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A GENERIC COORDINATION APPROACH APPLIED TO A MANUFACTURING ENVIRONMENT

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ABSTRACT

This paper describes a generic coordination approach applied to the field of manufacturing engineering. The objective of the coordination mechanism with respect to this application is twofold. Firstly, it is shown that utilising the developed system can result in the efficient organisation of processes leading to a near optimum time taken to manufacture a number of artefacts. Secondly, successful operation of the system in this environment will demonstrate that the approach is generic in nature. The results already achieved using this system within a computational analysis environment supports this hypothesis.

KEYWORDS

Coordination, Agents, Scheduling, Resource Management

1 INTRODUCTION

In order to compete with other organisations, manufacturing companies need to ensure that the artefacts they produce are of high quality and are delivered on time at the right cost. Concurrent Engineering is often cited as a means of achieving these objectives, however coordination has been recognised as a key issue in this area [1-5]. Quality issues are addressed by improving machines, tools, operators and processes. Manufacturing time can be improved significantly if the processes and resources are managed and coordinated in such a way that artefacts are produced in a timely manner. Dynamic coordination facilitates the optimisation of activities performed in the manufacturing process leading to reduced time to manufacture. As a result of optimising the manufacturing process the associated cost can also be reduced.

A generic coordination approach that allows the management and organisation of manufacturing process activities is described. A Computer Aided Coordination tool, namely the Design Coordination System (DCS), has been developed which will assist process coordination in a manufacturing environment. Within the DCS, a collection of agents act as members of a multi-functional team operating in a cooperative and coordinated manner in order to satisfy the objective of efficiently performing the manufacturing process. The emphasis of the coordination approach employed within the DCS is focused not simply on concurrent engineering but on optimising the complete process. That is, as much permissible activity is performed simultaneously. The objective of the DCS is to perform the right activity at the right time on the right resource.

2 REQUIREMENT FOR COORDINATION

Coordination can be thought of as the concept of the appropriate activities being performed, in a certain order, by a set of capable agents, in a fitting location, at a suitable time, in order to complete a set of tasks.

Thus, with respect to completing tasks, coordination can be viewed as comprising of five fundamental components: activity, agent, order, location, and time. Within any environment, in order to satisfy a particular requirement, an activity needs to be performed so that the appropriate task can be completed. The activity needs to be specified such that when it is performed it will have the desired effect and complete the task. Therefore, careful consideration needs to be given to determine which activity is the most appropriate to carry out in order to do the task. To perform an activity, an agent, or agents, must carry out the required actions in order to complete a particular task. An agent can be considered as a resource and may be human, software or hardware. Essentially, an agent is an entity capable of performing some activity to do a given task. The correct choice of agent, or agents, will ensure that the activity is performed in the most suitable fashion and the task is completed satisfactorily. Since relationships can exist between tasks, there may be an optimal order in which activities should be performed to complete the tasks. Consideration of this fact will assist in identifying those activities that can be carried out sequentially. When an agent is performing an activity it may be appropriate to do so in a certain location. This consideration may be of a particular importance and relevance when agents are working in the same team, or related teams, to complete the same task. For an activity, timeliness is usually of paramount importance, The time at which an activity is performed directly affect the completion of a task.

3 APPROACH

Coordination can be viewed as the decision making, controlling, modelling and planning/scheduling activities with respect to the design factors time, tasks, resources and aspects [1], [6]. The approach implemented within the DCS embraces this high level concept in that it involves the coordination of processes which aims to optimise the scheduling and planning of the manufacturing process with respect to the allocation and utilisation of available resources. The DCS incorporates an agent architecture consisting of a suite of disparate agents. Each agent fulfils a particular role and performs several different tasks. The behaviour of all agents is complimentary in that they assist other agents when necessary. Agent communication is facilitated by a message passing mechanism. Agents are able to send and receive messages and take appropriate action when required. An ontology is used for agent communication, which defines a dictionary of terms that are meaningful and unambiguous.

Within the DCS there are seven types of agent as illustrated in Figure 1.

In any application of the DCS, the number of certain agent types are fixed whereas other agent types are dependent on factors such as the number of processes being used in the manufacture of the artefacts and the number of available resources in the manufacturing environment. Only one Coordination Manager, Resource Manager and Scheduling Agent operate within the DCS. The number of Information Managers and Task Managers is equivalent to the number of different processes being performed. Each machine being employed by the DCS is allocated a Resource Monitor and an Activity Director.

