E-MANUFACTURING: A FRAMEWORK FOR INCREASING MANUFACTURING RESOURCE UTILISATION

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ABSTRACT

Manufacturers worldwide have shifted from the traditional mass production strategy to a more customer friendly and flexible make per order strategy. Competition is no longer limited to product quality and price only, but also encompasses delivery, product differentiation and great services. Due to globalisation manufacturing companies in South Africa are competing with companies in developed nations which have experienced rapid technology change in the last decade. SMMEs in South African manufacturing sector can take advantage of the opportunities created by cross-enterprise collaboration enabled by the exponential growth of the Internet. The paper presents a proposed framework which enables sharing of manufacturing resources to enable SMMEs to overcome their limitation in resources. The names of manufacturers and machinery available for different operations at any given time are obtained from a public registry that gives information on the manufacturing capabilities and capacities of manufacturers. Manufacturers send request for quotes (RFQs) for operations they require to subcontract or machinery available which they want to use and are replied with quotes. A multi agent system (MAS) is utilised to analyse the quotes. The framework seeks to create an internetwork of machinery to minimise bottlenecks, level machine workloads, increase machine utilisation, improve line and labour balancing in an industrial cluster.

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1 INTRODUCTION

Globalisation has posed a challenge to most of the manufacturing companies in the developing countries as they are now competing with advanced companies in developed nations. Technology in the developed nations has changed very fast in the last decade whilst advancing at a slower pace in developing countries. Customers have also changed and are now demanding customised products, more value on products at less cost and fast delivery and hence the need for companies to increase flexibility in their manufacturing systems. As a way of increasing flexibility companies have resorted to outsourcing and distributed manufacturing systems as they pursue a global manufacturing strategy. The South African manufacturing sector consists of advanced companies and small, medium and micro enterprises (SMMEs) integrated into the same supply chain. SMMEs might be limited in the technology they have but have made a significant contribution to the South African economy (Nyanga, [21]) and should be incorporated into the manufacturing networks to increase flexibility as they specialised and quickly adapt to new changes whereas large companies focus on their core tasks in manufacturing to make large volumes of products. The paper presents a proposed framework which enables sharing of manufacturing resources to enable SMMEs to overcome their limitation in resources. The organisation of the paper is as follows: we first discuss the changes that have taken place in manufacturing, we then discuss collaborative manufacturing and lastly we present the proposed framework for collaboration.

Figure 1 Development Of Manufacturing technology (Sources Cheng et al., [9], Bateman et al., [3])
2 DEVELOPMENTS IN MANUFACTURING TECHNOLOGY

The manufacturing model has shifted from the traditional mass production era which utilised economies of scale to mass customisation era dominated by lean and agile manufacturing systems (NCFAM, [20]) as shown in Figure 1. Various proposals have been made to enable the manufacturing enterprises to meet the requirements of agile manufacturing systems. Most of these proposals imply that the future of manufacturing lies in the loose and temporal federations of cooperative autonomous production entities (Monostori et al, [18]).

The internet and wireless technologies have enabled the manufacturing and business worlds to enter the era of E-Manufacturing. E-manufacturing is a transformation system that enables the manufacturing operations to achieve predictive near-zero-downtime performance as well as to synchronize with the business systems through the use of web-enabled and tether-free (i.e., wireless, web, etc.) technologies (Koc et al, [14]). E-manufacturing enables information exchanges among various plant level systems with business systems to eliminate data bottlenecks that can occur in conventional enterprise IT architectures (Kovacs [16]). In the e-manufacturing era, companies will be able to exchange all types of information with their suppliers at the speed of light. In addition, design cycle times and intercompany costs of manufacturing complex products will implode. Information on design floors will be instantly transmitted from repair shops to manufacturers and their supply chains (Cheng et al [8]).

An E-manufacturing system allows companies to access data of other companies, which helps in planning and scheduling as the flow of information takes place in both directions, from producer to supplier as well as from supplier to producer (Tiwari, [25]). According to Chan et al, [7], E-Manufacturing has changed the way people work in digitalization, globalization, mobility, collaborative work and immediacy and also changed the nature and characteristics of manufacturing operations as shown Figure 2.

