Design of a Multi Agent System for Machine Selection

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Abstract
In a machine shop effective assignment of jobs to machines is a multi-criteria decision making problem which is usually done by professionals and experienced planners. The skill of job assignment becomes handy in machine shops which are in the Small, Medium to Micro Enterprises (SMMEs) category as they work on a variety of products with limited machinery. The paper presents a machine selection system for helping decision makers when selecting machines to be scheduled. Customer order parameters which include product weight, clamping force, mould dimensions, due date and lead time are used to select moulding machines suitable to manufacture the desired parts. The criteria for machine selection was developed using Analytical Hierarchy Process (AHP) were quality, time and cost were considered as the key parameters. The available machines which meet the requirements for moulding a desired part are then made to compete for the part using an English auction. A Multi Agent System consisting of a managing agent, administrator and bidding agents was developed to conduct the auction that takes place between machine agents viewed as potential contractors representing available machines in the production line. The multi agent system is developed using Java Agent Development framework (JADE). An injection moulding plant with 11 injection moulders was used as a case study for application of the system.

Keywords
Multi Agent System, Analytical Hierarchy Process, JADE

1 INTRODUCTION

The production lines of many Small, Medium and Micro-sized Enterprises (SMMEs) in plastic manufacturing are composed of several similar injection moulding and extrusion machines. These machines have the same functionality but are different in terms of their specifications and capacity. Jobs are assigned to machines based on their capacities and their physical properties which are clamping force, dimension of tie bars, shot weight and the previous jobs characteristic e.g. material or colour.

Machine selection is determined by experienced planners making it biased and subjective to the person and also leads to loss of cost and time when the planner is absent. Since machine selection is mostly done by experienced personnel, the probability of matching a job with an appropriate machine when conducted by an inexperienced person would lead to uneconomical plan and defects. In the paper a decision support system is proposed to act as a tool to help in the job-machine assignment for an e-manufacturing system. A multi-agent based system with an auction based subcontracting approach in which bidding agents (representing machines) will bid for a job by evaluating acquired information and sending offers to the Managing agent which will select the winning bidding agent by using the Analytical Hierarchy Process (AHP).

The papers is organised as follows: section 2 discusses the background information and related research literature, section 3 discusses the proposed framework and the decision making methodology, section 4 discusses the system development with the results shown and discussed in section 5. The paper finally ends with a conclusion

2 RELATED LITERATURE

Selecting an injection moulding machine from a group of injection moulding machines is a Multi Criteria Decision Making (MCDM) problem. In the development of the problem a finite set of customer orders will be allocated on a finite set of machines [1]. However, some researchers suggested the use of parallel machine scheduling in simplifying the problem [2], [3], [4]. Usually, any machine will be selected when it matches with the clamping force, platens and mould's shot size. To improve the solution other qualities such as good for the design part and materials are required to be compatible with the existing tools under quality management [5]. Manufacturers use different criteria and priorities of criteria for the production resources available though the basis is the clamping force since it greatly affect the product [6], [7]. The selection criteria can be divided into technical factors (e.g. tonnage, pressure, open distance, tie-bar space, mould dimension, temperature, etc.) and economic factors (e.g. shot weight size) [2]. In this section we review some of the systems that have been developed to solve the injection moulding machine selection problem.

2.1 The Injection Moulding Machine Selection System

Suwannasri and Siroventnukul [8] used the fuzzy logic principle to deal with uncertainty and mechanical factors that affect quality in the development of an injection moulding selection system. The system was able to mimic the decision capabilities of humans in production planning despite limitation of time and massive information. The main setback of the systems is that the decision criteria used were not compared to another in terms of importance, thus each attribute is equally important to the next, even though in real life some factors are more important than others depending on the manufacturer being considered.

2.2 Decision system for Multi-criteria machine selection for Flexible Manufacturing Systems

To take care of the differences in importance of decision criteria Tabucanon, Batanov and Verma [9] proposed the use of Analytical Hierarchy Process (AHP) method and a rule based technique for selecting an appropriate machine for a flexible manufacturing system using a software called MASCEL. Input data was based on past information of the machine stored in a database. This system has an advantage that it allows users to add or deduct machines directly in the database via application of a Database Management System. However the system depended on all answer ratings of the users thus making the system require a high level of knowledge management and time consuming as it deals with non-standard data. MASCEL software has also been used is selecting a machine centre [10]. The results of the case studies carried out showed the use of AHP alone is not the best method to select a machine in a flexible manufacturing system as suggested by Rao [11].