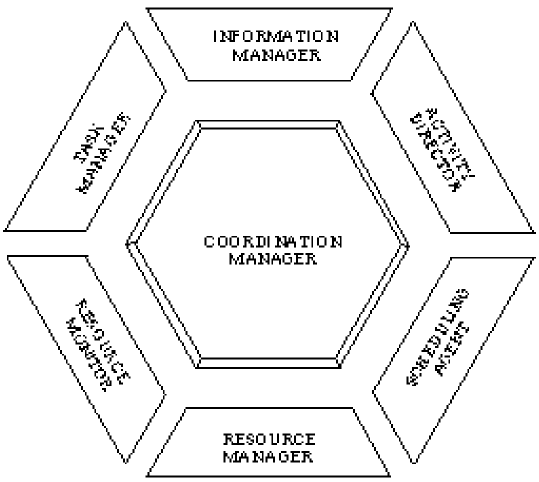

Figure 1. DCS Agent Architecture

3.1 Coordination Manager

As shown in Figure 1, the Coordination Manager is central to all agent activity within the DCS. In order for an agent to register its services, it must initially send a message to the Coordination Manager. Information contained within this first communication relates to attributes of the agent. This information, which is dependent on agent type, is registered by the Coordination Manager in an address book. Once the attributes of an agent have been recorded, the Coordination Manager acknowledges the existence of this agent. Subsequently, in the event of any one agent requiring particular information regarding another agent, the details can be obtained from the Coordination Manager. Knowledge of this information then enables the necessary agents to communicate directly, rather than via the Coordination Manager, and work cooperatively to perform their tasks and achieve their goals. This feature of agents having the ability to communicate directly with any other agent allows efficient message passing, removes the problem of communication bottlenecks, and promotes coordination.

Within the DCS, a number of agents request information regarding other agents so as they can communicate directly and coordinate their activities. Specifically, each Task Manager requests the address of their related Information Manager. These design agents are related if they are associated with the same process. If the Information Manager has registered, the Coordination Manager provides the Task Manager with the requested information. In the situation where the Information Manager has not yet registered, the Coordination Manager indicates to the Task Manager that the information will be provided once it becomes available. Similarly, Resource Monitors, Activity Directors and the Scheduling Agent request the address of the Resource Manager. These requests are managed by the Coordination Manager in exactly the same manner as described with the Task Manager and Information Manager.

3.2 Information Manager

An Information Manager is one of two agent types that is directly associated with a particular process. Responsibilities of this agent include ensuring that artefacts are managed before and after the associated process is performed on them. That is they are added to and removed from the right machine at the right time. Other duties include ensuring that any auxiliary tools and/or equipment associated with the process to which it has been assigned are made available to the related Task Manager when required.

After a Task Manager has performed its associated process on an artefact, and prior to preparing another artefact for manufacture, the Information Manager manages the artefact from the previous process. That is, the artefact may be removed from one machine and placed on another in preparation for the next process to be performed. This procedure needs to be carried out after every process is performed to avoid delays on any machines. Once all processes have been performed on an artefact it is placed in an area designated for completed artefacts.

An Information Manager needs to be able to provide a specifically requested artefact to the Task Manager while keeping a record of those artefacts that have already been released and those that are pending. This is due to the order in which the Scheduling Agent schedules processes.

3.3 Task Manager

In addition to the Information Manager, a Task Manager is also associated with a particular process. A relationship exists between a Task Manager and Information Manager if they are associated with the same process. A Task Manager's responsibilities include requesting artefacts from its related Information Manager and subsequently supervising the process being performed on the artefact on the assigned machine. Once a Task Manager has completed a process, the related Information Manager manages the artefact. Artefacts continue to be requested from the Information Manager by the related Task Manager until all have been dispensed and each process has been performed on them.

Task Managers need to be able to request a specific artefact from their respective Information Managers so as to accommodate the 'random' order of proposed artefact manufacture within any given schedule as calculated by the Scheduling Agent. Hence, the artefact identification number is recorded which can be checked by the Activity Director prior to the process being performed. An Activity Director is responsible for ensuring that the processes taking place on its associated machine are carried out in the correct order at the right time. Hence, a Task Manager will be instructed at the appropriate time to commence performing a process on a particular artefact by an Activity Director. Each Task Manager must act promptly when instructed to do so by an Activity Director. Prompt action will lead to the schedule being adhered to as closely as possible and the manufacturing process being completed in a near optimal time.