<table>
<thead>
<tr>
<th>Mass Production</th>
<th>Mass Customisation</th>
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</thead>
<tbody>
<tr>
<td>Long Pipeline</td>
<td>Shrinking supply chain</td>
</tr>
<tr>
<td>Sales from stock</td>
<td>Make to order</td>
</tr>
<tr>
<td>Sequential Process</td>
<td>Simultaneous processes</td>
</tr>
<tr>
<td>Cost of inventory</td>
<td>Capital working</td>
</tr>
<tr>
<td>Wait in line</td>
<td>First available slot</td>
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</tbody>
</table>

Figure 2 Transformation Driven By E-Manufacturing (Bateman et al., [2])

3 COLLABORATIVE MANUFACTURING

Companies, especially SMMEs, are motivated to join collaborative networks in order to reach the competitive level of performances in terms of reactivity, productivity, product quality and system availability (Slugal et al, [24]). The companies then focus on their own competencies whilst on the other hand they acquire complementary expertise and resources over collaborative networks. Thus, the companies cooperate vertically along supply chains and horizontally among peers. According to Zaletelj et al, [29] the so-called ‘virtual factory’ of the future will manufacture in adaptable networks linking original equipment manufacturers with value-chain partners (often SMMEs) and suppliers of factory equipment/services selected according to the needs at a given time. Its composition will not be limited by the presumption of physical co-location, or by a need to maintain rigid long-term relationships.
3.1 Collaborative Manufacturing Models

Montreuil et al [19] present the NetMan organization strategy which is meant enable a manufacturing enterprise to dynamically organise its operations through the configuration and activation of a distributed network of interdependent manufacturing entities called NetMan centres. Sluga et al [24] presents Adaptive Distributed Manufacturing System (ADMS) as a conceptual framework for collaboration within the networks. ADMS is structured as a network autonomous work systems (AWS), and represented by agents. The key elements of an AWS are: manufacturing operations, management and control, and measurement systems for inputs and outputs. Measurements support monitoring of real-time performance for important changes, threats and opportunities, for management of operations and prediction of appropriate actions for best operating results, for local decision making, as well as for providing visibility on the coordination level. Butala et al [5] presents a mechanism for dynamic structuring of manufacturing systems based on ADMS. The mechanism enables building of task-oriented manufacturing structures of work systems working in series and/or in parallel.

In trying to manage distributed manufacturing services with formal ontological support Cai et al [6] proposed a prototype Semantic Web system called ManuHub (i.e., Manufacturing Hub). The ManuHub architecture provides a Semantic Web service-based platform for the modelling, acquisition, and retrieval of manufacturing services associated with the management of service lifecycle. Garcia-Melo et al [10] proposed a collaborative distributed framework based on “web services” to assure effective service coordination in the execution of manufacturing processes in distributed environment. The framework has special features such as teleoperation and remote monitoring of manufacturing activities, users online request, and shared resources management.

Woo et al [28] proposed a framework which allocates manufacturers to the universal process plan through collaborative bidding. The product designer generates a resource-independent process plan for a particular product and obtains manufacturers suitable for each operation in the plan from a public registry that gives information on the manufacturing capabilities and capacities of manufacturers. After identifying suitable manufacturers, the product designer then enters into negotiations with each of these manufacturers in regard to manufacturing and handling costs. In the negotiation process, the designer issues RFQs for the operations, and the manufacturers reply with quotes. The manufacturers are then evaluated by analyzing the quotes they would have sent. Finally, a distributed process plan (DPP) is finalized by allocating each operation to the chosen manufacturer. The proposed framework is based on work done by Woo et al.

3.2 Subcontracting

As a way of enabling agile and lean manufacturing, manufacturers have resorted to subcontracting and use of production networks. The aim of a production network is to utilise external resources within the network by subcontracting entire orders or portions of them to cooperating companies (Wiendahl, [27]). This increases the flexibility of manufacturers to react promptly to market demands. Subcontracting can be put into the three categories i.e. classic, technology driven and capacity driven, as shown in Figure 3.

1) Classic subcontracting - goods are delivered after the production process is finished.
2) Technology-driven subcontracting - a company does not conduct certain steps of the production mainly due to lack of certain technology.
3) Capacity-driven subcontracting - the producer assigns parts of his production to external manufacturers when a lack of capacity occurs.
Uchikawa, [26] analysis knowledge spill over among large enterprises and small to medium enterprises brought by subcontracting in the Indian automotive industry. Many other researchers have written on spill over effects from multinational enterprises to small to medium enterprises (Blalock et al, [4], Kohpaiboon, [15], Kathuria, [13]). Huang et al, [11] presents a protocol for subcontracting in collaborative manufacturing.

