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Methodology – A Review of Intelligent Manufacturing: Scope, Strategy and Simulation

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Abstract. This paper presents a critical review of some existing modelling, control and optimization techniques for energy saving, carbon emission reduction in manufacturing processes. The study on various production issues reveals different levels of intelligent manufacturing approaches. Then methods and strategies to tackle the sustainability issues in manufacturing are summarized. Modelling tools such as discrete (dynamic) event system (DES/DEDS) and agent-based modelling/simulation (ABS) approaches are reviewed from the production planning and control prospective. These approaches will provide some guidelines for the development of advanced factory modelling, resource flow analysis and assisting the identification of improvement potentials, in order to achieve more sustainable manufacturing.

Keywords: Intelligent Manufacturing, Production Planning, Scheduling, Agent-based modelling, Discrete Event System.

1 Introduction

The manufacturing sector in industry, has a nonnegligible environmental impact coupled with the production process. In the manufacturing factory, materials and significant amounts of energy are consumed and only a part of them are renewable which impose considerable stress upon the earth. Some manufacturing activities release hazards solid, liquid and gaseous waste streams that leads to detrimental impact on to the environment.

There are increasing causes for the current manufacturing system [1]: environmental concerns, diminishing non-renewable resources, stricter legislations and inflated energy costs, and increasing consumer preference for environmentally friendly products, etc. The concept "sustainability" is gradually received more attentions from innovative industry. Efforts to develop a manufacturing system meeting the sustainable criteria have to make considerations of multi-level from product, process and of the whole factory system. Isolated approach cannot succeed in the sustainable upgradation.

The three pillars of sustainable development include environmental, economic and social aspects [2]. Efforts along the tree pillars should be synthesized for a more energy efficient and environment benign manufacturing. To meet the more stringent standards, proactive green behaviour such as conservation of energy, water, materials, reduction and recycle of the wasted energy and material treatment are extensively developed in recent years.

There are opportunities widely existing for efficient energy usage and improved material utilization in the manufacturing sectors to a resource efficient production. We can use efficiency and effectiveness to evaluate the energy and materials resource used in manufacturing cycle [3]. The definition of efficiency is about the amount of resources used to produce a required amount of product in which the efficiency index should be minimized as much as possible. We would like to use less resource to finish certain amount of output. However, the word "effectiveness" is defined by whether the resources are effectively used. In [4] the author name efficiency as "doing the things right", and describe effectiveness as "doing the right things".

Previous researchers have posed extensive works on makespan optimization and the minimization of makespan has been widely studied as the main objectives to improve production efficiency. In terms of green or energy-aware manufacturing, more attention should be paid in the sector to consideration of non-renewable resource consumption in the product life-cycle. In the [2], the authors focus on "sustainable manufacturing operations scheduling" approach and make summary on key challenges and research trends in the proposed area. These emerging challenges are high energy intensity machining, unsustainability and only partial consideration in control of the industrial operation.

The increasing complexity of the manufacturing environment makes it difficult to find easy solutions to modern energy/environment-oriented upgrading. Operations in widespread industrial manufacturing systems can be viewed as a discrete set [5] which provides the opportunity to implement complex scheduling and control method on the system. Successful simulation of the process modules, evaluation and visualization is one of the keys for enhancing the of strategic and operational management of the production planning and control. This survey discusses a broad manufacturing issues and challenges associated with energy and resources conservation techniques.

The remainder of the paper is organized as follows.

- Section 2 discusses the scope for energy/material managing improvement inside a single factory where solutions, possible techniques and strategies are reviewed for facilitating a more energy and resource efficient manufacturing. Structured approaches are used to distinguish the difference between different system levels.
- Section 3 focuses on manufacturing operation scheduling problems concerning typical objectives can be concerned in manufacturing operations and multi-objective optimization-based scheduling for production lines.
- Section 4 reviews two important modelling techniques for the support of production simulation. The discrete event system and agent-based modelling, and their capabilities for operation planning, process resource modelling and flexible system-based simulation.

