



DEVELOPMENT OF A RESOURCE AGENT FOR AN E-MANUFACTURING SYSTEM

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ABSTRACT

Due to globalisation and distributed manufacturing systems the development and manufacture of products is no longer an isolated activity undertaken by either one discipline or a single organization but has become a global process. Using e-manufacturing companies can now outsource to manufacturers outside their geographical area and make them dependent on the production capabilities and responsiveness of the suppliers. Hence there is need for the suppliers to provide reliable information on the state of the orders being processed. E-manufacturing promises companies to exchange the required information with their suppliers by increased visibility to the shop floor and providing a platform for information interchange. The paper discusses the development of an e-manufacturing resource agent to enable manufactures to predict the probability of their outsourced machinery being available and the probability to complete an order without having a breakdown. The Maintenance Free Operation Period (MFOP) method is used to develop the agent. This means that the manufacturer will be expected to have a guarantee that no unscheduled maintenance activities will occur during each defined period of operation with the predefined level of confidence.

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1 INTRODUCTION

Manufacturing companies have shifted from the traditional mass production strategy to lean and agile manufacturing strategies. Globalisation and distributed manufacturing systems have enabled companies to overcome the limitation of dealing only with companies in their geographical manufacturing process but have extended the manufacturing process into a global process. To enable these concepts to be a success there needs to be a more reliable platform for information exchange between the customers and suppliers in the supply chain which E-manufacturing seeks to provide. In this paper we develop a framework for a resource agent for an E-manufacturing system proposed by Nyanga et al [1]. The agent enables manufacturers to predict the availability of their machinery at the time when they are required to perform a specific job before outsourcing it or when it is being outsourced to them. The Maintenance Free Operation Period (MFOP) method is used to develop the agent by extending one cycle of MFOP into many cycles using the alternating renewal theory. The structure of the paper is as follows, MFOP methodology is discussed followed by the alternating renewal theory. We then give the framework for our proposed resource agent. We conclude the paper by giving the current status of the research and future work to be done.

2 INFORMATION GAP AND E-MANUFACTURING

According to Koc et al [2] competition in manufacturing industry no longer depends on lean manufacturing only, but also on the ability to provide customers with total solutions and life-cycle costs for sustainable value. Manufacturers are now under a pressure to improve their responsiveness and efficiency in terms of product development, operations, and resource utilization with a transparent visibility of production and quality control. A report by Unifi Technology Group [3] states that a survey of the top 50 global manufacturing executives carried out by Forrester revealed that the number one problem the executives have is poor visibility into the shop floor. In trying to improve the responsiveness and efficiency of the manufacturing plant the main challenge these manufacturers face is the existence of an information gap exists between the factory floor and the corporate systems that govern business and supply chains. Enterprise Resource Planning (ERP) systems have been developed to bridge the information gap in the manufacturing companies and have become the financial backbone of many corporations. As observed by Rockwell Automation group [3], ERP systems still have their own shortcomings as they cannot include the dynamics of the factory floor conditions such as unpredictable machine downtime, machine utilization, variability and reliability of suppliers and customers. Lee [4] states that the crucial link between Manufacturing Execution Systems (MES) which provides a higher-level view of production and ERP systems is hindered by the lack of integrated information coming from and flowing to control systems on the plant floor.

E-manufacturing fills the gaps between product development and supply chain consisting of lack of life cycle information and lack of information about supplier capabilities which exist in the traditional manufacturing systems as stated by Koç and Lee [5]. 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 as stated by Kovacs [6]. This enables the decision makers in an organization to make informed management decisions, efficiently respond to changing business conditions, and reply to customer inquiries in a timely manner. Koç and Lee [5] state that the intrinsic value of an e-Manufacturing system is to enable real-time decision making among product designers, process capabilities, and suppliers as shown in Figure 1. In the context of this research e-manufacturing is used to enable sharing of manufacturing resources to enable Small, Medium and Micro-sized Enterprises (SMMEs) to overcome their limitation in resources, increase their capacity and machine utilisation by implementation of capacity and technology subcontracting machines and jobs using the internet as a medium of communication.