3.3 Multi-Agent Systems (MAS)

As global manufacturing enterprises become popular industry’s strategists and academics agree that the availability, seamlessly exchangeability and quick processability of information lies at the core of organizations’ abilities of meeting escalating customer expectations in global markets. According to Zhang et al [30] multi-agent systems (MAS) have been recognized as one of the technologies that would facilitate agile and e-manufacturing by providing manufacturing enterprises with the capabilities to meet the ever-increasing needs for flexibility, robustness and adaptability to the rapid changes that occur in the manufacturing environment. Monostori et al, [17], [18] defines an agent as a software object that mimics the role of a competent personal assistant to perform a specific task on behalf of a user, intelligently or not, independently or with little guidance and also states that it is a computational system that is situated in a dynamic environment and is capable of exhibiting autonomous and intelligent behaviour. Shen, [22] states that agents can develop schedules using the same mechanisms that businesses use (negotiation rather than simple search) in the manufacturing supply chain. Thus, you can directly connect the manufacturing capabilities of different manufacturing enterprises. This will make optimisation possible at the supply chain level, in addition to the shop floor level and the enterprise level. Babiceanu, [1] states that the distributed architecture of multi-agent systems (MAS) and the agents’ characteristics of autonomy and cooperation make MAS a suitable tool for the implementation of the bionic, fractal and holonic manufacturing concepts. Shen et al [23], gives a review of how researchers have attempted to apply agent technology to manufacturing enterprise integration, enterprise collaboration (including supply chain management and virtual enterprises), manufacturing process planning and

Figure 3 Types Of Subcontracting In Production Networks (Source Wiendahl, [27])
scheduling, shop floor control, and to holonic manufacturing as an implementation methodology.

4 PROPOSED FRAMEWORK FOR CAPACITY AND TECHNOLOGY DRIVEN SUBCONTRACTING

The proposed framework concentrates on the technology driven and capacity driven subcontracting. It aims to enable companies with insufficient capacity to meet production demand to meet the demand by subcontracting companies with unused capacity. It also enables companies with less technology to manufacture high-tech products by subcontracting processes where they do not have equipment to perform with, to companies that have the technology.

The first stage in the proposed framework is preparation of a product process plan for the manufacture of products. A process in this instance is defined as an activity that changes the state of the product e.g. machining, drilling e.t.c. The state of a product is given by shape, size, quality, etc. The manufacturer loads the machines, and machines which are left unloaded are registered on the online registry. Manufacturers with insufficient machinery or technology select the processes which they want to subcontract depending on the capacity or technology of their plant. They then search for machinery they require to perform the processes on the registry. Once they have identified the machines they need, they then enter into negotiations in order to utilise the machinery.

For the framework to be successful the following requirements must be met:

1) Manufactures should provide trustworthy information on the registry.
2) Manufacturers should also trust information provided on the registry.
3) Only authorised personnel should have the right to change information on system.
4) All data sent through the system should be encrypted to increase security of the system.
5) Information on the registry should first of all be loaded onto the company server before being accessed on the internet and should be accessible in cases of internet failure.
6) Alternative communication media e.g. telephones should be used in cases of internet failure.
7) The order winning criterions for the bidding process is dependent only on the information on the registry and no other external relationships are considered.
8) The process of subcontracting should be well documented and manufacturers should be able to track back the companies that made the components if a product fails to function as per design.

4.1 Capacity Driven Subcontracting

Manufacturers with underutilised capacity register their underutilised machinery on an online public registry once a production plan has been created and machines have been loaded. The information registered includes location, machine capabilities, capacities, time available and machine usage cost. Manufactures with insufficient capacity search for idle machine available from the public registry. Once the machines are identified the manufacturers enter into negotiations. The manufacturer requesting use of machinery sends request for quotes (RFQs) for the operations and the manufacturers with idle machines reply with quotes. Once the quotes have been generated, the agents representing the machines available in the MAS bid for the job that has to be done. The machine with the lowest quote
and meeting all the other requirements for the job to be done wins the job. The framework for capacity driven subcontracting is shown in Figure 4.

**Figure 4 Framework For Capacity Driven Subcontracting**

### 4.2 Technology Driven Subcontracting

A manufacturer prepares the process plan of a product. If they realise that they do not have appropriate technology to manufacture some of the components of the product they search for appropriate machinery or individuals with the expertise on the online registry. Once the machinery is identified RFQs are sent and the manufacturers with technology being sought for reply with quotes. Once quotes have been generated, agents representing the machines available in the MAS bid for the job that has to be done. The machine with the lowest quote and meeting all the other requirements for the job to be done wins the job. The framework for capacity driven subcontracting is shown in Figure 5.