2.3 Combinational Auction and Lagrangean Relaxation for Distributed Resource Scheduling

Kutanoglu and David Wu [12] used the iterative-auction approach to solve a distributed resource scheduling problem, in which a set of jobs must be performed, each consisting of a set of operations, each operation requiring a particular machine for some duration. A Multi Agent System (MAS) in which an agent is associated with each job and set of biddable items as a set of discrete machine/time slot pairs, each pair having an associated price is used. Each agent generates a single bid and the auctioneer agent examines the bid and then updates the prices in an attempt to reduce resource conflicts. The procedure stops when the auctioneer finds all the bids that are compatible. This system maps a job to machine in a one to one fashion and uses the auctions to find sets of machines/timeslots pairs to satisfy the needs of each job. The biddable items are machines/timeslots pairs; these are too many and pose a disadvantage to the system. In this paper AHP is used to reduce the candidates for auction hence reducing the biddable items.

2.4 Multi Agent Systems

A multi agent system is defined as a network of software agents that interact to solve problems that are otherwise beyond the individual capacities of each problem solver. A multi agent system is therefore one that consist a number of agents, which interact with one another. In most general case, agents will be acting on behalf of users with different goals and motivations. To successfully interact, they will require the ability to cooperate, coordinate and negotiate with each other, much as people do [13]. With the rapid growth and promise of the agent technology, a number of methodologies for developing MAS have been proposed [15]. So far no standardized design methodology has been recognized for Multi Agent Systems [16] hence a researcher intending to employ a methodology for MAS need to fully exploit all agent concepts, evaluate and analyse different available methodologies to come up with the best suitable methodology that matches the environment or system under investigation. Some of the most common methodologies include Multi-agent systems Software Engineering (MaSE) [16], Societies in Open and Distributed Agent spaces (SODA) [15], [17], Generic Architecture for information Availability (GAIA) [18], [19], Agent Unified Modeling Language (AUML) [20], and Java Agent DEvelopment framework (JADE) [21]. This research uses the JADE methodology modelled using AUML which is an extension of UML (Unified Modelling Language) developed for agents.

JADE is fully developed in Java and is based on interoperability, pay-as-you go philosophy, ease of use, uniformity and portability making it to fit the constraints on environments with limited resources and to be integrated into complex [22]. It combines a top-down and bottom-up approach to account for the overall system and applications needs. There are four fundamental phases when using JADE: planning, analysis, design, and implementation with the methodology being in an iterative nature which allows the designer to move back and forth between the analysis and design phases and the steps therein [21].

2.5 Unified Modelling Language

The requirements analysis that consists of identifying relevant data and functions that a software system would support can be easily identified using UML. The data to be handled by the system could be described in terms of entity-relationship diagrams, while the functions could be described in terms of data flows [23]. Object-oriented software development utilizes new design methodologies, and computer-aided software engineering tools such as Visio can support these methodologies [24]. UML is a language used to specify, visually model [25], and document the artefacts of an Objected-Oriented system under development. It represents the unification of a number of ideas from different methodologists. Using UML to design a system improves its maintainability and reusability. Object oriented analysis techniques offer class, use case, state chart, sequence, and other diagrammatic notations for modelling [26]. UML has been used successfully in numerous projects to model varying architectures and requirements. [27], [28], [29], [30], [31], [32].

We selected Use Case Diagrams, Sequence Diagrams and Component Diagrams for analyzing the user's requirements, the ordering of messages and documenting relationship among components. We selected Class Diagrams for representing the static structure of classes.

2.6 Analytic Hierarchy Process (AHP)

AHP is defined as a multi-criteria decision-making approach which was first introduced by Saaty [33], [34]. It uses well-defined mathematical structure of consistent matrices and their Eigen vector to generate weights on the selection criteria [35], [36], [37]. A framework for selecting machines to machine a part uploaded on an internet registry has been developed by Nyanga et al [38], [39].

