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Designing Sustainable Flexible Manufacturing Cells with Multi-Objective Optimization Models †

Emine Bozoklar [1,*] and Ebru Yılmaz [2]

1 Department of Industrial Engineering, Faculty of Engineering and Natural Sciences, İskenderun Technical University, İskenderun, 31200 Hatay, Türkiye
2 Department of Industrial Engineering, Faculty of Engineering, Cukurova University, Sarıçam, 01250 Adana, Türkiye; eyilmaz@cu.edu.tr
* Correspondence: emine.bozoklar@iste.edu.tr

† This study is grounded in, under the supervision of Associate Professor Dr. Ebru YILMAZ, Emine BOZOKLAR's presently ongoing PhD thesis in the Department of Industrial Engineering, Institute of Natural and Applied Sciences, Cukurova University, Sarıçam, 01250 Adana, Türkiye.

Abstract: Having sustainable and flexible features is crucial for manufacturing companies considering the increasing competition in the globalized world. This study considers three aspects of sustainability, namely economic, social, and environmental factors, in the design of flexible manufacturing cells. Three different multi-objective integer mathematical programming models were developed with the objective of minimizing the costs associated with carbon emissions, inter-cellular movements, machine processing, machine replacement, worker training, and additional salary (bonus). Simultaneously, these models aim to minimize the carbon emission amount of the cells within the environmental dimension scope. The developed models are a goal programming model, an epsilon constraint method, and an augmented epsilon constraint (AUGMECON) method. In these models, alternative routes of parts are considered while assigning parts to machines. The results are obtained using the LINGO 20.0 optimization program with a developed illustrative example. The obtained results are tested and compared by performing sensitivity analyses. The sensitivity analyses include examinations of the effects of changes in part demands, machine capacity values, carbon limit value, and the maximum number of workers in cells.

Keywords: sustainable manufacturing; flexible manufacturing cells; multi-objective optimization; goal programming; epsilon constraint method; augmented epsilon constraint method

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1. Introduction

Sustainability refers to discussing economic, environmental, and social dimensions simultaneously. While the environmental dimension assesses various factors such as gas emissions, solid/liquid waste management, and energy consumption, the social dimension considers some aspects such as working conditions and work safety. The economic dimension considers providing economic benefits like increasing net present value [1]. Sustainable manufacturing examines products and techniques that have both an economic impact and the ability to minimize the adverse effects of environmental factors, while also protecting energy and natural resources and being reliable for workers [2]. The environmental aspect of sustainability relates to the well-being of people and relies on the responsible use of renewable and non-renewable resources and the Earth's capacity to breathe waste. The environmental aspect of sustainability points out that natural resources are not abundant and are continually consumed. Environmental indicators provide an early warning system to prohibit damage to the natural environment [3]. While manufacturing companies aim to transform natural resources, financial capital, and information into products that fulfill social needs, the human factor plays a crucial role in every aspect of the manufacturing process. Social sustainability indicators are essential in assessing and measuring the social impacts of manufacturing decisions [4]. Galal and Moneim [5] examine social factors within manufacturing systems, addressing elements such as education budget, overtime rate, security, and labor expenditure. In the context of manufacturing system sustainability, Rajak and Vinodh [6] investigate social sustainability indicators, encompassing aspects like job opportunities, health and safety applications, research and development, healthcare and education, and social cohesion. According to Vimal et al. [7], employee education and training emerge as significant strategies for advanced manufacturing systems. Lin et al. [8] categorize social factors in manufacturing systems into diverse criteria, including work accidents, physical workload, working conditions, employee productivity, knowledge and skills, and employee satisfaction. Mengistu and Panizzolo [9] gather a range of criteria, including employment opportunities, employee satisfaction, occupational health and safety, education, and development, and working conditions to define social factors within manufacturing systems. According to Ahmad et al. [3], the economic dimensions of sustainability encompass various indicators that are traditionally associated with financial accounting and intangible assets. The economic dimension of sustainability is indeed interconnected with the environmental and social pillars. Economic pillars are also associated with costs and profits [3].

Sustainable manufacturing systems development efforts contemplate solving problems at all levels (product, process, and system) [10]. The dynamic cellular manufacturing system is one of the manufacturing systems that has a high degree of flexibility and agility to handle product changes [11]. Flexible manufacturing systems are computer-controlled systems that can simultaneously process various parts, including automated material handling equipment and numerically controlled machine tools [12]. The systems divided into subsystems to produce certain parts are called cellular manufacturing systems [13]. The cell formation problem addressing the design of cellular manufacturing systems aims to group parts into part families and related machines into machine cells. This problem aims to ensure grouping efficiency by minimizing inter-cellular and intra-cellular movement costs. The classification of cellular manufacturing systems is based on the geometry of each part and the similarity in the working process. This classification aims to reduce inventory, improve flow time, optimize space utilization, and enhance system efficiency [11].

The organization of this study is as follows: In the second section, a comprehensive review of the related literature is presented, focusing on the environmental, social, and economic dimensions of sustainable factors in cellular manufacturing systems and cell formation. The primary purpose of this study is to design flexible manufacturing cells considering sustainable factors. To achieve this, three different mathematical programming models are presented in the following sections and discussed in Section 3 in detail. The goal programming model, the ε-constraint model, and the augmented ε-constraint (AUGMECON) model were developed. Section 4, Results and Discussion, includes the solution of the sample problem and the sensitivity analyses. In Section 5, the conclusions and future studies are presented.

2. Literature Review

A selection of studies related to the formation of cellular manufacturing systems with some sustainability criteria is given below. Ghodsi et al. [14] consider three aspects of sustainability simultaneously in their cellular manufacturing model. In terms of the economic aspects of sustainability, the lowest cost, the reduction in pollutant emissions as an environmental sustainability criteria, and the reduction in the negative impact on job satisfaction in terms of social factors are taken into consideration. Aljuneidi and Bulgak [15] develop a mixed integer linear programming model that combines reconfigurable cellular manufacturing systems and hybrid manufacturing–remanufacturing systems. They suggest an integrated strategy encompassing aspects of design optimization, analysis, and process planning, aiming to consider several design issues concerning sustainable manufacturing systems. Within the model aiming to minimize the total cost, cost items related to manufacturing and remanufacturing, as well as costs associated with returned products for remanufacturing, were also considered. Mehdizadeh et al. [16] summarize the cell formation problem and production planning and present a multi-objective model. The required time in terms of the time unit for the training of a worker to operate the machines, and some cost terms, such as training, hiring, firing, and salary costs, are considered in the model. Niakan et al. [11] present a two-objective mathematical model for the dynamic cell formation problem considering economic, environmental, and social criteria. In their study, the authors focused on minimizing total cost including cost terms such as inter-cell movement, intra-cell movement, hiring, firing, salary, and training costs, as well as reducing total manufacturing waste, which includes factors such as raw materials, chemicals, energy consumption, and CO_2 emissions. In addition, the maximum daily noise exposure level for worker assignments is added as a constraint to the model as a social criterion. Niakan et al. [17] address minimizing machine-related costs (machine fixed and variable costs, machine procurement and relocation costs, and intra-cell and inter-cell movement costs) and wages, while also considering social issues such as minimizing potential machine hazards and maximizing job opportunities. They state that they tried to establish a balance between economic and social criteria while designing the cells in each period. Imran et al. [18] consider the rated power of machines and the rated power of the material handling devices (AGVs) in the cell formation problem of cellular manufacturing systems. Additionally, the cost per kilowatt hour of electricity is also incorporated into the model. Arghish et al. [19] propose a mathematical model that considers economic and environmental criteria for the type 2 fuzzy cell formation problem. Iqbal and Al-Ghamdi [20] work on saving energy in a machine shop environment by optimizing the assignment of production processes to varied machines and grouping machines in multiple cells to minimize the movement distance. Kumar and Singh [21] propose a bi-objective stochastic mathematical model for sustainable cellular facility layout, along with suggesting an embedded metaheuristic to solve the model. The electricity consumption of AGVs between machines was incorporated into the model. The authors state that the environmental and economic aspects of sustainability in the process of designing a layout is considered in their model. Raoofpanah et al. [22] present a mixed-integer nonlinear programming model that considers environmental issues such as pollution and waste resulting from manufacturing and transportation in the context of cell formation. The cost of the pollution created by the types of vehicles used by the suppliers is considered in the model. Telegraphi and Bulgak [23] present a mixed integer linear programming model for designing optimization of a cellular manufacturing system within the context of a closed-loop supply chain to establish a sustainable manufacturing enterprise. In their study, the minimization of the costs of remanufacturing returned products and related costs such as the disposal, disassembly, and holding of the returned products are also considered. Forghani et al. [24] address an integrated cell formation and group layout model as a mixed-integer program, considering energy consumption, assembly considerations, and process routing. The electric energy consumption generated during processing of parts on machines is incorporated into the model. Jafarzadeh et al. [25] consider the sustainable manufacturing system in the dynamic cellular manufacturing system using fuzzy parameters. They propose a multi-objective sustainable mathematical model that minimizes costs, CO_2 emissions, and product shortages while considering customer satisfaction.

In the literature, various cost items have been considered in relation to cell formation problems. Table 1 provides a chronological presentation of some cost items and various studies that have addressed these costs in the context of cell formation problems.

Table 1. A selection of cost items in cell formation studies.

Authors	Movement Costs		Machine Relocation-Related Cost	Worker Training Cost	Hiring and Firing Cost	Salary Cost	Energy Cost	Remanufacturing Cost	Pollution Cost
	Intra-Cellular	Inter-Cellular							
Aryanezhad et al. [26]		√	√	√	√	√			
Fan and Feng [27]	√	√	√			√			
Bagheri and Bashiri [28]			√	√	√	√			
Aljuneidi and Bulgak [15]			√					√	
Azadeh et al. [29]	√	√	√						
Mehdizadeh and Rahimi [30]				√	√	√			
Mehdizadeh et al. [16]	√	√	√	√	√	√			
Niakan et al. [11]	√	√	√	√	√	√			
Nouri [31]	√	√	√		√	√			
Zohrevand et al. [32]		√	√		√				
Sadeghi et al. [33]	√	√	√	√	√	√			
Zhang and Zhou [34]	√	√				√			
Arghish et al. [19]	√	√					√		
Delgoshaei et al. [35]				√	√	√			
Fahmy [36]	√	√				√			
Raoofpanah et al. [22]	√		√						√

In this study, the design of flexible manufacturing cells is discussed by considering various factors related to economic, social, and environmental dimensions of sustainability. The study aims to design manufacturing cells that quickly adapt to dynamic and competitive market conditions with flexible and sustainable features. A general evaluation of cell formation studies regarding sustainable dimensions is given in Table 2. As seen in Table 2, this study examines the flexible cell formation problem by considering various factors related to sustainability dimensions including economic, environmental, and social dimensions.

Table 2. A selection of cell formation studies according to sustainability dimensions.

Authors	Economical	Environmental	Social
Fan and Feng [27]	√		√
Ghodsi et al. [14]	√	√	√
Aljuneidi and Bulgak [15]	√	√	
Mehdizadeh and Rahimi [30]	√		
Niakan et al. [11]	√	√	√
Niakan et al. [17]	√		√
Nouri [31]	√		
Imran et al. [18]	√		
Sadeghi et al. [33]	√		
Zhang and Zhou [34]	√		√
Arghish et al. [19]	√	√	
Delgoshaei et al. [35]	√		
Iqbal and Al-Ghamdi [20]		√	
Kumar and Singh [21]	√	√	
Raoofpanah et al. [22]	√	√	
Forghani et al. [24]		√	
Jafarzadeh et al. [25]	√	√	√
This article	√	√	√

In Table 3, a selection of various studies in the relevant literature in terms of some factors are listed. This study considers all factors listed in Table 3 and various sustainability factors in the design process of flexible cells.

This study focuses on the design of flexible manufacturing cells considering the economic, environmental, and social dimensions of sustainability. This study aims to ensure optimum results for the following three developed models: the goal programming method, the epsilon constraint (ε-constraint) method, and the AUGMECON method.

Table 3. A selection of cell formation studies in terms of some factors.

Authors	Worker Assignment	Skill	Route Flexibility	Period
Aryanezhad et al. [26]	√	√	√	√
Fan and Feng [27]	√	√	√	√
Bagheri and Bashiri [28]	√			√
Azadeh et al. [29]	√	√		√
Mehdizadeh and Rahimi [30]	√			√
Niakan et al. [11]	√	√		√
Nouri [31]	√		√	√
Sakhaii et al. [37]	√		√	√
Feng et al. [38]	√	√	√	
Raoofpanah et al. [22]				√
Shafiee-Gol et al. [39]			√	√
This article	√	√	√	√

3. Material and Methods

3.1. Problem Formulation

In this article, three different multi-objective mathematical programming models, named the goal programming method, the ε-constraint method, and the AUGMECON method, were developed to address the identified problem. The goal programming model is obtained by minimizing the sum of the deviations from the target values. As mentioned in the study of Felfel et al. [40], in the ε-constraint method, one of the objectives is accepted as the objective function. Thus, while the selected objective function is optimized, other objective functions are considered as constraints and limited by the epsilon value [40]. In the AUGMECON method, unlike the classical ε-constraint method, the slack or surplus variables are included in the model, and the constraints of the objective function are converted into equations [41]. Thus, some constraints that are typical for each multi-objective method were added to the mathematical programming models.

