Agent based Job Scheduling for a Vehicle Engine Reconditioning Machine Shop

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Abstract

Job scheduling at a machine shop is a multi-decision criteria problem whose skills are acquired after some years of experience. For Small, Medium to Micro Enterprises (SMMEs) with limited machinery the objective when scheduling jobs should not only focus on machine utilization but also on the increase of job through put. The paper presents an agent based job scheduling system for a vehicle engine reconditioning machine shop to assist decision makers in job scheduling. The Analytic Hierarchy Process (AHP) method was used to compute the relative weights of each decision criteria used for job scheduling considering the job priority. The value of the job, the number of operations to be performed, the engine type, the frequency of the customer and the company to customer relationship rating are used to prioritize the jobs. A Multi Agent System (MAS) comprising of the provider, job allocator and machine agents is developed using the Java Agent development framework (JADE) methodology and modelled using Unified Modelling Language (UML 2). The provider agent schedules all the jobs based on job weight and earliest due dates. The job allocator agent is responsible for making sure that all the scheduled jobs are allocated to all the machines after which they are registered as complete jobs and can leave the system.

Keywords

Multi Agent System, Analytic Hierarchy Process, JADE

1 INTRODUCTION

The increasing advancements in technology have resulted in an increase of complexity in the product designs. This places a huge impact on the machinery, equipment, tooling as well as skills needed for their repair and maintenance. Several machine shops in the Small, Medium to Micro Enterprises (SMMEs) category employ traditional methods of scheduling jobs as well as monitoring of their systems. Modern day technology has necessitated the need for more reliable, flexible and cheaper approaches during conduction of operations within a company in order to fully realize the associated profits.

A typical vehicle engine servicing machine shop has several machines used to perform different types of operations during the reconditioning of the vehicle engine and its components. Scheduling of jobs on the machines is a multi-decision criteria which can take up a significant amount of productive time if not properly planned. In one instance, jobs may be scheduled using First In First Out (FIFO), while in other cases due dates or price especially when the company wants to generate quick income. The frequency with which the customers bring in jobs is often used in certain instances but there is no standard logic to which these assignments are based. Decision makers often consider factors to do with the engine type, existing relationship between the customer and the company and the number of operations to be performed in coming up with the best schedule to execute the jobs. This paper seeks to design a job scheduling system that will minimize lead times, increase due date reliability and customer satisfaction as well as ensuring profitability to the company.

2 RELATED LITERATURE

A manufacturing scheduling problem is one of the most difficult of all scheduling problems in that it is almost impossible to find an optimal solution without the use of an enumerative algorithm, with computation time increasing exponentially with problem size. Bagchi [1] and French [2] have given a more detailed discussion on the scheduling problem. Various methods which include heuristics, constraint propagation techniques, constraint satisfaction problem formalisms, Tabu search, simulated annealing, GAs, neural networks, fuzzy logic have been suggested in finding the solution of the scheduling problem as discussed by Zweben and Fox [3].

Traditional scheduling methods i.e. analytical, heuristic, or met heuristic use simplified theoretical models and are centralized as all computations are carried out in a central computing unit. This makes them to face difficulties when they are applied in the real world [4]. To take care of the short comings of traditional methods, intelligent agent technologies which are innovative and have a distributed approach which is more flexible, efficient, and adaptable to real-world dynamic manufacturing environments can be implemented. Some of the advantages agent based approaches for distributed manufacturing scheduling are discussed by Shen [5].

2.1 Agent based manufacturing scheduling

Autonomous agents have been used in short term production planning by Lin and Soldberg [6]. The shop floor is modelled as a market place where agents negotiate on the basis of a fictitious currency using contract net protocol. Macchiaroli and Riemma [7] added an iterative auction process to the negotiation process to enable parts and resources to adjust price taking into consideration the resource contention. The model results show that the agent approach has a better performance to dispatching rules like SPT, EDD, MST and CR.

