time (for example, Lee et al[20]). Modularity , Network capability and communication are key requirements that's needed to achieve Real-time capability. In order to respond in real time, the system has to either reconfigure with the help of existing resources or request services (mostly cloud based). The system should be modular in nature to achieve the first solution and must have networkability for the second. proper communication infrastructure ensures data acquisition and information feedback in real time. Real-time capability could be applied to prevent breakdown[21], detect quality defects and ensure safety [22]. An extension to this ability would be the ability to provide intelligence/smartness to the system with the collected historical data and current real-time information [23].

2.10 Cooperation and collaboration

Cooperation in manufacturing systems is the ability of the systems to decide autonomously the parts/subsystems that would carry out work together to complete certain goal [21]. Even though Cooperation and collaboration has similar features, the concept of collaboration has a higher importance due to its ability to share resources and combine individual goals in achieve a common goal [24]. In Cyber Physical System there is actually a shift from a cooperative environment towards a collaborative one. In achieving this requirement, the CPSs could react to changes in the system and also achieve specific goals in an optimized manner. This collaborative environment in an autonomous system will enable smart factories with self-x characteristics like self-maintain, self-organized etc.

Another aspect of collaboration involves the use of human in the loop. This would enable a combination of accuracy & computational capability provided by the robots/machines with the intelligence and flexibility provided by the human [25]. This human-machine collaboration could be achieved through voice or hand gestures interactions. It should be noted that some researches use the term ”symbiosis” instead of collaboration to stress the fact that the abilities of the humans are not replaced in achieving the goals. Another role of collaboration is in the area of information sharing from lower level to higher level across involved parties.

2.11 Data Management

Data Management is the development and execution of architectures, policies, practices, and procedures to manage the information life cycle needs of an enterprise effectively. In data management, the information should be accurate, consistent, and secure [26].

The management of large and complex amount of data becomes more troubling while using traditional data process application. The encountered challenges are included gathering, curation, analysis and storage of large amount of dataset. The dataset sheet causes complexity of analysis along with commercial optimization which led to new tools for tackling down the obstacles like enhancement of technological tools[27][28] and further management of data. Other challenges are heterogeneity (un-structured data), incompleteness, scale (Moore's law meet the requirement of increasing volume of data as well as advance GPU system), timeliness of data (processing big volume of data in real time) and data privacy [29] and confidential right applied to keep the information safe [28].

2.12 Context-awareness

Context awareness refers to the ability of a system to collect information from its environment and to adapt their behaviours accordingly. Contextual information includes data which is relevant for a given entity e.g. machines, people software or hardware. This contextual information may fall into different categories and variables e.g. location, temperature, role, activities, tasks, processes, etc. Context awareness methods are widely used in computing systems to enable automatic and to some extent intelligent processes, giving actionable experiences to users. In manufacturing, the contextual information comes from sensors that are afterwards handled by a set of rules, event driven algorithms or computational intelligence methods. They provide the adaptation logic to change parameters, control variables and overall the behaviour of the system.

2.13 Autonomy and self-capabilities

The definition of autonomy is anchored in cooperative behavior. The cooperation is towards reaching a specific goal without any external influence [30]. The individual entities in an autonomous system should have the capability to collaborate, implement and move towards such a goal. These individual entities in themselves may have their own rules and control mechanisms but collectively compliment to a specific goal. Autonomy may also be generalised as the aptitude of individual components to take independent decisions [31]. In essence, the level of uncertainty of system is co related to its autonomy level. Higher capability of a system to adapt to uncertain conditions higher the level of autonomy of the system. An intelligent machine is considered to be autonomous if it is able to execute complex tasks and show dynamic adaptable behavior without inherently relying on detailed sequential programming and human-control [32].

The degree or level of autonomy can be related by the number of decision taken by the system [33] and also by a criteria based approach which determines where the system is based on its accomplishments [30]. As per this, the general definition of autonomy can be envisioned as the capability and capacity of the system to make decisions based on current and previous state, inherent system knowledge and environment. The aptitude with which it could plan, control and execute such actions without assistance gives an idea of autonomy level of the system.

These new requirements in the smart manufacturing has helped in developing new technologies to meet these requirements like agent based technologies. In further chapters will explain the current application of MAS and try to understand the strength & weakness of agents in manufacturing by comparing these requirements with the current application. Such a comparision will help in understanding the current status of agent in meeting the current requriments and guide the further development to tackling the challenges.

Chapter 3

Applications of Agents in Smart Manufacturing

MAS technology is being applied to several industrial applications in the context of smart manufacturing namely process control, production planning, scheduling, monitoring, quality control, diagnosis, process reconfiguration and manufacturing simulation and executions. Current section shortly surveys, and discusses some existing industrial applications which have been developed in the last decade. Results of this survey will be utilized to evaluate the current status of its industrial adoption, main advantages and current challenges.

3.1 Process and Manufacturing control

Li et al. [34] developed a MAS architecture for collaborative control in process industry. The MAS uses an hierarchical distributed co-operation architecture. A Deep Deterministic policy gradient algorithm is presented by the authors for collaborative control. The same authors in a different article [35] presented a optimization model for process control and also validated the model in a cement production process. The model uses MAS with Multi-Objective Particle Swarm Optimization (PSO) algorithm and is divided into two layers : control and execution. In order to reduce the time consumption, separate agents are used for algorithm storage, data and communication between agents. Raileanu et al.[36] extended the existing semi-heterarchical manufacturing control architecture with a Multi-agent solution for robotized holonic manufacturing. The solution provides an automated component supply with MAS control at central feeding station. The agents are in charge of operating physical components. The MAS control solution includes different types of agents : resource, order, supply and supply station agents. Vatankhah et al.[37] provided a solution to improve manufacturing control system with focus on improving self-organization and reducing the processing time using ant agents. The solution utilized an indirect coordination (stigmergy) mechanism based on ant colony intelligence. The developed system is based on indirect communication of the agents. Rocha et al.[38] expanded the MAS distributed system by introducing two more layers : Integration and Simulation, to achieve a digital twin for manufacturing control. Implementation of the framework helped in predicting and understanding the execution of systems in run time. As there doesn't exist a standard for digital twin, a widely-compatible programming language and file format was used to further develop the system. The results also showed that for effective control there is a need for not only to mimic the agent interactions but also other information like network connections, modules, computational devices.

MAS technologies clearly shows the advantage of its implementation in a distributed and collaborative control of manufacturing systems. MAS can be used as the extension of the existing control architecture. These can be further expanded by introducing some modularity and self-organization characteristics. In spite of the wide range of applications of MAS the TRL level of the adaptation is very low. Most of the works cited here are below TRL 6. This is due to the unpredictability and uncertainty associated with the distributed approaches. The lack of an industrial standard for agent technologies also contribute to the low adaptation of agents control systems in manufacturing.

In a presentation on Industry 4.0, Li et al.[39] detailed a smart manufacturing framework of Industry 4.0. A proposal will be presented which, among other things, involves the smart goods, cloud computing, and shop floor systems (machines, conveyers, etc.) that are all able to communicate and collaborate interactively via networks. According to the idea of MAS, the shop floor entities may be regarded as agents. These agents work in a collaborative way to accomplish dynamic reconfiguration for agility and flexibility. To decrease the load-unbalance with the help of big data feedback, smart assessment and control techniques are suggested. It seems that these algorithms may be readily used in smart production systems and help with both load distribution and overall efficiency.