Defects	Common causes	Point of trouble shooting	Ref
Short shots	Cavity not filling properly, insufficient melt volume, moisture in material, mold release agent used, high-pressure drop in mould, poor mould design	Machine, material	[5], [40]
Silver streaking	Melt temp too high, poor pressurization, water leak in mold	Mould, machine, material	[5], [40]
Sink marks	Under packing, mould malfunction, poor part design	Mould	[5]
Burn marks	Injection rate too high, lack of mould venting, clamp pressure too high	Mould, machine	[5], [40]
Flashing	Over pressurization of cavity, melt temp too high, mould malfunction	Mould, machine	[5], [40]

Table 1 - Defects in Injection Molding

2.7 Defects in Injection Molding

Table 1 shows the common types of defect and their common causes. The defect types that are affected by the selection criteria of this paper are Short Shot, Sink Mark and Burn marks.

3 METHODOLOGY

In this section a detailed empirical study based on the above stated research is presented.The system design and the algorithms employed are also described in this section.

3.1 System Requirements

The decision support tool developed will be used to award jobs to machines after an English auction between bidding agents seeking potential contractors who will be representing available machines has taken place. The User calls for an auction and inputs auction details while the Administrator agent creates an auction which is controlled and monitored by the Managing agent. The manager solicits proposal from other agents by issuing a call for proposals. The agents receiving the call for the proposals are viewed as potential contractors and are able to generate proposals to perform the tasks as propose acts. Bidding agents will participate in the auction and try to outbid one another in order to get a specific job depending on the availability of the machines. The winner of the auction/order is announced at the end of each auction.

3.2 Designing with UML notations

The decision support tool was designed using Use Case, Sequence, Class Diagrams offered by UML and the Visual Paradigm Tool.

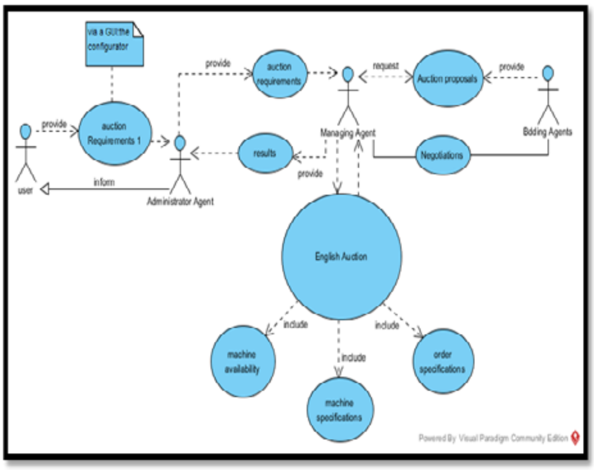


Figure 1 - Overall Use Case Diagram

3.2.1 Use Case Diagram

The Use Case Diagram is a visualization of a use-case, i.e., the interaction between the auction system that is going to be used to select the best machine for a job and the users. Figure 1 shows the Use Case Diagram for the overall actions that the User (qualified production personnel) can perform in an auction as the manager and the bidding agents are interacting.

3.2.2 Class diagram

A class diagram describes the types of objects that exist in the system and the static relationship among internal classes of the system. Class diagrams are important entities in object oriented-analysis and design as they show attributes and the operations of a class and the way the objects are connected. Figure 2 shows the class diagram for the auction system. An abstract class (e.g., user class) abstracts common characteristics (attribute, operations, machine capabilities and specifications) about an actor.