In this study, the developed multi-objective mathematical programming models aim to minimize cost items, including carbon emission, inter-cellular movements, machine processing, machine replacement, worker training, and bonus costs, which are calculated for workers based on their skills. Moreover, this study aims to reduce the amount of carbon emissions by considering the environmental dimension. The optimal route of each part is determined based on alternative routes. In addition, decisions are made to determine the number of machines assigned to cells, added to cells, and removed from cells for each period, the assignment of workers to cells, the number of workers in the cell and system, and the total training time that workers receive. Various assumptions of the developed model are stated below:

- In the system, the routing flexibility for each part is taken into account. Only one alternative route of each part can be chosen.
- The system has machine flexibility. Multiple part types can be processed on different machines.
- The capacities of the cells are limited, and there are upper and lower limits for the number of machines to be taken into account.
- The part demands are fixed and known values. The processing time of a part on its route is known.
- The amount of power that machines consume during production is considered. Indirect and energy-related carbon emissions arising from the operation of the machines are considered. Machine idle times are ignored.
- The movements of parts between cells are considered.
- The carbon emission conversion factor is a constant coefficient.
- The time required for the addition of machines to cells and the removal of machines from the cells is ignored.
- The system has worker flexibility, and different workers may have different skills.
- In addition, worker skills are assumed constant in each period.

3.2. Developed Goal Programming Model

The developed goal programming model consists of several components, including sets, parameters, decision variables, objective function, and constraint equations. These elements are defined as follows:

Indices:

W	Set of part types ($w \in W$).
R	Set of alternative routes ($r \in R$).
Q	Set of cells ($q \in Q$).
S	Set of machine types ($s \in S$).
I	Set of worker types ($I \in I$).
L	Set of skills ($l \in L$).
E	Set of periods ($e \in E$).

Parameters:

D_{ew}	The demand of part w in period e.
K_{es}	The time capacity of machine s in period e.
t_{wrqs}	The machining time of part w on machine s in cell q using alternative route r.
pw_{wrqs}	The amount of power consumed while machining part w on machine s in cell q using alternative route r.
HA_{ew}	The cost of moving part w between cells in a period e.
CE_{es}	The machine s carbon emission cost per period e.
O_{es}	The machine s processing/operation cost per period e.
NAC_{es}	The cost of adding machine s to cells per period e.
NRC_{es}	The cost of removing machine s from cells per period e.
EM_{eqi}	The training cost of worker i in cell q in period e.
ES_{il}	The time that worker i spends on an operation of skill l.
HY_{eql}	The limit value of skill l in cell q in period e.
TES_{eql}	The limit time that workers with skill l in cell q in period e can spend.
IK_{eq}	The maximum number of workers of cell q in period e.
HAL_{eq}	The lower bound for the number of machines in cell q in period e.
HUL_{eq}	The upper limit for the number of machines in cell q in period e.
F	The carbon emission conversion factor.
LB_{eq}	The carbon emission limit value of cell q in period e.
B_l	The bonus wage to be received by l skilled worker.
EST_{eil}	The training time received by worker i in the skill l in period e.
z_{ewrq}	$\begin{cases} 1, \text{if part } w \text{ is produced at least one time in cell } q \text{ with alternative route } r \\ \text{in the period } e \\ 0, \text{otherwise} \end{cases}$
IY_{il}	$\begin{cases} 1, \text{if the worker } i \text{ has skill } l \\ 0, \text{otherwise} \end{cases}$
GH_{wrqs}	$\begin{cases} 1, \text{if part } w \text{ has alternative route } r \text{ with machine } s \text{ in cell } q \\ 0, \text{otherwise} \end{cases}$

HD_1, HD_2, HD_3, HD_4, HD_5, HD_6, HD_7, and HD_8, respectively, represent the target values for the objective items.

Decision Variables

x_{ewr}	$\begin{cases} 1, \text{if alternative route } r \text{ is selected for part } w \text{ in period } e, \\ 0, \text{otherwise} \end{cases}$
V_{eqi}	$\begin{cases} 1, \text{if worker } i \text{ is assigned to cell } q \text{ in period } e, \\ 0, \text{otherwise} \end{cases}$
N_{eqs}	The number of machine s assigned to cell q in period e.
NA_{eqs}	The number of machine s added to cell q in period e.
NR_{eqs}	The number of machine s removed from cell q in period e.
IS_{eq}	The number of workers in cell q in period e.
EIS_e	The total number of workers in the system in period e.
TA_i	The total training time that worker i will receive during all periods according to the worker's abilities.

The parameters K_{es}, t_{wrqs}, ES_{il}, TES_{eql}, and EST_{eil} have the same time unit in the model. Additionally, the parameters HA_{ew}, CE_{es}, O_{es}, NAC_{es}, NRC_{es}, EM_{eqi}, and B_l have the same currency unit.

Objective Function

$$\text{Min } = d_1^+ + d_2^+ + d_3^+ + d_4^+ + d_5^+ + d_6^+ + d_7^+ + d_8^+ \quad (1)$$

The objective function of the goal programming model is given by Equation (1). Using Equation (1), the minimization of the sum of deviations from the handled targets is ensured. In the objective function (1), $d_1^+, d_2^+, d_3^+, d_4^+, d_5^+, d_6^+, d_7^+, d_8^+$,respectively, are the decision variables that represent positive deviations from the targets. In Equations (2)–(9), $d_1^-, d_2^-, d_3^-, d_4^-, d_5^-, d_6^-, d_7^-, d_8^-$, respectively, are negative deviations from the targets.

Constraints

$$\sum_{e=1}^{E}\sum_{w=1}^{W}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{s=1}^{S} t_{wrqs}x_{ewr}GH_{wrqs}D_{ew}pw_{wrqs}F + \left(d_1^- - d_1^+\right) = HD_1 \tag{2}$$

$$\sum_{e=1}^{E}\sum_{w=1}^{W}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{s=1}^{S} t_{wrqs}x_{ewr}GH_{wrqs}D_{ew}pw_{wrqs}CE_{es}F + \left(d_2^- - d_2^+\right) = HD_2 \tag{3}$$

The first goal constraint, Equation (2), aims to not exceed the carbon emission target value, as shown by HD_1. Conversion factors can vary according to factors such as fuel types and materials used. In this study, the carbon emissions released from the machines are calculated based on the energy consumption values of the machines. In Equation (3), the second goal constraint of the model, aims to not exceed the target value of the total carbon emission cost. This cost item varies depending on factors such as the power values of the machines, processing times, and part demands.

$$\sum_{e=1}^{E}\sum_{w=1}^{W}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{s=1}^{S} t_{wrqs}x_{ewr}N_{eqs}GH_{wrqs}D_{ew}O_{es} + \left(d_3^- - d_3^+\right) = HD_3 \tag{4}$$

Equation (4) aims to not exceed the target value of the total operation cost. The total operation cost is calculated according to factors such as part demands, part processing times, and the number of machines in the cell.

$$\sum_{e=1}^{E}\sum_{w=1}^{W}\sum_{r=1}^{R}\left[\left(\sum_{q=1}^{Q} z_{ewrq}\right) - 1\right]D_{ew}HA_{ew}x_{ewr} + \left(d_4^- - d_4^+\right) = HD_4 \tag{5}$$

$$\sum_{e=1}^{E}\sum_{q=1}^{Q}\sum_{i=1}^{I} V_{eqi}EM_{eqi} + \left(d_5^- - d_5^+\right) = HD_5 \tag{6}$$

Equation (5), the fourth goal constraint, aims to not pass over the target value of the total cost of movement between cells. The goal constraint indicated by Equation (6) aims to not pass over the target value of the total training cost of workers assigned to cells in each period.

$$\sum_{e=1}^{E}\sum_{q=1}^{Q}\sum_{s=1}^{S} NA_{eqs}NAC_{es} + \left(d_6^- - d_6^+\right) = HD_6 \tag{7}$$

$$\sum_{e=1}^{E}\sum_{q=1}^{Q}\sum_{s=1}^{S} NR_{eqs}NRC_{es} + \left(d_7^- - d_7^+\right) = HD_7 \tag{8}$$

Equations (7) and (8) are the goal constraints related to the total cost items generated during cell design. Equation (7) aims to not exceed the target value of total cost of the number of machines added to cells. Equation (8) aims to not exceed the target value of the total cost of the item associated with removing machines from cells.

$$\sum_{e=1}^{E}\sum_{q=1}^{Q}\sum_{i=1}^{I}\sum_{l=1}^{L} V_{eqi}IY_{il}B_l + \left(d_8^- - d_8^+\right) = HD_8 \tag{9}$$

Equation (9) aims to not exceed the target value of the total bonus wage that workers assigned to cells receive according to their abilities. In this study, the economic dimension of sustainability is also considered when designing the cells.

$$\sum_{r=1}^{R} x_{ewr} = 1 \forall e, w \tag{10}$$

In this study, it is assumed that the model has routing flexibility and each part has alternative routes. Equation (10) shows that the parts can choose only one of their alternative routes in each period.

$$\sum_{w=1}^{W}\sum_{r=1}^{R} z_{ewrq}x_{ewr} \geq 1 \forall e,q \tag{11}$$

$$\sum_{w=1}^{W}\sum_{r=1}^{R} t_{wrqs}x_{ewr}GH_{wrqs}D_{ew} \leq K_{es}N_{eqs} \forall e,q,s \tag{12}$$

Equation (11) shows that at least one part is processed in the selected route in each cell in each period. Equation (12) ensures that the machines cannot exceed their time capacity for each period and each cell.

$$\sum_{w=1}^{W}\sum_{r=1}^{R}\sum_{s=1}^{S} t_{wrqs}x_{ewr}GH_{wrqs}D_{ew}pw_{wrqs}F \leq LB_{\text{eq}} \forall e,q \tag{13}$$

Equation (13) shows that the total amount of carbon emissions for each cell in each period cannot exceed a limit value. With this constraint, the environmental dimension of sustainability for the cells is also regarded when designing the cells.

$$N_{e-1,qs} + NA_{eqs} - NR_{eqs} = N_{eqs} \forall e,q,s,e > 1 \tag{14}$$

$$\sum_{s=1}^{S} N_{eqs} \leq HUL_{eq} \forall e,q \tag{15}$$

$$\sum_{s=1}^{S} N_{eqs} \geq HAL_{eq} \forall e,q \tag{16}$$

In Equation (14), regarding cell design, the numbers of machine types in each cell in each period are calculated. The numbers of machine types in each cell are calculated considering that machines may be added to and removed from the cells in each period. Thus, the machine numbers and types change dynamically in each period. Equation (15) shows the upper limit value for the total number of machine types in each cell in each period. In Equation (16), the lower limit value of the total number of machine types for each cell is given.

$$\sum_{i=1}^{I} IY_{il}ES_{il}V_{eqi} \leq TES_{eql} \ \forall e,q,\ l \tag{17}$$

Equation (17) shows that in each period, in each cell and according to each skill, the total time spent by workers cannot exceed a certain limit value. With this constraint, workers are assigned to cells according to their abilities.

$$\sum_{i=1}^{I} V_{eqi} = IS_{eq} \forall e,q \tag{18}$$

$$\sum_{i=1}^{I} V_{eqi} \leq IK_{eq} \forall e,q \tag{19}$$

Equation (18) calculates the total number of workers assigned to each cell in each period. Equation (19) provides that the number of workers assigned to each cell in each period cannot exceed a particular limit value.

$$\sum_{q=1}^{Q} IS_{eq} = EIS_{e} \forall e \tag{20}$$

Equation (20) shows the total number of workers assigned to the cells in each period.

$$\sum_{q=1}^{Q} V_{eqi} \geq 1 \forall e, i \tag{21}$$

$$\sum_{i=1}^{I} IY_{il} V_{eqi} \leq HY_{eql} \forall e, q,\ l \tag{22}$$

$$\sum_{e=1}^{E} \sum_{q=1}^{Q} \sum_{l=1}^{L} V_{eqi} EST_{eil} = TA_i \forall i \tag{23}$$

$$x_{ewr} GH_{wrqs} \leq N_{eqs} \forall e, w, r, q, s \tag{24}$$

Equation (21) provides for the assignment of each worker to at least one cell in each period. Equation (22) shows that the total number of workers for each skill type in each cell for each period cannot exceed the limit value. The total training time received by each worker in all periods is calculated by Equation (23). With Equation (23), the social dimension of sustainability is also regarded when designing the cells. In Equation (24), if the part is produced on its alternative route in a period and the machine type and cell are available with the alternative route of the part, then there is at least one machine assignment to the cell in that period.

$$x_{ewr}, V_{eqi} \in \{0, 1\} \forall e, w, r,\ q, i \tag{25}$$

$$N_{eqs}, NA_{eqs}, NR_{eqs}, EIS_e, IS_{eq} \geq 0 \text{ and integer} \forall e, q, s \tag{26}$$

$$TA_i \geq 0 \forall i \tag{27}$$

$$d_1^+, d_2^+, d_3^+, d_4^+, d_5^+, d_6^+, d_7^+, d_8^+,\ d_1^-, d_2^-, d_3^-, d_4^-, d_5^-, d_6^-, d_7^-, d_8^- \geq 0 \tag{28}$$

0–1 binary decision variables are shown in Equation (25). Decision variables that are positive integers are represented by Equation (26). Equations (27) and (28) indicate that the total training time and the goal deviation values must be positive, respectively.