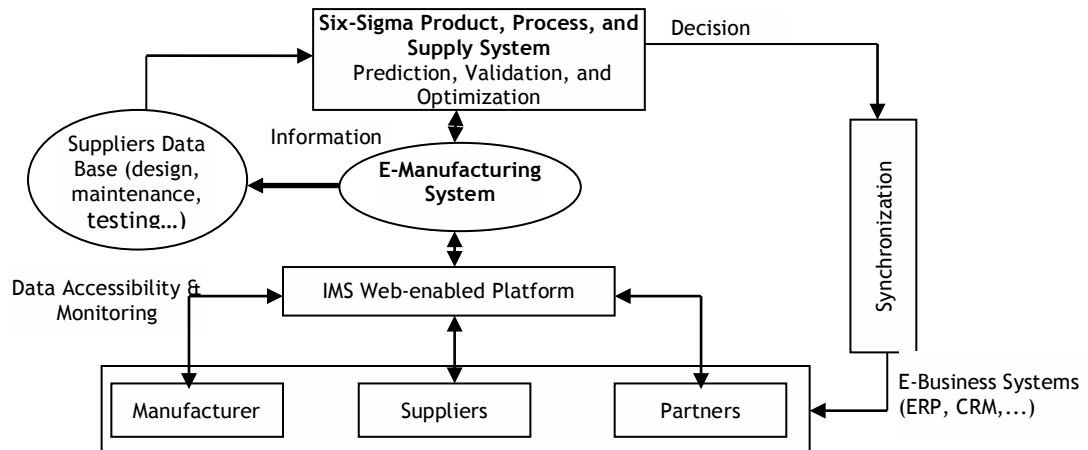


Figure 1 Intrinsic value of an E-Manufacturing system

3 PROBLEM ENVIRONMENT

The proposed framework seeks to enable manufacturers intending to subcontract machinery uploaded on an online registry proposed by Nyanga et al [1] to be able to predict the availability of machinery at the time the machinery would be used. The names of manufacturers and machinery available for different operations at any given time are uploaded on to a public registry which 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 and issue out orders based on machine availability, capabilities and cost of use. Unlike most of the e-manufacturing systems which uses e-diagnosis [7],[8],[9], to predict machine availability the proposed system uses the concept of Maintenance Free Operating Period (MFOP) as a way of reducing the complexity of the system, set and operational costs of the e-manufacturing system. The aim of the framework is to increase visibility into the shop floor and enable managers to make informed decisions when subcontracting machinery. The proposed resource agent predicts the availability of machinery from the machine schedule developed by the job scheduling agent and the maintenance module using the Maintenance Free Operating Period (MFOP) concept.

4 RELIABILITY-CENTRED MAINTENANCE (RCM)

A reliability-centred maintenance (RCM) strategy can be used to increase the operational reliability of the system and decrease both downtime and maintenance cost [10]. Using Graber's [11] approach, reliability is expressed as the probability that a machine will perform its function or task under stated conditions for a defined observation period (mission time). Considering the drawbacks of Mean Operating Time Between Failure (MTBF) or its reciprocal - the 'failure rate' which makes it almost impossible to demonstrate reliability. Hockley and Appleton [12] state that the Royal Air Force (RAF) are considering maintenance free operating period (MFOP) as the prime reliability and maintainability requirement for their future generation aircraft. According to Relf [13] the RAF set a target to have MFOP replace its fleet of strike aircraft in approximately 2015.

5 MAINTANCE FREE OPERATING PERIOD (MFOP)

Dinesh-Kumar et al [14] defines the MFOP as a period of operation during which an item will be able to carry out all its assigned missions without the operator being restricted to system faults or limitations, with the minimum of maintenance. Every MFOP is followed by a Maintenance Recovery Period (MRP). This is the downtime during which the equipment is

recovered to such a level that the next MFOP can be achieved successfully. Unlike the mean time between failures and Mean Time To Failure (MTTF) approaches which accept that failure cannot be accurately forecast and avoided, MFOP focuses on enabling equipment to achieve operational success with minimal within-MFOP maintenance intervention, through combined use of failure avoidance, failure anticipation, and maintenance delay as stated by Warrington [15].

According to Wu et al [16] MFOP is an extension of warranty period extended throughout the life of the system which reduces direct maintenance costs (DMC). The machine owner is guaranteed that no unscheduled maintenance activities will be required during each defined period of operation with the predefined level of confidence. Not all Maintenance Recovery Periods (MRPs) will have same duration because of the different maintenance activities for individual Line Replaceable Unit (LRU). Brown and Hockley [17] state that the length of the MRP varies depending upon the previous and subsequent MFOP and also the depth of maintenance required hence a flexible approach to the duration of the MRP is required. However the authors do not explain how to deal with the differences in the MRP. Fritzsche [18] shows how the MFOP concept is to reduce maintenance costs by replacing unscheduled corrective maintenance with more scheduled activities. The focus this paper is to show how MFOP can be used to predict machine availability.

5.1 MFOP models

Todinov [19] presented models for limiting the risk of failure below a maximum acceptable level, guaranteeing an availability target and guaranteeing a minimum failure-free operating interval before each random failure in a finite time interval. Chew et al [20] proposed the use of a Petri net (PN) to model the reliability of the MFOP and phased missions scenario. A mission is taken in phases with a combination of several sequential phased missions without maintenance considered to produce a maintenance-free operating period.

