A review on Integrated Process Planning and Scheduling

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Abstract: Traditionally, process planning and scheduling for parts were carried out in a sequential way, where scheduling was done after process plans had been generated. Considering the fact that the two functions are usually complementary, it is necessary to integrate them more tightly so that performance of a manufacturing system can be improved greatly. In this paper, we present a review of the reported research in Integrated Process Planning and Scheduling (IPPS), discuss the extent of applicability of various approaches and suggest some future research trends.

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1 Introduction

Process planning and scheduling used to link product design and manufacturing are two of the most important functions in a manufacturing system. A process plan specifies what manufacturing resources and technical operations/routes are needed to produce a product (a job). The outcome of process planning includes the identification of machines, tools and fixtures suitable for a job, and the arrangement of operations and processes for the job. Typically, a job may have one or more alternative process plans. With the process plans of jobs as input, a scheduling task is to schedule the operations of all the jobs on machines while precedence relationships in the process plans are satisfied (Sugimura et al., 2001). Although there is a close relationship between process planning and scheduling, the integration of them is still a challenge in both research and applications.

Process planning and scheduling are two key techniques of the development of distributed and collaborative manufacturing (Wang and Shen, 2007). Although process planning can enhance productivity of manufacturing systems and scheduling can optimise process series, some researches showed that the separated process planning and scheduling systems could not improve the productivity of manufacturing system largely (Shobrys and White, 2000; Saygin and Kilic, 1999). In fact, IPPS can improve the productivity of the manufacturing system greatly.

The purpose of this paper is to review the research works on IPPS. Various integration models and implementation methods are surveyed and summarised. And then, some future research trends are identified and discussed. The remainder of this paper is organised as follows. Section 2 discusses the background of study. Section 3 reviews the IPPS. Some future research trends and conclusions are reported in Section 4.

2 Background of study

Process planning is the act of preparing detailed operation instructions to transform an engineering design to a final part. The output of the process planning contains the route, processes, process parameters, machines, tools and fixtures required for production (Tan and Khoshnevis, 2000). Scheduling can be defined as a process that allocates the operations to limited resources in time aspect to satisfy or optimise several criteria. Scheduling is not only the sequencing, but also the determining of the starting and completing time of each operation based on the sequence. In the manufacturing system, the scheduling is the production scheduling.

In the following sections, the authors will provide brief reviews on the research in the areas that are directly relevant to IPPS; they are process planning and production scheduling. We will also provide the problems in the traditional manufacturing system without IPPS.

2.1 Brief review of process planning

A process plan specifies what raw materials or components are needed to produce a product, and what processes and operations are necessary to transform those raw materials into the final product. It provides the information to the shop floor on how to produce the designed products (Tan and Khoshnevis, 2000). The outcome of process planning is the information required for manufacturing processes, including the identification of the machines, tools and fixtures. Since Niebel (1965) proposed the method that used computer to aid the selection of process, there have been numerous research efforts in the development of Computer-Aided Process Planning (CAPP) systems. Many systems and many implementation approaches have been reported. Some earlier works of the CAPP systems had been summarised in Zhang and Alting (1994). It had reported about 187 CAPP systems.

There are two traditional types of approach to CAPP: variant approach and generative approach (Zhang and Xie, 2007). The variant approach uses group technology to retrieve an existing plan for a similar part and makes the necessary modifications to the plan for the new part. This method is especially suitable for companies with few product families and a large number of parts per family. One of the main disadvantages of this method is that the quality of a process plan depends on the knowledge background of the process planners (Zhang and Xie, 2007). The generative approach is based on generating a plan for each part without referring to existing plans. It uses a more powerful software programme to develop a process plan based on the part geometry, the number of parts and information about facilities in the plant. Generative approach mostly meets the requirements of large companies and research organisations, especially those that have a number of different products but each product type is in small production batches. However, there are still difficulties in developing truly generative CAPP systems to meet industrial needs (Zhang and Xie, 2007). Most current CAPP systems use these two approaches.