2 The scope of intelligent manufacturing systems

Manufacturing activities are complex that can be discomposed into multiple scopes of production levels [3]. The lower level starts from single machine where unit processes is conducted within a small region, and then to a wider scope contains multiple devices forming a process chain. When comprising all the production line within the factory to deliver the final products, all of the activities can be considered in a holistic view through which production planning and control regarding all of the sustainable potentials can be achieved. In the context of this section we only distinguish three levels of activities: one single machine/unit process, multi-machine/process chain system, and the whole factory level. Manufacturing types can be broadly separated into process and discrete where process manufactures using batch or continuous operation; discrete manufactures parts and assembling products in sequential steps. The difference in the production type leads to different scheduling problems. Nevertheless, both types will be examined below in term of green manufacturing.

2.1 Unit process/machine level

Each single machine in a process can be treated as a subsystem in a process. Successful auditing and identification, determination of energy and material consumption at each unit is one of the key to facilitate a detailed in-depth and more complete understanding in ways to improve sustainability in manufacturing.

Operations adopted on a single machine such as machining tools allocation in the discrete manufacturing and production planning to unit machine for better duty control are part of the approaches. Other solutions include all machines and the whole production are allocated near the nominal capacity level, the parameter settings are set at the optimum, and the machines and processes are optimally controlled, and thus the energy consumption is minimized.

2.1.1 Energy and material flow auditing

At this level, to identify how a single process unit consumes energy and material is the first step towards transparency. This energy/material auditing on each machine provides a fundamental reference for researchers and practitioners to identify any critical problem in the system.

Not only the consumption of energy and resources, but also the waste/emission generation during the production process should be identified to each process unit. Inspired by Abele at al. [6], the energy consumption can be separated into essential energy requirement of the normal production process, the extra energy demands of processing and peripheral demand in product development. Auditing one or series of production units requires to calculate the cost of energy, losses of materials and to identify improvable process variable. [7] Proposed a more instructive approach about different aspects can be analysed in the input/output details. The time, power consumption, consumable and emission studies are analysed thoroughly. After acquiring detailed description of each process to a data inventory, statistical study of these industrial measurements results will assist understanding behaviours in the process for better management.

2.1.2 Strategies for minimizing energy and resource consumption

At this level, strategies for minimizing energy/resource consumption need to be considered firstly to reduce environmental impact. Fundamentally, most production device can be improved from a better efficiency design, while for a machine at a fixed production line, to optimize the process parameters, and its working duty can be considered as energy/resource demand reduction methods.

Re-design and structural improvement of process unit

Once the most energy intensive machines or processes are identified and audited, significant improvement of efficiency can be achieved by using more efficient components, and re-designing towards more energy efficient tools [8]. Instead of redesigning of current machine and process, the new technologies transplant on existing production line can guarantee improvement. For instance, it is reported that updating the conventional laser source with new technology in the forming industry can lead to 18% increase of efficiency [9].

Energy and resource efficiency of a single process can be improved by recovery of energy (heat, kinetic) and materials within a machine. [10] developed a method to recycled the powder materials in a polymer laser sintering process. [11] investigated kinetic energy recovery system to improve energy efficiency of high-speed cutting process up to 25%. This kind of strategies can be implemented at different levels which will be discussed in the following subsections. Peripherals like compressed air, heated air, cooling air and lubrication etc. are consumables supplied locally or centrally to each machine. The energy of compressed air can be paid back and recovered at the machine level [12].

Process control and optimization methods

The aforementioned methods in fact change the inherent structure of the process unit though effective, may not be cost effective or may need significant investment. New control methods are however relatively easy to implement on the existing production line. Machine duty can be flexible controlled and the process parameters can be relatively easily optimized.

Controlling the load condition of machines is a straightforward approach to reduce the energy cost where the most convenient way is to shut down machines that are not used. Machines usually have several operating such as heavy duty, nominal duty, light duty, idle and stand-by mode when turned on. Therefore, to minimize the overload and idle time during a manufacturing process will save energy. In [13] the author used a self-learning solution to control the process of a production line system to have a reduced time and efforts. For the process with fixed power level, the energy waste is significant at a non-loaded mode. There is a need for the optimal production plan which uses the nominal capacity of each equipment.