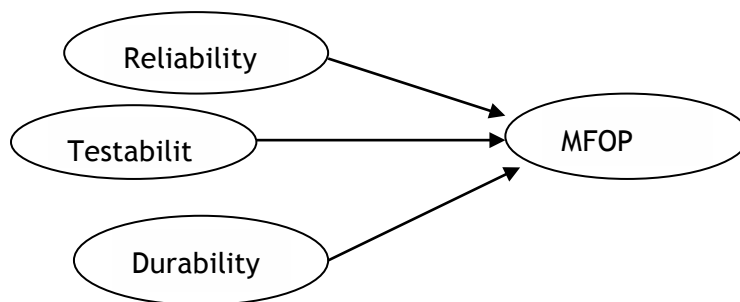


Figure 2 MFOP fundamental elements [17]

Using Knezevic's toasting fork model Brown and Hockley [17] came up with three elements fundamental to the philosophy of MFOP, which are reliability (increased reliability over existing platforms), testability (ability to diagnose faults and failures efficaciously) and durability (redundancy and fault tolerance) as shown in Figure 2. They also state that MRP is of specified duration dependent upon the maintenance task required. Maintenance would be carried out on the platform to ensure that the probability of completion of subsequent MFOPs would be the same as that given for the previous MFOP. Thus the duration and content of each MRP would be predicated by the duration and content of the MFOP.

According to Guertin and Bruhns [21] an MFOP-enabled system is inherently reliable with continuous health monitoring status to provide confidence that the tactical application availability requirement is highly likely to be met. To achieve this in their Navy ships MFOP system design the following design enablers were incorporated (1) Fault Tolerant Design (2) Data Collection, and (3) Remote Connectivity as shown in Figure 3.

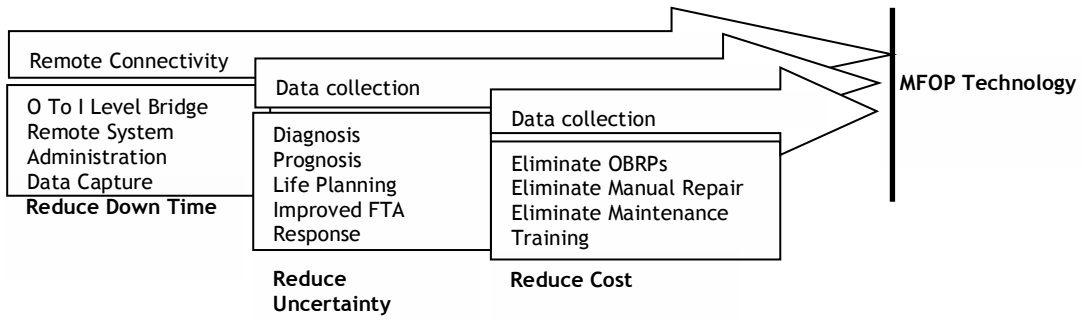


Figure 3 MFOP design enablers [21]

5.2 MFOP Analysis

The MFOP analysis for the system follows the 5 step methodology proposed by Shaalane [22]:

- 1) Identification of System
- 2) Setting System Boundaries
- 3) Identification of Correct Failure Data
- 4) Data Collection and Management
- 5) Determination of Data Set Trends

The steps for data analysis are shown in the schematic diagram in Figure 4. The data is tested if it is a Homogenous Poisson Process (HPP) or Non-homogenous Poisson Process (NHPP) using the centroid test or the Laplace test as recommended by O'Connor et al [23].

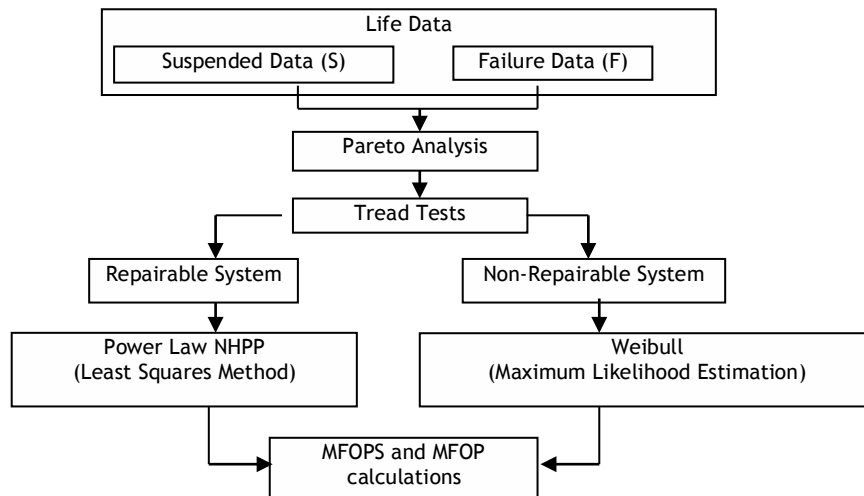


Figure 4 MFOP data analysis [21]

Using the Laplace test the following hypothesis is tested:

$$H_0 : \text{HPP}$$

$$H_a : \text{NHPP}$$

The test Laplace test equation is given by Equation (1):

$$U_L = \frac{\sum_{i=1}^{n-1} T_{i/n-1} - T_{n/2}}{T_n \sqrt{1/12(n-1)}} \quad (1)$$

Where U_L approximates a standardised normal variate at a 5 % level of significance when $n \geq 4$, n is number of failures, and T_i is the i^{th} failure arrival time.