2.2 Brief review of scheduling

Scheduling is the process to allocate the operations to time intervals on the machines. A scheduling problem can be classified into different types based on four parameters (Convay et al., 1967): job arrival patterns, number of machines in the shop, flow patterns in the shop and the criteria by which the schedule is to be evaluated. Among various scheduling types, job shop scheduling is one of the most important scheduling types. Job shop Scheduling Problem (JSP) can be defined as (French, 1982): given a set of *n* jobs, which are to be processed on *m* machines with defined technological constraints for each job, find a sequence in which jobs pass between machines such that it satisfies the technological constraints and it is optimal with respect to some performance criteria (Tan and Khoshnevis, 2000).

The JSP is one of the hardest combinatorial optimisation problems. It is widely acknowledged as one of the most difficult NP-complete problems (Garey et al., 1976).

JSP has been studied by a significant number of researchers. Many optimisation algorithms and approximation algorithms have been proposed. The optimisation algorithms, which are mainly based on the brand and bound scheme such as Carlier and Pinson (1989), and Brucker et al. (1994), have been successfully applied in solving small instances. However, they could not solve instances larger than 250 operations in a reasonable time. On the other hand, approximation algorithms, which include priority dispatch, shifting bottleneck approach, meta-heuristic methods and so on, provide quite good alternatives for the JSP. Approximation algorithms were first developed on the basis of dispatching rules, which were very fast, but the quality of solutions that they provided usually leaves plenty of room for improvement. A more elaborate algorithm, which could produce considerably better approximations at a higher computational cost, is the shifting bottleneck approach proposed by Adams et al. (1988). More recently, the meta-heuristic methods, such as Genetic Algorithm (GA) (Croce et al., 1995), Simulated Annealing (SA) (Van et al., 1992) and Tabu Search (TS) (Taillard, 1994; Nowicki and Smutnicki, 1996; Zhang et al., 2007, 2008), could provide the high-quality solutions with reasonable computing time and have captured the attention of many researchers. The relevant researches had been summarised in Vaessens et al. (1996), Blazewicz et al. (1996), and Jain and Meeran (1999).

2.3 Statement of problems

In traditional approaches, process planning and scheduling were carried out in a sequential way. Scheduling was conducted after the process plan had been generated. These approaches have become an obstacle to improve the productivity and responsiveness of manufacturing systems and to cause the following problems (Kumar and Rajotia, 2002, 2003):

1 In manufacturing practice, process planner plans jobs individually. For each job, manufacturing resources on the shop floor are usually assigned on it without considering the competition for the resources from other jobs (Usher and Fernandes, 1996). This may lead to the process planners favouring to select the desirable machines for each job repeatedly. Therefore, the generated process plans are somewhat unrealistic and cannot be readily executed on the shop floor for a group of jobs (Lee and Kim, 2001). Accordingly, the resulting optimal process plans often become infeasible when they are carried out in practice at the later stage.

2 Scheduling plans are often determined after process plans. Fixed process plans may drive scheduling plans to end up with severely unbalanced resource load and create superfluous bottlenecks.

3 Even though process planners consider the restriction of the current resources on the shop floor, the constraints in the process-planning phase may have already changed owing to the time delay between the planning phase and execution phase. This may lead to the infeasibility of the optimised process plan (Kuhnle et al., 1994). Investigations have shown that 20–30% of the total production plans in a given period have to be modified to adapt to the dynamic change in a production environment (Kumar and Rajotia, 2003).

4 In most cases, both for process planning and scheduling, a single criterion optimisation technique is used for determining the best solution. However, the real production environment is best represented by considering more than one criterion simultaneously (Kumar and Rajotia, 2003). Furthermore, the process planning and scheduling may have conflicting objectives. Process planning emphasises the technological requirements of a job, while scheduling involves the timing aspects and resource sharing of all jobs. If there is no appropriate coordination, it may create conflicting problems.

To overcome these problems, there is an increasing need for deep research and application of IPPS system. The IPPS introduces significant improvements to the efficiency of manufacturing resources through eliminating or reducing scheduling conflicts, reducing flow-time and work-in-process, improving production resources utilising and adapting to irregular shop floor disturbances (Lee and Kim, 2001). Through the integration of these two systems, IPPS can provide better process plans and schedules than the traditional manufacturing systems to improve the productivity of the manufacturing system greatly. In the following section, the review on the research of IPPS is presented.