Hussain et al.[40] suggested that the performance of flexible production systems is affected by design and control variables. To address these issues, industrial control systems developed into distributed manufacturing control systems via the use of various control architectures. These distributed control systems offer an effective method for optimising system performance in a reactive and dynamic manner. The system is assessed based on its make span, average machine usage, and average time spent waiting for parts in the queue. To perform simulation experiments, discrete-event simulation models are created. The acquired findings were submitted to multi-response optimization in accordance with the Grey-based Taguchi technique. The impact of control design on the performance of a flexible production system was statistically significant.

Bulatov [41] suggests that the event model of the multi-agent control system of dispersed generating facilities should include a design, description, and Joiner-network of turbines and generators. The distributed generating system's central control is hindered by the excessive quantity of data needed to transmit to the control centre. Use of peripheral systems based on the agent approach increases control efficiency. The agents of the interactive network describe the primary functions of the interactive network. Results modelling indicated that gains from a multi-agent control system were present. The flexibility of the system in regard to changes in circumstances and the MAS' usefulness for building dynamic adaptive power networks is shown.

3.2 Production Planning and Scheduling

Manufacturing scheduling is considered a difficult problem as it involves multiple resources and multiple operations. Integration of process planning and scheduling becomes even more complex.

Without use of enumerative algorithms, it is hard to find optimal solutions, and computation time increases exponentially with problem size.

Intelligent manufacturing has applications for entire industries that can benefit from cutting edge technologies, like MAS that have been applied also in manufacturing scheduling [42, 43].

An agent based framework is a suitable solution for problems related to production planning and scheduling by defining work-flows and following manufacturing logic facilitating decision making [44].

The work done by [45] presents a methodology of using hierarchical agent bidding system to enhance operational performance, robustness and flexibility by dealing with dynamic changes in real-time business environment. Advantage offered by this technology utilisation is realisation of the capability in manufacturing setup, reorganising within system constraints for orders with minimum disturbance. Other works [46] utilise production smoothing by agent technology to balance out the production load across workstations decreasing work in process, effective material flow and shorter lead times.

The work proposed by [47] shows an application that utilizes event driven RFID for planning and scheduling (collective intelligence). Data from RFID along with standard operation times allow the reasoning about planning and scheduling activities. The approach breaks the traditional architecture between planing and scheduling into a continuous and automated feedback operation, enhancing the decision making. Collective intelligence and RFID are based on agent-based technologies.

Negotiation mechanism in agent based technologies have been used in manufacturing production to improve system efficiency [48]. The mechanism could be anchored by have agent negotiations map managerial structure of the manufacturing enterprise. The insight could then be decentralised to product formulation at each step of production process where each aspect could be monitored and controlled at every period of production [49].This gives leverage to controlling accumulating production costs over time [50].

[51] presented a detailed review on application of machine learning in production planning, control and scheduling aspect of manufacturing systems. Tools, techniques, data sources and activities realised by and through machine learning can aid in better production system performance and consistency while incrementally increasing efficiency along the time period. Recent works have shown a shift of incorporation of control, machine learning and agent technology for getting higher efficiency. Co-operative multi-agent behavior by means of reinforcement learning can factor in key-performance indicators to develop effective production control [52] and planning phase for problems considering complex tasks performed by manipulators for task-agent assignment [53].

Much larger scheduling problem have been addressed in research [54] where transport in production facility was controlled by multi-agent interaction by self-controlling and self-organising agents. Elaboration on these works need to be done for targeting or mapping all the characteristics of supply chain process [55]. A greater need for integration of learning and testing models remains evident for production planning and scheduling.

3.3 Manufacturing monitoring, Quality Control and Diagnosis

Peres et al. [56] presented a pluggable framework for real time monitoring with three components : CPPS component, Real-time Data Analysis Component and Knowledge Management Component. In implementing the CPPS component - to extract data from the shop floor - a MAS was implemented using JADE based on work carried out in FP7 PRIME project[57]. The same framework was also implemented in a different work for multi-stage quality control in earlier prediction of defects [58]. This was implemented in assembly of tailgate for automotive industry.The MAS abstracts both components and subsystems. The system includes three types of agents : Component Monitoring Agent, Subsystem Monitoring Agent and Deployment Agents. Baer et al.[59] developed an initial concept for handling un-foreseen machine failures using Deep RL agents. Each product is controlled by its own agents and handles re-configurations of the plant topology by considering local and global optimization goals. Rokhforoz et al.[60] integrated central coordination system and distributed agents for developing a multi-agent decision support framework for maintenance in power grid. The decision support system works in two levels. The framework uses distributed algorithm for maintenance decisions & to communicate with central co-ordinator and a negotiation algorithm for co-ordination problems. Cui et al.[61] provided a multi-agent based solution for a two-level multi-component system addressing its maintenance resource scheduling problem. The user can choose between two selection criteria - Fixed-pair and nearest distance - according to the failure situation. Mantravadia et al.[62] developed a ML based anomaly detection algorithm and an architecture for multi-agent MES. The author's demonstrated that the MES executes the 'turning off' command of a machine without human intervention.

MAS is these applications is largely used for the abstraction of resources or the sub-systems in the shop-floor. These abstraction provide information in monitoring, predicting failures and decision support. The use of ML especially deep learning techniques provide skills to predict un-foreseen machine failures.The applications of MAS in shop-floor for monitoring and maintenance activities shows that it adapts to the changes in the shop-floor quickly and provides additional flexibility and robustness.

3.4 Manufacturing simulation and Execution

According to [63], simulation that includes many agents is a technique that may analyse complicated systems. Simulation of complex systems using many autonomous agents is known as Agent-based modelling and simulation (ABMS). When discussing the model of the production system, there may be instances when a batch of model production system agents is produced apart from other kinds of production system agents like machine tools, conveyors, or replacement stands. Multi-agent modelling is a versatile method for conducting and generating models that is adaptable enough to meet various research goals.

Major effort is made to design continuous flow production systems for today's market needs. When the manufacturing is disrupted, it degrades the efficacy. Current research initiatives, such as those that are under way, utilise flexible production systems with a high degree of self-organization to counteract this issue.

As part of his proposal, Blesing [64] presented a new idea for a flexible decentralised production system that integrates a precedence graph-based planning approach with a multi-agent control system. In addition, the initial findings of a pilot demonstration and simulation tests are given.

Production firms have to adjust to increased competition and rising market dynamics to allow for more flexibility in their manufacturing processes. Therefore, more innovative methods that go beyond the conventional production system's capabilities are required. The simulation modelling of such systems must be revisited as well. This is an important point, since the tools industry uses for simulation, often known as industrial grade simulation tools, are not adequate for this purpose. Büth et al. [65] is interested in creating a complex manufacturing system simulation model from scratch in an industrial-grade discrete-event simulation tool. An example application is based on a matrix-structural manufacturing system that offers a flexible and scalable method without a set cycle time, due to the structure and to the entities operating as separate and independent agents.

