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An optimization algorithm for integrated remanufacturing production planning and scheduling system

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ABSTRACT

It is known that production planning and scheduling are mutual influence and restriction. In this paper, we aim to obtain the minimum remanufacturing time of recycling parts by use of birandom variables and further optimize an integrated remanufacturing production planning and scheduling system under uncertain conditions. An integrated production planning and scheduling optimization model with birandom variable restraints is firstly established. Then we develop a hybrid intelligent algorithm including random simulation technique, neural network, and genetic algorithms to optimize an integrated remanufacturing production planning and scheduling system. Furthermore, we generate a random variable samples matrix through random simulation technique and a trained neural network is embedded into genetic algorithm. Finally, this hybrid intelligent algorithm is applied to optimize an integrated remanufacturing production planning and scheduling system through a case study.

1. Introduction

As energy shortage is becoming increasingly serious, the price of raw material is rising and demographic dividend is diminishing gradually, and remanufacturing has become an inevitable choice for the promotion of circular economy and social sustainable development [1]. In response to the enlargement of remanufacturing industry scale, scientific and reasonable operation and management is becoming more and more important. Traditional production planning and scheduling adopts serial mode from top to bottom, where the production schedule was obtained according to the production plan first, and then the shudule was carried out in terms of the planning target [2,3]. However, the remanufacturing production includes many links, such as recycling, disassembly, verification, reproducing and assembly, complex constraint relationship and uncertain factors [4]. If detailed scheduling constraints are ignored on planning level, then the production plan will have difficulty in responsing to variation correctly or timely, which leads o an unsatisfying production planning and scheduling scheme. It is necessary to optimize the production planning and scheduling integratelly by establishing a whole optimization model based on different level constraints.

Many significative explorations aiming at decision-making optimization problem of remanufacturing production have been done by many researchers. Mukhopadhyay and Ma studied the recovery of remanufacturing production and demand when they are taken as the random variable separately [5]. Su and Sha constructed a production planning approach based on hybrid uncertainty and evidence theory considering of the random and fuzzy parameters in remanufacturing [6]. Some work described the uncertainty of production demand, recycled products quantity, remanufacturing cost and remanufacturing rate by adopting of discrete scenes collection under given probability distribution, and built a manufacturing-remanufacturing mixture producing plan model considering of the heterogeneity of demand [7]. For the uncertainty of production scheduling in remanufacturing, Lee et al. modelled a key chain based on uncertain production scheduling approach for remanufacturing [8]. Liu et al. established a remanufacturing production scheduling model based on fuzzy random chance constraints by the use of fuzzy random variable to show the processing time of recycled pieces [9]. Moreover, some scholars established a nonlinear mixed integer programming model for integrated optimization of remanufacturing production planning and scheduling in Job-Shop environment [10–15]. These results resolved the integrated optimization problem of production planning and scheduling properly. However, they did not start from the particular uncertainty in remanufacturing job-shop. In this sense, these models and meth-

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ods can not be applied to remanufacturing production decision directly.

This article established an integrated optimization model of remanufacturing production planning and scheduling on the basis of the present study results. The proposed model incorporated remanufacturing scheduling target and constraints into the production planning optimization model, took the uncertainty of recycled parts process time of remanufacturing into consideration, and described the reprocessing operation with different state by use of double random variables. A hybrid optimization algorithm was also designed to resolve the model in order to provide a new solution for integrated optimization of remanufacturing.

2. Mathematical model

The problem of production planning and scheduling integrated optimization in remanufacturing under uncertain conditions can be described as: there are M machines in total in remanufacturing job shop, and the reprocessing operation of N categories of components are finished in T planning cycles. For each kind of recylced part$i$ there are N_{i} processes. For each process, more than one machine can be choosed. The target of production plan is to determine the production $X_{it}$of every kind of recycled parts, satisfying that the total cost (including the cost of production, stock-holding and shortage) be minimized. The aim of the scheduling is to allocate machines to every recycled part, determine the reprocessing sequence on the same machine with minimal machine assign costs. The aim of integrated optimization is to optimize the two parts of costs on the whole based on some feasible scheduling under uncertain conditions. Considering the features of the remanufacturing production, the establishment of integrated model should satisfy the following assumed conditions:

1) Only one work piece can be repaired on the same machine at the same time.
2) It can't be interrupted once the process of a work pieces started within one cycle.
3) The work pieces of the same cycle have the same priority, arriving at the same time, and they are not allowed to be processed preemptively.
4) The work pieces are reprocessed by batch, and the same process of the same batch of work pieces is remanufactured steadily on the same machine.
5) The work pieces reach the new product condition by repeocessing, and the inferior-quality product is ignored.