Shaw [8] also used the contract-net method in developing a dynamic scheduling system for cellular manufacturing systems. Once a cell completes a job it broadcasts the task announcement to the other cells which checks if they have the required resources and submit the estimation of the earliest finishing time (EFT) or shortest processing time (SPT) to the job. The cells then negotiate to determine the route of the job. Shaw's experimental results indicated that the bidding scheme with EFT (earliest finishing time) outperformed the bidding scheme with SPT (shortest processing time).

Oulhadj et al. [9] presented a negotiation strategy similar to the Shaw's [8] approach. They added a resource agent responsible for establishing the negotiation with other resource agents in order to select the most appropriate resources to allocate to the specific task operations. The contract-net protocol was extended to a multi-contract net protocol allowing it to schedule several tasks simultaneously. Their experimental results showed that the time required to schedule operations with this approach and the run time including scheduling and execution both are linear rather than exponential with the increase of the number of scheduled tasks.

Dewan and Joshi [10], [11] developed an auction-based scheduling mechanism for a job shop environment where Lagrangian relaxation is used to decompose the problem and currency is used as the means for agent negotiation.. Whenever a machine has free time slots the machine agent announces an auction for time slots. Job agents then bid for the time slots by submitting the cost that they are willing to pay. The goal of the job agent is to minimize cost, while the machine agent tries to maximize the cost of the time slot. After the auction is complete the machine agent will then determine the best bid for the earliest time slot of the next operation.

Siwamogsatham and Saygin [12] used a model developed by Macchiaroli and Riemma [7] to develop an auction based algorithm for real-time scheduling of flexible manufacturing systems with alternate routings. They modified the cost function of Macchiaroli and Riemma [7] to incorporate time as the primary criterion. The model was compared with various priority rules on the basis of average tardiness, average lateness, average due date deviation, utilization balance, average throughput, average wait time and total cost, using simulation. The results show that auction based approach outperformed the priority rules on most performance measures.

In this paper an agent based job scheduling system developed uses the Analytic Hierarchy Process (AHP) to compute the relative contribution of each criteria used by the case study company and hence determine their corresponding weight for each job. AHP is used to solve multiple criteria decision making problems. Data is decomposed into a hierarchy of alternatives and criteria after which the information is synthesized to determine relative ranking of alternatives. Comparisons of the analytic hierarchy process contains both qualitative and quantitative information using informed judgments to derive weights and priorities. According to Saaty [13] the analytic hierarchy process is one of the most effective tools for dealing with complex decision making. This may help the decision maker to set priorities and make the best decision. In the system developed weights found from AHP are jointly used with Earliest Due Dates (EDD) and Shortest Processing Times (SPT) to create a job schedule with which the jobs are to be processed. The primary ordering is done on each job weighting after which the earliest due dates are used to order between the jobs of the similar weighting.

3 METHODOLOGY

Interviews with the company middle and top management were used to determine criteria for order winning and scheduling at the case study company. The main job scheduling criteria was found to be the value of the job (V), the number of operations to be completed on the job (NO), the engine type (ET), the frequency of the customer (CF) and the relationship between the customer and the company (RR). Time study, company historical records and interviews were used to determine the criteria ranking utilised in the AHP decision making. A multi agent system based on the AHP and EDD and SPT dispatching rules was then developed to automate the decision making process.

4 DECISION CRITERIA FOR THE SCHEDULING SYSTEM

The agent based job scheduling system consists of five main criteria to which the scheduling decision are based on. A pair wise comparison matrix is developed using a scale of numbers that indicates how many times more important or dominant one criteria is over another as shown in Table 1. The scale of numbers used in the pair wise matrix is shown in Table 2. Consistency checks are done as shown in Nyanga et al [14].

	V	ET	NO	CF	RR
V	1	5	3	3	7
ET	1/5	1	1/5	1/4	1/3
NO	1/3	5	1	3	5
CF	1/3	4	1/3	1	4
RR	1/7	3	1/5	1/4	1
Total	2.01	18.00	4.73	7.50	17.33

Table 1 - Pairwise comparison matrix for the five decision criteria

Intensity of Importance	Definition
1	Equal Importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i
1.1–1.9	If the activities are very close

Table 2 - Scale of absolute numbers [13]

	V	ET	NO	CF	RR	Total
V	0.50	0.28	0.63	0.40	0.40	0.44
ET	0.10	0.06	0.04	0.03	0.02	0.05
NO	0.17	0.28	0.21	0.40	0.29	0.27
CF	0.17	0.22	0.07	0.13	0.23	0.16
RR	0.07	0.17	0.04	0.03	0.06	0.07

Table 3 - Normalized pair wise comparison

The normalised pair wise comparison matrix is shown in Table 3.