Linearization of the Model

The goal constraint, indicated by Equation (4), is non-linear due to the multiplication of the two decision variables. For this reason, the constraint in this article is made linear by using the binary-in-integer linearization technique mentioned by Mahdavi et al. [42].

The following new constraint expressions and a decision variable are considered to linearize the model:

$$xn_{ewrqs} = x_{ewr} N_{eqs} \tag{29}$$

$$xn_{ewrqs} \leq N_{eqs} \forall e, w, r, q, s \tag{30}$$

$$xn_{ewrqs} \leq x_{ewr} M\ \forall e, w, r, q, s \tag{31}$$

$$xn_{ewrqs} - N_{eqs} \geq (x_{ewr} - 1) M \forall e, w, r, q, s \tag{32}$$

$$xn_{ewrqs} \geq 0 \text{ and integer} \forall e, w, r, q, s \tag{33}$$

$$\sum_{e=1}^{E} \sum_{w=1}^{W} \sum_{r=1}^{R} \sum_{q=1}^{Q} \sum_{s=1}^{S} t_{wrqs} xn_{ewrqs} GH_{wrqs}\ D_{ew} O_{es} + \left(d_3^- - d_3^+\right) = HD_3 \tag{34}$$

M is a big enough number coefficient than the decision variables x_{ewr} and N_{eqs}. The model was made linear with the addition of new Equations (30)–(33), and thus Equation (34) is the edited version of Equation (4). That is, the new Equations (30)–(33) are added to the goal programming model and Equation (34) is added to the model instead of Equation (4).

3.3. Developed ε-Constraint Model

In the ε-constraint method, one of the multi-objective functions is considered as the primary objective function and the other objectives are converted into constraints by applying a limitation with an upper bound. Then, the ε_j level is changed to generate all Pareto solutions [40].

The ε-constraint problem formulation stated in Felfel et al. [40] is taken into account. The below equations are considered for the ε-constraint model in this study. The minimization of total cost items was assigned a relatively higher priority and is considered as a single objective function item in Equation (35).

$$\begin{aligned} MinSNC_2 \quad &= \sum_{e=1}^{E}\sum_{w=1}^{W}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{s=1}^{S} t_{wrqs}x_{ewr}GH_{wrqs}D_{ew}pw_{wrqs}CE_{es}F \\ &+\sum_{e=1}^{E}\sum_{w=1}^{W}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{s=1}^{S} t_{wrqs}xn_{ewrqs}GH_{wrqs}D_{ew}O_{es} \\ &+\sum_{e=1}^{E}\sum_{w=1}^{W}\sum_{r=1}^{R}\left[\left(\sum_{q=1}^{Q} z_{ewrq}\right)-1\right]D_{ew}HA_{ew}x_{ewr}+\sum_{e=1}^{E}\sum_{q=1}^{Q}\sum_{i=1}^{I} V_{eqi}EM_{eqi} \\ &+\sum_{e=1}^{E}\sum_{q=1}^{Q}\sum_{s=1}^{S} NA_{eqs}NAC_{es}+\sum_{e=1}^{E}\sum_{q=1}^{Q}\sum_{s=1}^{S} NR_{eqs}NRC_{es} \\ &+\sum_{e=1}^{E}\sum_{q=1}^{Q}\sum_{i=1}^{I}\sum_{l=1}^{L} V_{eqi}IY_{il}B_l \end{aligned} \tag{35}$$

The minimization of the total amount of carbon emissions is represented with SNC_1 and is shown in Equation (36). It was changed to an ε-constraint and thus, Equation (37) is subject to this constraint:

$$\sum_{e=1}^{E}\sum_{w=1}^{W}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{s=1}^{S} t_{wrqs}x_{ewr}GH_{wrqs}D_{ew}pw_{wrqs}F = SNC_1 \tag{36}$$

$$\sum_{e=1}^{E}\sum_{w=1}^{W}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{s=1}^{S} t_{wrqs}x_{ewr}GH_{wrqs}D_{ew}pw_{wrqs}F \le \varepsilon_1 \tag{37}$$

Equations (10)–(27), Equations (30)–(33), and Equations (35)–(37) are included in the ε-constraint model in this study.

3.4. Developed Augmented ε-Constraint Model (AUGMECON)

The AUGMECON method is a novel version of the classical ε-constraint method. This method suggests transforming the objective function constraints into equations by including the slack or surplus variables of the classical method [41].

The AUGMECON method improves the classical epsilon constraint method by employing lexicographic optimization to structure the payoff table in alignment with the desired priorities, subsequently optimizing the objective functions in accordance with these priorities. The lexicographic optimization initially focuses on optimizing the first objective function f_1, resulting in the optimal value z_1*. To maintain this optimality for the first objective function, a constraint is introduced, setting $f_1 = z_1$*, in a model dedicated to optimizing the second objective function. This process is iterated until each individual objective function has been separately optimized. To address another weakness of the epsilon constraint method, the objective function constraints are converted into equalities by introducing slack or surplus variables. The value of δ is a small number [43]. r_i is the range of the i-th objective function, which is determined based on the data in the payoff table [41].

The AUGMECON model formulation stated in Yadollahi et al. [43] was considered. In this study, the below equations are presented. As in the ε-constraint method, minimization of the total cost is considered as relatively important and modeled as a single objective function as shown in Equation (35). The expression SNC_2 represents the total cost and is shown in Equation (35). The minimization of the total amount of carbon emissions is represented with SNC_1. The expression indicated by SLV_1 is a slack or surplus variable in the model.

$$Min(SNC_2 - \delta * (SLV_1/r_1)) \tag{38}$$

$$s.t: \ SNC_1 + SLV_1 = \varepsilon_1 \tag{39}$$

$$SLV_1 \in R^+ \tag{40}$$

In this study, the value of δ is assumed to be 0.0001 as shown in Equation (38). In addition, Equations (10)–(27) and Equations (30)–(33) are included in the AUGMECON model. Additionally, Equations (36) and (38)–(40) are included in the AUGMECON model in this study.

The following Section 4 consists of the results and discussion, where the solution of the sample problem, obtained results, and corresponding sensitivity analyses are presented.

4. Results and Discussion

In this study, a sample problem was created to test the developed mathematical programming model and analyze its sensitivity. The processing time and power consumption of the machines in the cells according to the alternative routes are presented in Table A1 in Appendix A. Table A2 in Appendix A indicates part demands and part movement costs between cells of the sample problem in each planning period.

Figure 1 shows a schematic presentation of the flexible manufacturing cells created using Table A1. In this figure, for example, the flow in the system according to the alternate route 1 of part 1 can be seen.

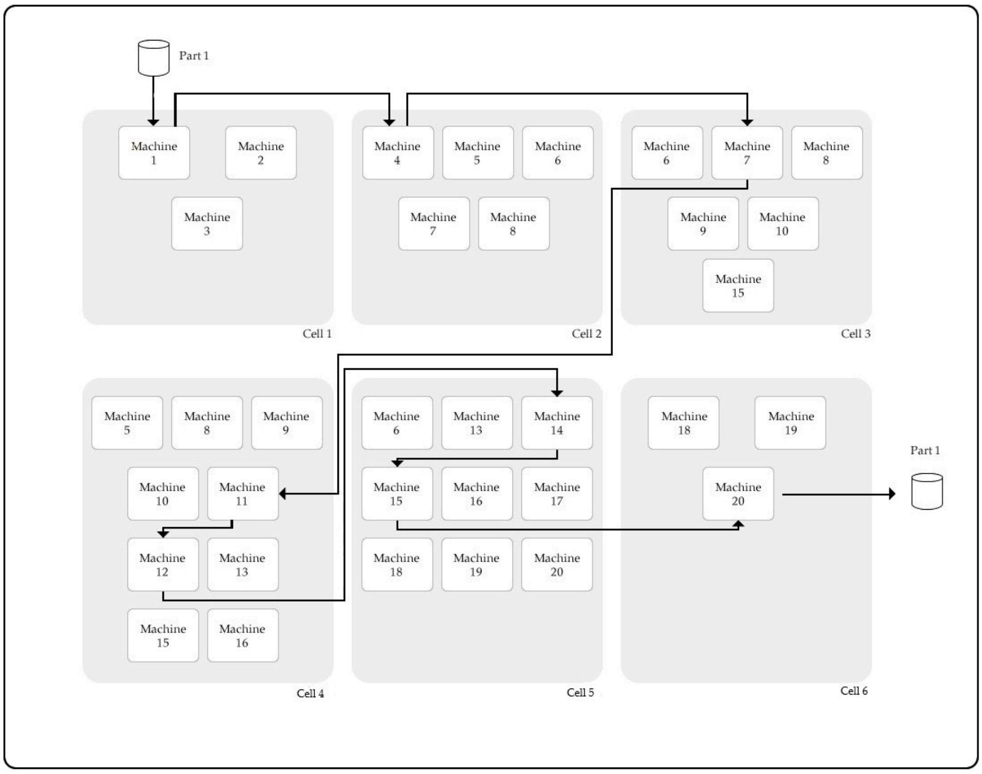

Figure 1. The schematic presentation of the flexible manufacturing cells.

Table 4 shows the time capacities of all machines in each period of the sample problem.

Table 4. Machine time capacities.

Machine	Capacity				
	1. Period	2. Period	3. Period	4. Period	5. Period
1	55,200	51,900	48,800	45,400	35,400
2	48,900	45,400	44,200	43,900	42,900
3	50,100	46,300	44,100	43,300	42,300
4	49,200	48,100	47,100	45,100	44,100
5	48,900	46,800	45,500	44,800	43,800
6	46,200	45,000	44,000	43,500	41,000
7	47,500	45,900	42,000	40,900	38,900
8	44,850	42,750	41,800	40,750	38,750
9	47,200	46,900	45,800	43,900	37,900
10	48,900	44,400	43,700	38,900	35,900
11	51,100	50,300	48,800	45,300	42,900
12	58,200	55,100	53,500	50,400	48,900
13	47,900	45,800	44,800	43,800	41,800
14	48,200	47,000	45,800	45,000	43,900
15	54,500	52,900	50,500	48,900	46,900
16	52,850	50,750	48,200	46,750	41,750
17	48,900	45,800	43,220	42,800	40,800
18	48,200	45,000	43,400	42,000	41,500
19	45,500	43,900	42,000	41,600	40,300
20	47,850	45,750	43,500	42,750	41,750

Table 5 presents the process/operation costs of all machines and carbon emission costs in each period of the sample problem. Table 6 indicates the costs associated with adding machines to the cells and removing machines from the cells in each period.

Table 5. Operation costs of all machines and carbon emission costs.

Machine	Operation Costs					Carbon Emission Costs				
	1. Period	2. Period	3. Period	4. Period	5. Period	1. Period	2. Period	3. Period	4. Period	5. Period
1	9	10	12	13	15	7	8	9	8	12
2	8	10	13	16	17	6	9	10	9	11
3	10	11	14	15	19	7	8	9	9	14
4	11	12	16	18	20	9	7	9	10	13
5	13	13	18	19	23	7	7	7	9	12
6	14	15	16	16	22	6	6	9	8	13
7	15	17	12	13	18	8	7	8	9	12
8	13	15	16	17	19	7	9	9	11	13
9	15	18	19	20	21	7	8	10	12	14
10	9	12	14	18	19	6	9	8	7	13
11	10	13	13	13	19	7	8	6	7	12
12	12	15	19	20	24	9	7	9	8	11
13	12	13	16	17	20	7	7	7	9	12
14	16	18	19	17	18	5	6	10	10	14
15	13	15	16	18	22	8	6	9	10	12
16	12	15	16	17	20	7	9	8	9	10
17	14	18	18	20	23	6	7	9	8	11
18	16	17	21	23	26	6	8	9	8	12
19	13	15	14	17	22	7	6	9	12	13
20	12	16	15	18	20	8	9	9	10	11

Table 6. Machine addition and removal costs.