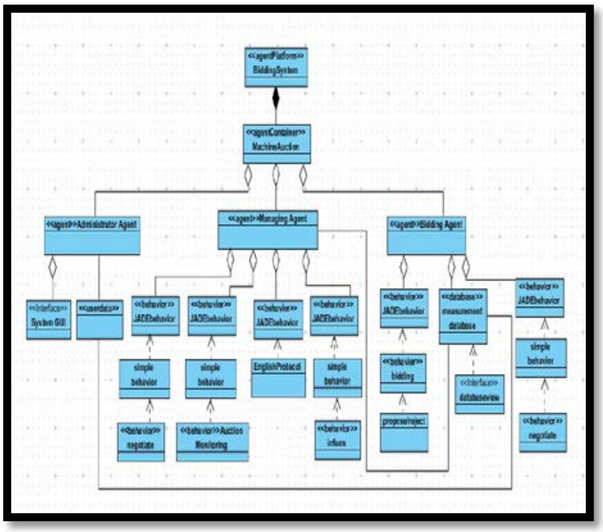


Figure 2 - Overall Class Diagram

3.2.3 Sequence Diagram.

The role of the Sequence Diagram is to display the overall flow of control in an object-oriented program. Typically, it captures the behaviour of a use-case. Figure 3 shows the Sequence Diagram for the events that occur during the auction and the role and decisions that are to be made by each agent.

3.2.4 Machine selection

A machine selection framework with three factors which are the quality, cost and time based on the framework developed by Nyanga et al [38], [39] was used in selecting the machines that will participate in

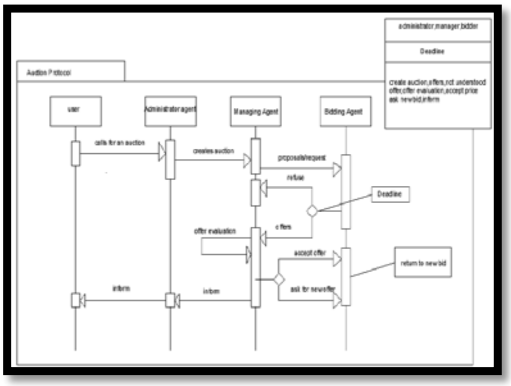


Figure 3 - Sequence Diagram

the auction. Figure 4 shows the three main factors and their sub criteria. Analytic Hierarchy Process (AHP) was used to give weights to the machinery factors that were considered when the auctioning system is taking place.

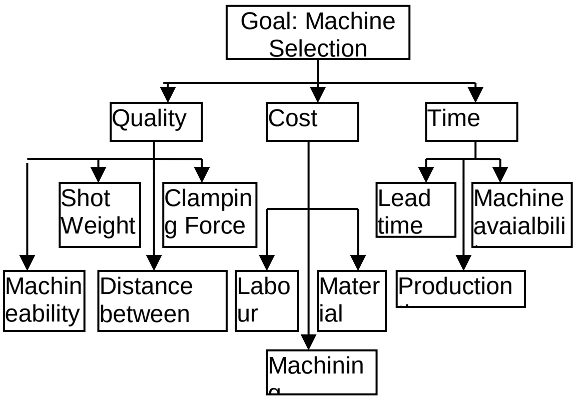


Figure 4: Machine Selection Factors

The pairwise comparisons were developed by considering the relationship between the general criteria i.e. quality, cost and time. A half matrix where the relationships of the criteria on the rows are compared to the criteria on the column is developed. To develop the matrix questions like: "How important is quality of the product as compared to the cost of production?" The answers

	QUALITY	COST	TIME
QUALITY	1	6	8
COST	$\frac{1}{6}$	1	$\frac{1}{5}$
TIME	$\frac{1}{8}$	5	1

Table 2 - Main Criteria Ranking

to the question are given in the scale 1-9. The values for the pair wise comparisons were obtained through interviews of work workers (production manager, sales manager and clerk). Table 2 shows the main criteria ranking of the factors that are considered in the plastic manufacturing company where the information was taken from.

Three iterations were performed on the square matrix to find the Eigen vectors for the criteria. The results of the final iteration are shown in Table 3.

	Quality	Cost	Time	Total	
Quality	6142.7	69337	26118	101597	0.7554
Cost	544.08	6142.7	2311.1	8998	0.0669
Time	1444.3	16323	61427	23910	0.1777
Total				134505	1.000

Table 3 - First level criteria Eigen vectors

Thus the Eigen vector values for the first level are as followes: Quality =0.7554, Cost=0.0669 and Time=0.1777.

Each machine attribute will be used by multi-agents in the bidding process. The contribution is given by the following

$$f(x) = \frac{machine\ attribute}{required\ part\ attribute} \quad (1)$$

The machine attribute is multiplied by the Eigen value of the main factor then by the Eigen value of the sub-criteria to get the weight of each attribute.