3 Review on Integrated Process Planning and Scheduling

The IPPS can be defined as: give a set of n parts, which are to be processed on m machines with alternative process plans, manufacturing resources and other technological constraints, select suitable process plan and manufacturing resources and sequence the operations so as to determine a schedule in which the technological constraints among operations can be satisfied and the corresponding objectives can be achieved (Guo et al., 2009). In the following sections, the authors will provide the research on IPPS.

3.1 IPPS in support of distributed and collaborative manufacturing

In the 21st century, to win the competition in a dynamic marketplace, which demands short response time to changing markets and agility in production, the manufacturers need to change their manufacturing system from centralised environment to a distributed environment (Wang and Shen, 2007). In this case, owing to recent business decentralisation and manufacturing outsourcing, the distributed and collaborative manufacturing is very important for the manufacturing companies.

In the distributed manufacturing system, there are many unpredictable issues like job delay, urgent-order insertion, fixture shortage, missing tool, and even machine breakdown, which are challenging manufacturing companies. And, engineers often demand adaptive planning and scheduling capability in dealing with daily operations in a distributed manufacturing environment (Wang and Shen, 2007). Process planning and scheduling are two of the most important sub-systems in distributed manufacturing systems. To overcome the above-mentioned uncertain issues in distributed manufacturing system, the development of process planning and scheduling is very important. Many researches have focused on process planning and scheduling to improve flexibility, dynamism, adaptability, agility and productivity of distributed manufacturing system (Wang and Shen, 2007).

While process planning and scheduling are crucial in distributed manufacturing, their integration is also very important (Wang, 2009). Without the IPPS, a true Computer-Integrated Manufacturing System (CIMS), which strives to integrate the various phases of manufacturing in a single comprehensive system, may not be effectively realised. And, IPPS can also improve the flexibility, adaptability, agility and global optimisation of the distributed and collaborative manufacturing. Therefore, the research on IPPS is necessary. And, it can well support the distributed and collaborative manufacturing system.

3.2 Integration models of IPPS

In the early studies of CIMS, it has been identified that IPPS is very important to the development of CIMS (Tan and Khoshnevis, 2000; Kumar and Rajotia, 2005). The preliminary idea of IPPS was first introduced by Chryssolouris et al. (1984), and Chryssolouris and Chan (1985). Beckendorff et al. (1991) used alternative process plans to improve the flexibility of manufacturing systems. Khoshnevis and Chen (1989) introduced the concept of dynamic feedback into the IPPS. The integration model proposed by Zhang (1993) and Larsen (1993) extended the concepts of alternative process plans and dynamic feedback and defined an expression to the methodology of hierarchical approach. Some earlier works of the integration strategy had been summarised in Tan and Khoshnevis (2000), and Wang et al. (2006). In recent years, in the area of IPPS, some integration models have been reported and several implementation approaches have been employed.

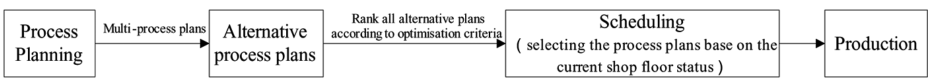
Many models of IPPS have been proposed, and they can be classified into three basic models based on IPPS: Non-linear Process Planning (NLPP) (Beckendorff et al., 1991), Closed-Loop Process Planning (CLPP) (Khoshnevis and Chen, 1989) and Distributed Process Planning (DPP) (Zhang, 1993; Larsen, 1993).

3.2.1 Non-linear Process Planning

The methodology of NLPP is to make all alternative process plans for each part with a rank according to process-planning optimisation criteria. The plan with highest priority is always ready for submission when the job is required. If the first-priority plan is not suitable for the current shop floor status, the second-priority plan will be provided to the scheduling system.

NLPP can also be called as flexible process-planning, multi-process planning or alternative process planning. The basic flow chart of NLPP is shown in Figure 1. On the basis of the basic flow chart of NLPP, the process planning system and scheduling system are separate. NLPP only uses alternative process plans to enhance the flexibility of the manufacturing system.