Machine	Machine Addition Costs					Machine Removal Costs				
	1. Period	2. Period	3. Period	4. Period	5. Period	1. Period	2. Period	3. Period	4. Period	5. Period
1	25	45	30	40	49	55	46	40	45	55
2	55	30	35	38	48	75	55	50	55	58
3	45	35	30	38	51	45	55	50	55	59
4	65	62	45	49	59	65	62	65	75	78
5	48	63	50	59	65	48	75	70	75	79
6	55	55	55	60	63	65	55	55	65	75
7	40	56	50	55	65	60	65	60	65	69
8	50	63	60	60	66	45	50	55	65	70
9	25	45	45	55	58	55	46	40	45	55
10	55	30	35	38	48	75	55	50	55	58
11	45	35	42	43	53	45	55	55	58	65
12	65	62	40	60	65	65	62	60	65	70
13	48	63	45	65	68	48	75	70	73	75
14	55	55	50	50	55	65	55	50	54	60
15	40	56	55	59	63	60	65	60	63	65
16	50	63	60	63	65	45	50	70	74	75
17	48	63	60	65	68	48	75	45	48	55
18	55	55	50	55	65	65	55	55	58	60
19	40	56	55	55	65	60	65	60	65	70
20	50	63	60	65	70	45	50	55	58	70

In Table 7, the minimum and maximum number of machines, the maximum number of workers, and the carbon emission upper limit values of each cell for each period are indicated. In Table 8, the skill types of the workers and the time data pertaining to the amount of time workers spend according to these skill types are shown.

Table 7. Upper and lower limits for cells.

Period	Cell Machine Upper Limit						Cell Machine Lower Limit						Cell Worker Upper Limit						Cell Carbon Emission Upper Limit					
	Cell						Cell						Cell						Cell					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
1	5	5	4	4	4	5	1	1	1	1	1	1	4	4	4	4	4	4	365,100	376,400	397,500	425,100	376,400	377,500
2	5	5	4	5	5	4	1	1	1	1	1	1	4	4	4	4	4	4	375,000	388,500	387,000	395,000	438,500	377,000
3	5	5	4	5	5	4	1	1	1	1	1	1	4	4	4	4	4	4	385,000	354,000	350,000	405,000	415,000	357,800
4	5	5	4	5	5	4	1	1	1	1	1	1	4	4	4	4	4	4	395,000	364,000	390,000	425,000	435,000	387,800
5	4	4	5	4	5	4	1	1	1	1	1	1	4	4	4	4	4	4	355,000	334,000	370,000	405,000	405,000	357,800

Table 8. Worker–skill matrix and workers' skill durations.

Skill	Worker					
	I1	I2	I3	I4	I5	I6
1	1	0	1	0	0	1
2	1	1	0	0	1	0
3	0	0	1	1	0	0
Skill	**Worker**					
	I1	**I2**	**I3**	**I4**	**I5**	**I6**
1	5	0	2	0	0	3
2	4	8	0	0	7	0
3	0	0	3	9	0	0

The limit times that workers can spend in each cell in each period according to their skill types and training costs are shown in Table 9. Training times received by workers according to their skills are shown in Table 10.

Table 9. The limit values, the limit times of workers with skills, and the training costs.

	The Limit Value of Workers with Skills			The Limit Time of Workers with Skills			Training Cost of Workers					
	Skill			Skill			Workers					
1. Period	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**4**	**5**	**6**
Cell 1	1	2	0	25	20	0	50	65	75	45	35	70
Cell 2	2	2	1	15	30	25	30	80	55	65	35	25
Cell 3	2	0	3	35	0	30	33	65	78	40	25	30
Cell 4	1	2	0	25	20	0	40	75	45	35	35	70
Cell 5	2	2	1	15	30	25	30	80	65	55	35	25
Cell 6	2	0	3	35	0	30	38	65	78	40	25	30
2. Period	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**4**	**5**	**6**
Cell 1	3	2	0	20	15	0	50	65	75	45	35	70
Cell 2	1	3	0	40	25	0	30	80	55	65	35	25
Cell 3	2	1	2	35	40	25	33	65	78	40	25	30
Cell 4	3	2	0	20	15	0	40	75	45	35	35	70
Cell 5	1	3	0	40	25	0	30	80	65	55	35	25
Cell 6	2	1	2	35	40	25	38	65	78	40	25	30
3. Period	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**4**	**5**	**6**
Cell 1	3	2	0	20	15	0	50	65	75	45	35	70
Cell 2	1	3	0	40	25	0	30	80	55	65	35	25
Cell 3	2	1	2	35	40	25	33	65	78	40	25	30
Cell 4	3	2	0	20	15	0	40	75	45	35	35	70
Cell 5	1	3	0	40	25	0	30	80	65	55	35	25
Cell 6	2	1	2	55	45	35	38	65	78	40	25	30
4. Period	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**4**	**5**	**6**
Cell 1	4	3	0	30	35	0	60	75	85	55	45	75
Cell 2	2	3	0	50	35	0	35	70	65	75	55	35
Cell 3	3	2	3	45	40	25	39	65	75	45	35	35
Cell 4	4	2	0	30	35	0	45	78	48	55	45	80
Cell 5	3	3	0	45	35	0	35	85	75	59	45	35
Cell 6	4	2	3	40	50	35	40	75	80	50	30	40
5. Period	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**4**	**5**	**6**
Cell 1	1	1	0	22	17	0	40	55	70	40	30	65
Cell 2	2	2	1	13	20	20	25	70	50	60	30	20
Cell 3	2	0	3	30	0	25	30	60	70	35	20	25
Cell 4	1	2	0	20	20	0	38	65	40	30	33	68
Cell 5	2	2	1	13	25	27	28	70	60	50	30	23
Cell 6	2	0	2	30	0	25	35	60	75	35	20	28

The carbon emission conversion factor denoted by F is assumed as 0.426 kg/kWh. The bonus wages to be received by the workers according to each skill type are assumed as 900, 700, and 800 currency units, respectively. HD_1, HD_2, HD_3, HD_4, HD_5, HD_6, HD_7, and HD_8 are assumed as 600,000, 610,000, 535,000, 450,000, 8000, 5000, 5000, and 7000, respectively. Additionally, the M value is assumed to be 1000. The GH_{wrqs} parameter is derived based on the t_{wrqs} parameter found in Table A1 in Appendix A. It takes a value of 1 if there is an available machine process time for the alternative route r with machine s in cell q for part w; otherwise, it assumes a value of 0. z_{ewrq} is a parameter that is created according to periods and considers the machine processes in the cells according to the routes of the parts in Table A1 in Appendix A.

In this study, the LINGO 20.0 optimization program was employed to solve the multi-objective integer mathematical programming models, which addresses the design of sustainable and flexible manufacturing cells. The developed goal programming, ε-constraint, and AUGMECON mathematical programming models were solved separately using the LINGO 20.0 optimization program using a MacBook Air (M1, 2020) with 8 GB of RAM. The global optimal results were obtained in 12 min and 38 s, 18 min and 31 s, and 19 min and 51 s for the goal programming method, the ε-constraint method, and the AUGMECON method, respectively. In the results obtained in the goal programming model, the positive and negative deviation values from the related targets are obtained as $d_1^+ =$ 5,330,653, $d_2^+ =$ 52,162,290, $d_3^+ =$ 14,190,360, $d_4^+ =$ 3,317,127, $d_5^+ = 0$, $d_6^+ = 0$, $d_7^+ = 0$, $d_8^+ =$ 25,000, $d_1^- = 0$, $d_2^- = 0$, $d_3^- = 0$, $d_4^- = 0$, $d_5^- = 6413$, $d_6^- = 4506$, $d_7^- = 4613$, $d_8^- = 0$. Additionally, the objective function value of the goal programming model is obtained as 75,025,430. In Table A3 seen in Appendix B, the results related to optimal routes obtained from these three methods are presented separately. The optimal machine assignments results for the goal programming, ε-constraint, and AUGMECON methods are shown in Tables 11–13, respectively.

Table 10. Training times received by workers according to skills.

	Training Time According to Skill			
	Worker	Skill 1	Skill 2	Skill 3
1. Period	1	15	10	0
	2	0	15	0
	3	17	0	15
	4	0	0	11
	5	0	18	10
	6	18	0	0
	Worker	Skill 1	Skill 2	Skill 3
2. Period	1	10	8	0
	2	0	18	0
	3	17	0	13
	4	0	0	11
	5	0	13	0
	6	17	0	0
	Worker	Skill 1	Skill 2	Skill 3
3.Period	1	10	8	0
	2	0	13	0
	3	15	0	18
	4	0	0	12
	5	0	12	0
	6	23	0	0
	Worker	Skill 1	Skill 2	Skill 3
4.Period	1	15	17	0
	2	0	18	0
	3	22	0	13
	4	0	0	16
	5	0	16	0
	6	20	0	0
	Worker	Skill 1	Skill 2	Skill 3
5.Period	1	11	7	0
	2	0	16	0
	3	15	0	14
	4	0	0	10
	5	0	23	0
	6	15	0	0

Table 11. Optimal machine assignments for the goal programming.

Period	Cell	Optimal Machine Assignments	Optimal Machine Addition	Optimal Machine Removal
1	1	$N_{111}(1)$, $N_{112}(1)$, $N_{113}(1)$		
	2	$N_{124}(1)$, $N_{125}(1)$, $N_{126}(1)$		
	3	$N_{136}(1)$, $N_{137}(1)$, $N_{138}(1)$, $N_{139}(1)$		
	4	$N_{148}(1)$, $N_{1,4,11}(1)$, $N_{1,4,12}(1)$, $N_{1,4,15}(1)$		
	5	$N_{1,5,14}(1)$, $N_{1,5,15}(1)$, $N_{1,5,16}(1)$, $N_{1,5,17}(1)$		
	6	$N_{1,6,18}(1)$, $N_{1,6,19}(1)$, $N_{1,6,20}(1)$		
2	1	$N_{211}(1)$, $N_{212}(1)$, $N_{213}(1)$		
	2	$N_{224}(1)$, $N_{225}(1)$, $N_{226}(1)$		
	3	$N_{236}(1)$, $N_{237}(1)$, $N_{238}(1)$, $N_{239}(1)$		
	4	$N_{2,4,10}(1)$, $N_{2,4,11}(1)$, $N_{2,4,12}(1)$, $N_{2,4,13}(1)$, $N_{2,4,15}(1)$	$NA_{2,4,10}(1)$ $NA_{2,4,13}(1)$	$NR_{248}(1)$
	5	$N_{2,5,14}(1)$, $N_{2,5,15}(1)$, $N_{2,5,16}(1)$, $N_{2,5,17}(1)$		
	6	$N_{2,6,18}(1)$, $N_{2,6,19}(1)$, $N_{2,6,20}(1)$		
3	1	$N_{311}(1)$, $N_{312}(1)$, $N_{313}(1)$		
	2	$N_{324}(1)$, $N_{325}(1)$, $N_{326}(1)$		
	3	$N_{336}(1)$, $N_{337}(1)$, $N_{338}(1)$, $N_{339}(1)$		
	4	$N_{3,4,8}(1)$, $N_{3,4,10}(1)$, $N_{3,4,11}(1)$, $N_{3,4,12}(1)$, $N_{3,4,15}(1)$	$NA_{348}(1)$	$NR_{3,4,13}(1)$
	5	$N_{3,5,14}(1)$, $N_{3,5,15}(1)$, $N_{3,5,16}(1)$, $N_{3,5,17}(1)$		
	6	$N_{3,6,18}(1)$, $N_{3,6,19}(1)$, $N_{3,6,20}(1)$	$NA_{3,6,13}(1)$	
4	1	$N_{411}(1)$, $N_{412}(1)$, $N_{413}(1)$		
	2	$N_{424}(1)$, $N_{425}(1)$, $N_{426}(1)$, $N_{427}(1)$	$NA_{427}(1)$	
	3	$N_{436}(1)$, $N_{437}(1)$, $N_{438}(1)$, $N_{439}(1)$		
	4	$N_{4,4,10}(1)$, $N_{4,4,11}(1)$, $N_{4,4,12}(1)$, $N_{4,4,13}(1)$, $N_{4,4,15}(1)$	$NA_{4,4,13}(1)$	$NR_{448}(1)$
	5	$N_{4,5,14}(1)$, $N_{4,5,15}(1)$, $N_{4,5,16}(1)$, $N_{4,5,17}(1)$, $N_{4,5,18}(1)$	$NA_{4,5,18}(1)$	
	6	$N_{4,6,18}(1)$, $N_{4,6,19}(1)$, $N_{4,6,20}(1)$		
5	1	$N_{511}(1)$, $N_{512}(1)$, $N_{513}(1)$, $N_{5,1,14}(1)$	$NA_{5,1,14}(1)$	
	2	$N_{524}(1)$, $N_{525}(1)$, $N_{526}(1)$		$NR_{527}(1)$
	3	$N_{536}(1)$, $N_{537}(1)$, $N_{538}(1)$, $N_{539}(1)$		
	4	$N_{548}(1)$, $N_{5,4,11}(1)$, $N_{5,4,12}(1)$, $N_{5,4,15}(1)$	$NA_{548}(1)$	$NR_{5,4,10}(1)$ $NR_{5,4,13}(1)$
	5	$N_{5,5,14}(1)$, $N_{5,5,15}(1)$, $N_{5,5,16}(1)$, $N_{5,5,17}(1)$, $N_{5,5,18}(1)$		
	6	$N_{5,6,13}(1)$, $N_{5,6,18}(1)$, $N_{5,6,19}(1)$, $N_{5,6,20}(1)$		

Table 12. Optimal machine assignments for the ε-constraint method.