3.5 Reconfiguration, Self-adaptation and Plug & Produce

Agents solutions for re-configurable manufacturing systems have been developed for more than two decades [66]. Generally they are based on negotiation protocols, where agentified manufacturing entities collaborate and negotiate to fulfill a specific order or requirement. Generally they follow a specific paradigm e.g. PROSA [67], COBASA [68], ADACOR [69] or they are simply a variation of them with the main focus of showing adaptability in the event of changes.

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Leitao et al [70], present a dynamic self-organizing holonic manufacturing system. The works shows a 2-dimensional model based on a behavioral (low level) and structural (macro level) reconfiguration. In this reference architecture there is an entity that is in charge of the global control. It consists on a discovery, reasoning and learning mechanism. Also it presents a nervousness stabilizer block in case of chaotic behaviors. The process is based on a rule base engine in a flexible manufacturing system where the objective is the assembly various parts. Zhang et al [71] show a reconfiguration process assisted by the use of a cloud infrastructure. This work is based on negotiation between products, machines and conveyors. It also includes big data that supports the process negotiation. Additionally, it considers a deadlock prevention. Wang et al [72], [73] proposed a similar approach. In the context of industry 4.0 they introduce big data analysis of sensorial information of resources that is processed in the cloud. In [74], a different application uses the multi-agent reconfiguration approach as a way to dynamic reconfigure services (they act as resource functionalities: e.g. quality control, welding, transportation). By a continuous monitoring, this approach constantly finds opportunities to reconfigure, considering also optimization indicators. The process comprises the elaboration of a pool of possible service reconfiguration solutions, which compatibility should be tested by using a context and semantic matching. The decision of the service reconfiguration is based on the evaluation of various alternatives considering costs, stability mechanisms and collaboration i.e. deadlock, non-beneficial solutions, etc.

A slightly different work is presented in CASOA (An Architecture for Agent-Based Manufacturing System in the Context of Industry 4.0) [75]. There is an ontological representation to provide a basis for decision making. Additionally, this work introduces cloud-assisted mechanisms to coordinates agents globally.

One of the few works that does not considered a negotiation mechanism is BIOSOARM [76]. It applies an attraction mechanism (bio-inspired implementation/firefly algorithm) as a way to select an adequate path for the self-organization process and to find also the most adequate resources. In this work, there is no need to define a self-organizing mechanism. In fact, ”entities do not need to be fully awarded of sequences” [76] e.g. If a part or resource is missing, the system will automatically attract another part to take place of the removed one.

Agent used for reconfiguration technology are mostly catered to introducing aspects of modularity in production settings such as in case of research done by [77]. The collaboration between agents in the research proved to an anchor for rapid factory transformation when applied to discrete component assembly, machine shops and customisation of products. The propagation of transformation is encapsulated by using agents for control applications driven by infrared communication along with sate management by protocol guided update mechanism for rapid workstation deployment [77] resulting in time-saving in re-configuration. [78] presented an agent driven reconfiguration method that identified demand and used it to generate feasible alternatives for the system. A suitable intelligence mechanism is a necessary requirement to evaluate among the alternatives and go for optimum selection. [78] while discussing this approach for intelligence in their prototype tried to tackle issue of time-taken for reconfiguration. Significant work is needed on the approach as current intelligence design is not concrete, resulting in error-prone method compatibility, not reaching optimum for reconfiguration and high human-dependency [78].

Plug and produce approach applied for reconfiguration gives a product-centric control to the assembly components. However, this requires protocols for the components to interact with the environment like the work done by [79] which used OPC-UA to interact with IEC 61499 based environment. This kind of approach requires an accurate representation in terms of information model regarding manufacturing services present in environment. This approach is feasible for products that are present in small lot sizes requiring customisation and huge environmental agility for adaptation.

A number of projects have focused on deployment of agent based solutions for automated configurations and co-ordination in robotic systems [80]. Ontology based principles have seen significant acceptance for agent-based control and co-ordination for dynamic operations. This type of deployment couples with service-oriented architecture to reduce setup and programming time shifting by agent based configuration through ontology-based registration of resource network settings. [81] presents an approach based on this for development of controls strategies based on ontology knowledge base and factual inferences. In a similar manner the configuration of PLC controllers have been exploited for control at high level whereas IEC 61499 controllers exploit low level functionalities. [81] stressed the work for protocols that are needed to establish communication between CPS for real-time adaptation. Other works on agent implementation for reconfiguration have targeted service-oriented architecture for enabling self-organisation behavior in resource networks [82], developing of production system for industrial robotics [83], self-repairing of manufacturing systems [84], and adaptive automation assembly systems [85]. Agent technology has been significant application to solve challenges of dynamic adaptation such as for reorganisation, task execution, resource network variation, part and system diagnosis. Most of these application require in some essence need for reconfiguration to be made either to cyber or physical infrastructure.

Agents for further progression in manufacturing should target, in regards to reconfiguration, continuous production operations. Feasible application demonstrations are necessary to ensure ROI to address economic concerns. Agents for modular transformations can be further enforced by proper transformable jigs and fixtures, proper tracking and tracing and in-process quality inspection [77]. Intelligence must be incorporated in agents for proper reconfiguration strategy deployment mainly targeting intelligence integration at the machine level to ensure optimisation of production parameters [78]. Agent driven protocols require proper commissioning and standardisation mechanism [79] for proper environmental interaction. Agent systems can be used for fault detection, failure event prediction and real-time diagnosis [80]. A proper control mechanism however requires proper communication for handling frequent changes and constant uncertainties [81].

Significant challenges to agent implementation to reconfiguration problems are pivoted by lack of monitoring and analysis tools along with platforms to develop dynamic context-based insight [82]. These challenges are further enforced by lack of integration mechanisms between cloud/edge computing resources, WSANs coupled with ontology frameworks [83]. Proper learning mechanisms are necessary in the system to achieve self-diagnosis with focus on varying demand and costing needs [84].

3.6 Service and cloud base applications

Agents and web services can be integrated to provide the best of both worlds, considering the autonomy of agent technology and the interoperability provided by service oriented architectures. Generally, the components at the lowest level e.g. controllers or PLC (device layer) provide their functionalities as services using the DPWS protocol [86]. This creates a kind of virtual resource which highest control and interoperability can be implemented using a multi-agent approach (execution layer).

The integration of low level controllers with MAS normally relies on legacy PLC programming standards like IEC-61131 and IEC-61149. These standards are based on a control logic and in service based function block respectively. In higher levels this control logic is managed by a multi agent based logic [87].

This execution is normally designed in a higher level which can adapt its behavior to different scenarios (logic layer). To complete the orchestration, this process is normally governed by business or higher functions that manage the whole enterprise integration [86].

In various cases the utilization of service and specially cloud based infrastructures assists the interaction of negotiation of the cyber-physical units. However, very few works utilize such infrastructures to run agent operations. Additionally, several approaches utilize cloud technologies to support the operation and data distribution at the shop floor level.