The consistence ratio (CR) is given by the formula

$$CR = \frac{CI}{RI} \quad (1)$$

Where CI is the Consistency Index and RI is the Random Consistence Index

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

Where λ_{max} the Principal Eigen is value of the pair wise comparison matrix and n is the dimension of the matrix.

Using the column and row totals in Table 1 and Table 3

$$\lambda_{max} = 2.01 * 0.44 + 18 * 0{,}05 + 4.73 * 0.27 + 7.5 * 0.16 + 17.33 * 0.07 = 5.58$$

From Equation 2 and Equation 1, CI= 0.145 and CR =0.13% respectively

Since CR is less than 10% the judgments are trustworthy as stated by Coyle [15].

4.1 Job Value

For the value criteria, the alternatives are bound by the range of income that each job generates into the company. The value is divided into classes depending with the level of contribution of each job. This is done so that the results of the AHP are not totally biased towards the value of the only. Figure 1 shows the relative contributions of each range of values.

Matrix		0-250 1	251-500 2	501-750 3	751-1000 4	1001-1500 5	1501-2000 6	2001-2500 7	2501-10000 8	0 9	0 10	normalized principal Eigenvector
0-250	1	1	1/2	1/3	1/4	1/5	1/6	1/7	1/8	-	-	2.36%
251-500	2	2	1	1/2	1/3	1/4	1/5	1/6	1/7	-	-	3.27%
501-750	3	3	2	1	1/2	1/3	1/4	1/5	1/6	-	-	4.77%
751-1000	4	4	3	2	1	1/2	1/3	1/4	1/5	-	-	7.09%
1001-1500	5	5	4	3	2	1	1/2	1/3	1/4	-	-	10.59%
1501-2000	6	6	5	4	3	2	1	1/2	1/3	-	-	15.72%
2001-2500	7	7	6	5	4	3	2	1	1/2	-	-	23.07%
2501-10000	8	8	7	6	5	4	3	2	1	-	-	33.13%

Figure 1 - Contribution for the value alternatives

The system allows the user to enter any value for the job after which the provider agent will use its knowledge of the relative contributions of each amount to calculate the weight contribution of the value alternative.

4.2 Number of Operations

The cylinder head has the maximum number of operations that can be performed compared to the rest of the vehicle engine components. The cylinder head has 18 different operations feasible and is therefore used as reference for the computation of criteria alternative contributions. Table 4 below shows the normalized Eigen vectors and the corresponding number of operations.

Number of operations	2	4	6	8	10	12	14	18
Contribution	36.32	23.71	15.33	9.85	6.31	4.05	2.64	1.78

Table 1 - Number of Operations Alternative Contributions

The fewer the number of operations, the more the job contributes to the total weighting implying that that jobs with less operations are more preferable compared to the other jobs.

4.3 Customer Frequency

The customer frequency alternatives entail the timely distribution of the same customer jobs. These are determined at fortnightly, monthly, quarterly, biannually and yearly intervals of the last jobs. The normalized Eigen vectors for the customer frequency are shown in Table 5 below.

Timeframe	Fortnightly	Monthly	Quarterly	Biyearly	Yearly
% Contribution	4 1 . 2 3	30.26	1 4 . 4 5	8 . 2 4	5 . 8 2

Table 5 - Customer Frequency Alternatives Contributions

4.4 Engine Type

The company classified the engines serviced into five groups based on the size of the engine. The engine classes are:

- Passenger
- A – B18, B16 - petrol , minibuses
- B – 22 diesel , 3L , 4L, 5L Mazda-T35
- C – Tractor, civilian, ford, MF
- D – Nissan UD, DAF (mostly buses)
- E – Caterpillar, Cummins and all earth moving equipment

The relative contributions of the engine type criteria are shown in Table 6.