Period	Cell	Optimal Machine Assignments	Optimal Machine Addition	Optimal Machine Removal
1	1	$N_{111}(1)$, $N_{112}(1)$, $N_{113}(1)$		
	2	$N_{124}(1)$, $N_{125}(1)$, $N_{126}(1)$, $N_{127}(1)$		
	3	$N_{136}(1)$, $N_{137}(1)$, $N_{138}(1)$, $N_{139}(1)$		
	4	$N_{1,4,11}(1)$, $N_{1,4,12}(1)$, $N_{1,4,13}(1)$, $N_{1,4,15}(1)$		
	5	$N_{1,5,14}(1)$, $N_{1,5,15}(1)$, $N_{1,5,16}(1)$, $N_{1,5,17}(1)$		
	6	$N_{1,6,18}(1)$, $N_{1,6,19}(1)$, $N_{1,6,20}(1)$		
2	1	$N_{211}(1)$, $N_{212}(1)$, $N_{213}(1)$		
	2	$N_{224}(1)$, $N_{225}(1)$, $N_{226}(1)$, $N_{227}(1)$		
	3	$N_{236}(1)$, $N_{237}(1)$, $N_{238}(1)$, $N_{239}(1)$		
	4	$N_{2,4,10}(1)$, $N_{2,4,11}(1)$, $N_{2,4,12}(1)$, $N_{2,4,13}(1)$, $N_{2,4,15}(1)$	$NA_{2,4,10}(1)$	
	5	$N_{2,5,14}(1)$, $N_{2,5,15}(1)$, $N_{2,5,16}(1)$, $N_{2,5,17}(1)$		
	6	$N_{2,6,18}(1)$, $N_{2,6,19}(1)$, $N_{2,6,20}(1)$		
3	1	$N_{311}(1)$, $N_{312}(1)$, $N_{313}(1)$		
	2	$N_{324}(1)$, $N_{325}(1)$, $N_{326}(1)$, $N_{327}(1)$		
	3	$N_{336}(1)$, $N_{337}(1)$, $N_{338}(1)$, $N_{339}(1)$		
	4	$N_{3,4,8}(1)$, $N_{3,4,10}(1)$, $N_{3,4,11}(1)$, $N_{3,4,12}(1)$, $N_{3,4,15}(1)$	$NA_{3,4,8}(1)$	$NR_{3,4,13}(1)$
	5	$N_{3,5,14}(1)$, $N_{3,5,15}(1)$, $N_{3,5,16}(1)$, $N_{3,5,17}(1)$		
	6	$N_{3,6,18}(1)$, $N_{3,6,19}(1)$, $N_{3,6,20}(1)$		
4	1	$N_{411}(1)$, $N_{412}(1)$, $N_{413}(1)$		
	2	$N_{424}(1)$, $N_{425}(1)$, $N_{426}(1)$, $N_{427}(1)$		
	3	$N_{436}(1)$, $N_{437}(1)$, $N_{438}(1)$, $N_{439}(1)$		
	4	$N_{4,4,10}(1)$, $N_{4,4,11}(1)$, $N_{4,4,12}(1)$, $N_{4,4,13}(1)$, $N_{4,4,15}(1)$	$NA_{4,4,13}(1)$	$NR_{4,4,8}(1)$
	5	$N_{4,5,14}(1)$, $N_{4,5,15}(1)$, $N_{4,5,16}(1)$, $N_{4,5,17}(1)$		
	6	$N_{4,6,18}(1)$, $N_{4,6,19}(1)$, $N_{4,6,20}(1)$		
5	1	$N_{511}(1)$, $N_{512}(1)$, $N_{513}(1)$		
	2	$N_{524}(1)$, $N_{525}(1)$, $N_{526}(1)$, $N_{527}(1)$		
	3	$N_{536}(1)$, $N_{537}(1)$, $N_{538}(1)$, $N_{539}(1)$		
	4	$N_{548}(1)$, $N_{5,4,11}(1)$, $N_{5,4,12}(1)$, $N_{5,4,15}(1)$	$NA_{548}(1)$	$NR_{5,4,10}(1)$ $NR_{5,4,13}(1)$
	5	$N_{5,5,14}(1)$, $N_{5,5,15}(1)$, $N_{5,5,16}(1)$, $N_{5,5,17}(1)$		
	6	$N_{5,6,18}(1)$, $N_{5,6,19}(1)$, $N_{5,6,20}(1)$		

Table 13. Optimal machine assignments for the AUGMECON method.

Period	Cell	Optimal Machine Assignments	Optimal Machine Addition	Optimal Machine Removal
1	1	$N_{111}(1), N_{112}(1), N_{113}(1)$		
	2	$N_{124}(1), N_{125}(1), N_{126}(1)$		
	3	$N_{136}(1), N_{137}(1), N_{138}(1), N_{139}(1)$		
	4	$N_{1,4,11}(1), N_{1,4,12}(1), N_{1,4,13}(1), N_{1,4,15}(1)$		
	5	$N_{1,5,14}(1), N_{1,5,15}(1), N_{1,5,16}(1), N_{1,5,17}(1)$		
	6	$N_{1,6,18}(1), N_{1,6,19}(1), N_{1,6,20}(1)$		
2	1	$N_{211}(1), N_{212}(1), N_{213}(1)$		
	2	$N_{224}(1), N_{225}(1), N_{226}(1)$		
	3	$N_{236}(1), N_{237}(1), N_{238}(1), N_{239}(1)$		
	4	$N_{2,4,10}(1), N_{2,4,11}(1), N_{2,4,12}(1), N_{2,4,13}(1), N_{2,4,15}(1)$	$NA_{2,4,10}(1)$	
	5	$N_{2,5,14}(1), N_{2,5,15}(1), N_{2,5,16}(1), N_{2,5,17}(1)$		
	6	$N_{2,6,18}(1), N_{2,6,19}(1), N_{2,6,20}(1)$		
3	1	$N_{311}(1), N_{312}(1), N_{313}(1)$		
	2	$N_{324}(1), N_{325}(1), N_{326}(1)$		
	3	$N_{336}(1), N_{337}(1), N_{338}(1), N_{339}(1)$		
	4	$N_{3,4,8}(1), N_{3,4,10}(1), N_{3,4,11}(1), N_{3,4,12}(1), N_{3,4,15}(1)$	$NA_{3,4,8}(1)$	$NR_{3,4,13}(1)$
	5	$N_{3,5,14}(1), N_{3,5,15}(1), N_{3,5,16}(1), N_{3,5,17}(1)$		
	6	$N_{3,6,18}(1), N_{3,6,19}(1), N_{3,6,20}(1)$		
4	1	$N_{411}(1), N_{412}(1), N_{413}(1)$		
	2	$N_{424}(1), N_{425}(1), N_{426}(1)$		
	3	$N_{436}(1), N_{437}(1), N_{438}(1), N_{439}(1)$		
	4	$N_{4,4,8}(1), N_{4,4,10}(1), N_{4,4,11}(1), N_{4,4,12}(1), N_{4,4,15}(1)$		
	5	$N_{4,5,14}(1), N_{4,5,15}(1), N_{4,5,16}(1), N_{4,5,17}(1)$		
	6	$N_{4,6,18}(1), N_{4,6,19}(1), N_{4,6,20}(1)$		
5	1	$N_{511}(1), N_{512}(1), N_{513}(1)$		
	2	$N_{524}(1), N_{525}(1), N_{526}(1)$		
	3	$N_{536}(1), N_{537}(1), N_{538}(1), N_{539}(1)$		
	4	$N_{5,4,8}(1), N_{5,4,11}(1), N_{5,4,12}(1), N_{5,4,15}(1)$		$NR_{5,4,10}(1)$
	5	$N_{5,5,14}(1), N_{5,5,15}(1), N_{5,5,16}(1), N_{5,5,17}(1)$		
	6	$N_{5,6,18}(1), N_{5,6,19}(1), N_{5,6,20}(1)$		

The optimal worker assignments for multi-objective approaches are shown in Table 14. In Table 15, the number of workers in cell q in the period e is shown for each multi-objective approach. Moreover, for each multi-objective approach it was determined that $EIS_1 = 6$, $EIS_2 = 6$, $EIS_3 = 6$, $EIS_4 = 6$, $EIS_5 = 6$, $TA_1 = 111$, $TA_2 = 80$, $TA_3 = 159$, $TA_4 = 60$, $TA_5 = 82$, and $TA_6 = 93$.

Table 14. Optimal worker assignments to cells for each period for the multi-objective approaches.

Period	Optimal Worker Assignment for Goal Programming	Optimal Worker Assignment for ε-Constraint	Optimal Worker Assignment for AUGMECON
1	$V_{111}, V_{112}, V_{146}, V_{155}, V_{163}, V_{164}$	$V_{112}, V_{121}, V_{123}, V_{155}, V_{156}, V_{164}$	$V_{112}, V_{121}, V_{123}, V_{155}, V_{156}, V_{164}$
2	$V_{241}, V_{233}, V_{234}, V_{246}, V_{252}, V_{255}$	$V_{226}, V_{232}, V_{233}, V_{234}, V_{251}, V_{265}$	$V_{226}, V_{232}, V_{233}, V_{234}, V_{251}, V_{265}$
3	$V_{333}, V_{334}, V_{341}, V_{346}, V_{352}, V_{355}$	$V_{326}, V_{332}, V_{333}, V_{334}, V_{351}, V_{365}$	$V_{326}, V_{332}, V_{333}, V_{334}, V_{351}, V_{365}$
4	$V_{421}, V_{422}, V_{425}, V_{426}, V_{433}, V_{434}$	$V_{421}, V_{426}, V_{432}, V_{433}, V_{434}, V_{465}$	$V_{421}, V_{426}, V_{432}, V_{433}, V_{434}, V_{465}$
5	$V_{512}, V_{521}, V_{525}, V_{563}, V_{564}, V_{566}$	$V_{512}, V_{521}, V_{523}, V_{525}, V_{556}, V_{564}$	$V_{512}, V_{521}, V_{523}, V_{525}, V_{556}, V_{564}$

Table 15. Optimal number of workers in cells for each period for the multi-objective approaches.

Period	Optimal Total Worker for Goal Programming	Optimal Total Worker for ε-Constraint	Optimal Total Worker for AUGMECON
1	$IS_{11}(2), IS_{12}(0), IS_{13}(0), IS_{14}(1), IS_{15}(1), IS_{16}(2)$	$IS_{11}(1), IS_{12}(2), IS_{13}(0), IS_{14}(0), IS_{15}(2), IS_{16}(1)$	$IS_{11}(1), IS_{12}(2), IS_{13}(0), IS_{14}(0), IS_{15}(2), IS_{16}(1)$
2	$IS_{21}(0), IS_{22}(0), IS_{23}(2), IS_{24}(2), IS_{25}(2), IS_{26}(0)$	$IS_{21}(0), IS_{22}(1), IS_{23}(3), IS_{24}(0), IS_{25}(1), IS_{26}(1)$	$IS_{21}(0), IS_{22}(1), IS_{23}(3), IS_{24}(0), IS_{25}(1), IS_{26}(1)$
3	$IS_{31}(0), IS_{32}(0), IS_{33}(2), IS_{34}(2), IS_{35}(2), IS_{36}(0)$	$IS_{31}(0), IS_{32}(1), IS_{33}(3), IS_{34}(0), IS_{35}(1), IS_{36}(1)$	$IS_{31}(0), IS_{32}(1), IS_{33}(3), IS_{34}(0), IS_{35}(1), IS_{36}(1)$
4	$IS_{41}(0), IS_{42}(4), IS_{43}(2), IS_{44}(0), IS_{45}(0)$ $IS_{46}(0)$	$IS_{41}(0), IS_{42}(2), IS_{43}(3), IS_{44}(0), IS_{45}(0), IS_{46}(1)$	$IS_{41}(0), IS_{42}(2), IS_{43}(3), IS_{44}(0), IS_{45}(0), IS_{46}(1)$
5	$IS_{51}(1), IS_{52}(2), IS_{53}(0), IS_{54}(0), IS_{55}(0)$ $IS_{56}(3)$	$IS_{51}(1), IS_{52}(3), IS_{53}(0), IS_{54}(0), IS_{55}(1), IS_{56}(1)$	$IS_{51}(1), IS_{52}(3), IS_{53}(0), IS_{54}(0), IS_{55}(1), IS_{56}(1)$

When calculating ε values, the minimum objective function values were obtained for each objective function; hence, the calculated pay-off table for the ε-constraint method is shown in Table 16. The epsilon values for the ε-constraint method are taken between these ε_1 = 5,958,372, . . ., 5,910,828 ranges. The calculated lexicographic optimization pay-off table for the AUGMECON method is shown in Table 17. In the AUGMECON model, the value of r_1 is 45,157. The epsilon values for the AUGMECON method are taken between these ε_1= 5,966,694, . . ., 5,929,064 ranges.

Table 16. Pay-off table for the ε-constraint method.

	SNC_1	SNC_2
Min SNC_1	**5,902,903**	72,492,480
Min SNC_2	5,974,220	**71,788,790**

Table 17. Pay-off table with the lexicographic optimization for the AUGMECON method.