For the process units, the setting parameters are always related to resource consumption. [14] examined the parameter settings for cutting conditions and acceleration control to achieve a reduced power consumption in machine tool operation. Process control, in some cases, can maintain or even improve the quality with less energy cost. For instance, [15] optimized the process parameters of a paper machine's dryer section to reduce the steam consumption in the multi-cylinder dryer and to decrease the loads of centrifugal blowers.

In most industrial processes the process units are interconnected and system level optimization with multi-objective control methods. [16] analysed the historical process data in a paper mill and proposed a multi-objective energy optimization method. They were able to reduce the thermal energy consumption by changing vacuum pressure at an upstream subsystem and optimized the stream usage.

2.2 Production line/multi-machine level

2.2.1 Resource recycle and reuse

The optimization of a single machine has limited effect on the reduction of energy and resource consumption, and practical industrial processes are often complex with multiple process units. Production plan or control wide control exhibit specific energy consumption characteristics. When multi-machine or even a process chain in the factory is involved, problems of interactions and synergies between different machines often arises. According to different process structure, the network of connected machines in a plant can be organized in parallel or sequence topology, and in these machine networks the output of one machine might be treated as input for another. Therefore, it is important to get enough knowledge on the trace of resource flow in these multi-machine production chain systems. In iron and steel plants, it is possible to reuse scrap to reduce material cost. During the steel production, the by-product and semi-finished product contain much of the thermal energy which can be harvested to reduce energy consumption [17]. Establishment of cogeneration systems exist in these environments where the valuable steam and fuels can be partially recovery to be utilized to generate electricity in combined cycles.

Energy flow such as steam can be perceived as an energy-cascade system. The concepts, exergy and entropy describe the quality and quantity of energy inside multi-machine ecosystem. These set up analytic foundation to acquire, describe and analyse energetic flow through connected machines. The exergy concept clarifies the different interactions like in- and outputs, work and heat in a system; and helps determine the extent to which the system destroys exergy [18]. By accounting the exergy in a multi-machine system, it is easier to pinpoint the exergy distribution. Then using exergy cascading analysis method, energy and material recycle ability can be estimated. To minimize exergy losses is to minimize energy consumption of the processes. In [19], Wang et al. applied the flowrate-exergy diagram for thermodynamic analysis and energy integration and achieved 37.5% decrease on natural gas consumption through acetylene and power polygeneration.

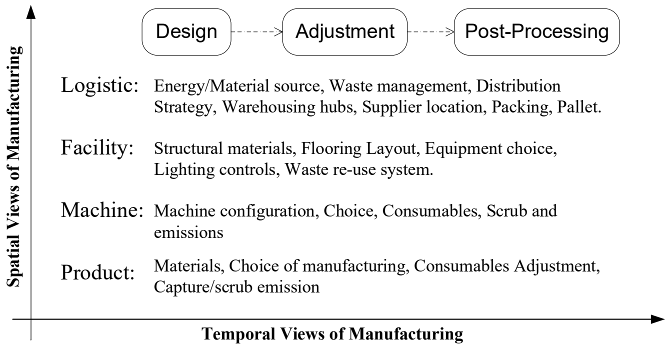

Fig. 1. Manufacturing design level with decision on each stage in respect of temporal view and spatial view.

Waste heat exists in many industries like melting furnace in steel company where excessive heat can be reused for a heat treatment process. For instance, the flue gases which flow in the opposite direction against material flow can make the flue gas reused. Rankine cycle is another way to generate electricity from waste heat besides recycle the heat flow directly and organic Rankine cycle (ORC) has been a hot research topic in recent years. [20] reported that ORC can be used in aluminium, steel, food and battery manufacturing. Analysing the system energetically and exergetically assist efficiency boosting, in [21] used water-steam Rankin cycle and an organic Rankine cycle to recover heat in cement industry.