Engine Type/Group	Passenger	A	B	C	D	E
% Contribution	29.6	29.6	18.0	11.2	7.0	4.6

Table 6 - Engine Type Alternatives Contributions

4.5 Customer Relationship

The customer to company relationship is also an important decision criteria. A strong relationship is assigned a +1 whilst a moderate relationship is assigned a +. All neutral relationships are assigned 0s and weak and very weak relationships are given as – and -1 respectively. The percentage contribution of each of these relationship ratings are given in Table 7.

Relationship Rating	-1	-	0	+	+1
% Contribution	4.53	8.19	12.14	25.82	49.33

Table 7 - Relationship Rating Alternative Contributions

5 MULTI AGENT SYSTEM

According to Russell & Norvig [16] an agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors. Several methodologies for developing multi agent systems have been discussed by Omicini and Molesini [17], DeLoach [18], Omicini [19], Zambonelli, Jennings and Wooldridge [20], Juan, Pearce, and Sterling [21], Bauer and Muller [22], Nikraz, Caire and Bahri [23], Bellifemine, Bergenti, Caire and Poggi [24]. This paper focuses on the development of the multi-agent system for the job scheduling system using the JADE methodology and Unified Modelling Language 2. The JADE methodology was chosen after a detailed evaluation of the other methodologies as discussed by Dewa et al [25], Singh et al [26] and Nikraz et al [26].

The system consists of a provider agent which is responsible for executing the scheduling of jobs and a job allocator agent which is responsible for assigning these jobs to the machines. The provider agent uses the job weighting in conjunction with the due dates to schedule the jobs and then provide them to the job allocator for allocation to the machines. The provider agent is responsible for providing relevant machining information to the job allocator as well as keeping record of the states of the machines. The agent is also responsible for storing all the relevant information concerning the jobs and the machines to which they will be allocated.

5.1 System Use Case Diagram

According to Bauer and Odell [27] use cases are a means for specifying required usages of a system. The use case diagram for the agent based job scheduling system was developed using the Unified Modelling Language 2.0. Based on the description of the agent-based job scheduling system and after conducting sufficient research and physically observing and assessing the requirements of the system, a preliminary list of possible system functions was built. As noted by Aruväli et al [28] the preconditions for productivity are technological capabilities and human competences. Machinery monitoring can develop both of these preconditions. The use case diagram for the system is shown in Figure 2. Three actors job allocator, operator and scheduling data provider were identified for the system.

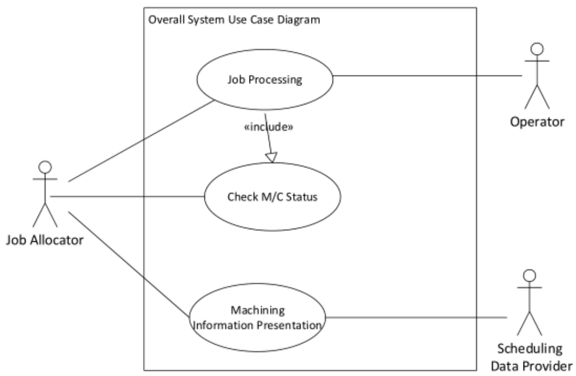

Figure 2 - System Use Case Diagram

5.2 Agent Diagram for the Job Scheduling System

The agent diagram indicates who needs to interact with who as stated by Nikraz et al [26]. The agent-based job scheduling system requires an acquaintance relation between the job allocator agent and the provider agent. Another acquaintance relation is also required between the job allocator agent and the machine state agents. Figure 3 shows the system agent diagram for the system.