If $U_L \geq 2$ there is reliability degradation. If $U_L \leq 2$ there is reliability improvement. If $-1 \leq U_L \leq 1$ there is no evidence of an underlying trend. A test for dependencies between the inter arrival times should be performed as discussed by Cohen [24] and Gretton et al. [25]. A positive result on a test for dependence would mean that a Branching Poisson Process (BPP) would be applicable. The test for dependence is however omitted as stated by Cox and Lewis [26] since approximately 30 failure observations are required to perform such a test with reasonable confidence. In reality it is rare to have more than 30 observations in reliability data

If $-2 \leq U_L \leq -1$ or $1 \leq U_L \leq 2$ the Laplace test cannot provide indication with certainty that a trend is present in the data set hence the Lewis-Robinson will be used.

In the Lewis-Robinson test following hypothesis is tested:

H_0 : renewal process

H_a : not a renewal process

The Lewis-Robinson test is given by Equation (2):

$$U_{LR} = U_L / CV \quad (2)$$

where CV is the estimated coefficient of the variation of the inter-arrival times, U_L is the Laplace test statistic.

CV can be calculated by Equation (3):

$$CV[X] = \frac{\widehat{var}[X]}{\bar{x}} \quad (3)$$

where X represents the variable of inter-arrival times. The results of the Lewis-Robinson test are interpreted the same way as the Laplace test.

5.2.1 Distribution parameters

If U_L falls in the region $-1 \leq U_L \leq 1$ there is no dependence of the data hence the non-repairable systems theory will be applied. The pdf for non repairable systems which shows the probability of system failure $f(x)$ at the exact instant x , is given by Equation (4):

$$f(x) = \frac{\beta}{\eta} \left(\frac{x}{\eta}\right)^{\beta-1} \exp\left(-\left(x/\eta\right)^\beta\right) \quad (4)$$

Where β is the shape parameter and η the scale parameter of the Weibull distribution, where $\beta > 0$ and $\eta > 0$.

If $U_L \geq 2$ or If $U_L \leq 2$ there is a data trend hence the repairable systems theory has to be used. For repairable systems the power law Non-homogenous Poisson Process (NHPP) is used to model the repairable system using Equation (5):

$$\rho_1 = \lambda \delta t^{\delta-1} \quad (5)$$

Where λ is *scale* parameter and δ is a *shape* parameter. The parameters λ and δ are determined using the least-squares method i.e. difference between the observed number of failures and the number of failures expected.

For a failure

$$\min(\hat{\lambda}, \hat{\delta}) : \sum_{r=1}^r [E[N(\mathbf{0} \rightarrow T_i)] - N(\mathbf{0} \rightarrow T_i)]^2 \quad (6)$$

For a suspend

$$\min(\hat{\lambda}, \hat{\delta}) : \sum_{r=1}^{r-1} [E[N(\mathbf{0} \rightarrow T_i)] - N(\mathbf{0} \rightarrow T_i)]^2 \quad (7)$$



5.2.2 Maintenance Free Operating Period Survivability (MFOPS)

The MFOPS of non repairable systems will be calculated as shown by Denish-Kumar et al [14] and Denish-Kumar [27]. The MFOPS of non repairable systems is given by Equation (8):

$$MFOPS_{(t_{mf})} = \exp\left(-\frac{t^\beta - (t+t_{mf})^\beta}{\eta^\beta}\right) \quad (8)$$

Where η is the scale parameter and β is the shape parameter of the Weibull distribution. The reliability of the system $R(t)$ in Equation (9) is given by Long et al [10] and Moss [28]:

$$R(t) = \exp\left[-\left(\frac{t}{\eta}\right)^\beta\right] \quad (9)$$

For repairable systems the MFOPS is given by Equation 10:

$$MFOPS(t_{mf}) = e^{-\lambda((t_{mf}+T_r)^\delta - (T_r)^\delta)} \quad (10)$$

Where T_r is the global time unit of the last known failure event and the parameters, λ and δ are the system parameters found through the least squares

5.2.3 Determine Maintenance Free Operating Period (MFOP)

In order to calculate the MFOP period for a non-repairable system for a given level of confidence Equation 8 is rearranged to the form of Equation (11):

$$t_{mf} = \left[t^\beta - \eta^\beta \ln(MFOPS_{(t_{mf})})\right]^{1/\beta} - t \quad (11)$$

The MFOP duration for a specified MFOPS requirement is given by Equation (12):

$$MFOP = \eta * \left\{\ln\left(\frac{1}{MFOPS}\right)\right\}^{1/\beta} \quad (12)$$

The probability of achieving MFOP length at a confidence MFOPS can now be found by plotting MFOPS against MFOP. The MFOP methodology implemented by Shaalane [22] and has been preferred more than the MTBF.