In [72], in the context of a process reconfiguration based on multi-agent negotiation, a cloud infrastructure is used as an interaction management framework. It hosts a SQL server and various virtual machines. One is a Hadoop cluster that performs distributed data processing, the other one is a Flume server, and finally a MySQL server. The cloud is utilized as a multi-layer interaction to integrate consumers, management and shop-floor entities. Also, the cloud assists the interaction between robots functionalities and transport systems. This work is showcased by means of the flow control of a prototype for packaging assorted candies. A similar approach is presented in [73]. Here the cloud acts as a supervisory control entity. Likewise, a cloud based self-organizing architecture with agents is presented in [75]. There is an ontological representation to provide decision making support during jobs execution. Also communication methods are proposed to meet interoperability communication demands. These methods are based on OPC-UA, that is used as a network bridge for monitoring and data acquisition. The framework also supports higher integration levels e.g. ERP and PLM.

[71] proposes a self-organizing and self-adaptable manufacturing framework, service oriented technologies wrapped the functionalities of machines and resources which can be invoked and deployed on demand considering various models and intelligent algorithms for task allocation. Importance is given to functionalities like proactive service discovery, conflict resolution models, and optimal configuration of resources according to a manufacturing cost evaluation. The lack of a complex case study analysis, is one of the limitations of the work. Manufacturing shop floor include complex environments and therefore more intelligent service discovery, composition and orchestration should be developed.

In [74] an extensive work for dynamic service reconfiguration is presented. In general, services are wrapped for quality control, welding or transport operations and a dynamic orchestration looking for opportunities to reconfigure is done by a multi-agent layer. The compatibility of services and operations utilizes a semantic matching to reduce the dimensions of alternative solutions. Various alternatives of reconfiguration are evaluated based on metrics of reconfiguration, deadlock situations, collaboration, etc. The non-consideration of possible nervousness (instability) of the system because of its high dynamicty is one of the drawbacks in this research.

The section provides a brief overview of the various applications of agents in manufacturing sector. A summary of these applications is provided in Table 3.1. Understanding of these applications will provide a clear understanding of the current status, limitations, challenges and future opportunities in the implementation of agent technologies.

Table 3.1: Summary of agent applications

Applications	**Area of Interest**
Process and Manufacturing control	MAS architecture for collaborative control, solution to improve manufacturing control system, distributive control
Production Planning and Scheduling	Advanced Planning and Scheduling for Manufacturing, collaboration among multiple planners
Manufacturing monitoring, quality control and diagnosis	MAS on shop-floor for monitoring and maintenance, quality control,how much money to spend on quality improvement, quality assurance specifications, centralized control in production
Manufacturing simulation and execution	agent-based simulation model, simulation environment
Reconfiguration, self-adaption and plug, produce	PROSA, COBASA, ADACOR, BIOSOARM, dynamic reconfiguration services, agent-driven protocols
Service and cloud base applications	cloud infrastructure, Cloud based self-organizing architecture with agents, dynamic service reconfiguration

Chapter 4

Pros/Cons on the Integration of Agents Technology in smart manufacturing

This section provides an overview of the Strengths, Weakness, Opportunities, and Threats SWOT of the application of agent technologies in manufacturing. The SWOT analysis as a strategic planning framework provides details about a system's organization capabilities [88]. It is used here to identify internal and external factors that affect the application of agent technologies in manufacturing and as a baseline to evaluate their advantages and disadvantages. Also, current section intends to harmonize and link concepts and applications of chapters 2 and 3.

The result of the SWOT analysis is represented in Tables 4.1, 4.2, 4.3 and 4.4. First columns show a description of each of the SWOT variables. Second columns show related requirements in the context of smart manufacturing. The last column shows some application examples.

4.1 Strengths

The integration of MAS in manufacturing potentiates the decentralization and distribution of process control. Less centralized systems are more adaptable and fault tolerant. Decentralization also means the development of units with local intelligence and the increase of the level of autonomy. In manufacturing, this is the result of machines that have context base decision making i.e. they can take autonomous decisions.

Likewise, social ability properties increase the cooperation of manufacturing elements. This has been exemplified with direct and indirect communication between resources, orders, logistic agents, etc. which work together to perform assembly operations (for control and diagnosis). This fosters the design and implementation of process modules, which are software and hardware abstractions developed with the purpose of increasing process customization. Modules can form different processes when re-arranged without major engineering effort. This is commonly known as plug and produce.

Current agent technological capabilities are also compliant with emerging technologies like web services, cloud computing, machine learning, interoperability thought ontological models, etc. This technological integration add additional functionalities and features in manufacturing operations.

Table 4.1: Strengths on the application of agent technologies in manufacturing

Strengths	Requirement	Applications
Distributed control	Decentralization, Safety and Security	Process Control
Autonomous control	Autonomy and self-capabilities, Intelligence/smartness	Manufacturing control
Co-ordination and Social Ability	Cooperation and collaboration , Connectivity and Communication, Real-time capability	Monitoring and Diagnosis
Plug and Produce Ability	Reconfigurability, Compositionality	Reconfiguration and Self-adaptation
Mass- customization	Adaptability	Production Planning and Scheduling
Modularity	Modularity	Reconfiguration and Self-adaptation
Service and cloud based integration	Data Management, Service Orientation, Integration, Computational capability	Others - ex. SOA based, Cloud based
Ontology based principles integration	Complexity/heterogeneity encapsulation, Integration	Reconfiguration and Self-adaptation
Creative thinking	Context awareness	Reconfiguration and Self-adaptation
Low level device integration	Integration	Process control

For example agent-service integration adds software scalability for modules. Machine learning techniques can be used as an input for agent negotiation.

In a more conceptual discussion, MAS push more creative ways of thinking when designing distributed systems. As traditional centralized approaches cannot cope with current market dynamism (mass customization), distributed solutions should be pushed forward in smart manufacturing applications.

4.2 Weaknesses

Agent technology application are constrained in their application because of lack of integration between production and process systems. This integration issue primarily is contributed by adaptability restriction in systems usually involving protocols, standards, framework similarity, and synergy at low-level component. These restrictions lead to significant difficulty in adapting agent technology at the system level as the program needs to be molded to address each component.

Along with these to ensure proper integration of these technologies for decentralised control a significant capital investment is incumbent. This is to assure standard is maintained across the production system, and program consistency is maintained. Production planning and scheduling activities can be homogenised if a matching framework is adopted.

The applications in some cases need to be simulated before execution, there a robust software that can align and accommodate multiple scenarios is required. Currently this is one of the major

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Table 4.2: Weaknesses on the application of agent technologies in manufacturing

Weakness	**Requirement**	**Applications**
Legacy systems integration	Integration, Adaptability	Process and Manufacturing control
Investment cost	NA	Production Planning and Scheduling
Standardization	NA	Manufacturing monitoring and Quality Control
Robust software	Safety and Security , Interoperability	Manufacturing simulation and Execution
Low computing device programming	Computational capability	Manufacturing monitoring and Diagnosis
High execution time	Real-time capability	Manufacturing Execution
Predefined negotiation rules	NA	Manufacturing Execution
Human in the loop integration	Safety and Security	Manufacturing monitoring and Diagnosis
Lack of experts and awareness	NA	Process and Manufacturing control , Manufacturing monitoring and Diagnosis

hurdles to wide spread adoption as safety and security of execution needs to be validated before operation. In a similar case due to extensive programming requirements agent technology is less significantly used, however making standard interfaces could be helpful in monitoring and diagnosis of manufacturing applications.