The acquaintance relations that exist between the job allocator agent and the provider agent to facilitate retrieval of relevant machining information are also shown in the diagram. Another acquaintance relation exist between the job allocator agent and the machine state agents in order for the

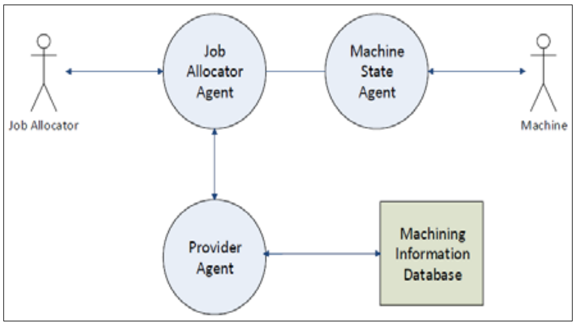

Figure 3 - System Agent Diagram showing acquaintance relationships

job allocator to constantly send jobs to the machines and these are monitored by the machine state agents.

5.3 The Jade Platform

JADE was used to develop the platform since the toolkit is free, open source and is FIPA compliant among the very many advantages and features that it offers. JADE is a software framework which is fully implemented in Java language. JADE simplifies the implementation of multi-agent systems through a middle-ware which complies with the latest Foundation for Intelligent Physical Agents (FIPA) 2000 specifications. There is a broad set of graphical tools provided that supports the debugging and deployment phases of agent development.

6 MULTI AGENT SYSTEM ARCHITECTURE

The multi agent system consists of a society of interacting agents and an external database. The job allocator frequently communicates with the provider agent which plays a vital role in the agent based job scheduling system since it is the one responsible for creating the job schedules. Figure 4 shows the skeletal multi agent system architecture.

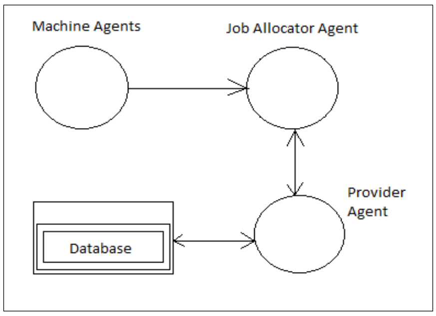

Figure 4 - Multi Agent System Architecture

Information about new job entries is captured through a graphical user interface which captures and stores the data into an external database shown in Figure 5

The utilization of the system, which is the proportion of the available time (expressed usually as a percentage) that a piece of equipment or a system is operating as defined by Hansen [29] is influenced greatly by the system proposed in this paper since bulk of decision making time is substituted by production time.

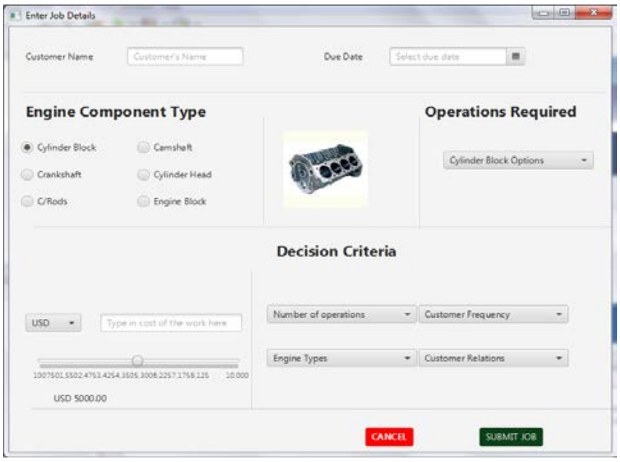

Figure 5 - Job Input Interface

The provider agent is responsible for creating job schedules which it then uses to send jobs to the job allocator to allocate the jobs for processing at the different machines. Jobs with the highest weighting are scheduled first and assigned to machines for processing. If there are two jobs with conflicting weighting, the provider agent uses the earliest due dates in order to give preference to the job with the earliest due date. Figure 6 shows the system allocating a job to a machine and checking the availability of machines.