	SNC_1	SNC_2
Min SNC_1	**5,929,063**	**71,788,790**
Min SNC_2	5,974,220	**71,788,790**

The Pareto optimal front graph obtained by using epsilon values in the ε-constraint method is presented in Figure 2.

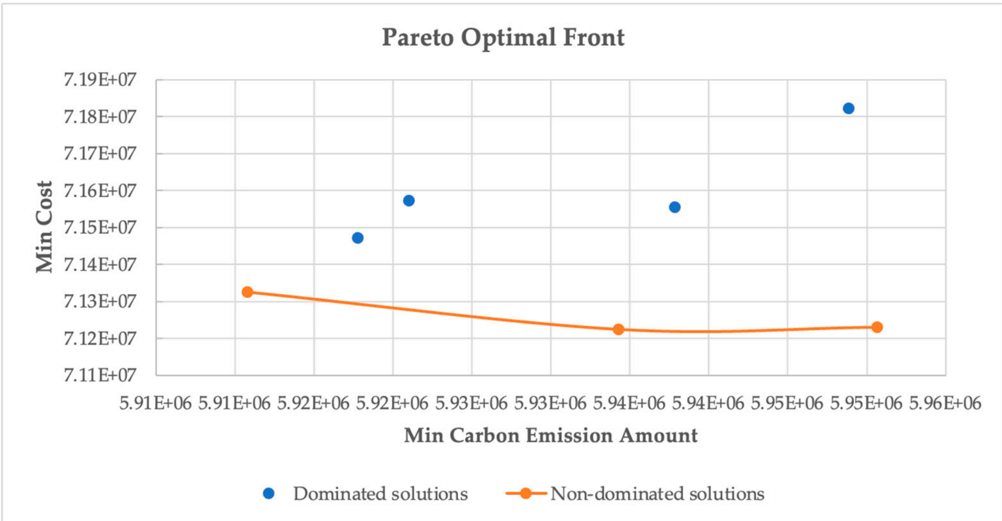

Figure 2. Pareto front for the ε-constraint method.

The following section presents the obtained results from the analyses.

Sensitivity Analyses

Sensitivity analyses were conducted to evaluate the impact of some parameters on the objective function value in the sample problem. The analyses were performed for the three developed multi-objective models: the goal programming, the ε-constraint, and the AUGMECON methods. Firstly, a sensitivity analysis is conducted using the goal programming method to examine the impact of changes in part demands. The results of the analysis are depicted in Figure 3, which illustrates the effect of a 10% decrease in demand for each period individually. For instance, in the first period, the demand value for part 1 is 150, and thus, for the purpose of this analysis, the demand for part 1 is considered as 135. Similarly, the analysis considers a 10% decrease in demand for each part in every period. The impact of percentage changes in part demand values on the cost items of the objective function was evaluated using the goal programming method, and the results are presented in Figure 4. When there is an increase in demand for parts, the costs related to carbon emission, operation, inter-cellular movement, and adding and removing machines are higher than in their current situations. It can be observed in Figure 4 that an increase in part demand does not cause any change in worker training cost and bonus wage items. Raoofpanah et al. [22] examine the effect of changes in demand on costs related to cell formation, inventory, and environmental issues. They state that cell formation costs are more sensitive to changes in demand compared with the other two costs.

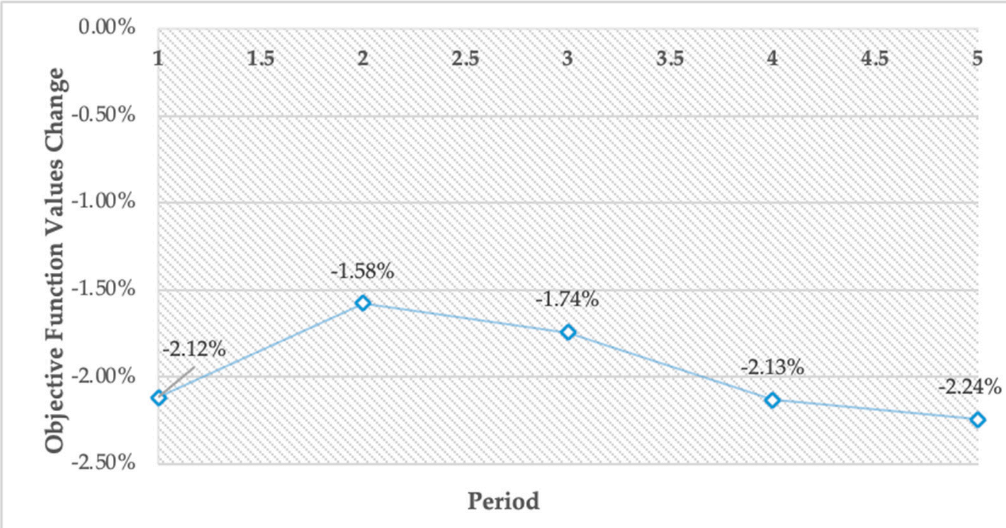

Figure 3. The impact of part demand changes using the goal programming method.

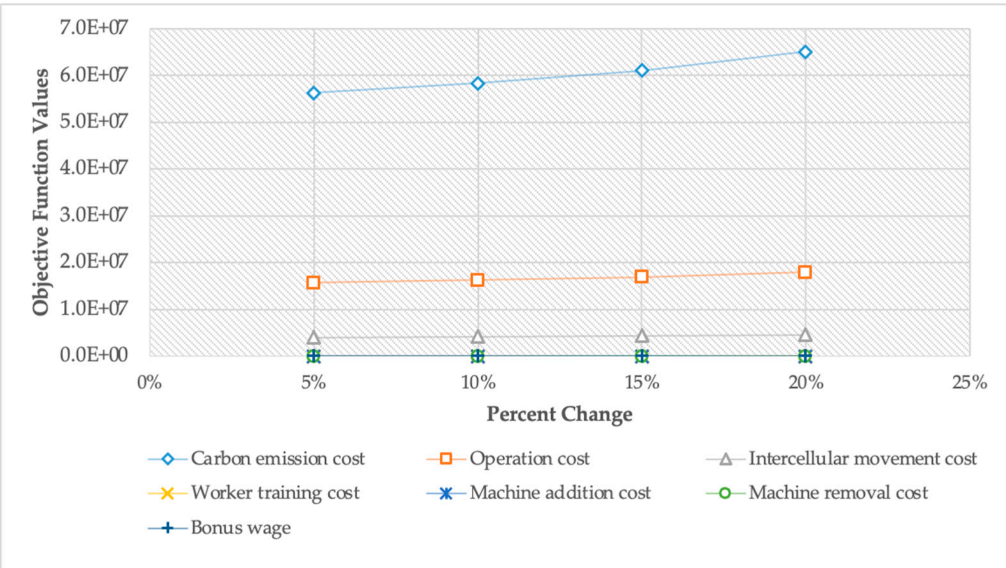

Figure 4. The effect of the increase in demand for parts on the values of cost items using the goal programming method.

Changes in the capacity values of the machines may affect the objective function values of the model. For example, Figure 5 illustrates the analysis of the impact of a 10% increase in capacity value of machine 1 in period 5 on both the carbon emission amount and total cost, which are objective functions, using the ε-constraint method and hence epsilon values. The 10% increase mentioned here is applied for only period 5. In the fifth period, the capacity of machine 1, whose capacity value is 35,400, is analyzed as 38,940 by considering a 10% increase in its capacity. Table 18 shows the status numbers corresponding to the epsilon values for the analysis of change in machine 1 capacity in period 5. The analysis shows that the change in the machine capacity first increases and then decreases the amount of carbon emissions.

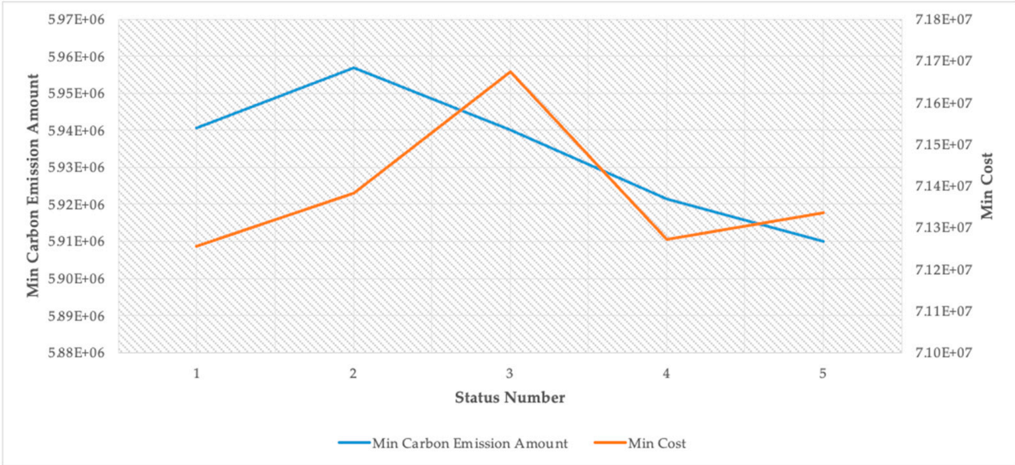

Figure 5. Machine capacity value change for the ε-constraint method.

Table 18. Status numbers regarding epsilon values using the ε-constraint method for the analysis of change in machine 1 capacity in period 5.

Status Number	1	2	3	4	5
Epsilon Value	5,977,181	5,958,612	5,940,043	5,921,474	5,902,905

Objective function values of the model may be affected by alterations in carbon limit values. For instance, Figure 6 shows the impact of a 10% increase in the carbon limit value for cell 6 in the fifth period on both the amount of carbon emission and the total cost. The analysis examines the influence of increasing the carbon limit value on emission amount and total cost using the ε-constraint method and hence epsilon values. In the fifth period of cell number 6, the carbon emission limit value of 357,800 is investigated as 393,580 due to a 10% increment. Table 19 indicates the status numbers regarding the epsilon values for the analysis of change in the carbon limit value for cell 6 in the period 5. As can be seen in the figure, with the increase in carbon emission limit value, the objective functions related to the cost and carbon emission amounts initially show an increase. Then, it is seen that the cost and carbon emission amounts decrease.

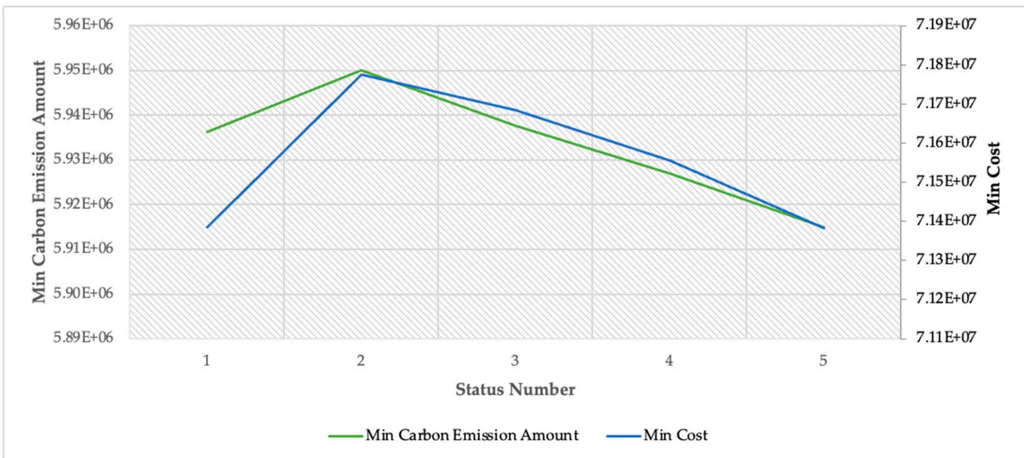

Figure 6. Carbon limit value change for the ε-constraint method.

Table 19. Status number regarding the epsilon value using the ε-constraint method for the analysis of change in the carbon limit value for cell 6 in period 5.

Status Number	1	2	3	4	5
Epsilon Value	5,963,143	5,951,103	5,939,063	5,927,023	5,914,983

Figure 7 shows the effect on objective functions by changing the maximum number of workers that can be assigned to cells in each period. In the current situation, the maximum number of workers that can be assigned to each cell in each period is taken as four. For this analysis the maximum number of workers for six cells are assumed as 6, 5, 5, 5, 6, and 6 in the first period, 5, 6, 5, 5, 6, and 4 in the second period, 5, 5, 6, 5, 6, and 5 in the third period, 6, 6, 5, 6, 5, and 6 in the fourth period, and 5, 5, 4, 6, 6, and 6 in the fifth period, respectively. The status numbers corresponding to the epsilon values for the analysis of change in the maximum number of workers that can be assigned to cells in each period are shown in Table 20. As seen in Figure 7, the analysis shows that the change in the maximum number of workers leads to a gradual decrease in the amount of carbon emissions.