6 ALTERNATING RENEWAL THEORY

To incorporate the MRP after an MFOP for a repairable system Denish-Kumar et al [14] and Nowakowski et al [29] derive MFOPS for a repairable item using renewal theory by allowing a maintenance recovery period after an MFOP. Considering a repairable item and assuming that:

1. The time to failure distribution of the item follows arbitrary distribution with density function represented by $f(t)$.
2. Maintenance recovery time of the item follows some arbitrary distribution with density function represented by $g(t)$.
3. The item can be in one of two states $\{1, 0\}$, where “1” is up state and “0” is down state.

Let $P_1(T)$ be the probability that the item will have t_{mf} hours of maintenance free operating period throughout the mission T . Maintenance is carried out as soon as the item fails. The expression for $P_1(T)$ can be written as:

$$P_1(T) = R(t_{mf}) + \int_0^T f(\mu|t_{mf}) P_0(T - \mu) d\mu \quad (13)$$

and

$$P_0(T) = \int_0^T g(v) P_1(T - v) dv \quad (14)$$

where $f(\mu|t_{mf})$ is the probability that the system fails at time u , given that it has survived up to time t_{mf} .

Various approaches have been used to solve the integral equation of renewal type like Equation 13. Yevkin and Krivtsov [30] state that in repairable systems reliability analysis the four states to which a system can be repaired to following a failure (1) good-as-new, (2) same-as-old,(3) better-than-old-but-worse-than-new and (4) worse-than-old should be considered. After a failure if a repairable system is restored to a “good-as-new” condition, and the time between system failures can be treated as an *independent and identically distributed (i.i.d.)* random variable, then the failure occurrence can be modelled by the Ordinary Renewal Process (ORP) indicated by equation 13. If upon a failure the system is restored to the “same-as-old” condition, then an appropriate model to describe the failure occurrence is the Non-Homogeneous Poisson Process (NHPP) given that the time to repair can be neglected. ORP and NHPP can be treated as special cases of Generalized Renewal Process (GRP). They use two-point pade approximants to solve the ordinary renewal equation. Politis and Pitts [31] use approximations for the renewal density based on the derivatives of the renewal density functional. The derived explicit formulae for approximations can then be easily implemented on computer algebra software. Tortorella [32] uses the trapezoid rule and Simpson-like rules to solve the integral equation of renewal type. Taking note that equation 13 is a system of integral equations, we find the numerical approximation proposed by Gopalan and Dinesh-Kumar [33] most appropriate to use in developing our resource agent.

7 MULTI AGENT SYSTEM

An agent can be defined an object of a program, which has its own value and means to solve some sub-tasks independently and finally communicate its solution to a large problem solving process to achieve the objective [34] or as any piece of software or object which can perform a specific given task [35]. Properties of agents include autonomy, socialability, responsiveness, adaptability, mobility, and protectiveness [36]. Agents also have reasoning capabilities [37] have the ability to make a plan to achieve the goal [34]. A group of agents existing in the same environment which collaborate with each other to achieve common goals forms a Multi Agent System (MAS). These agents share information, knowledge and tasks among themselves.

The proposed multi agent system consists of functional agents which are managed and supervised by the Managing Agent (MA) through the internet as shown in Figure 5. The functional agents are Order Agent (OA), Mediator Agent (MdA), Job Agent (JA), Manufacturability Agent (Mfg A), Job Scheduling Agent (JSA), Process Planning Agent (PPA) and Resource Agent (RA).

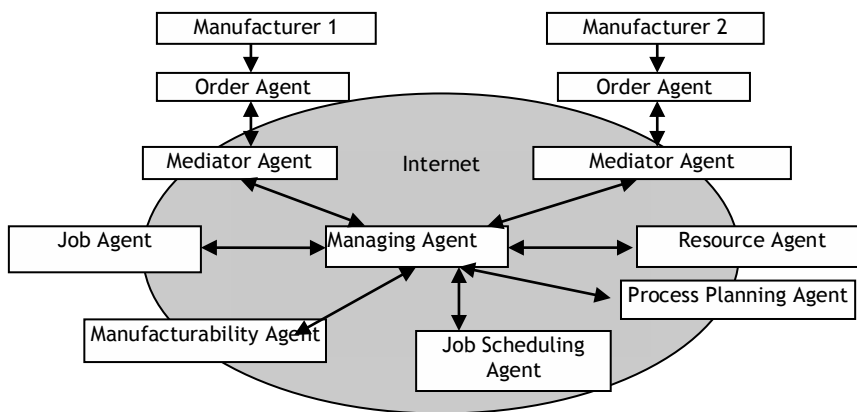


Figure 5 Multi-Agent System

The multi agent system makes decisions in allocating orders to machines registered on an online registry for capacity and technology subcontracting as shown in Figure 6. A manufacturer prepares a product process plan for the product one wants to manufacture. The manufacturer's mediator agent then searches for machines which are capable of carrying out the required manufacturing processes from the machines with sufficient capacity available the online registry. Once the machines have been identified the mediator agents from the manufacturer with the part to be manufactured or process to be done enters into negotiations using the Contract Net Protocol (CNP) to allocate jobs to the machines available.