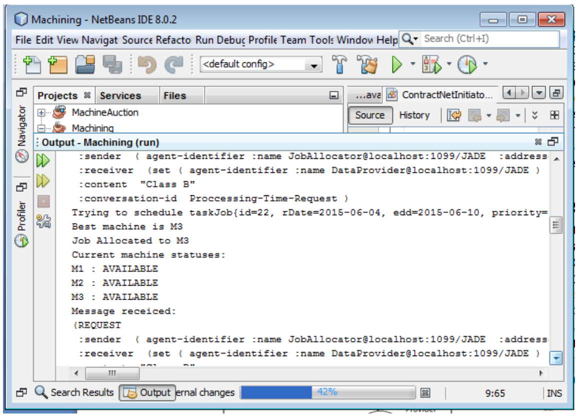

Figure 6 - Job allocation

7 SYSTEM JOB SCHEDULE RESULTS

The multi agent system consists of a main controller interface which collectively gathers all the necessary supporting features for the agent based job scheduling system. The main controller interface allows the user to review the current schedule, search for the various fields including, earliest due dates, date orders were received, completion dates and more. Figure 6 shows the main user interface.

The advantage of using the main user interface is that, all features of the system may be accessed from a single focal point. All the machines can be monitored from this interface as well as a review of the system log which is always available.The system results were compared with the results of the human expect at the comnpany. Average weekly tardness was reduced from two days to half a day.

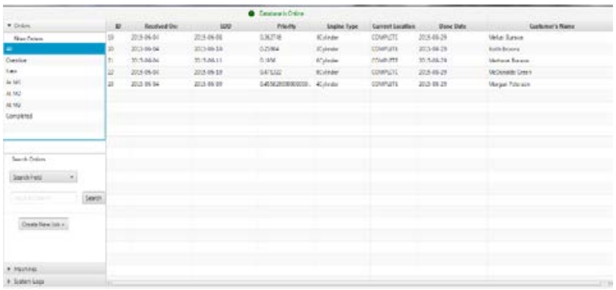

Figure 7 - Main User Interface

8 CONCLUSION

This paper discussed a collective approach to solving the problem related to making decisions when faced with a series of possible alternatives. The agent based job scheduling system, enables the decision to be made concurrently as the jobs are being captured into the system. With the system proposed in this paper, it is quite easy to keep track of all operations, jobs, machines due dates and customers. The chance of making random decisions is eliminated and it is thus easier to keep record of system performance with the view of improvement.

9 REFERENCES

[1] Bagchi, T. P., 1999. Multi objective scheduling by Genetic Algorithms. Norwell, MA: Kluwer.

[2] French, S., 1982. Sequencing and Scheduling: An Introduction to the Mathematics of the Job-Shop. New York: Wiley.

[3] Zweben, M. and Fox, M. S., 1994. Intelligent Scheduling. CA: Morgan Kaufmann, San Francisco.

[4] Shen, M., Wang, L. and Hao, Q., 2006. Agent-Based Distributed Manufacturing Process Planning and Scheduling: A State-of-the-Art Survey, IEEE Transactions On Systems, Man, And Cybernetics—Part C: Applications And Reviews, 36(4), 563-577

[5] Shen, W., 2002. Distributed manufacturing scheduling using intelligent agents, IEEE Expert/Intell. Syst., 17(1), 88–94.

[6] Lin, G. Y. J. and Solberg, J. J. 1992. Integrated shop floor control using autonomous agents, IIE Transactions: Design and Manufacturing, 24, 57-71.

[7] Macchiaroli, R. and Riemma, S., 2002. A negotiation scheme for autonomous agents in job shop scheduling, International Journal of Computer Integrated Manufacturing, 15, 222-232,

[8] Shen, W. and Norrie, D.H., 1999. Agent-Based Systems for Intelligent Manufacturing: A State-of-the-Art Survey, Knowledge and Information Systems: an International Journal, 1(2), 129-156.

[9] Ouelhadj, D., Hanachi, C., and Bouzouia, B., 1998. Multi-Agent Systems for Dynamic Scheduling and Control in Manufacturing Cells, Proc. of the 1998 IEEE International Conference on Robotics & Automation, May 1998, Leuven, Belgium, 2128-2133.

[10] Dewan, P. and Joshi, S., 2000. Dynamic Single Machine Scheduling Under Distributed Decision Making, International Journal of Production Research, 38(16), 3759-3777.