3.4 Resource Manager

The Resource Manager is the agent responsible for managing the available resources. Functions of this agent include constructing a process matrix and a machine matrix. The process matrix contains information such as dependencies between processes and datum process durations, which is very much akin to the representation of the design structure matrix [7]. The Resource Manager uses the information held in this matrix to identify those processes that can be executed simultaneously. The machine matrix contains a status flag and an efficiency measure for each machine within the manufacturing environment. A machine's status flag is an indication of whether or not a machine is available for use. Efficiency is a relative measure of the speed of a machine. The Resource Manager updates the machine matrix when necessary, following notification of a shift in a particular machine's efficiency by the associated Resource Monitor.

On receiving notification from any of the Resource Monitors that their associated machine's efficiency has fallen below a certain level, the Resource Manager determines whether this change is significant enough to warrant an instruction to the Scheduling Agent to produce a new schedule. The Resource Manager decides whether or not the scheduling mechanism should be invoked as it may not always be appropriate to do so. Similarly, if a machine's efficiency increases beyond a certain level causing it to be more efficient than a machine currently being utilised in the manufacturing process then the Resource Manager should also consider requesting a new schedule. If the Resource Manager decides, that based on the information it has available, a new schedule is required then an instruction is sent to the Scheduling Agent to proceed in doing so.

In the decision making process concerning whether or not to re-schedule the Resource Manager must take into account several factors. The number of artefacts remaining to be manufactured and the likelihood that a new schedule will be adhered to for the remainder of the manufacturing process should also be considered. If it is probable that a schedule may need to be superseded due to changes in machine efficiency or state, rather than scheduling all remaining artefacts, it may be more appropriate to schedule only a number of the outstanding artefacts. This consideration of scheduling only a proportion of pending artefacts will reduce the time taken for the Scheduling Agent to produce a schedule. Given that re-scheduling would need to be done regardless due to machine efficiency variability, time would be saved due to building part schedules each time as opposed to complete schedules. However, this re-scheduling policy may prove ineffective if machine efficiencies are unlikely to alter significantly throughout the course of the manufacturing process. In this case it may be more suitable to produce a schedule for all outstanding artefacts. A potential disadvantage of part scheduling is that re-scheduling is guaranteed. Even if a schedule is followed to completion the remaining artefacts will need to be re-scheduled.

In the situation where one of the machines is to be withdrawn from those being utilised then a new schedule needs to be calculated. Possible reasons for machine withdrawal could be reduced efficiency or that it has become inoperative. Only the remaining machines will be considered for selection within the new schedule. Similarly, if the efficiency of a machine not currently in use is increased then it may be sufficient to cause a new schedule to be calculated since it may be appropriate to replace a machine presently being utilised.

The Resource Manager oversees a resource pool in which machines can be selected for utilisation within the manufacturing process. Machines can be one of four states, namely active, idle, temporarily unavailable or redundant. If a machine is active or idle then it should be included within the resource pool. Temporarily unavailable and redundant machines are excluded from the resource pool. Active machines are those that are currently being used, or initially intended to be used, within the manufacturing process. Idle machines are those that are currently available for use within the manufacturing process but, due to their efficiency level, have not been selected for use. A temporarily unavailable machine is one which cannot currently be used but at some later time may become available. Machines classed as redundant are those that are inoperable for the duration of the manufacturing process. Machines are relegated from the resource pool if their state changes from active or idle to temporarily unavailable or redundant. A new schedule would only need to be calculated in the event where a machine's state changes:

(i) from active to another state,

(ii) to potentially active from another state.

A machine becomes potentially active if its efficiency becomes higher than a machine that is currently active. Machines are promoted to the resource pool if their state changes from temporarily unavailable to idle. If a machine becomes redundant then an event has occurred such that the machine is unusable within the expected lifetime of the manufacturing process. Redundant machines are relegated from the resource pool permanently.

A schedule will be calculated if a machine is being removed from or added to the manufacturing process. When a schedule is being calculated due to the removal of a machine from the manufacturing process the Scheduling Agent should take into account all machines within the resource pool at that time, that is active and idle machines, with the exception of the active machine being removed. Conversely, a schedule being calculated due to the addition of a machine should take into account all machines currently in the resource pool. Machines within the resource pool should be ranked in order of efficiency such that if *m* machines are required to be used to perform the manufacturing process then the *m* most efficient machines should be selected.

3.5 Scheduling Agent

A Multi Criteria Genetic Algorithm [8] is utilised by the Scheduling Agent to facilitate the optimum utilisation of the available resources. The Scheduling Agent views the scheduling problem as the total manufacturing time, of a given number of processes with interdependencies between them, should be minimised by assigning them to be performed on an optimum number of the most efficient machines to facilitate the manufacture of a known number of artefacts.