Negotiation rules need to be programmed which requires high-level experts, an intuitive means of inserting negotiation rules as functional blocks may be helpful in wider adaptation. Agents framework must also be expanded to include aspects of humans as agents.

4.3 Opportunities

Opportunities refer to favorable external factors that could give an organization a competitive advantage. In this case, we refer to competitive advantages to the benefits that the implementation of MAS may bring to manufacturing industries.

The first point to consider is the digitization of factories. As it is essential the abstraction of physical resources, decision making and processes as software units, agent-based design is paving the way towards achieving this goal, with several use cases already implemented. At the same time agent-based applications promote integration and interoperability in the manufacturing chain.

New design methods in distributed solutions are talking advantage of agent-based principles. This is specially applied for manufacturing control and diagnosis; for example when mimicking the behavior of natural processes. Various applications have been referenced in this work that use pheromones, chemical reactions, or attraction mechanisms. Those provide new sources of inspiration to overcome current engineer limitations.

This new methodological ideas and design result in more flexibility and agility at the shop floor level. In other words, software and hardware modules that can be easily adapted for new processes, requiring few/none engineering effort and time.

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Table 4.3: Opportunities on the application of agent technologies in manufacturing

Opportunities	Requirement	Applications
Digitalization of factories	Virtualization	Manufacturing simulation and Execution
Novel Distributed thinking sources	Decentralization, Safety and Security	Process and Manufacturing control
Flexibility and Agility	NA	Production Planning and Scheduling
Mass- customization Adoption	Adaptability, Reconfigurability and Modularity	Production Planning and Scheduling
Autonomous needs	Autonomy and self-capabilities, Intelligence/smartness	Manufacturing control

4.4 Threats

A significant threat to application and acceptance of agents in manufacturing organisations is the bias towards centralised control. A distributed control thinking must be propagated to take full benefit from agent technology. To ensure this proper safety and security standard must be developed and validated.

There also exists a lack of practical examples of implementation of agent technologies that must be worked on. A mechanism where these technologies can be integrated will significantly build trust in industrial organisations.

Table 4.4: Threats on the application of agent technologies in manufacturing

Threats	Requirement	Applications
Acceptance of Distributed thinking	Decentralization, Safety and Security	Process Control
New Safety and Security standards	Safety and Security	Manufacturing monitoring and Quality Control
Centralized control	NA	Manufacturing control
New technologies	NA	Others - ex. SOA based, Cloud based

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Chapter 5

Expert Evaluation on Agents integration in manufacturing

In order to evaluate main features, advantages and disadvantages of the implementation of MAS in manufacturing and to understand the industrial need of this technology, we conducted a survey to various industrial experts. The methodology, findings, results and analysis of the survey are described in the rest of this section.

5.1 Methodology

The survey considers the experience of the authors, the SWOT analysis and the review of the state of the art applications made in previous sections. From these results, we try to evaluate various aspects that have influenced and will influence the implementation of MAS in manufacturing.

We have analyzed four categories namely:

- Current market variability
- Current technological status
- Feasibility of new technological adaptation
- Future of autonomous Systems

The market variability section responds to the analysis of the flexibility and agility of contemporary manufacturing systems i.e. how easy can they be adapted and how quickly this adaptation process can be carried out in different contexts. It is focused on factors that appear as a consequence of the parading shift (from mass production to mass customization) i.e. setup time, deployment time, type of machines used and programming skills needed.

The current technological status section aims to evaluate which emerging technologies are being applied in industries. A lot of current research assumes that manufacturers have already adopted various emerging technologies i.e. AI, cloud computing, collaborative robotics, etc. or at least assume that they are willing to do it. The feasibility of new technological adaptation section, unlike previous one, tries to understand how practical it is for companies to adopt new solutions, what opportunities they have to fulfill their needs and how easy it is for them to support legacy systems and traditional standards. Finally, the future of autonomous systems section, explores some benefits

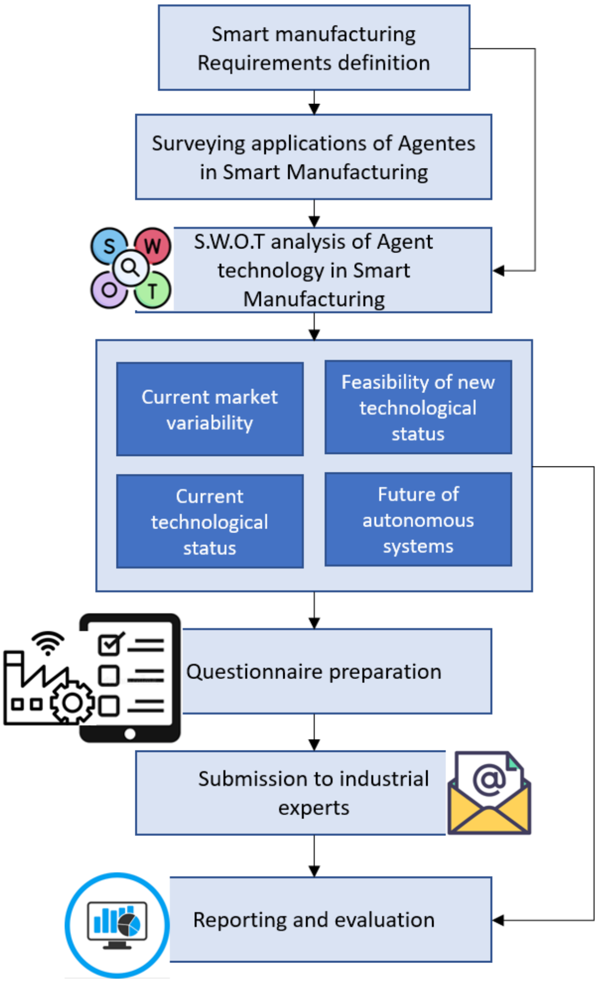

Figure 5.1: Methodology for Expert evaluation on Agent integration in manufacturing

and effects of these new technologies, emphasizing the role of autonomous control, digitization and the future of humans in shop floor lines. Questions were prepared and sent to various industrial experts using google forms. The results of the survey and the study made during this work were used to discuss, compare and evaluate the application of agents in industry as will shown in next subsections. A summary of this process is shown in Fig 5.1.

5.2 Results

The survey results present a focus on the present understanding of the industry towards multi-agent system applications and approach leading to industrial acceptance and adoption. The acquired number of responses albeit not enough to infer a definitive picture but it could assist in establishing current industrial perception on the technology and its application.

Company details

The survey was carried out in mainly the region of Europe, targeting small, medium and large scale industry.