To make it convenient to describe the model, the following symbols are introduced:

i	is the number of parts to be repaired, $i = 1, 2, \cdots N$;
j	is the operation number of reprocessing, $j = 1, 2, \cdots N_i$;
k	is the machine number of reprocessing; $k = 1, 2, \cdots M$;
t	is the number of planning cycles; $t = 1, 2, \cdots T$;
s	is quality grade separation of recycled parts, $s = 1, 2, \cdots S$;
O_{ij}	is the jth operation of part $i$to be repaired;
M_{ij}	is the collection of reprocessing machine of O_{ij};
$WIPC_i$	is work-in-process inventory cost for each part $i$in each cycle;
Q_{it}	is the inventory of part$i$ at the beginning of each circle t;
MHC_i	is the hourly rate of part i;
RT_{ijk}	is the actual reprocessing time of RT_{ijk}on machine k;
X_{it}	is the planning reprocessing number of part i in cycle t;
AC_{ijk}	is the additional cost of jth operation of part i on machine k;
AT_{ijk}	is additional time of jth operation of part $i$on machine k (including set-up time) ;
B	is the maximum capacity for the machine processing part by batch;
ε_{it}	In cycle t, when the part i is processed on machine by batch,$\varepsilon_{it} = 1/B$. when processed on general machine, $\varepsilon_{it} = 1$;
$ceil(\cdot)$	is function to round up to an integer, When the part is processed on the batch processing machine, $ceil(X_{it} \cdot \varepsilon_{it})$ can output the number of batches;
τ_{it}	In cycle t, if part i is arranged to be reprocessed, $\tau_{it} = 1$. Else, $\tau_{it} = 0$;
η_{ijkt}	In cycle t, if the jth operation of part i is processed on machine k, $\eta_{ijkt} = 1$. Else, $\eta_{ijkt} = 0$;
IC_k	is the overtime cost per unit on machine k;
IT_{kt}	is the overtime of cycle t on the machine k;
OPC_i	is penalty cost of over production of part$i$;
OPN_{it}	is the over production number of part i in cycle t;
SFC_i	is shortfall penalty fee of part i;
SFN_{it}	is the shortfall number of part i in cycle t;
d_{it}	is the demand of assembly workshop for part$i$ in cycle t;
BT_{ijt}	In cycle t, the starting time of process j of part i;
ET_{ijt}	In cycle t, completion time of process j of part$i$;
W	is a large enough number;
$\lambda_{iji'j'kt}$	In cycle t, if jth operation of part$i$ is processed beforej'th operation of parti' on machine k, $\lambda_{iji'j'kt} = 1$.Else,$\lambda_{iji'j'kt} = 0$;
APC_{kt}	is the available production capacity on machine k in cycle t;
F_{kt}	is the completion time of the last part on machine k in cycle t;
$J(k)$	is the collections of operations that canbe reprocessed on machine k.

To make it convenient to describe, two virtual part $J_0$and J_{N+1} are added to every machine in each cycle, corresponding to the first and the last part respectively. The process of virtual part is called virtual process, whose number is equal to the number of the available machine. Reprocessing time of virtual part J_0andJ_{N+1} satisfies $RT_{0jk} = RT_{(N+1)jk} = 0$, and additional time satisfies $AT_{0jk} = AT_{(N+1)jk} = 0$.

$J_1(k)$	is the process collection that can be repaired on machine k, including the process of virtual part J_0.
$J_2(k)$	is the process collection that can be repaired on machine k, including the process of virtual part J_{N+1}.

The objective function of production planning and scheduling integratedoptimization model for remanufacturing job shop is as follows:

$$\begin{aligned} \min Z = & \sum_{t-1}^{T}\sum_{i=1}^{N} WIPC_i \cdot Q_{it} + \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{j=1}^{N_i} MHC_i \cdot RT_{ijk} \cdot ceil(X_{it} \cdot \varepsilon_{it}) \\ & + \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{j=1}^{N_i}\sum_{k=1}^{M_{ij}} AC_{ijk} \cdot \eta_{ijkt} \cdot AT_{ijk} + \sum_{t=1}^{T}\sum_{k=1}^{M_{ij}} IC_k \cdot IT_{kt} \\ & + \sum_{t=1}^{T}\sum_{i=1}^{N} (OPC_i \cdot OPN_{it} + SFC_i \cdot SFN_{it}), \end{aligned} \tag{1}$$

s.t.

$$Q_{i1} + SFN_{i1} - OPN_{it} + X_{i1} = Q_{i2} + d_{i1},\ \forall i \tag{2}$$

$$Q_{it} + SFN_{it} - OPN_{it} + X_{it} = Q_{i(t+1)} + d_{it},\ t = 2, \cdots, T,\ \forall i \tag{3}$$

$$\sum_{t=1}^{T} X_{it} - OPN_{it} + SFN_{it} = \sum_{t=1}^{T} d_{it}, \tag{4}$$

$$\sum_{k=1}^{M_{ij}} \eta_{ijkt} = \tau_{it},\ \forall i, j, t, \tag{5}$$