The Scheduling Agent prepares the information required for the Multi Criteria Genetic Algorithm (MCGA). This information is held in the process and machine matrices. Relationships between processes, number of artefacts to be manufactured, and available machines is information which is used by the Scheduling Agent in order to establish a schedule and, hence, an order to perform processes on each artefact. When instructed by the Resource Manager, the Scheduling Agent executes the MCGA to enable the optimum utilisation of the available resources. The Scheduling Agent notifies the Resource Manager when a new schedule has been produced. In addition, each Activity Director is notified of the schedule of processes to take place on the machine to which it is associated. When a new schedule is produced, only those Activity Directors with a change to their current schedule need to be notified. It is conceivable that the process load and/or order may change on only a number of the machines being utilised rather than on all of them. This feature of decomposing the global schedule into local schedules creates the opportunity for a more efficient re-scheduling mechanism.

3.6 Resource Monitor

A Resource Monitor exists for each machine within the manufacturing environment. Each Resource Monitor continuously monitors and records the efficiency and status of its associated machine. If a Resource Monitor observes that the associated machine’s efficiency has deviated from the current value, then it will inform the Resource Manager of this fact and supply the machine’s latest details. This may result in the Resource Manager deciding to remove/add that particular machine from/to the manufacturing process and request that a new schedule be calculated by the Scheduling Agent. It is important to note that not only can a machine be removed from the manufacturing process due to its depreciating efficiency but a machine can also be added due to improved efficiency. If a machine’s efficiency becomes greater than that of a machine currently being used in the manufacturing process then it will result in the Resource Manager deciding if a new schedule is required. It may, in some instances, not be advantageous to have a new schedule calculated and then acted upon, for example in the situation where almost all artefacts have been manufactured and the overall manufacturing process is near completion.

3.7 Activity Director

As with a Resource Monitor, an Activity Director exists for each machine within the manufacturing process. An Activity Director is responsible for directing the processes on the associated machine. This agent also facilitates the operational coordination of the processes and machines involved in the manufacturing process.

Each Activity Director must orchestrate the processes being performed on its associated machine. In particular, an Activity Director is responsible for instructing Task Managers to perform their associated process on a particular artefact on the associated machine in the appropriate order. A Task Manager will only be able to perform its associated process if permission is given by the Activity Director. Once the Task Manager receives this instruction it proceeds to perform the process on a given artefact. On completion it informs the Activity Director that it has finished. The Activity Director then proceeds to instruct the next Task Manager in the local schedule to perform its process for a particular artefact, and so on.

If, while a process is being performed, machine failure occurs, then the artefact being manufactured will only be partially complete. A mechanism exists that enables this artefact to be passed to a different machine such that the process can be completed. Since the Activity Director holds the artefact identification number currently being manufactured using a particular process, in the event of associated machine failure, it can proceed to take corrective action. The artefact being manufactured at the time of machine failure, and the artefacts next in the line of manufacture on the failed machine, will be included in the schedule now needing to be produced by the Scheduling Agent. This schedule is calculated once the Resource Monitor has informed the Resource Manager of the machine failure which in turn informs the Scheduling Agent to re-schedule. This new schedule is then communicated in the normal manner as described earlier.

4 MANUFACTURING PROCESS PROBLEM

The problem being considered involves a set of *p* processes being performed on a number of *m* machines in order to manufacture a numbers of *n* artefacts. Each process must be performed on an artefact in a particular sequence. That is, dependencies exist between processes.

In this example, 8 processes are performed in a particular order on each of 50 artefacts. Within the manufacturing environment 5 machines are available for use. At certain points in the manufacturing process events occur such that corrective action must be taken by the appropriate agents if the time to produce all of the artefacts is to be optimised. That is, the impact on delivery time must be minimised. The events occurring during the manufacturing process are as follows:

Event A: The manufacture of 50 artefacts commences. Information regarding the processes and machines is presented in the matrices defined in Table 1 and 2 respectively.

Event B: After 50% completion of the first schedule the efficiency of machines 2 and 4 drops to 0.85 and 0.7 respectively.

Event C: After 70% completion of the second schedule machine 3 fails.

Event D: The third schedule completes uninterrupted.

Event E: After the completion of the fourth schedule machine 1 fails and the efficiency of machine 4 increases to 1.

Event F: The fifth schedule completes uninterrupted.