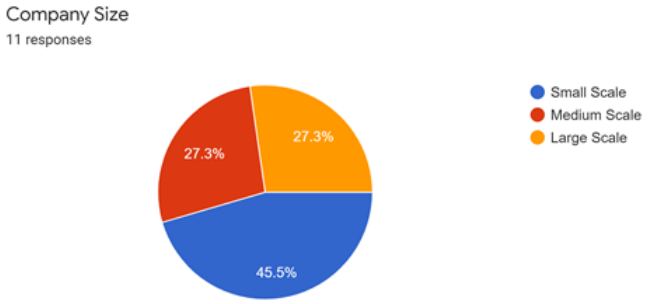

Figure 5.2: Survey response by company size

As seen in the figure 5.2, 45.5 % of the survey response came for individuals associated with large scale setup. Equivalent population (27.3 %) of responders were from small and medium scale setups. The setup size for small and medium scale industry ranged from 10-200 people, large scale industries was around 1000 people or greater.

Survey was carried out among industries belonging to different sectors like oil and gas, metal processing, automotive, moulding, medical implants, sensor manufacturing and manufacturing services. The targeted population for the survey was mid to upper level management of the industries, as they are directly involved in decision making process and could give insight on the applicability of this technology in manufacturing setting (figure 5.3).

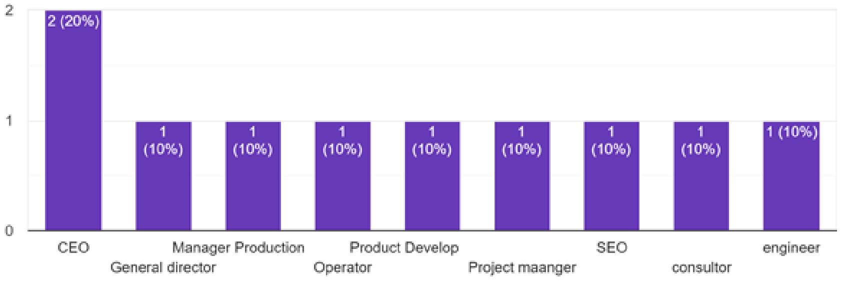

Figure 5.3: Survey response by company management level.

Market variability

The application of distributed manufacturing could be best realised where industries have higher product customisation. To accumulate and factor in this information, and relating it to multi-agent system application the question was framed. The insight basically targeted 'different products produced in a month at the shop floor, especially those that involved manual changeover'. The survey (figure 5.4) yielded an increasing trend towards product variability that stresses the need for distributed manufacturing.

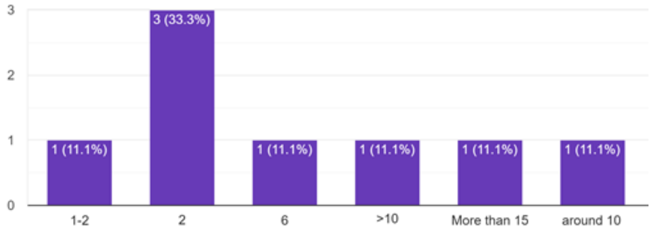

Figure 5.4: Survey response by product variability. [Question: In average, How many different products* in a month are produced in a shop floor line of your plant? (*different product is the product that needs a manual change on the line)]

An increasing problem in manufacturing in the significant changeover time required to make the production line ready for manufacturing a different product. Efforts are usually carried out at the production facility to reduce this time but still a major time wastage is attributed to setup. The survey (figure 5.5) highlighted this trend with 44.4 % associating 1-12 hours with changeover.

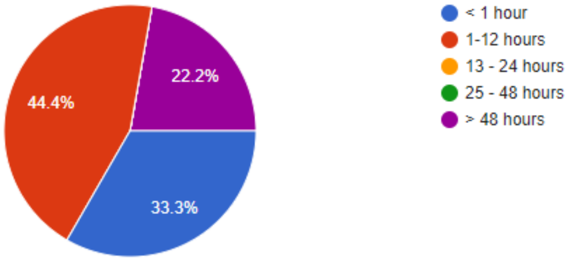

Figure 5.5: Survey response by product changeover time. [Question: In average, to cope with product variation, how long does it take to make a manual change in your shop-floor line?)]

A trend in distributed manufacturing is towards the 'plug and produce' concept where the setup time is greatly reduced. Application of multi-agent systems in manufacturing is supposed to make it instantaneous. Current insight generated by the survey (figure 5.6) highlights the issue where the 'commissioning of new equipment on shop floor' usually takes more than 4 weeks to be made functional.

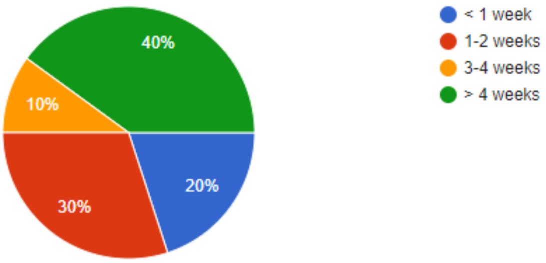

Figure 5.6: Survey response by equipment commission time. [Question: In average, how long does it take to setup (deployment) a new machine (a common machine in your production line) to your shop-floor?]

Some level of programming is required to integrate the components in a production system. However, mostly industries tend to 'rely on components that come with applications that assist in integration'(figure 5.7).

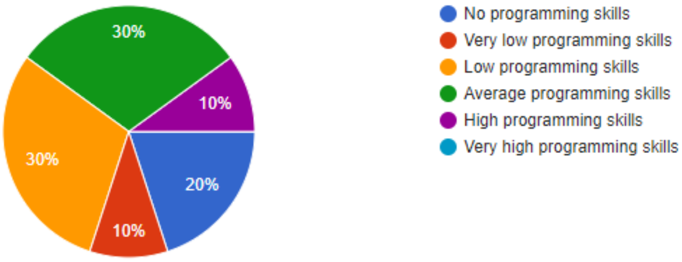

Figure 5.7: Survey response by programming skills required. [Question: What is the level of programming skill on the person who is resposible for making changes (fix/ change-over) to machines in the shop-floor ?]

Current technological status

In industrial settings, the prime motivator for technology adoption is to make processes economical and productive. Mass customisation and variability is achieved as real-time data is interchanged. As industries move to data oriented decision making more and more data interchange is required. Most of the survey responders (figure 5.8) were of the view that there is some at data interchange once an hour almost 50 % of the time, while an increasing trend was towards real time data interchange (30 %).

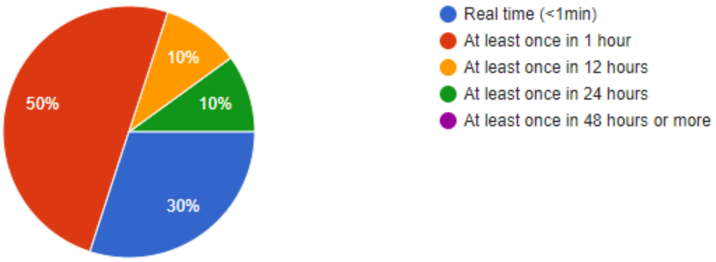

Figure 5.8: Survey response by information transfer on shop-floor[Question: How fast information is transferred from shop-floor to production department?]

Most of the industrial sectors adopt PLCs for their shop-floor automation which is quite rigid in terms of flexibility required for distributed control. However, this rigidity is paramount for secure application execution. This security risks are of much larger concerns in data oriented manufacturing. Conventional programming is still more widely accepted followed by PLC standard application.