Similarly, the material flow at multi-machine level can also be optimized to reduce the waste. Resources flow can be described between different machines in a factory. [22] investigated the aluminium recycling economic efficiency by examining the in-plant transportation between different units as material input or output and optimized the model with linear optimization method. [22] revealed that environmental and economic objectives are not always contradictory and their approach was able to lower the emissions up to 10%.

2.2.2 Process chain control and scheduling

In a multi-machine scope, each unit has its load profile and they are accumulated in a production line to exhibit specific energy and resource consumption behaviour. [23] reviewed the potential of production efficiency improvement by the production control. The interlinkage of process units and production features such as batch size and scheduling orders/speed can all influence the efficiency.

Electricity is widely used by many kinds of machines. Appropriate selection of machine, optimal duty control setting and minimizing idling state of each machine can reduce electrical work. In many systems, if some machines in a production line can be switched on and off during the process, the operation control of multi-machine switching considering their transients performance may achieve high energy efficiency

[24] where a the serial production line has a number of Bernoulli machines with finite capacity buffers and switching capability has been studied.

Another aspect of cost reduction method is to avoid consumption peak. By optimization methods in production simulation, improved planning solution can be found to minimize peak power and to some extent reduce total energy cost. The peak power in some places causes cost extra charges in the electric bill and similarly, it is possible to shift electricity consumption from day to night when the price is less expensive.

In the process chain, depending on the complex interaction within multiple machines with different states, energy and material consumption behavior is not static but dynamic. To handle those dynamics changes, simulation is a promising approach [23]. This means an energy-oriented manufacturing system simulation is needed to provide the information for decision support. Fig. 2. describes a conceptual structure of a systematic approaches of a highly flexible simulation environment with relevant energy flow of the subsystems in the factory [25].

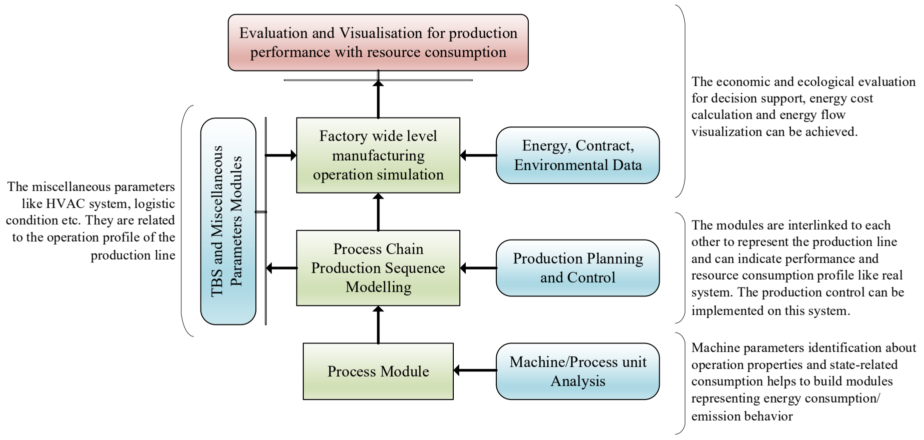

Fig. 2. Conceptual structure of energy-oriented manufacturing system simulation.

2.3 Factory level

At the factory or whole plant level, there is a greater scope to adopt higher level simulation tools covering whole system configuration, production flow and management to improve efficiency. [3] the author elaborated two orthogonal frameworks: spatial and temporal consideration at factory level. The spatial framework is concerns with the spatial views of product feature, machine, line and supply chain. These spatial levels define the material choice, geometric design, machine-facility configuration, energy-source-waste chain and logistics issues. [26] summarizes the temporal framework characterizes the control of the whole environmental impact and the influence of facility consumptions. It covers the considerations through product design to manufacturing live-cycle assessment such as product/facility design, process/logistics design, process adjustment and pros-processing etc. As the decision-making moves along the temporal axis, the flexibility decreases which means less control over the planning.