Event G: After 40% completion of the sixth schedule machine 3 becomes available with an efficiency of 0.95.

Event H: The seventh schedule finishes uninterrupted leading to the manufacturing process and all 50 artefacts being completed.

Agents operating within the DCS facilitate the optimisation of the manufacturing process such that the delivery time of the artefacts is minimised.

5 WORKED EXAMPLE

As in any environment, one Coordination Manager, Resource Manager and Scheduling Agent operate within the DCS. Eight Information Managers and Task Managers are utilised, that is one for each process. Five machines are available, therefore there exists the same number of Resource Monitors and Activity Directors.

Event A

Once Event A occurs, all necessary agent introductions are facilitated by the Coordination Manager. The Resource Manager then constructs a process matrix and machine matrix as presented in Table 1 and Table 2 respectively.

Process	1	2	3	4	5	6	7	8
1	9	0	0	0	0	0	0	0
2	0	7	0	0	0	0	0	0
3	0	0	4	0	0	0	0	0
4	1	1	0	5	0	0	0	0
5	0	1	1	0	3	0	0	0
6	0	0	0	1	1	8	0	0
7	0	0	1	0	0	0	4	0
8	0	0	0	0	0	1	1	6

Table 1. Process Matrix

With respect to the process matrix, off-diagonal elements indicate whether or not a dependency exists between processes. These elements can be either 0 or 1 which represent the existence of a non-dependency and dependency respectively. Process durations, performed on a machine with an efficiency of 1, are shown along the diagonal. This process matrix is lower triangular which implies that no process iteration is involved. However, the Resource Manager can employ an ordering algorithm to deal with iteration if it were necessary.

Machine	Status	Efficiency
1	1	1
2	1	1
3	1	1
4	1	1
5	1	1

Table 2. Machine Matrix

The machine matrix holds information regarding the status and efficiency of each machine. A machine's status can be 0 or 1 representing unavailable and available for use respectively. A machine's efficiency can range from 0 to 1. In this example, prior to the manufacturing process commencing, all machines have been serviced resulting in an efficiency of 1 for all machines.

After constructing the matrices, the Resource Manager determines which scheduling policy to adopt for the problem under consideration. In this case, the Resource Manager decides that with 50 artefacts to be manufactured, batches of 10 artefacts at a time should be scheduled. This decision is based on experience that manufacturing comparable artefacts with such processes often leads to a decline in machine efficiency or even failure. Consequently a new schedule needs to be prepared reflecting these fluctuations. Scheduling all artefacts would be inefficient as it is unlikely that it will be adhered to throughout the manufacturing process. The Resource Manager instructs the Scheduling Agent to prepare a schedule for 10 artefacts based on the information contained within the matrices. The Scheduling Agent employs the MCGA to calculate a schedule and then informs each Activity Director of the order of processes to be performed, on their associated machine, with regard to the artefacts being manufactured. The schedule prepared states that all 5 machines must be utilised and the manufacture of the first 10 artefacts will take 97 units of time. As the manufacturing process starts, each Activity Director informs the appropriate Task Manager to commence performing the associated process on a certain artefact. Prior to the Task Manager starting the related process, it requests that its related Information Manager ensure that the required artefact is placed on the correct machine. Throughout the manufacturing process, each Task Manager and related Information Manager work cooperatively so as to ensure that the right artefact is placed on the right machine prior to the process being performed.

Event B

After 48 units of time have elapsed of the first schedule, the Resource Monitors for both machine 2 and 4 report to the Resource Manager that their efficiencies have reduced to 0.85 and 0.7 respectively. The Resource Manager instructs all Activity Directors to allow all Task Managers to complete the process that they are currently performing and then await further instruction. A further 6 time units elapse before the final Activity Director reports to the Resource Manager that the Task Manager has completed the current process on its associated machine, that is the Activity Director for machine 1 and the Task Manager associated with performing process 1 on artefact number 2. As a result of this schedule interruption, only 47 processes are performed of the 80 scheduled. During the period of time taken for each respective Task Manager to conclude their current process, the Resource Manager instructs the Scheduling Agent to prepare a new schedule. This new schedule should include all 33 outstanding processes on artefacts 1 to 10 in the abandoned schedule and the processes performed on artefacts 11 to 16 are included. That is, a total of 81 processes. The Scheduling Agent re-schedules and informs the appropriate Activity Directors. Activity then re-commences on each machine with respect to the current schedule.