### 5 PROPOSED MULTI-AGENT SYSTEM FRAMEWORK.

The proposed multi agent system is shown in Figure 6. It is based on the framework proposed by Jai et al [12]. The framework consists of functional agents which are managed and supervised by the Managing Agent through the internet. The managing agent represents the different manufacturers and is installed on the manufacturer’s central control system. The functional agents consist of Order Agent, Mediator Agent, Job Agent, Manufacturability Agent, Job Scheduling Agent, Process Planning Agent and Resource Agent. They can be installed in different computers and distributed in different geographical places. The managing agent controls functional agents that represents each manufacturer and communicates with managing agents representing other manufacturers through the mediator.
agent. Figure 7 shows flowchart for the bidding algorithm of the system. A due date and maximum cost threshold has been set to prevent the explosion of the solution space.

![Figure 5 Framework For Technology Driven Subcontracting](image)

![Figure 6 Framework For Multi-Agent System](image)
Are all processes complete?

Update managing agent and move on to the next process not yet allocated to a resource

Start

Managing agent issues out order agents

Order agent announces arrival of order to resource agent

Order agent dispatches job agents

Manufacturability agent verifies if the jobs can be performed on the resource.

Can job be performed on the resource available?

No

Resource agent notifies job agent.

Yes

Resource agents submit bids to perform the job

Bids meets due date

No

Resource agent removed from job agent candidates for performing the jobs

Bids below max order cost

No

Job agent selects resource with best total bid

Is the bid the optimum solution?

No

Yes

Job agent allocates operations to resource agents with optimum solution

Are all processes complete?

No

Yes

Update managing agent

Stop

Figure 7 Flowchart For The Bidding Algorithm Of The System
5.1 Functional Definition Of Individual Agents

Each agent has its specific functionality and the agents communicate and are coordinated through the internet to achieve a common goal of increasing resource utilisation of the plant. The functionality of each agent in the system is as follows:

5.1.1 Managing Agent

The managing agent is responsible for managing collaborations and resolving conflicts between the functional agents in the system. It has the rules for agent management and conflicts resolution. It registers and coordinates the agents that leave and/or enter the system. It also sends and requests updates from the different agents that are in the system to co-ordinate their functions. The managing agent is also updated on all the bids that have been sent to or from the system, makes the decision as to whether the solution reached is optimum or not and updates the state of the resources in the system.

5.1.2 Mediator Agent

The mediator agent enables communication in-between different manufacturers. It contains the interests of the managing agent sending it. It notifies the managing agent of new order requests, functional agents that are leaving or entering the system.

5.1.3 Order Agent

The order agent carries information about the orders sent into the system. This includes what has to be made, order size, due dates, maximum order cost e.t.c. It also contains job orders which contain the production process and requirements of the product to be manufactured.

5.1.4 Job Agent

The job agent contains the production process for the product to be manufactured. This includes the shape, material, sequence of processes, tolerances e.t.c. Once the order agent is accepted into the system it dispatches the job agent which will be evaluated by the manufacturability agent if the processes it contains can be performed on the resources available. The managing agent also liaises with the job agent to find out if and order has been completed.

5.1.5 Job scheduling Agent

From the process plan contained in the job agent, the job scheduling agent generates an optimal production schedule according to a scheduling objective such as minimizing production cost or manufacturing make-span.

5.1.6 Process planning Agent

The process planning agent generates an optimal process plan based on the product features and the manufacturing resources in the selected factory.

5.1.7 Resource Agent

The resource agent contains information of the capabilities and availability of machinery in the plant. Once an order has been sent the resource agent liaise with the manufacturability agent to determine if the resource is able to manufacture the desired component. It also contains information of machine loading and notifies the managing agent and mediator agent, the times the machine will be idle. If there is an order that the machinery can perform, the resource agent submits a bid for the order through the mediator agent.
6 CONCLUSION

Small, medium and micro enterprises in South Africa can benefit from the distributed manufacturing systems which companies are pursuing nowadays as a way of meeting flexibility required in agile manufacturing by being integrated into production networks with large companies. The paper presents a framework which enables the integration of large companies and SMMEs in the supply chain. It enables SMMEs to share manufacturing resources and hence enable them to overcome their limitation in resources. SMMEs can also benefit from the knowledge spillover through subcontracting and use of high-tech machinery they cannot afford to purchase and hence they can increase their production volumes. Large companies can increase flexibility and profitability by reducing the scope of their activity and consequently the number of employees and focus on their core tasks in manufacturing and subcontract some of the work to specialised and smaller SMMEs which possess flexibility. Selected companies in the tooling industry in Western Cape Province in South Africa will be used as case studies in the implementation and validation of the framework. Once the framework has been implemented methods of optimising manufacturing costs using the framework will then be sort for and implemented.

7 REFERENCES