4 SYSTEM IMPLEMENTATION AND RESULTS

This section sets out the artefacts of our study as well as the implementation which followed the system analysis and design. The details of system configuration and analysis of the result of the empirical study are presented.

Machine name	Shot weight (g)	Clamping force(ton)	Distance between tie bar x(mm)	Distance between tie bar y(mm)
INJ1	28	30	260	260
INJ2	28	30	260	260
INJ3	45	50	300	300
INJ4	45	50	300	300
INJ5	45	50	300	300
INJ6	56	50	310	300
IINJ7	56	50	310	310
MC1	60	60	310	300
MC2	80	70	330	350
MC3	100	85	350	380
MC4	100	85	350	380

Table 4 - Machine Specification

4.1 Data Collection

Eleven machines with the specifications shown in Table 4 were selected to develop the proposed system. Information on the machines was obtained through interviews and data collected from the production planner of the plastic manufacturing company

4.2 Graphical User Interface Design

The user interface for the MAS program was developed that eliminated the need to create scripts or to type commands at the command line so as to accomplish a specific task. This enables the interaction of the program with the user. The GUI is shown in Figure 5: Graphical User Interface Design and serves the purpose of adding the values of the main parameters for job-machine allocation. The user page shows six main parameters that require the user to enter details, and these are the product weight, clamping force, mould dimensions the due date and the lead time. The Administrator agent will terminate if any on the values are not entered upon start up. The user will also able to view the orders in the database.

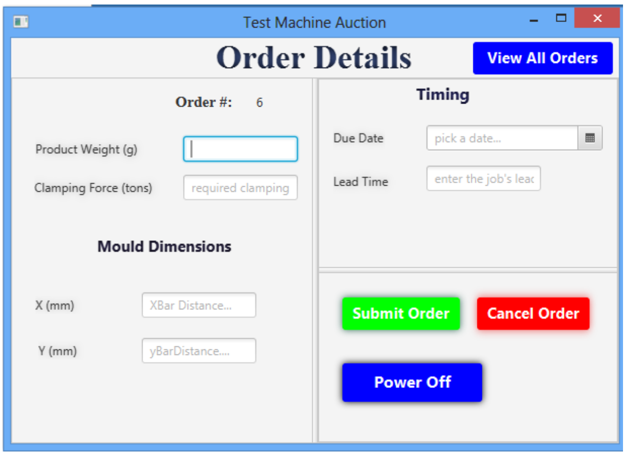


Figure 5 - Graphical User Interface Design

4.3 Agent Support System

The MySQL database storesr all the computed data up to the last decision is made. The data store is only temporary, as data can be removed from the structure. MySQL runs under the XAMPP Platform.

4.4 MAS Decision Support System Processing Procedure

Figure 6: System Flow Chart shows the system flow chart for the job auction. The Managing agent searches for available bidding agents who are able to process the job. The available machines reply to the managing agent calls by sending status messages. The auction starts, and the available bidding agents send bids to the managing agent. The auction has four main rounds. Each round lasts for 10 seconds. The manager calls for proposals and the available bidding agents respond by sending bids to the managing agent and the managing agent acknowledges the bids by sending Bid Received Message to the bidding agents thus the start of the auction. As the auction progresses the English protocol is used to get the winner of the auction. The manager then announces the winner to the bidding agents. The winning agent acknowledges that it can perform the given order by sending a message of acceptance. The loosing agents acknowledge to the managing agent that they have received the winning agent message and the auction ends. After the auction, the managing agent asks the administrator agent if there are more orders in the database and then it given permission to go and look for more orders in the database and then conduct another auction until there are no orders left with a status of zero.For each auction, the results are stored in MySQL database and the user can access the information to see the different states on jobs that have been allocated to different machines.