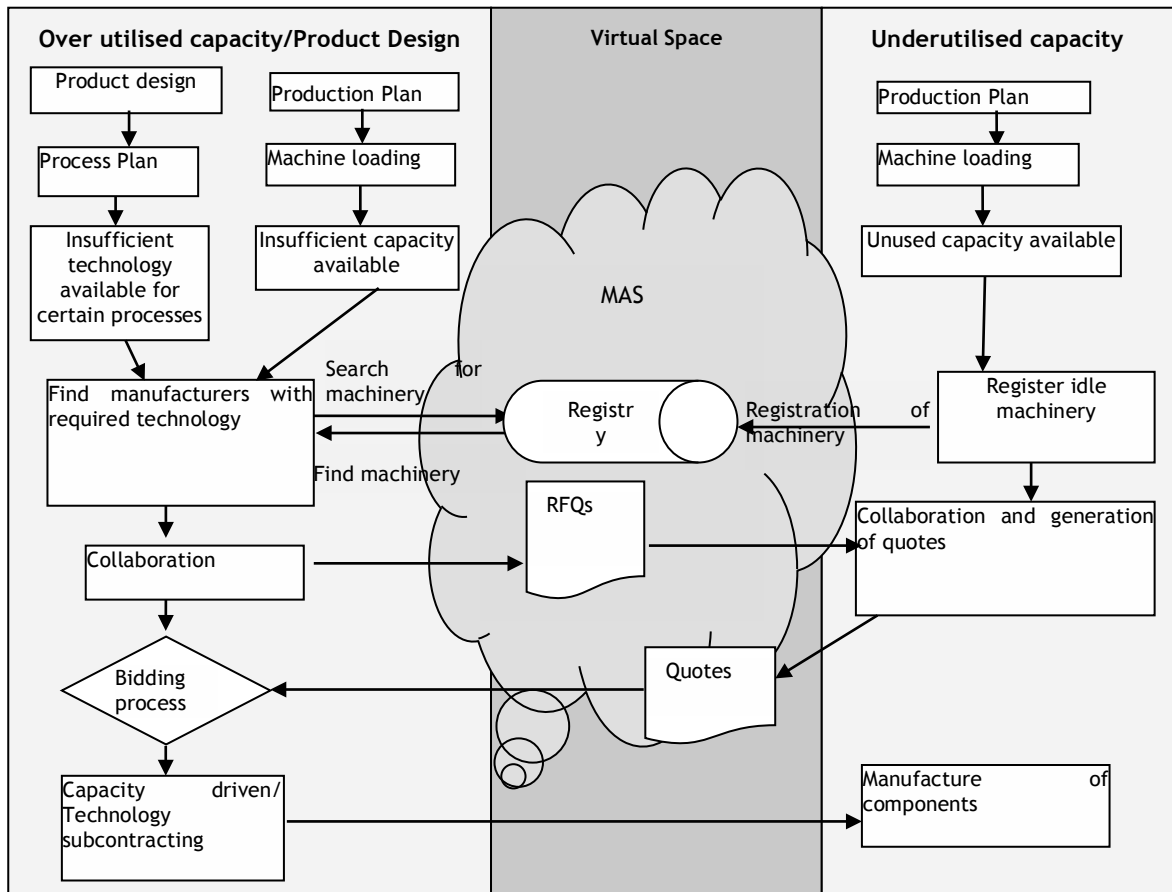


Figure 6 Framework for Capacity and Technology Driven Subcontracting

8 RESOURCE AGENT

The physical hierarchy for the resource agent is shown in Figure 7. The agent consists of three main modules: Machine schedule Module, Maintenance module and Communication module. The machine schedule module contains the machine schedule updated by the Job scheduling agent and maintenance module. The job agent determines the availability of the machinery from the scheduled workload for the machine. The maintenance module determines the probability of the availability of machinery from the maintenance point of view. The communication module enables the resource agent to communicate with the other agents in the multi agent system. The functionality diagram for the resource agent is shown in Figure 8.