EtherCAT remains the most effective mode of data interchange for M2M communication followed by TCP-IP with increased adoption of OPC UA (figure 5.9, 5.10 and 5.11)

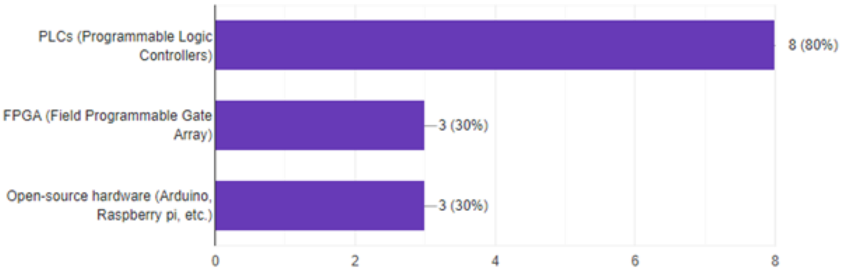

Figure 5.9: Survey response by technologies present on shop-floor [Question: What technologies you use for shop-floor automation?]

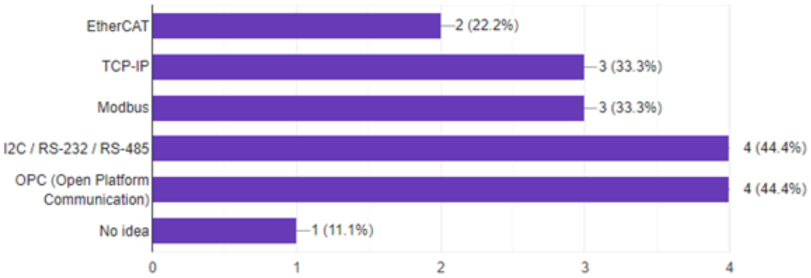

Figure 5.10: Survey response by industrial communication protocol [Question: What industrial communication protocols you use for shop-floor automation?]

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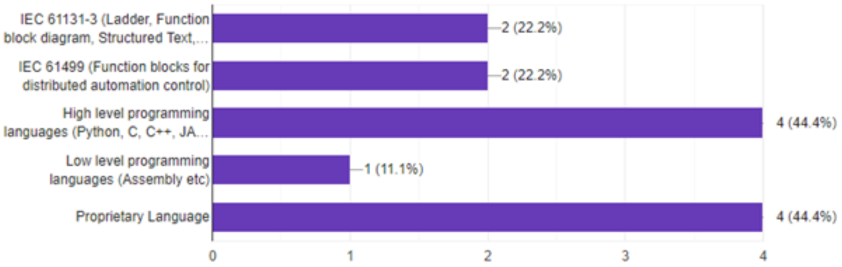

Figure 5.11: Survey response by industrial standards [Question: What programming languages/standards you use for shop-floor automation?]

Feasibility for new technology adaptation

Most of the industrial settings require some kind of software support, primarily dealing with websites, emails and cloud infrastructure (figure 5.12).However, these settings require scaling up and maintenance support (figure 5.13). From the survey, we could also observe that all companies are familiar with internet/intranet-based services in shop-floor operation.

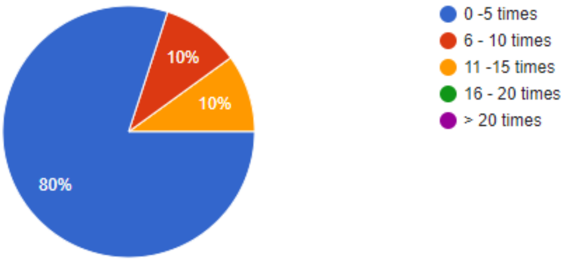

Figure 5.12: Survey response by programming software support required [Question: in average, how many times do you need software support in shop-floor operations in a month?]

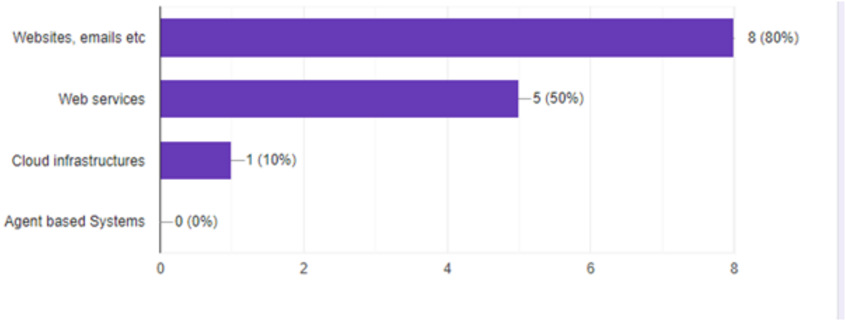

Figure 5.13: Survey response by digital technologies on shop-floor [Question: Select which digital technologies people working in the shop-floor are familiar with]

Future of autonomous systems

More industrial insight is observed towards automated machine adoption. Distributed manufacturing systems make systems more autonomous with less reliance on human operators (figure 5.14, 5.15, 5.16, and 5.17).

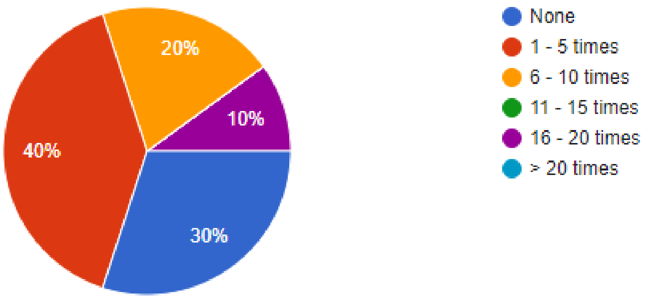

Figure 5.14: Survey response by stoppage due to maintenance [Question: In average, how many times per month a part of shop floor line is stopped for maintenance?"]

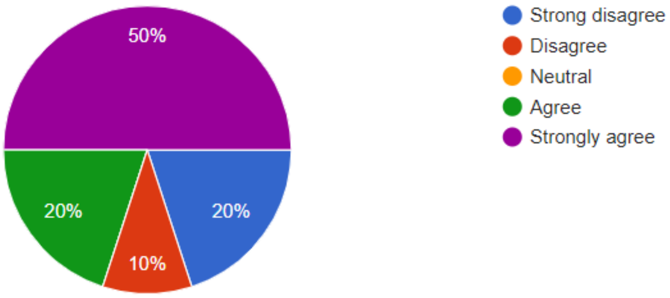

Figure 5.15: Survey response for future technologies [Question: How much do you agree with this statement "In the near future (5 years), your company will invest in digital technologies for shop-floor automation"]

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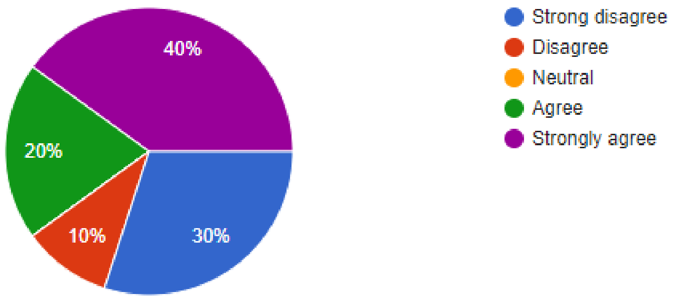

Figure 5.16: Survey response by future of automation machines [Question: How much do you agree with this statement "In the near future (5 years), there will be more autonomous machines in your shop-floor"?]