Figure 1 The basic flow chart of NLPP

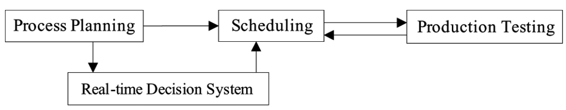


NLPP is the most basic model of IPPS. Because the integration methodology of this model is very simple, most of the current research works on the integration model focus on the improvement and implementation of this model. Jablonski et al. (1990) described the concept and prototype implementation of a flexible integrated production planning and scheduling system. Kim et al. (1997) gave a scheduling system, which was supported by flexible process plans and based on negotiation. Kim and Egbelu (1998) formulated a mixed-integer programming model for job shop scheduling with multiple process plans. Kim and Egbelu (1999) developed a mixed-integer programming model for job shop scheduling with multiple process plans, and proposed two algorithms to solve this problem. Saygin and Kilic (1999) presented a framework that integrated flexible process plans with off-line scheduling in flexible manufacturing system. And, it also proposed an approach, namely the dissimilarity maximisation method, for selecting the appropriate process plans for a part mix where parts had alternative process plans. Lee and Kim (2001) presented the NLPP model based on the GA. Thomalla (2001) investigated an optimisation methodology for scheduling jobs with alternative process plans in a just-in-time environment. Yang et al. (2001) presented a prototype of a feature-based multiple alternative process planning system. Gan and Lee (2002) described a process-planning and scheduling system that makes use of the branch and bound approach to optimise priority weighted earliness of jobs scheduled in a mould manufacturing shop. Kim et al. (2003) used a symbiotic evolutionary algorithm for IPPS. Kis (2003) developed two heuristic algorithms for the JSP with alternative process plans: a TS and a GA. Jain et al. (2006) proposed a scheme for IPPS that could be implemented in a company with existing process planning and scheduling departments when multiple process plans for each part type were available. Li and McMahon (2007) used an SA-based approach for IPPS. Shao et al. (2009) used a modified GA to solve this problem. However, through a number of experimental computations, Usher (2003) concluded that the advantages gained by increasing the number of alternative process plans for a scheduling system diminishes rapidly when the number of the plans reaches a certain level. The computational efficiency needs to be improved when applying to a complex system with a large number of alternative solutions.

3.2.2 Closed-Loop Process Planning

The methodology of CLPP is using a dynamic process-planning system with a feedback mechanism. CLPP can be used to generate real-time process plans by means of a dynamic feedback from production scheduling system. The process-planning mechanism generates process plans based on available resources. Production scheduling provides the information about which machines are available on the shop floor for an incoming job to process planning, so that every plan is feasible and respects to the current availability of production facilities. This dynamic simulation system can enhance the real-time, intuition and manipulability of process-planning system and also enhance the utilisation of alternative process plans. CLPP can also be called as dynamic process planning or online process planning. The basic flow chart of CLPP is shown in Figure 2.

Figure 2 The basic flow chart of CLPP

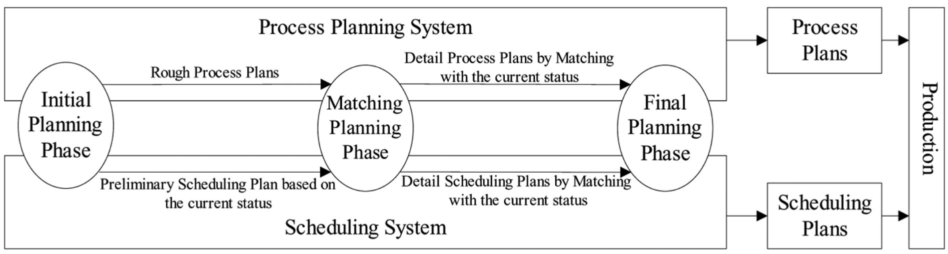


CLPP can bring the IPPS to a real integration system very well. Khoshnevis and Chen (1990) developed an automated planning environment to treat the process planning and scheduling as a unified whole. This method could use time window to control the planning quantity in every stage. Usher and Fernandes (1996) divided the dynamic process planning to the static phase and the dynamic phase. Baker and Maropoulos (2000) defined architecture to enable the vertical integration of tooling considerations from early design to process planning and scheduling. The architecture was based on a five-level tool selection procedure, which was mapped to a time-phased aggregate, management and detailed process-planning framework. Seethaler and Yellowley (2000) presented a dynamic process-planning system, which could give the process plans based on the feedback of scheduling system. Wang et al. (2002) and Zhang et al. (2003a) introduced a dynamic facilitating mechanism for IPPS in a batch manufacturing environment. Kumar and Rajotia (2003) introduced a method of scheduling and its integration with CAPP, so that online process plan could be generated taking into account the availability of machines and alternative routes. Wang et al. (2004) introduced a kind of dynamic CAPP system integration model and used the Back Propagation (BP)-based neural network and relevant algorithm to make machine decision. And, the process plans from this dynamic CAPP system could accord with the production situation and the requirements of the job shop scheduling.