Factory wide planning and scheduling methodologies are critically needed. The method should have the ability to accommodate complex interactions. Monitoring and data communication strategies are able to track the facility performance over spatial and temporal dimensions views. Production planning can be optimized at a facility level which is wider than the multi-machine scope in order to limit the total energy consumption.

Load management can also be conducted at the factory level where the peak load surcharge can be minimized; different workloads can be predicted and controlled. However, the monitoring and control at the whole factory level require significant amount of information about the machine/process status and more complex interdependencies between systems.

There are a number of building services that account for energy consumption in support of production, and in [23] Hermann and Thiede incorporated the energy efficiency improvement with production and technical building service (TBS). In support of production and demand for higher productivity, the TBS must consider facility management energy optimization. Technical measures can be used to locate unnecessary demands in temperature and pressures, insufficient utilization. And efficient process control (e.g. continuous runs, processing at favourite working points) to avoid unnecessary cost. Using techniques like combined heat and power cycles, and heat recovery with linked systems to use regenerative energy source and to reduce system losses (e.g. leakages and lacking of insulation). Apart from the energy consumed by machines, it is also found that the energy cost in HVAC and lighting of the working hall were found to be significant (40~65%) when he analysed the energy consumption and CO_2 emission for milling machine tool environment [27].

The concept of “green factory” is important for the process design where the energy and resources waste can be minimized and recovered. For the existing factories which cannot be re-designed, modifications, such as thermal insulation of facades, improvement on fenestration and control of gates or material ports, and illumination control can lead to energy saving.

2.4 Section Summary

In this section, we have summarized different methods for three levels scope of more energy awareness and resource conservation at three levels, namely the unit process, multi-machine system and the whole factory (plant). The methods are further summarized in Table 1.

3 Scheduling for sustainability

All relevant aspects must be taken into account to develop manufacturing systems, and with a systematic approach including product, process and system. To understand the

Table 1. Stratergies for promoting efficient and effectiveness manufacturing within a factory.

Methods	Scope	Objectives
Monitoring of energy or resource consumptions	I II III	Build profile for each unit/process Understanding energy/material flow Identify the saving/reuse potentials
Re-design and improvement of process unit	I	More energy efficient tool design
Process control, parameter optimization	I II	Working duty control to balance consumption and to improve energy efficiency and machine life-cycle Improve quality/cost ratio
Energy/Exergy cascade description	I II	Clarify the energy/exergy cascade pattern Re-use of waste heat, steam, water, scratch etc.
Production planning and scheduling	II III	Switch control of machines to energy efficiency Avoid consumption peak Take advantage of electricity price shift Enable energy-oriented manufacturing decision support
Spatial and temporal consideration	III	To have an integrated view of manufacturing design concerning energy consumption and environmental impact
Green building	III	To save the energy cost in the technical building services

I, II, III represent the scope level discussed in 2.1, 2.2, 2.3 respectively.

linkage among these levels are crucial to achieve of sustainability. In section 2, the most fundamental work needed includes the resource monitoring, analysis and reporting.

To make the whole manufacturing process truly intelligent with energy-ware capability. Scheduling is a prominent methodology in operation to determine the quality, quantity, and cost of production. Besides, scheduling can influence resource consumption efficiency and waste output. In the early stage, waste reducing with process efficiency improvement realized by process sequence scheduling was introduced in chemical industry [28]. More recent interests focus on wider industrial activities concerning operation scheduling for sustainable production has increased.

3.1 Operation scheduling

The author in [29] reviewed several issues related to the sustainability in current manufacturing system including diverse nature of different conflicting objectives handled by the scheduling system, large numbers of objectives with complex relation with classical ones, increasing volatility of resources and mechanisms in processes, difficulty in designing accurate model for decision making and evaluation, and the oversized range of elements needed to be considered.

