A multi-objective robust optimization model for RMTs selection in Sustainable Reconfigurable Manufacturing System

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1 Introduction

This paper presents a novel approach to handle capacity scalability and configuration changes for product families in RMS through mixed integer linear programming. Two objective functions are taken into consideration: minimizing the system's overall cost and energy consumption by utilizing the various RMT production capacities. The costs include the exploitation cost of RMTs, reconfiguring cost, maintaining inventory, and purchasing raw materials. The reconfiguration cost can be in module changes and/or exploitations of new tools. The two most crucial parameters have been deemed uncertain in order to handle shifting demand and market fluctuations, and a scenario-based robust optimization is put into practice. Hence, the main contributions of this study encompass the formulation of a novel multi-objective optimization approach for selecting the optimal configuration of RMTs in RMS, as well as the utilization of a robust optimization technique to effectively address uncertainties.

The utilization of the two key characteristics of RMS, namely scalability and convertibility, can be leveraged to provide adaptable capacity and flexible functionality. Convertibility refers to the ability to transfer production activities between distinct members of a component family, utilizing various machine and system functions. The scalability of capacity pertains to the capability to increase production by including additional tools or altering the existing configuration. The present work focuses on the scalability and convertibility of configuration design for sustainable reconfigurable manufacturing system in an uncertain environment. The operational capacity of RMTs can be modified through two methods: firstly, by incorporating or removing auxiliary modules inside a specific RMT configuration, and secondly, by utilizing the same RMT configuration to conduct alternative operations [1]. The primary objective function is to minimize the total cost. The total cost of the system comprises the RMT exploitation cost, inventory cost, reconfiguration cost, and raw material cost. Furthermore, the energy consumption of the RMTs used and their reconfiguration are the second objective function. Eq.1 and Eq.2 present the mathematical expressions for the total cost and energy usage, respectively. Since the demand in the RMS system fluctuates too frequently and the system's capacity should respond quickly to fluctuating demand, this parameter is considered uncertain in this research. The exploitation cost is also considered an uncertain parameter.

$$\begin{aligned}\min Z_1 = &\sum_{p,t}(IP_{p,t} \times CIP_P) + \sum_{c,t}(IC_{c,t} \times CIR_c) + \sum_{c,t}(S_{c,t} \times Ct_C) + \sum_{i,j,i',j',t}(Y_{i,j,i',j',t} \times CF_{j,j'}) \\ &+ \sum_{j,t} CD_j \times (T+1-t)X_{j,t}\end{aligned} \tag{1}$$

$$\min Z_2 = \sum_{i,j,i',j',t} Y_{i,j,i',j',t} \times ec_{j,j'} + \sum_{i,j,t} eo_{i,j} \times Z_{i,j,t} \tag{2}$$

In order to effectively manage uncertainty, an approach known as a scenario-based robust approach is employed. The Mulvey method is employed to mitigate the model's inherent uncertainty while reducing its level of conservatism [2]. This approach yields a collection of solutions that are purportedly more resilient. In order to account for the variability in the input data, multiple scenarios are established for the problem, and the parameters and variables are adjusted accordingly in each scenario. Furthermore, our aim is to transform the model into a single objective mode by the utilization of the Lp-metric technique.

TAB. 1: The result of the model with deterministic parameters

	z1	z2	Exploitation cost	Reconfiguration cost	Inventory cost	purchasing cost
Single obejctive z1	79510.7	782	67900	2475	0	9135
Single obejctive z2	1.30E+07	647	1.29E+07	275	30	8615.7
LP metric	83024	715	72640	2200	0	8184.6

TAB. 2: The result of the model with uncertain parameters

	z_s	z2	exploitation cost	Reconfiguration cost	Inventory cost	purchasing cost
Single objective z1	288857	1429.219	132860	1000	0	13897.2
Single objective z2	2.59E+07	1025.194	1.29E+07	0	1717.873	12586.004
Lp-metric	280183	1068.237	128200	550	75	11127.07

The various cost components for each approach with deterministic parameters are listed in Table.1. The weight of each objective function in the lp-metric approach equals 0.5. According to 1, When taking into account the bi-objective mode, it is observed that the reconfiguration cost not only remains stable, but significantly falls in comparison to the default assumptions. The cost of reconfiguring in bi-objective mode is 11% lower than the reconfiguration cost in singular objective function minimizing cost mode. The exploitation cost of RMTs and the inventory cost are independent of the periods in the input data. Consequently, the optimal state of the model favors producing products according to demand in each period and does not maintain inventory during the horizon plan. Avoidance in the singular objective of energy consumption, as the primary objective of the problem, is to select the RMTs that consume the least amount of energy, so the model has maintained some inventory in this mode.
In the second phase, the model output is analyzed under uncertain parameters All scenarios are generated randomly and attempt to cover a wide range of data for uncertain parameters. Comparable to the first phase, The outcome of the scenario-based robust model for each of the three approaches is shown in Table 2. The results have been established by the relative weight of lp-metric (w=0.5).

References

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