3.2.3 Distributed Process Planning

The methodology of DPP uses concurrent engineering approach to perform both the process planning and the scheduling simultaneously. It divides the process planning and scheduling tasks into two phases. The first phase is the initial planning phase. In this phase, the characteristics of parts and the relationship between the parts are analysed. And, the primary process plans and scheduling plan are determined. The process resources are also evaluated simultaneously. The second phase is the detailed planning phase. It has been divided into two phases: the matching planning phase and the final planning phase. In this phase, the process plans are adjusted to the current status of shop floor. The detailed process plans and scheduling plans are obtained simultaneously. DPP can also be called as just-in-time process planning, concurrent process planning, or collaborative process planning. The basic flow chart of DPP is shown in Figure 3.

Figure 3 The basic flow chart of DPP



Brandimarte and Calderini (1995) proposed a two-phase hierarchical method to integrate these two systems together. In the first phase, a relaxed version of the problem was solved, yielding an approximation of the set of efficient process plans with respect to cost and load-balancing objectives. Each process plan was then considered and the corresponding scheduling problem was solved by TS, and the process plan selection was improved by a two-level hierarchical TS algorithm. Kempenaers et al. (1996) demonstrated three modules of the collaborative process-planning system. Sadeh et al. (1998) described an Integrated Process Planning/Production Scheduling (IP3S) system for agile manufacturing. And, IP3S was based on a blackboard architecture that supported concurrent development and dynamic revision of IP3S solutions along with powerful workflow management functionalities for 'what–if' development and maintenance of multiple problem assumptions and associated solutions. Wu et al. (2002) gave the integration model of IPPS in the distributed virtual manufacturing environment. Zhang et al. (2003b) presented the framework of concurrent process planning based on Holon. Wang and Shen (2003) proposed a methodology of DPP, and used multi-agent negotiation and cooperation to construct the architecture of the new process-planning method. And, this paper also focused on the supporting technologies such as machining-feature-based planning and function-block-based control. Wang et al. (2005) presented the framework of collaborative process-planning system supported by a real-time monitoring system. Sugimura et al. (2006) developed an IPPS and applied it to the holonic manufacturing systems. Li et al. (2008a) used game-theory-based approach to solve IPPS.

3.2.4 Comparison of integration models

Every model has its advantages and disadvantages. A comparison among integration models is given in Table 1.

Table 1 Comparison of integration models

	Advantages	*Disadvantages*
NLPP	Providing all the alternative process plans of, and enhancing the flexibility and the availability of process plans	Because of the need to give all alternative process plans of the parts, this will cause a combinational-explosive problem
CLPP	Based on the current shop floor status, the process plans are all very useful	CLPP needs the real-time data of the current status, if it has to re-generate process plans in every scheduling phase, the real-time data is hard to be assured and updated
DPP	This model works in an interactive, collaborative, and cooperative way	Because the basic integration principle of DPP is a hierarchical approach, it cannot optimise the process plans and scheduling plans as a whole

3.3 Implementation approaches of IPPS

Various Artificial Intelligence (AI)-based approaches have been developed to solve IPPS. The following sections will discuss several typical methods: they are agent-based approaches, petri-net-based approaches and optimisation-algorithm-based approaches. The critique of the current approaches is also given.

3.3.1 Agent-based approaches of IPPS

The concept of an agent came from the research of AI (Zhang and Xie, 2007). A typical definition of an agent is given by Nwana and Ndumu (1997) as: "An agent is defined as referring to a component of software and/or hardware which is capable of acting exactly in order to accomplish tasks on behalf of its user". On the basis of the definition, one conclusion is that an agent is a software system that communicates and cooperates with other software systems to solve a complex problem that is beyond the capability of each individual software system (Wang et al., 2006). Therefore, the agent-based approach has been considered as one important method for studying distributed intelligent manufacturing systems. In the area of IPPS, the agent-based approach has captured the interest of a number of researchers.