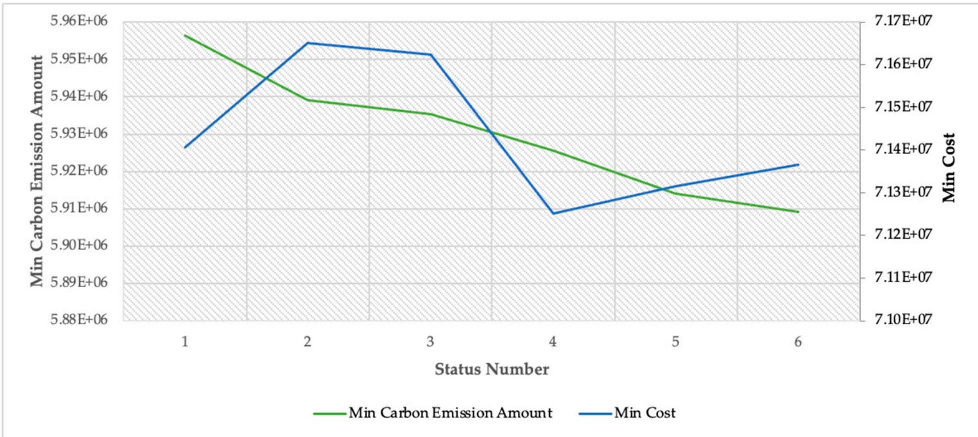

Figure 7. Maximum number of workers in the cell change process for the ε-constraint method.

Table 20. Status number regarding the epsilon value using the ε-constraint method for the analysis of change in the maximum number of workers.

Status Number	1	2	3	4	5	6
Epsilon Value	5,959,367	5,948,075	5,936,783	5,925,491	5,914,199	5,909,193

Alterations in carbon limit values can affect the objective function values of the model. For example, Figure 8 illustrates a 10% increase in carbon limit value for cell 6 in period 5 using the AUGMECON method. Table 21 shows the status numbers regarding the epsilon values using the AUGMECON method for the analysis of change in carbon limit value for cell 6 in the fifth period. As seen in Figure 8, the analysis shows that the change in carbon limit value for cell 6 in period 5 causes a decrease in the amount of carbon emissions.

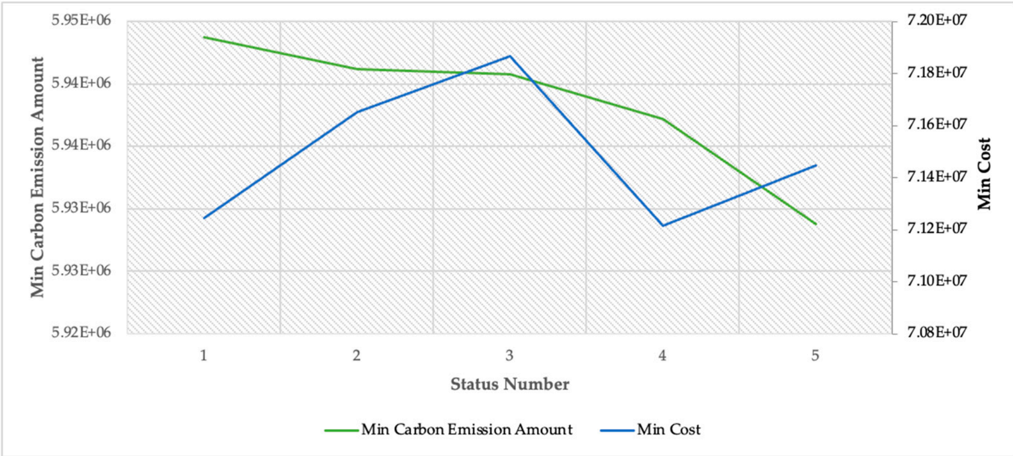

Figure 8. Carbon limit value change for the AUGMECON method.

Table 21. Status number regarding the epsilon value using the AUGMECON method for the analysis of change in the carbon limit value for cell 6 in period 5.

Status Number	**1**	**2**	**3**	**4**	**5**
Epsilon Value	5,962,379	5,953,925	5,945,771	5,937,417	5,929,064

The objective functions of the model can be affected by changes in machine capacity values. For instance, Figure 9 displays the impact of a 10% increase in the capacity values of machine 3 in period 3. The status numbers regarding the epsilon values using the AUGMECON method for the analysis of change in machine 3 capacity in period 3 are indicated in Table 22. As seen in Figure 9, in the analysis, as the machine capacity changes, the carbon emission amount value, which is the objective function, first increases and then decreases.

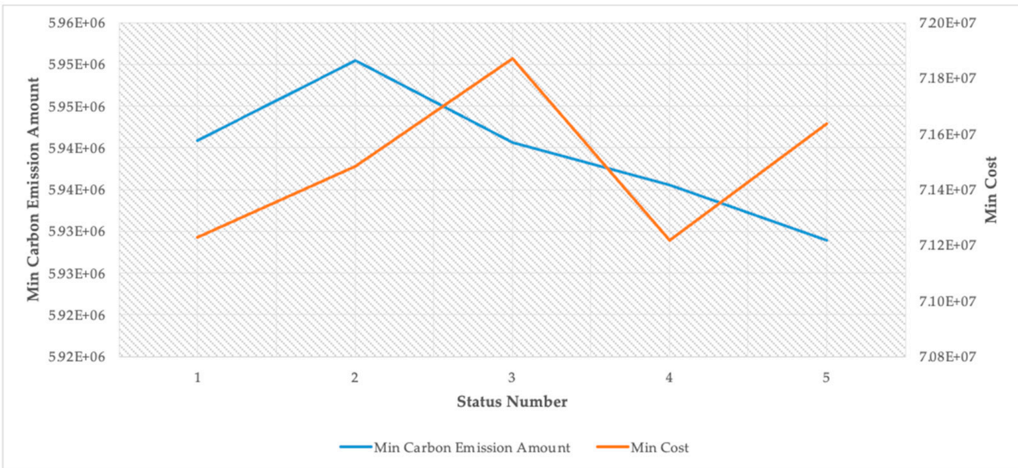

Figure 9. Machine capacity value change for the AUGMECON method.

Table 22. Status number regarding epsilon value using the AUGMECON method for the analysis of change in machine 3 capacity in period 3.

Status Number	**1**	**2**	**3**	**4**	**5**
Epsilon Value	5,965,359	5,955,535	5,945,711	5,935,887	5,929,064

5. Conclusions and Future Studies

In this study, three multi-objective mathematical programming models were presented that focus on the design of flexible manufacturing cells while incorporating sustainable factors. The study considers economic, environmental, and social dimensions, which are the three key dimensions of sustainability, by including various parameters. By considering these dimensions, this study aimed to develop the design of flexible manufacturing cells within a sustainable framework. In addition to minimizing the number of carbon emissions within the scope of the environmental dimension, this study aimed to minimize various cost items considering carbon emissions, inter-cellular movement, machine replacement, machine operation, worker training, and bonus wages for workers as the economic dimension. The total training time received by each worker in all periods is shown as a constraint in the model within the scope of the social dimension. Since the study involves multi-objectives, the identified problem is modeled using multi-objective optimization techniques. Firstly, the goal programming model related to the problem was developed. Then, the ε-constraint and AUGMECON models for the examined problem were presented. In all developed multi-objective models, various decision variables were considered to optimize the flexible manufacturing cells. They cover the decision variables such as determining the optimal routes between the alternative routes of parts, the number of machines to be added to or removed from cells, the number of workers assigned to cells, and the total training time of workers. In this study, all the developed multi-objective mathematical programming models were solved using the LINGO 20.0 optimization program on the developed sample problem. These global optimal solutions were reached in 12 min and 38 s, 18 min and 31 s, and 19 min and 51 s for the goal programming method, the ε-constraint method, and the AUGMECON method, respectively. When the results obtained from each of the developed multi-objective optimization models were examined, it was observed that the decision variables regarding determining optimal routes of parts, assigning optimal machines to cells, adding them to cells, and removing them from cells provide different results. While the ε-constraint and AUGMECON models provided the same results in the optimal worker assignments and the optimal number of workers in cells for each period, the goal programming model provided different results. The decision variables of the total number of workers in the system in each period and the total training times received by workers provided the same results for all developed models. The results were tested by performing sensitivity analyzes for each developed multi-objective optimization model.

In future studies, metaheuristic algorithms can be proposed to solve larger-scale problems in the context of sustainable manufacturing systems. Additionally, the consideration of parameters such as machining times and demands such as fuzzy variables can enhance modeling capabilities and address uncertainties in real-world scenarios. Furthermore, the development of a decision support system specifically designed for modeling sustainable manufacturing systems holds the potential to yield valuable insights for making informed decisions.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Alternative routes of parts, machine process time, and power consumption.

Part	Route	Cell–Machine (Operating Time)/(Machine Power Amount)
1	1	Q1-S1(9)/PW(14) Q2-S4(4)/PW(15) Q3-S7(6)/PW(13) Q4-S11(3)/PW(14)-S12(7)/PW(17) Q5-S14(7)/PW(18)-S15(5)/PW(14) Q6-S20(8)/PW(18)
	2	Q1-S2(6)/PW(13)-S3(5)/PW(15) Q2-S5(7)/PW(17) Q4-S11(7)/PW(19)-S12(8)/PW(17)-S13(4)/PW(15) Q5-S14(9)/PW(18)-S15(4)/PW(14) Q6-S18(5)/PW(14) Q6-S20(7)/PW(18)
	3	Q1-S1(6)/PW(16)-S2(9)/PW(19)-S3(4)/PW(14) Q3-S8(2)/PW(22) Q4-S12(9)/PW(19)-S13(6)/PW(26) Q5-S14(8)/PW(18)-S15(4)/PW(24) Q6-S18(9)/PW(19)-S20(8)/PW(18)
	4	Q1-S1(11)/PW(19)-S2(6)/PW(18)-S3(5)PW(25) Q2-S5(5)/PW(25) Q4-S11(8)/PW(19)-S12(5)/PW(24)-S13(5)/PW(15) Q5-S14(5)/PW(23) Q5-S15(4)/PW(24) Q6-S20(8)/PW(18)
	5	Q1-S1(8)/PW(16)-S2(5)/PW(19)-S3(4)/PW(24) Q3-S8(8)/PW(16) Q4-S12(9)/PW(19)-S13(6)/PW(16) Q5-S14(7)/PW(18)-S15(4)/PW(24) Q6-S18(8)/PW(19)-S20(5)/PW(18)
2	1	Q1-S3(8)/PW(18) Q2-S6(5)/PW(15) Q3-S7(4)/PW(14) Q4-S9(8)PW(14)-S10(6)/PW(15) Q5-S13(7)/PW(18)-S14(9)/PW(19) Q6-S19(4)/PW(24)
	2	Q1-S1(6)/PW(20) Q2-S6(7)/PW(18) Q4-S11(8)/PW(18)-S13(5)/PW(23) Q5-S14(6)/PW(27) Q6-S18(8)/PW(18)-S19(3)/PW(22)
	3	Q1-S2(5)/PW(25)-S3(3)/PW(23) Q2-S6(6)/PW(16) Q3-S7(4)/PW(24)-S8(7)/PW(17) Q4-S8(8)/PW(8) Q5-S16(4)/PW(14) Q6-S20(7)/PW(17)
	4	Q1-S1(8)/PW(18)-S2(9)/PW(17)-S3(3)/PW(23) Q2-S6(8)/PW(8) Q4-S11(8)/PW(8)-S13(3)/PW(23) Q5-S14(7)/PW(17) Q6-S18(8)/PW(18)-S19(3)/PW(22)
	5	Q1-S2(5)/PW(15)-S3(3)/PW(23) Q3-S7(5)/PW(24)-S8(7)/PW(17) Q4-S8(7)/PW(18) Q5-S15(5)/PW(25)-S16(4)/PW(24) Q6-S20(9)/PW(17)
3	1	Q1-S1(9)/PW(12)-S3(4)/PW(14) Q2-S6(6)/PW(17) Q4-S10(5)/PW(17)-S12(4)/PW(22) Q5-S15(5)/PW(18) Q6-S19(7)/PW(14)-S20(6)/PW(15)
	2	Q1-S1(2)/PW(23) Q2-S4(5)/PW(15)-S5(7)/PW(18) Q3-S8(6)/PW(26) Q5-S16(4)/PW(24) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(7)/PW(17)-S2(5)/PW(21)-S3(3)/PW(13) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(5)/PW(23)-S2(7)/PW(17) Q2-S4(1)/PW(19)-S5(6)/PW(18) Q3-S8(5)/PW(16)-S9(6)/PW(16) Q6-S20(7)/PW(27)
	5	Q1-S1(8)/PW(11)-S2(1)/PW(17) Q2-S5(8)/PW(18) Q3-S8(2)/PW(14)-S9(6)/PW(16) Q6-S20(7)/PW(17)
4	1	Q1-S1(5)/PW(21)-S2(7)/PW(22)-S3(3)/PW(14) Q2-S4(5)/PW(15)-S6(8)/PW(17) Q4-S10(7)/PW(17)-S12(4)/PW(12) Q5-S15(6)/PW(18) Q6-S19(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(4)/PW(14) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(6)/PW(17)-S2(9)/PW(22)-S3(3)/PW(23) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(3)/PW(23)-S2(4)/PW(17) Q2-S4(6)/PW(21)-S5(1)7PW(18) Q3-S8(5)/PW(16)-S9(6)/PW(26) Q6-S20(7)/PW(17)
	5	Q1-S1(4)/PW(21)-S2(6)/PW(17) Q2-S5(7)/PW(18) Q3-S8(8)/PW(24)-S9(6)/PW(26) Q6-S20(3)/PW(27)
5	1	Q1-S1(2)/PW(14)-S2(5)/PW(15)-S3(4)/PW(19) Q2-S6(8)/PW(18)-S7(10)/PW(19) Q4-S10(5)/PW(15)-S12(2)/PW(12) Q5-S15(6)/PW(16)-S16(5)/PW(15) Q6-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23)-S2(11)/PW(17) Q2-S4(9)/PW(19)-S5(8)/PW(18)-S6(6)/PW(16) Q3-S8(6)/PW(16)-S9(7)/PW(7) Q5-S16(4)/PW(24)-S17(5)/PW(25) Q6-S18(5)/PW(15)-S19(3)/PW(23)-S20(4)/PW(14)
	3	Q1-S1(8)/PW(18)-S3(3)/PW(23) Q2-S5(9)/PW(19) Q3-S7(7)/PW(17) Q4-S15(9)/PW(19)-S16(8)/PW(18)
	4	Q1-S1(6)/PW(16)-S2(8)/PW(18)-S3(5)/PW(25) Q2-S4(4)/PW(24)-S5(7)/PW(17)-S6(6)/PW(26) Q3-S8(6)/PW(16)-S9(5)/PW(25) Q6-S19(4)/PW(24)-S20(7)/PW(17)
	5	Q1-S1(5)/PW(15)-S2(6)/PW(16) Q2-S5(8)/PW(18) Q3-S8(8)/PW(18)-S9(6)/PW(16) Q6-S19(6)/PW(19)
6	1	Q1-S1(9)/PW(17)-S2(6)/PW(15)-S3(8)/PW(18) Q2-S6(7)/PW(17)-S7(6)/PW(26) Q4-S10(7)/PW(17)-S12(2)/PW(22) Q5-S15(8)/PW(28) Q6-S19(4)/PW(24)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(9)/PW(15)-S5(8)/PW(8) Q3-S8(6)/PW(16) Q5-S16(4)/PW(14) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(8)/PW(17)-S2(2)/PW(22)-S3(1)/PW(23) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(5)/PW(13)-S2(7)/PW(17) Q2-S4(2)/PW(19)-S5(4)/PW(18) Q3-S8(5)/PW(16)-S9(6)/PW(16) Q6-S20(3)/PW(17)
	5	Q1-S1(6)/PW(18)-S2(3)/PW(17) Q2-S5(8)/PW(8) Q3-S8(2)/PW(4)-S9(6)/PW(6) Q6-S20(6)/PW(7)
7	1	Q1-S3(8)/PW(24) Q2-S5(5)/PW(8)-S6(7)/PW(17) Q4-S10(7)/PW(17)-S12(8)/PW(12) Q5-S15(8)/PW(8) Q6-S19(4)/PW(4)-S20(5)/PW(5)
	2	Q1-S1(3)/PW(23) Q2-S4(7)/PW(5)-S5(8)/PW(8) Q3-S8(6)/PW(6) Q5-S16(5)/PW(14) Q6-S19(3)/PW(13)-S20(4)/PW(4)
	3	Q1-S1(7)/PW(7)-S2(1)/PW(18)-S3(3)/PW(13) Q2-S5(5)/PW(5) Q3-S7(6)/PW(6) Q4-S15(6)/PW(7)
	4	Q1-S1(4)/PW(3)-S2(7)/PW(7) Q2-S4(3)/PW(11)-S5(8)/PW(8) Q3-S8(9)/PW(6)-S9(6)/PW(6) Q6-S20(7)/PW(7)
	5	Q1-S1(5)/PW(12)-S2(6)/PW(17) Q2-S5(8)/PW(18) Q3-S8(4)/PW(14)-S9(5)/PW(16) Q6-S20(6)/PW(7)