[11] Dewan, P. and Joshi, S., 2001. Implementation of An Auction-Based Distributed Scheduling Model for A Dynamic Job Shop Environment, International Journal of Computer Integrated Manufacturing, 14(5), 446- 456.

[12] Siwamogsatham, T. and Saygin, C., 2004. Auction-based distributed scheduling and control scheme for flexible manufacturing systems, International Journal of Production Research, 42, 547-572.

[13] Saaty, T.L. 1980. The Analytic Hierarchy Process, McGraw-Hill, New York.

[14] Nyanga, L., Van der Merwe, A.F., Matope, S. and Dewa, M.T., 2014, A decision support system framework for machine selection, SAIIE26 Proceedings, 14th – 16th of July 2014, Magaliesburg, South Africa

[15] Coyle, G., 2004. The Analytic Hierarchy Process, Pearson Education Limited.

[16] Russell, S. & Norvig, P., 1995. Artificial Intelligence: A Modern Approach. Eaglewood Cliffs, USA: Prentice-Hall, Inc..

[17] Omicini, A. and Molesini, A, 2007. The SODA Methodology Multiagent Systems LS Sistemi Multiagente LS, Universita di Bologna a Cesena, Academic Year 2007/2008

[18] DeLoach, S.A., 2004. The MaSE methodology in Methodologies and Software Engineering for Agent Systems, in Bergenti, F., Gleizes, M.P. and Zambonelli, F. (Eds). The Agent-oriented Software Engineering Handbook. Kluwer Academic Publishers, 107–125

[19] Omicini, A., 2001. SODA: Societies and Infrastructures in the Analysis and Design of Agent-Based Systems, Agent-Oriented Software Engineering, 1957, 185-193.

[20] Zambonelli, F., Jennings, N. and Wooldridge, M., 2003. Developing Multiagent Systems:The GAIA methodology. ACM Transactions on Software Engineering and Methodologies, 3(12), 417-70.

[21] Juan, T., Pearce, A. and Sterling, L., 2002. ROADMAP:Extending the GAIA Methodology for complex Open Systems, Autonomous

Agents and Multiagent Systems, 15-19 July. pp.3-10.

[22] Bauer, B. and Muller, P. J., 2001. Agent UML: A Formalism for Specifying Multiagent Interaction. In: P. Ciancarini & M. Wooldridge, Agent-Oriented Software Engineering. Berlin:

[23] Nikraz, M., Caire, G. and Bahri, P. A., 2006. A Methodology for the Analysis and Design of Multi-Agent Systems using JADE, Software Engineering for Multi-Agent Systems, 21(2), 91-103.

[24] Bellifemine, F., Bergenti, F., Caire, G. and Poggi, A. 2005. JADE – A Java Agent Development Framework, in Bordini, R.H. et al (ed), Multi-Agent Programming Languages, Platforms and Applications, 1st ed, Springer Science+Business Media Inc

[25] Dewa, M. T., Matope, S., Nyanga, L. & Van Der Merwe, A. F., 2014. An Analysis of Methodologies for Agent-Based Modeling for E-Manufacturing Systems in South Africa. International Journal of Advances in Mechanical and Automobile Engineering, 1(1), p. 74.

[26] Singh, A., Juneja, D. & Sharma, A. K., 2011. Agent Development Toolkits. International Journal of Advancements in Technology, 2(1), pp. 158-164.

[27] Nikraz, M., Caire, G. & Bahri, P. A., 2006. A Methodology for the Analysis and Design of Multi-Agent System using JADE. JADE Methodology, May.pp. 1-41.

[28] Bauer, B. & Odell, J., n.d. How to Build Agent-based Systems with the new UML Standard. UML 2.0 and Agents, pp. 1-21.

[29] Aruväli, T., Serg, R. & Otto, T., 2012. Machinery Utilization Monitoring and Pause Identification Prototype Model Design. Tallinn, Estonia, s.n., pp. 19-21.

[30] Hansen, R. C., 2001. Overall Equipment Effectiveness. 1st ed. s.l.:Industrial Press.

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