Event C, D, E, F & G

The reaction to these events is essentially the same as that described for Event B. Following the occurrence of each event the appropriate Resource Monitor(s) inform the Resource Manager of the particular situation regarding its associated machine. A Resource Monitor communicates the fact that their associated machine has:

(i) had a change in efficiency,

(ii) had a change in status.

The Resource Manager then decides whether the changes that have been reported are significant enough to warrant a new schedule to be calculated. Within this example, all events cause the Resource Manager to decide that a new schedule must be prepared by the Scheduling Agent. Prior to instructing the Scheduling Agent to re-schedule, the Resource Manager informs all Activity Directors to instruct the Task Manager operating on their associated machines at that time to complete the process that they are currently performing. In the situation where machine failure has occurred this action will not be able to be taken by the associated Activity Director and Task Manager. However, it is recognised that the process that was being performed on a particular artefact when machine failure occurred needs to be included in the next schedule. In order to promote concurrency among agents, it is during the completion of current processes that the Resource Manager instructs the Scheduling Agent to re-schedule and the action is carried out. Once this has been done the Scheduling Agent informs each appropriate Activity Director of the new order of performing processes on certain artefacts on the associated machine. Activity Directors then resume the procedure of informing Task Managers to perform their process on a particular artefact. This process continues until either the schedule is completed without interruption, or, due to circumstances relating to machine efficiency or status, a decision is made to abandon the current schedule. In either case a schedule is produced which needs to be relayed to the appropriate agents so that the manufacturing process can continue.

Event H

Once the manufacturing process is complete and all artefacts have been produced, they are ready for the next steps in the procedure which may be quality inspection and then despatch to the customer.

During the process of determining the delivery date of a number of artefacts, based on experience and probabilities that machines efficiencies may fluctuate or even fail, an organisation may be able to simulate the time to perform the manufacturing process using this coordination mechanism. This would enable an organisation to accurately model and predict the behaviour of the manufacturing environment leading to declaring equally as accurate delivery dates.

6 RESULTS & DISCUSSION

Table 3 presents information obtained when the manufacturing process was modelled as described by Events A through to H. It can be seen that the manufacture of the 50 artefacts took 637 units of time. Due to the variability of machine efficiency and status throughout the manufacturing process, 7 schedules were required to ensure that the artefacts were produced in a near optimal time. The ability of the agents to react to the uncertain and variable nature of the manufacturing environment has enabled the artefacts to be produced in a near optimal time.

The comprehensive approach adopted exhibits all of the characteristics identified that facilitate effective coordination. Existing approaches identify scheduling as the sole means of effective coordination [9]. The approach described in this paper not only seeks near optimal scheduling but simultaneously ensures that the near optimal use is made of the available manufacturing resources [10].

Schedule (Event)	Number of Processes Scheduled	Predicted Time (units)	Number of Processes Completed	Actual Time (units)
1 (*A-B*)	80	97	47	54
2 (*B-C*)	81	108	62	81
3 (*C-D*)	83	135	83	135
4 (*D-E*)	80	126	80	126
5 (*E-F*)	80	159	80	159
6 (*F-G*)	48	95	18	38
7 (*G-H*)	30	44	30	44
			400	637

Table 3. Schedule Information

Coordination in manufacturing environments requires real-time control of all of the machine resources. An approach to coordination requires proper management of detailed information regarding the various tasks and processes [11]. Presently, a limitation of the approach described, and the system implemented, is the lack of information and data available for the purposes of coordination.

7 CONCLUSION

The DCS has enabled the time taken to perform the manufacturing process in order to produce a given number of artefacts to be optimised. Essentially, the optimisation achieved by the DCS is attributed to the dynamic coordination of the available resources which is facilitated by the agents. The DCS has ensured competitiveness as a result of significantly reducing the manufacturing process time.

It has been shown that the family of agents operating within the DCS can work cooperatively in a coordinated fashion with effective results. It is this ability of the agents to operate in a coordinated manner that permits the time to perform the manufacturing process to be reduced. Simply committing greater resources to the manufacturing process will not necessarily result in an appropriate reduction in the time to perform the processes involved. It is the capacity to coordinate the activity performed by each of the team members, taking into account the available resources and knowledge of their roles and effects, that enables the optimum manufacturing time to be achieved.

The results achieved have satisfied the objectives defined earlier in this paper. That is, it has been shown that utilising the agents within the DCS can result in the efficient organisation of processes leading to an optimum time taken to manufacture a number of artefacts. In addition, successful operation of the system in this environment has demonstrated the generic nature of the coordination approach employed within the DCS.

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