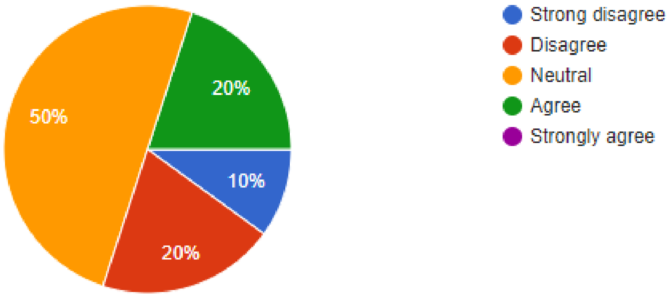

Figure 5.17: Survey response by humans on shopfloor [Question: How much do you agree with this statement "In the future (10 years), there will be less humans in your shop-floor line"?]

5.3 Analysis

The results of this survey is not indented to give a accurate results of the questions asked but to show the trends in the current manufacturing shop floor.

Company details

The results shows that the survey has been conducted with a even mix of large, medium and small size companies. This shows that the survey could be a representative of the entire manufacturing scale. This result is further validated in analysing the number of employees in the company. The companies in the survey has employees ranging from as low as three to a large manufacturing plant of 1800 employees. These manufacturing companies also produces a wide variety of products like implants, sensors, automotive parts, electric vehicles etc but also includes oil and gas plants. This shows the results is not restricted to one sector. Almost all the participants in the survey are from managerial position in the company, this is important as they have an overall picture of the company and not restricted to just the shop-floor.

Market variability

We find that both large and medium scale companies have high product variability, around 10 different parts in a month per shop floor line. This shows the trend of the market moving towards mass-customization. The implementation of agent based technologies will help in this trend. More than half of the companies takes more than an hour to adapt to this product change with some companies taking beyond 2 days. Also we see that in installing a new machine to cope with the market variability it takes more than one week for most of the companies, if fact half of these companies takes more than 3 weeks (in setting up machines like cutting, injection molding, gluing). These results clearly show the lack of readiness in the current manufacturing to cope with the market need for mass-customization. New technologies especially agent based technologies could help in this process in implementing systems with faster response to product change and characteristics like plug and produce. A weakness of agent technologies is the lack of experts in the shop-floor to support its implementation and monitor the process. This statement is further validated with this survey. The results show that in most of the companies the person responsible for the deployment of the new machines and making changes to existing machines in the shop-floor have zero to low programming skills. At the current stage, implementing and maintaining the agent technologies in shop-floor require experts with high programming skills and the current manufacturing plants are not prepared for that.

Current technological status

There is a push toward a faster information transfer with-in the shop-floor and information transfer from the shop-floor to other departments. This is evident from the survey results which shows almost all companies transfer data from shop-floor to the production department within 1 hour and some even transfer in real-time. Agent technologies with their distributed nature could help in this requirement, but its development should take into consideration the high execution time during negotiations. A threat to the implementation of agent technologies is increasing need for data safety and security. Even though, the results of the survey shows that only one company had a data privacy breach in last 5 years, this threat is real and the development of agent technologies should take it in consideration. The agent technologies implementation in its current stage lacks integration features with legacy systems. the results shows that almost all the companies mainly use only PLCs. A robust integration of agents technologies with PLCs would help in integration of Agents in the current industrial settings. Currently most of them are restricted to only open source hardware like Arduino, Raspberry pi etc which is not widely used outside research communities. The widely used platform for implementing agents is JADE. Some of the communication protocol used in industries like EtherCAT , TCP-IP etc have already being supported by JADE but there is still a need for other communication protocol support. The same is true for also the programming languages used, with very few companies uses high level programming languages like Java in their shop floor.

Feasibility for new technology adaptation

The use of agent technologies could considerably reduce the need for software updates and supports and have a higher level of autonomy. The industrial survey results shows that this is not of greater advantage to the shop-floor as most of them require only very few software support / updates. In any case, the advantage would be helpful for some companies in the survey which needs more than 5 times software support and constant software updation. All companies in the list uses internet based services in the shop-floor which is a good sign as this provides a easier adaption of digital technologies in the shop-floor including agent-based which could be integrated with web-based services. Even though the survey shows none of the companies are familiar with agent-based systems, some companies familiar with web service and cloud based infrastructures is a positive sign. Finally, the strong interest in using standards like IEC, ISO etc in the manufacturing shop-floor shows the greater need for the development of standards for agent based technologies.

Future of autonomous systems

The need for maintenance in the shop-floor line with the stoppage of the line would guide us in understanding how far we have reached in developing autonomous systems. Excluding the Oil & Gas plants which require No maintenance by stopping of the line almost all the plants require certain level of maintenance by stopping the production - Some even as high as 16-20 times in a month. Agent technologies would help in this aspect. The view of most companies in investing in digital technologies and autonomous machines in the upcoming years is positive sign and an opportunity for the development of agent technologies. The lack of similar view when it comes to the need for humans shows the increasing need for developing system with human-in-loop and better human-machine interactions.

Chapter 6

Conclusions

This work has given an overview of the integration of agent's technology in manufacturing. First of all, the requirements of smart manufacturing are discussed in detail. Manufacturers are required to fulfil smart manufacturing requirements in order to compete with expanding markets and mass customisation. There are lots of requirements in smart manufacturing. Some of them are: computational capability, integration, virtualization, service orientation, complexity, interoperability and re-configurability.

Furthermore, MAS technology and the application of MAS are introduced to meet some requirement of the manufacturing. MAS can be used in smart manufacturing, such as process control, production planning, scheduling, monitoring, quality control,diagnosis, process reconfiguration and manufacturing simulation and executions. For example, in process and manufacturing control, MAS architecture can be used for collaborative control and as the solution to improve manufacturing system.

What's more, the Strengths, Weakness, Opportunities, and Threats SWOT analysis method are used to evaluate the application of agent technologies in manufacturing. For example, the integration of MAS means more decentralized and distributed process control, coordination and social ability, plug and produce ability, modularity and cloud based integration. However, the agent technologies has also limitations, such as investment cost, legacy system integration, lack of experts and awareness. With the development of digitalization, Mass- customization adoption and autonomous needs, the MAS technologies can be potentially used more widely in manufacturing industry.

At last, a survey is conducted through industrial experts to evaluate the pros/cons of integration of MAS in practice. These results should be carefully taken into account by future practitioners and researchers. The more general conclusion that we may extrapolate from this work, is that despite the big plethora of research and implementation results, companies are still not prepared in terms of technological capabilities for the implementation of emerging technologies like MAS; however, the benefits are more than clear. The research community should push the implementation of methodologies and use cases in this direction to increase this technological awareness.

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