Shen et al. (2006) reviewed the research on manufacturing process planning, scheduling as well as their integration. Wang et al. (2006) provided a literature review on the IPPS, particularly on the agent-based approaches for the problem. The advantages of the agent-based approach for scheduling were discussed. Zhang and Xie (2007) reviewed the agent technology for collaborative process planning. The focus of this research was on how the agent technology can be further developed in support of collaborative process planning as well as its future research issues and directions in process planning.

Gu et al. (1997) proposed a Multi-Agent System (MAS) where process routes and schedules of a part were accomplished through the contract net bids. IDCPPS (Chan et al., 2001) was an integrated, distributed and cooperative process-planning system. The process-planning tasks were separated into three levels, namely initial planning, decision-making and detail planning. The results of these three steps were general process plans, a ranked list of near-optimal alternative plans and the final detailed linear process plans, respectively. The integration with scheduling was considered at each stage with process planning. Wu et al. (2002) presented a computerised model that can integrate the manufacturing functions and resolve some of the critical problems in distributed virtual manufacturing. This integration model was realised through a multi-agent approach that provided a practical approach for software integration in a distributed environment.

Lim and Zhang (2003, 2004) introduced a multi-agent-based framework for IPPS. This framework could also be used to optimise the utilisation of manufacturing resources dynamically as well as provide a platform on which alternative configurations of manufacturing systems could be assessed. Denkena et al. (2003) developed an MAS-based approach to study the IPPS in collaborative manufacturing. Wang and Shen (2003) proposed a new methodology of DPP. It focused on the architecture of the new approach, using multi-agent negotiation and cooperation, and on the other supporting technologies such as machining-feature-based planning and function-block-based control. Wong et al. (2006a, 2006b) developed an online hybrid-agent-based negotiation MAS for integrated process planning with scheduling/rescheduling. With the introduction of the supervisory control into the decentralised negotiations, this approach was able to provide solutions with a better global performance. Shukla et al. (2008) presented a bidding-based MAS for IPPS. The proposed architecture consisted of various autonomous agents capable of communicating (bidding) with each other and making decisions based on their knowledge. Fuji et al. (2008) proposed a new method in IPPS. A multi-agent-learning-based integration method was devised in the study to solve the conflict between the optimality of the process plan and the production schedule. In the method, each machine made decisions about process planning and scheduling simultaneously, and it had been modelled as a learning agent using evolutionary artificial neural networks to realise proper decisions resulting from interactions between other machines. Nejad et al. (2008) proposed an agent-based architecture of an IPPS system for multi-jobs in flexible manufacturing systems.

In the literature of agent-based manufacturing applications, many researches applied with simple algorithms such as dispatching rules are applicable for real-time decision-making (Shen et al., 2006). These methods are simple and applicable, but they do not guarantee the effectiveness for complex problem in the manufacturing systems. As the efficiency become important in the agent-based manufacturing, the recent research works are trying to combine the agent-based approach with other techniques such as GA, neural network and some mathematical modelling methods (Shen et al., 2006). Therefore, one future research trend is presenting more effective algorithms to improve the effectiveness of agent-based approaches.

On the basis of the above-mentioned comments, one conclusion can be made that the agent-based approach is an effective method to solve IPPS. Because single-agent environments cannot solve the problem effectively, MAS is more suitable to solve it (Zhang and Xie, 2007). Although the architecture and the negotiation among agents may be very complex, MAS will have a promising future in solving this problem (Shen et al., 2006; Wong et al., 2006a; Zhang and Xie, 2007).

3.3.2 Petri-net-based approaches of IPPS

Petri-net is a mathematical description of the discrete and parallel system. It is suitable to describe the asynchronous and concurrent computer system. Petri-net has the strict mathematical formulation, and it also has intuitive graphical expression. Petri-net has been widely used in the Flexible Production Scheduling System (FPSS). It also can be used in the IPPS: first, the flexible process plans are described by the Petri-net, second, we communicate it with the Petri-net of the dynamic scheduling system, and then we can integrate the process-planning system and scheduling system together by Petri-net. Kis et al. (2000) proposed the integration model of IPPS based on the multi-level Petri-net and analysed it.