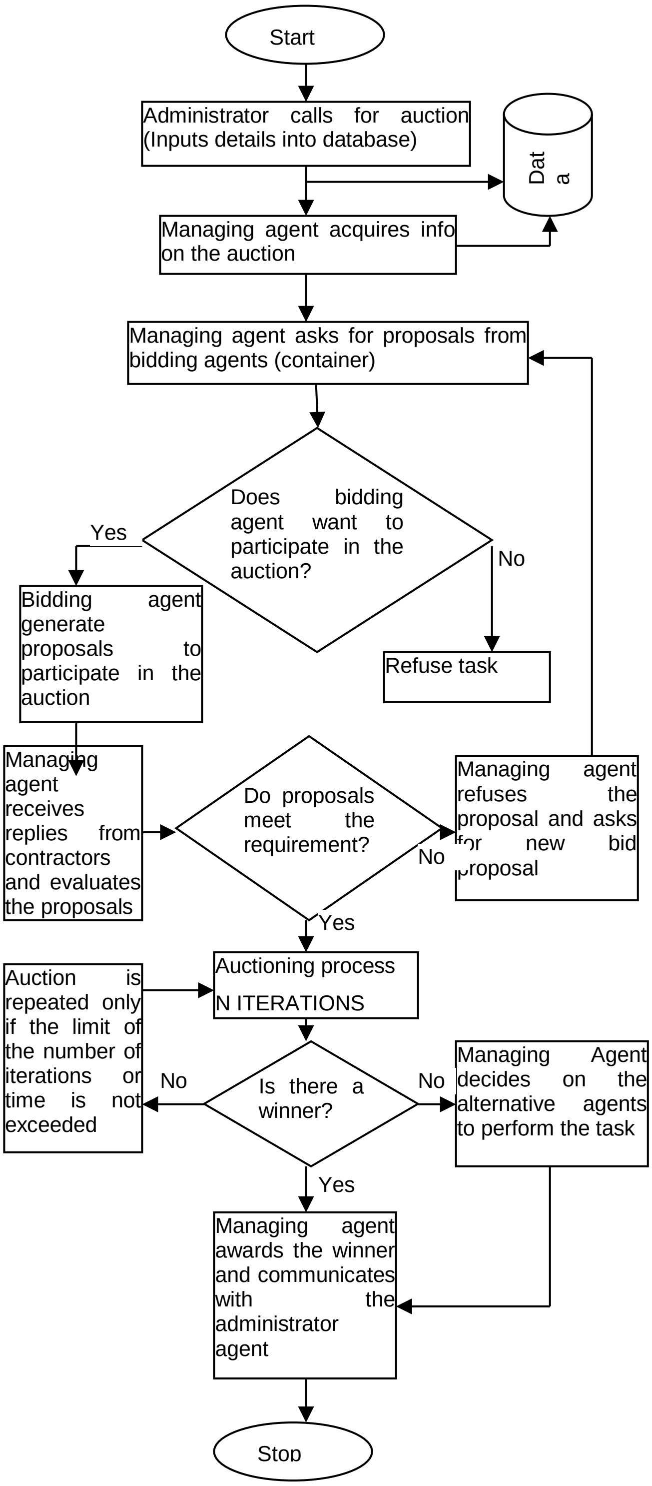


Figure 6 - System Flow Chart

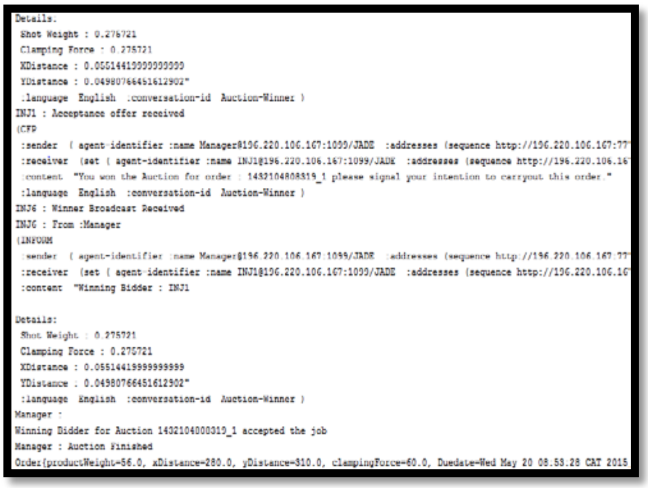
4.5 Agent Communication

A Sniffer agent shown in Figure 7 was used to view agent messages between the Managing agent and the Bidding agents as the auction was in progress. Messages were intercepted to observe how the agent society was exchanging communicative or systematic messages thus debagging the MAS.