Giret et al. [29] analysed the common procedures for finding a satisfying sustainable operation scheduling solution. These procedures are described in Table 2., where four main steps are explained in the table. Firstly, a model representing operation system be developed with several objectives to optimize, and secondly, the scheduling model needed to be solved where multi-criteria must be handled. Depending on the objective models, the energy consumption, gas emission and waste generation etc. can all be modelled in relationship to the production operation state and control. However, due to the conflicting nature of many objectives, the scheduling problem may not have optimum solution and the problem is usually solved using a Pareto front and a satisfactory solution within multi-constrains can be achieved instead.

Table 2. Steps to solve sustainable manufacturing operations scheduling problems.

Step	Task	Approaches
1	Build Optimization Model	Consider Sustainability Features (Consumption, emission) such as: Energy Consumption Model, CO2 Emission Model, Pollution Model, Waste Model.
2	Formulize Scheduling Model	Multi-criteria: a) Optimize sustainability features subject to maintaining quality (e.g. effectiveness) of the scheduling, b) Optimize scheduling quality subject to maintaining a minimal level of sustainability, c) Optimize Jointly sustainability level and scheduling quality.
3	Solve the Scheduling Problem	Scheduling method to use to solve the problem: a) Find the Pareto front, using the selected scheduling method, b) Find the solution in the Pareto front that satisfies the constraints.
4	Evaluate the solution	To judge whether the solution is feasible. To judge whether relaxation or modification are needed.

For example [30] proposed a pareto-based estimation of distribution algorithm to solve the multi-objective multi-mode resource-constrained project scheduling model with makespan and carbon emissions criteria in metal forming industry. The authors adopt an activity-mode list to encode and a modified serial schedule generation scheme to decode. A hybrid probability model to predict and track the probability distribution of the makespan and carbon emission scheduling solution space. The non-dominated solutions explored in search process and newly found updated solutions are stored in two Pareto archives. The newly updated individuals stored in archive are sampled in probability model.

3.2 Multi-objective approaches for solving production scheduling problems

The production system inputs include energy, material, inventory, machine, etc. and the output are products, waste/pollution and scrap etc. A low-carbon production process might take more than one objectives, e.g. to minimize cost, to improve efficiency or to lower the pollution. In the multi-objective scheme, optimisation is to get an estimation of the Pareto optimal front, where the non-dominated solutions to the problem are presented.

3.2.1 Objective considerations

It is a common practice to consider several performance indicators as the objectives in scheduling problems, e.g. processing time, the cost and quality of production. With the advent of green manufacturing, most of researchers prioritize energy as the key objective. Some researchers further consider green-house-gas (GHG) emissions, pollutions, or waste materials. The indicators relating to energy input and waste output can also be combined into a multi-objective operation problem, forming a mixed target with different priorities.

3.2.2 Case examples of manufacturing operation scheduling

Single machine systems

Considerable changes on energy consumption (mainly electricity) and the associated cost can be achieved when both dynamic pricing and peak energy reduction are combined as scheduling and control objectives [29]. [31] used a greedy randomised adaptive search procedure to solve the scheduling problem, in order to minimising the total energy consumption and total tardiness on a single machine with unequal release dates. [32] Considered the continuous changes in energy prices, the study shows that reduced energy consumption during peak times can be reduced and the proposed heuristic approach can provide optimal solutions in most cases.

In [33], the operational decision-making problem incorporating both economic and environmental performance on single machine system was studied. Focusing on deterministic product arrival time and processing rule, an optimization model with multi-objectives was developed to minimize the total completion time and at the same time reduce total carbon dioxide emission. A non-dominated sorting genetic algorithm II was shown to be superior to a previous proposed multi-objective genetic algorithm [34].

Job shop scheduling

[35] developed a genetic algorithm which excels for many classical job-shop scheduling problems where each operation has to be executed by one machine and that machine can work at different speeds, and the proposed method is better than commercial tools which are not able to solve large scale problem in a reasonable time. In [35] energy consumption was coded in a genetic algorithm to guide effective search for the optimized solution.