3.3.3 Algorithm-based approaches of IPPS

The basic steps of the algorithm-based approach are as follows. First, process-planning system is used to generate the alternative process plans for all jobs and select user-defined number optimal plans based on the simulation results. Then, the algorithm in the scheduling system is used to simulate scheduling plans based on the alternative process plans for all jobs. Finally, based on the simulation results, the process plan of each job and the scheduling plan are determined. This approach is workable. However, the biggest shortcoming is that the simulation time may be long and the approach cannot be used in the real manufacturing system. Therefore, one important future research trend is finding effective algorithm for IPPS and developing effective system. In this approach, the most researches focused on the evolutionary algorithm. Swarm intelligence, some other meta-heuristic methods, such as SA, TS and Artificial Immune System (AIS), and some hybrid algorithms were also used to solve IPPS.

Morad and Zalzala (1999) described a GA-based algorithm that only considered the time aspect of the alternative machines, and then they extended this scope to include the processing capabilities of alternative machines, different tolerance limits and process costs. Lee and Kim (2001) presented the NLPP model, which was based on a GA. Moon et al. (2002) proposed an IPPS model for the multi-plants supply chain, which behaved like a single company through strong coordination and cooperation towards mutual goals. And, then they developed a GA-based heuristic approach to solve this model. Kim et al. (2003) used a symbiotic evolutionary algorithm for IPPS. Zhao et al. (2004) used a fuzzy inference system to select alternative machines for IPPS, and used a GA to balance the load of every machine. Moon and Seo (2005) proposed an advanced process planning and scheduling model for the multi-plant, and used an evolutionary algorithm to solve this model. Chan et al. (2005, 2008) proposed a GA with dominant genes to solve distributed scheduling problems. Park and Choi (2006) designed a GA-based method to solve IPPS by taking advantage of the flexibility that alternative process plans offer. Choi and Park (2006) designed a GA-based method to solve IPPS. Moon et al. (2008) first developed mixed-integer linear programming formulations for IPPS based on NLPP model. And, then they used a GA to solve this model. Li et al. (2008b) presented a GA-based approach to solve this problem. Shao et al. (2009) proposed a modified GA-based approach to solve IPPS based on NLPP model.

Rossi and Dini (2007) proposed an ant-colony-optimisation-based software system for solving FMS scheduling in a job shop environment with routing flexibility, sequence-dependent set-up and transportation time. Guo et al. (2009) developed the IPPS as a combinatorial optimisation model, and modified a Particle Swarm Optimisation (PSO) algorithm to solve IPPS. Yang et al. (2005) and Zhao et al. (2006a, 2006b) used a fuzzy inference system to choose alternative machines for IPPS of a job shop manufacturing system, and used the hybrid PSO algorithms to balance the load of each machine.

Palmer (1996) proposed an SA-based approach to solve IPPS. Chen (2003) used an SA algorithm to solve IPPS in mass customisation. Li and McMahon (2007) used an SA-based approach for IPPS. Chan et al. (2009) proposed an Enhanced Swift Converging Simulated Annealing (ESCSA) to solve IPPS. Weintraub et al. (1999) presented a procedure for scheduling jobs with alternative processes in a general job shop, and then proposed a TS-based scheduling algorithm to solve it. Chan et al. (2006) proposed an AIS-based AIS-FLC algorithm embedded with the Fuzzy Logic Controller (FLC) to solve the complex IPPS.

Some other methods, such as heuristic dispatching rules (Gindy et al., 1999), neural network (Ueda et al., 2007), object-oriented integration approach (Zhang and Zhang, 1999; Bang, 2002) and web-based approach (Wang et al., 2008), have also been proposed to do the research on IPPS.

3.3.4 Critique of current implementation approaches

For the above-mentioned three implementation approaches of IPPS, the first and the second methods (agent-based approach and petri-net) are used to model the integration system. And, the third one (algorithm-based approach) is used to optimise the integration system.