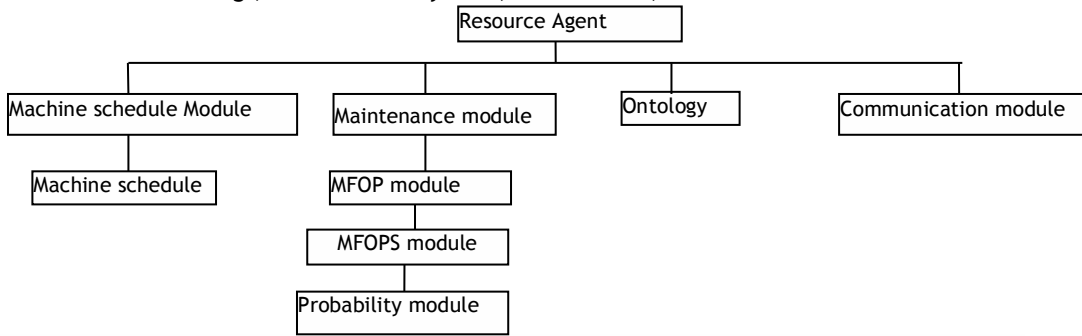


Figure 7 Physical hierarchy for the resource agent

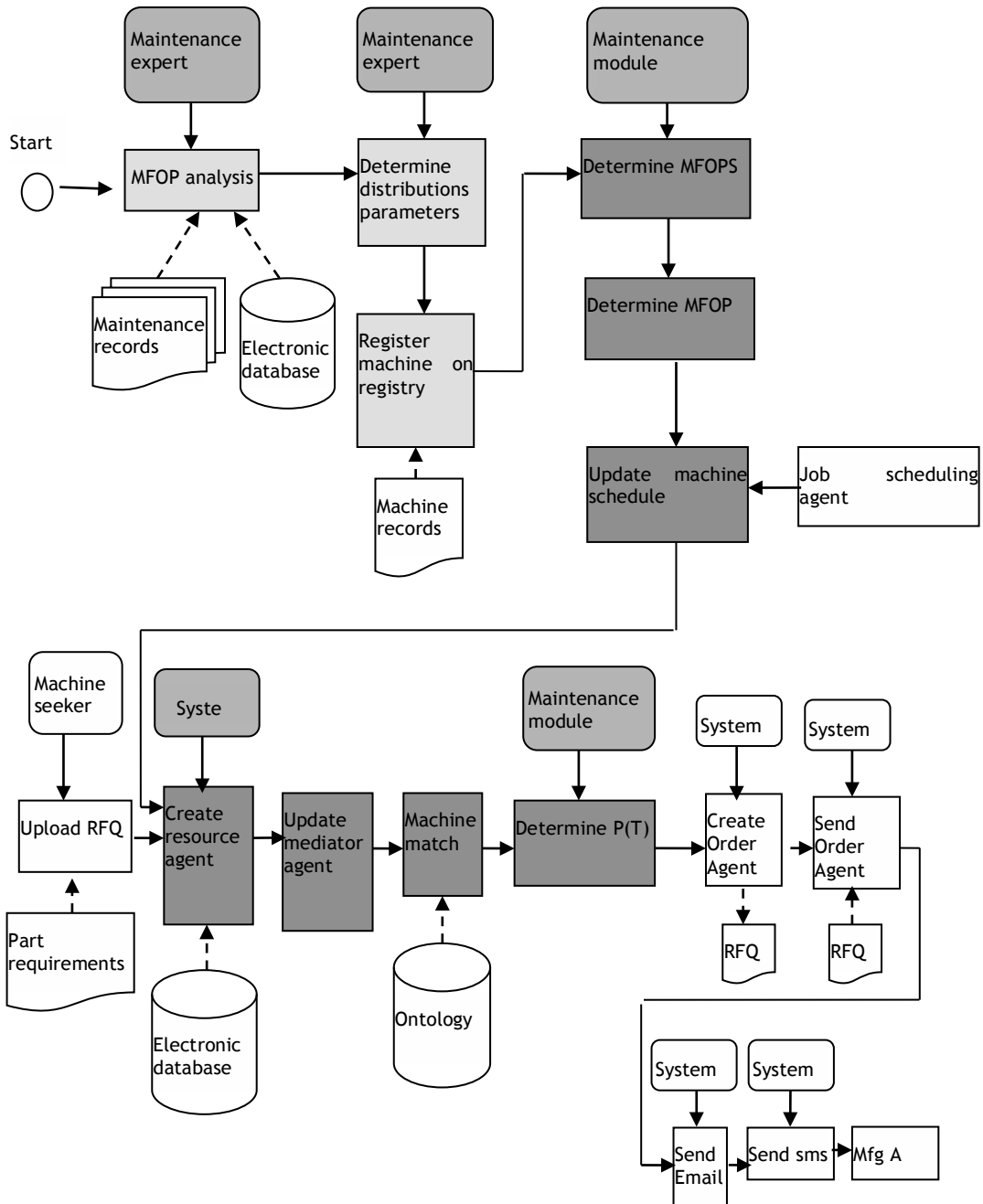


Figure 8 Functional Flow Diagram for Resource agent



A maintenance expert in the company will be responsible in carrying out the MFOP analysis in order to determine the using historical of machine maintenance. Data trends, MFOP and MFOPS will be determined as shown in Section 5.2. The distribution of MRP is sought and the alternating recovery theory discussed in Section 4 is used to determine the probability function of machine availability with many MFOP cycles. The MFOP analysis is used to update machine schedule developed by the Job processing agent by removing the machine workload where the machine is under MRP. When a Request For Quote (RFQ) has been raised a resource agent is generated. It updates the Mediator Agent (MA) on the states of machine availability during the period the machine is being requested. If the machine will be available at the time of request the machine is made available on the ontology to for process and machine matching. The probability of machine availability is calculated and the information is passed on to the Order Agent and then sent to the Manufacturability Agent (Mfg A). The machine selection process is represented by the process definition in an extended Business Process Modelling Notation (BNMN) shown in Figure 9.