Energy and makespan consideration

[36] introduced a hybrid honey-bee mating optimization and simulated annealing to optimize multi-criteria including energy consumption, makespan, and machine utilization balancing. Similarly, [37] explored a multi-objective energy efficient

scheduling problem with two objectives: makespan and energy consumption using mathematical model based on an energy-efficient mechanism in flexible flow shop scheduling problem. In order to generate Pareto-efficient solutions the weighted additive utility function technique was used, together with an improved genetic simulated annealing algorithm inspired from a hormone modulation mechanism.

[38] investigated a hybrid flexible system scheduling problem considering the energy efficiency aspect. The electricity price at different time of use was incorporated into a multi-objective optimization problem concerning production and energy efficiency. An ant colony optimization (MOACO) metaheuristic was developed to optimize both makespan and electric power consumption cost. They further compared MOACO with two popular multi-objective evolutionary algorithms: NSGA-II and SPEA2 and it was shown that though MOACO was slower but had generated better solutions.

In [39] the energy consumption for each operation was modelled and parameterized as a function of the operation execution time, and the energy-optimal schedule was derived by solving a mixed-integer nonlinear programming problem. Further, different objectives including the cycle time, energy consumption and sequences were considered.

Waste management and low-carbon manufacturing

Scheduling plays an important role in optimal allocation of plant resources. [40] used a non-dominant sorting genetic and local search algorithm to search for the minimal makespan, and minimal cleaning cost, and optimal solutions for composed objectives in paint industry batch production.

Focused on scheduling problem for a single machine, [41] used a mixed integer programming scheduling model to minimize the total carbon emissions during the whole planning horizon.

[42] developed a ε-archived genetic algorithm (ε-AGA) multi-objective genetic algorithm to obtain a wide range of near-Pareto-optimal solutions for two bi-criteria batch scheduling problems where the CO_2 emissions and due date-based objective are minimized. The proposed ε-AGA outperformed NSGA-II in the solutions by the former converge near the true Pareto-optimal set.

4 Modelling and simulation techniques

A feature of the intelligent manufacturing is transparency which means the details of manufacturing activities can be gained by manufactures. Then managers can use production control methods to control different aspects to fulfil various objectives, such as producing low cost products without compromising quality or even improving quality, and yet maintain the ability to prepare for production demand change with enough flexibility. When the optimization scope contains multiple machine interactions in production chain, advanced modelling techniques are extremely useful to cope with the complex individual cooperation and resource prediction.

The manufacturing system may experience structural changes during their operational life span resulting from adding new system components, replacing or retiring old equipment to react to the changes in products, technology or markets [43]. Because of the complexity and dynamic nature in the manufacturing systems the spreadsheet and flowcharts are almost impossible to capture the complicated process configuration and its complex constraints. [44] used Energy Blocks methodology for accurate energy consumption prediction, based on the segmentation of the production process into unit operations.

Simulation method provides practical and plausible way to investigate and evaluate manufacturing system issues. Using this tool, system information details and material flow can be clearly simulated and managed. And the simulation realizes the validation of production plan, control policy and reactions to operational problems. The discrete event system (DES) and agent-based simulation are two popular modelling tools for operation scheduling and control in manufacturing.

4.1 Discrete event system technique

The discrete event system is suitable for visually modelling dynamic nature of a complex discrete system. For example, problems like queue set up, visualization of each process status and process resource behaviours. Examples include: system simulation during the design stage, evaluating system performance such as utilization of machines, system design, and comparing operation strategies [43]. Discrete event system/ Discrete event dynamic system (DES/DEDS) can be defined as an interacting set of entities that evolve through different states as internal or external events occur [45]. In the discrete event system modelling, simulated system changes only at discrete time when the event is triggered to change.

4.1.1 Planning and queues, delivering

In manufacturing, the supply is not constant and the production schedule of resources varies frequently. [46] investigated the procedures used for the planning of a material delivery system in a manufacturing line of an electronic company. [47] used discrete event simulation model to allow dynamic interaction with the scheduler of the planning support system. A virtual steel yard model is built to manage the steel-plate piling plan efficiently.