Agent-based approach is a good method to solve IPPS. However, when the number of the agents is large, agents will spend more time processing message than doing actual work, and it is often difficult to apply the generic agent architectures directly to IPPS systems (Zhang and Xie, 2007). Therefore, one future research trend is proposing simpler, more effective and workable MAS approach for IPPS applications. The petri-net has been used in the FPSS. If the flexible process plans can be denoted by petri-net and linked with the petri-net for FPSS, the petri-net for IPPS can be well implemented. Therefore, the key technique of petri-net for IPPS is how to denote the flexible process plans by petri-net. This is another future research trend for the modelling of IPPS.

The algorithm-based approach is workable, but the biggest shortcoming of this approach is that the simulation time may be long and it cannot be used in the real manufacturing system. Therefore, one important future research trend is researching and finding effective algorithm for IPPS and developing effective system.

4 Future research trends and conclusions

Although various integration models and implementation approaches have been proposed and several researchers have examined many aspects of IPPS, there are still many questions, which have to be answered. For example, how to eliminate the disadvantages of each integration model? The current optimisation algorithms are still some traditional algorithms, are there some new and more efficient algorithms? If yes, how to develop these algorithms for the IPPS? How to develop the real IPPS system for the manufacturing system? These and many other questions, if properly addressed, may lead to significant progress in the study of IPPS, and can improve the productivity of the manufacturing system greatly. Combining with the existing research results, future studies can be carried out in the following aspects:

1 Integration model of IPPS

The current integration models have their own advantages and disadvantages. One future research trend is integrating these models together to exploit their advantages and eliminate their disadvantages. We can use the simulation techniques to propose better and more practical integration models.

2 IPPS with set-up and transportation time

IPPS with set-up and transportation time is more practical. Most current researches ignore the impact of set-up and transportation time. However, in the modern business environment, the customs need the products with small batches and multi-type. In this case, the set-up and transportation time cannot be ignored. Therefore, the research on IPPS with set-up and transportation time is very important.

3 IPPS with orders' due dates

Most existing approaches used makespan as their objective and did not consider the orders' due dates. However, the models that consider the orders' due dates are more in line with the requirements of the modern business environment. And, this has not been very well studied. Therefore, one future research trend is proposing the integration models with the orders' due dates and developing effective algorithms to solve them.

4 Multi-objective IPPS

The manufacturing system cannot require only one criterion. Therefore, the IPPS is a multi-objective problem. Some other evaluation criteria except makespan, such as total processing cost, total weighted tardiness, lateness, earliness and the weighted number of tardy jobs, which are also of practical interest and importance, have not been very well studied. Therefore, another important future research trend is the research on the multi-objective IPPS.

5 Dynamic IPPS

To cope with the competitiveness and globalisation of the modern business environment, the products have to be manufactured in more types and smaller batches. In this case, supply chains and manufacturing systems become more complex and production processes are required to have more flexibility and sensitive. Therefore, it is essential to find effective and efficient process plans and schedules to cope with the highly dynamic manufacturing requirements. Therefore, the dynamic IPPS is a very important future research trend.

6 Hybrid algorithm for IPPS

Every optimisation algorithm has its own advantages and disadvantages. Only one algorithm cannot solve the IPPS effectively. For example, GA has very good global search ability, but it lacks the good local search ability. Some local search methods, such as TS, SA and variable neighbourhood search, do not have very good global search ability, but they have very good local search ability. Therefore, only using one of them cannot obtain very high quality results. In this case, one good future research trend is developing hybrid algorithm to solve IPPS. The hybrid algorithm combines the merits of several different algorithms to solve IPPS more efficiently and effectively, both in the reduction of solution time and the improvement of solution quality. The study of hybrid algorithm on JSP has succeeded. This shows that the hybrid algorithm for IPPS can be a good and feasible future research trend.

This paper has reviewed the recent developments in the area of IPPS, and pointed out some future research trends in this area. The review may not provide a complete survey of literature in this area. However, it has presented some representative integration models and implementation methods.

Although IPPS is a hard work, its research is necessary. IPPS is very important because it impacts the ability of manufacturers to meet customers' demands and make a profit. It also impacts the ability of manufacturing systems to optimise their operations. And, the research on IPPS is not enough. Many models and methods can be proposed in this area. For these reasons, the researchers and engineers will continue to do the further and deeper study on IPPS.

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