Figure 7 - Sniffer Agent Interactions

4.6 Results and Discussion

When the auction is complete the manager agent announces the winner to the bidding agents. The winning agent receives a message from the manager that reads "you have won the auction for order number #". The winning agent then acknowledges that it can perform the given order by sending a message of acceptance. The loosing agents acknowledge to the managing agent that they have received the winning agent and the auction ends. Figure 8 shows the details in JADE as the managing agent announces the winner as the auction ends. Though the system could select a machine the suitability of the machine needed to be tested. The level of defects discussed in Section 2.7 were used to compare the outcome of the system to that of a human expert whiuch is the current system used at company. The system was tested based on daily production reports which were collected in mid-July to mid-August 2015. Due to limited resourses only one machine was used for evaluating the ststem. In order to to compare how the proposed



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Details:
 Shot Weight : 0.276721
 Clamping Force : 0.275721
 XDistance : 0.05514419999999999
 YDistance : 0.04980766451612902"
 :language  English  :conversation-id  Auction-Winner )
INJ1 : Acceptance offer received
(CFP
 :sender  ( agent-identifier :name Manager@196.220.106.167:1099/JADE  :addresses (sequence http://196.220.106.167:77
 :receiver  (set ( agent-identifier :name INJ1@196.220.106.167:1099/JADE  :addresses (sequence http://196.220.106.16
 :content  "You won the Auction for order : 1432104808819_1 please signal your intention to carryout this order."
 :language  English  :conversation-id  Auction-Winner )
INJ6 : Winner Broadcast Received
INJ6 : From :Manager
(INFORM
 :sender  ( agent-identifier :name Manager@196.220.106.167:1099/JADE  :addresses (sequence http://196.220.106.167:77
 :receiver  (set ( agent-identifier :name INJ1@196.220.106.167:1099/JADE  :addresses (sequence http://196.220.106.16
 :content  "Winning Bidder : INJ1

Details:
 Shot Weight : 0.275721
 Clamping Force : 0.275721
 XDistance : 0.05514419999999999
 YDistance : 0.04980766451612902"
 :language  English  :conversation-id  Auction-Winner )
Manager :
Winning Bidder for Auction 1432104000319_1 accepted the job
Manager : Auction Finished
Order{productWeight=56.0, xDistance=280.0, yDistance=310.0, clampingForce=60.0, Duedate=Wed May 20 08:53:28 CAT 2015
```

Figure 8 - Auction end output on JADE

system improved the defects only the top five defect types that were produced on the examined machine as they accounted for 75% of all defects.

From Table 5 Short Shot, Sink Mark and Flashing were reduced to 22.0% ,5.0% and 30% respectively. These results show that if the proposed system was used, there can be a reduction costs of reprocessing, waste treatment, and inventory. Short Shot and Sink Mark are affected by selecting the machines that have maximum clamping force lower than required force for products and low shot size. There is unconformity of mold closing, low density of melted material and leads to Sink Mark

Faults	Current System	Proposed System	Reducing percentage (%)
Short shots	400	312	22
Sink Marks	200	190	5
Burn marks	100	100	0
Flashing	450	315	30

Table 5 - Defective volume recorded from the test machine

5 CONCLUSION

This research was carried out in an aim to develop a machine subcontracting system for plastic injection moulding machines as a tool to help users in making decisions when it comes toin the job-machine assignment. The effective machine-job assignment of injection moulding machines is crucial because it directly affects the quality of the product, performance and the life time of the machines. This research proposed a decision support system based on a multi agent based system to select the most suitable machine for a given order. The five criteria of clamping force, distances between tie bars, shot weight, time and cost were obtained from a plastic manufacturer's case study in order to construct the multi agent system using JADE. Data of job orders and defectives were recorded within July to August 2015 and were categorized by defect types. The results showed that the system was able to reduce the defects of Short Shot and Sink Mark by 10% and 5% respectively. Moreover, Flashing was decreased by 30%.

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