4.1.2 Behaviour of process resources

In [32] the authors used discrete system modelling to identify three states of a machine: processing' (i.e., productive), ‘idle’ (i.e., working but non-productive), and ‘shut down’. Two transition times and their energy costs are incorporated in this model, including the elapsed time when switching from shut down to processing (i.e., turning on) and vice versa (i.e., turning off).

In electronics assembly line where many decisions are based on workers experience, [48] introduced the DES to provide better understanding of the production environment showing the bottlenecks and the impact of each production parameters. [49] investigation on the capacity planning of a mobile phone remanufacturing industry is discussed by Franke et al. The discrete event system was applied to represent quick changing product, process and market constraints. A flexible discrete event system model for identifying production resource usage and line capacity planning with cost analysis in a manufacturing system was proposed in [50].

4.2 Agent-based modelling

The agent-based system is often built using the bottom up approach. It starts with individual agents, define their characteristics and behaviours, and let them interact in the agent's environment [51]. Each agent can be defined as a computational system which means that the knowledge of discrete event system techniques can be used to represent the dynamics of the agent. In the dynamics of the environment where an agent may have an environment that includes other agents, community of interacting agents as a whole operates as a multi-agent system [52]. A typical agent can contain attributes, goals, rules, behaviour and memories, then each agent can interact with other agents, the agents can also interact with environment.

4.2.1 Multi-agent modelling simulation

A multi-agent system (MAS) can be formed by a network of computational agents that interact and typically communicate with each other as the big family of distributed information system [53]. Each agent has the ability to represent a production resource, not only the machines can be modelled, but the production itself can be represented. Therefore, the production order and logistical scheduling can be modelled using MAS. The MAS needs advanced algorithms in distributed control where each agent representing machine/product can generate decisions for manufacturing control. The distributed control solution takes the advantage of resource allocation possibility and coordination result from automated negotiation among agents.

Yeung proposed a formal approach to address the potential behavioural problems of multi-agent systems for manufacturing control applications, and verified the [54].

Li et al. applied a pheromone based approach using the multi-agent system for a scheduling problem in a cellular manufacturing system to establish flexible route for machine performing in multiple jobs [55]. And the colony optimization technique was used for negotiation among agents.

In [56], a system-based simulation methodology was proposed to solve a backward on-line job change scheduling problem. The system performed with a state transition defined as a combination of the job and machine states. It has been widely believed that the future work of agent-based manufacturing should focus on the integration of agent-abased planning and scheduling with existing systems used in the manufacturing enterprises. The most important integration is with real time data collection systems, including SCADA systems and RFID systems as well as ERP and MRP systems.

5 Conclusion

Currently most of the research of intelligent scheduling are for discrete manufacturing system, and less effort in continuous batch processing. Practical case study on factory level wide planning and scheduling methodologies considering multiple interactions are required to solve complex interdependent and synergistic problems. Some prospects about future research can be drawn from the literatures. Proactive and reactive response to scheduling under uncertainty need further investigation.

In this paper, the resource efficient intelligent manufacturing is reviewed at three different levels, namely the unit process, production line and factory wide where strategies of energy saving, resource recycling and process control are discussed. Various methodologies to describe the energy/material flow and process states are reviewed, which can support decision-making for and identification of the bottlenecks of further improvements. Resource recycle scheme and process chain control play a key role in production line energy-aware optimization. The load and capacity control can be conducted through each level and performs well in energy cost reduction. At the factory level, considerations other than direct manufacturing subsystem like building service cannot be neglected. The energy awareness and resource flow need to be taken into account throughout the design, processing, post-processing stages.

Approaches to the multiple objective scheduling problems approaches are also surveyed in section 3. The diverse nature of different conflicting objectives in production scheduling constitutes complex operation control problem. The problem is usually solved through a pareto front based on which a desirable solution is selected. Simulation is the required to investigate and evaluate manufacturing issues. Various simulation models also help manage material and information flows in the system. The discrete event system is able to build up a queue system and include information about the process resources, while assist to visualize internal aspects for supervision. Agent-based modelling technique which is more flexible than the DES method, allows adaptability, scalability and modularity which are essential for modelling a plant-wide complex system.

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