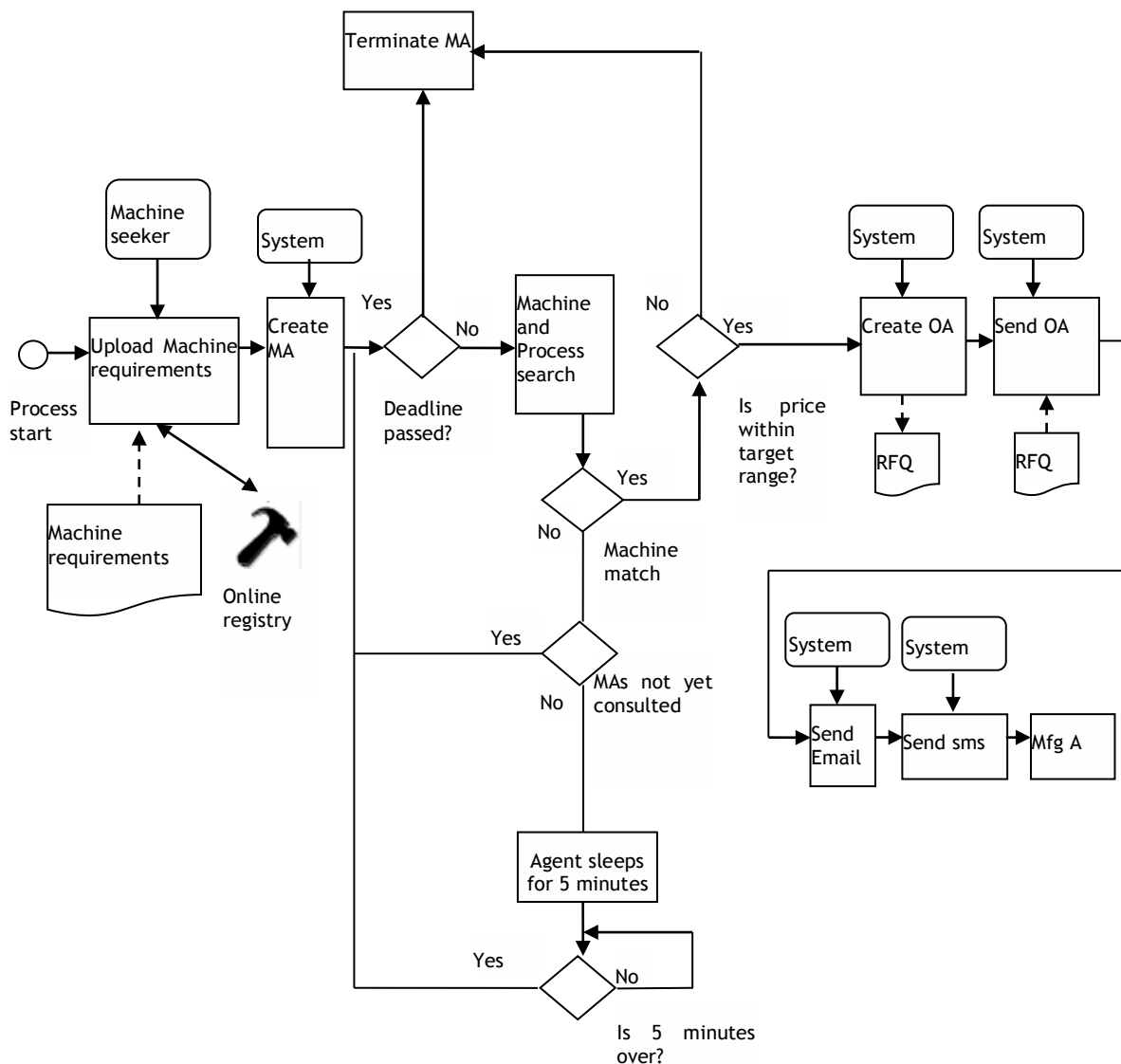


Figure 9 Machine and Process definition in extended BPMN notation



9 CONCLUSION

The paper discussed a framework for a resource agent for a multi agent system of an e-manufacturing system. The MFOP and alternating renewal process methodologies were looked at. Unlike the MTTF which accepts that failure cannot be accurately forecast and avoided the MFOP gives the machine owner a guarantee that no unscheduled maintenance activities will be required during each defined period of operation. The MFOP and alternating renewal process methodologies are then used to develop a framework for the resource agent which seeks to predict the availability of machinery at a given time requested in a request for quote. The agent also updates the machine schedule generated by a job agent.

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