Table A1. *Cont.*

Part	Route	Cell–Machine (Operating Time)/(Machine Power Amount)
8	1	Q1-S1(9)/PW(9)-S3(8)/PW(8) Q2-S6(8)/PW(7) Q4-S10(5)/PW(7)-S12(3)/PW(12) Q5-S15(6)/PW(8) Q6-S19(5)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(9)/PW(9) Q2-S4(6)/PW(16)-S5(8)/PW(8) Q3-S8(6)/PW(6) Q5-S16(4)/PW(14) Q6-S19(3)/PW(13)-S20(4)/PW(14)
	3	Q1-S1(7)/PW(17)-S2(5)/PW(15)-S3(3)/PW(13) Q2-S5(5)/PW(5) Q3-S7(6)/PW(16) Q4-S15(7)/PW(7)
	4	Q1-S1(7)PW(13)-S2(7)/PW(7) Q2-S4(9)/PW(11)-S5(8)/PW(8) Q3-S8(10)/PW(16)-S9(6)/PW(16) Q6-S20(7)/PW(7)
	5	Q1-S1(4)/PW(14)-S2(7)/PW(7) Q2-S5(8)/PW(8) Q3-S8(5)/PW(14)-S9(6)/PW(16) Q6-S20(2)/PW(7)
9	1	Q1-S3(8)/PW(8) Q2-S5(8)/PW(18)-S6(3)/PW(17)-S7(12)/PW(19) Q4-S11(7)/PW(9)-S12(2)/PW(12) Q5-S15(8)/PW(18) Q6-S19(4)/PW(4)-S20(5)/PW(5)
	2	Q1-S1(5)/PW(8)-S2(9/PW(9) Q2-S4(6)/PW(15)-S5(8)/PW(8) Q3-S7(7)/PW(7)-S8(6)/PW(6) Q5-S16(4)/PW(14)-S17(6)/PW(6) Q6-S20(4)/PW(4)
	3	Q1-S1(9)/PW(7)-S3(7)/PW(13) Q2-S5(6)/PW(5)-S6(8)/PW(8) Q3-S7(6)/PW(6)-S8(8)/PW(8) Q4-S15(7)/PW(17)-S16(9)/PW(9)
	4	Q1-S1(3)/PW(13)-S2(7)/PW(7)-S3(4)/PW(14) Q2-S4(6)/PW(11)-S5(8)/PW(18) Q3-S8(6)/PW(16)-S9(6)/PW(6) Q6-S20(2)/PW(7)
	5	Q1-S1(3)/PW(15)-S2(5)/PW(7)-S3(7)/PW(7) Q2-S5(8)/PW(8) Q3-S8(4)/PW(14)-S9(6)/PW(16) Q6-S19(3)/PW(18)-S20(6)/PW(17)
10	1	Q2-S5(4)/PW(14)-S6(4)/PW(15) Q4-S10(7)/PW(17)-S11(8)/PW(18)-S12(5)/PW(22) Q5-S15(8)/PW(8)-S17(9)/PW(9) Q6-S19(1)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23)-S2(5)/PW(25) Q2-S4(5)/PW(25)-S5(8)/PW(28)-S6(4)/PW(24) Q3-S8(6)/PW(6) Q5-S16(4)/PW(14)-S17(5)/PW(15) Q6-S19(3)/PW(13)-S20(4)/PW(14)
	3	Q1-S1(9)/PW(16)-S2(8)/PW(18)-S3(3)/PW(13) Q2-S5(5)/PW(15)-S6(6)/PW(17) Q3-S7(6)/PW(16)-S8(8)/PW(18) Q4-S15(7)/PW(17)
	4	Q1-S1(5)/PW(15)-S2(7)/PW(17) Q2-S4(4)/PW(14)-S5(8)/PW(8) Q3-S8(6)/PW(16)-S9(6)/PW(16) Q6-S18(8)/PW(18)-S20(7)/PW(17)
	5	Q1-S1(3)/PW(14)-S2(7)/PW(17)-S3(8)/PW(18) Q2-S5(8)/PW(18) Q3-S8(4)/PW(14)-S9(6)/PW(26) Q6-S19(4)/PW(17)
11	1	Q1-S2(8)/PW(18) Q2-S5(4)/PW(14)-S6(7)7PW(17) Q4-S10(4)/PW(14)-S11(8)/PW(18)-S12(5)/PW(15) Q5-S15(8)/PW(8)-S16(7)/PW(7) Q6-S18(6)/PW(16)-S19(6)/PW(18)-S20(9)/PW(9)
	2	Q1-S1(8)/PW(18)-S2(6)/PW(8) Q2-S4(5)/PW(15)-S5(4)/PW(8)-S6(9)/PW(9) Q3-S8(6)/PW(16) Q5-S16(4)/PW(14) Q6-S19(3)/PW(11)-S20(4)/PW(14)
	3	Q1-S2(5)/PW(15) Q2-S6(7)/PW(17)-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(10)/PW(19)-S2(7)/PW(17)-S3(9)/PW(9) Q2-S4(3)/PW(8)-S5(8)/PW(8) Q3-S8(5)/PW(15)-S9(6)/PW(16) Q6-S18(4)/PW(14)-S19(8)/PW(18)-S20(7)/PW(17)
	5	Q1-S1(9)/PW(16)-S2(7)/PW(17) Q2-S4(7)/PW(17)-S5(8)/PW(8) Q3-S7(5)/PW(15)-S8(4)/PW(24)-S9(6)/PW(16) Q6-S19(4)/PW(18)-S20(6)/PW(16)
12	1	Q1-S3(8)/PW(13) Q2-S6(6)/PW(16)-S7(5)/PW(15) Q4-S10(4)/PW(14)-S11(3)/PW(13)-S12(2)/PW(12) Q5-S15(8)/PW(18) Q6-S20(5)/PW(15)
	2	Q1-S1(3)/PW(13)-S2(7)/PW(17) Q2-S4(7)/PW(26)-S5(7)/PW(17) Q3-S8(7)/PW(14) Q5-S16(5)/PW(15)-S17(4)/PW(14) Q6-S19(7)/PW(17)-S20(8)/PW(18)
	3	Q1-S1(2)/PW(22)-S2(8)/PW(18) Q2-S5(7)/PW(17)-S6(4)/PW(24) Q3-S7(6)/PW(6)-S8(5)/PW(5) Q4-S15(7)/PW(19)-S16(8)/PW(18)
	4	Q1-S1(6)/PW(7)-S2(6)/PW(16) Q2-S4(5)/PW(15)-S5(4)/PW(24) Q3-S8(4)/PW(24) Q6-S20(7)/PW(17)
	5	Q1-S2(1)/PW(8) Q2-S5(11)/PW(18) Q3-S8(2)/PW(24)-S9(6)/PW(16) Q6-S19(8)/PW(18)
13	1	Q1-S2(7)/PW(18)-S3(5)/PW(12) Q2-S4(3)/PW(16)-S6(7)/PW(17) Q4-S10(6)/PW(17)-S11(3)/PW(18)-S12(2)/PW(22) Q5-S15(8)/PW(18)-S16(9)/PW(9) Q6-S18(7)/PW(17)-S19(6)/PW(16)-S20(5)/PW(25)
	2	Q1-S1(5)/PW(15)-S2(7)/PW(26) Q2-S4(5)/PW(15)-S5(4)/PW(18)-S6(7)/PW(17) Q3-S8(6)/PW(6)-S9(7)/PW(7) Q5-S16(4)/PW(24)-S17(5)/PW(15) Q6-S19(6)/PW(16)
	3	Q1-S3(3)/PW(13) Q2-S5(3)/PW(15)-S6(7)/PW(17) Q3-S7(6)/PW(16)-S8(7)/PW(17) Q4-S15(7)/PW(17)-S16(6)/PW(16)
	4	Q1-S2(10)/PW(17) Q2-S5(8)/PW(18) Q3-S8(9)/PW(15)-S9(6)/PW(16)-S10(4)/PW(24) Q6-S19(8)/PW(18)
	5	Q1-S1(6)/PW(24)-S2(7)/PW(17) Q2-S5(1)/PW(21) Q3-S8(4)/PW(24)-S9(6)/PW(16) Q6-S18(9)/PW(9)-S19(8)/PW(18)
14	1	Q2-S6(9)/PW(17) Q4-S10(5)/PW(21)-S12(2)/PW(22) Q5-S15(8)/PW(18) Q6-S19(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(4)/PW(24) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(8)/PW(17)-S2(1)/PW(22)-S3(3)/PW(13) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(4)/PW(13)-S2(7)(PW(17) Q2-S4(1)/PW(21)-S5(5)/PW(28) Q3-S8(6)/PW(26)-S9(6)/PW(16) Q6-S20(7)/PW(17)
	5	Q1-S1(11)/PW(21)-S2(3)/PW(17) Q2-S5(8)/PW(18) Q3-S8(4)/PW(14)-S9(6)/PW(16) Q6-S20(4)/PW(17)
15	1	Q1-S1(11)/PW(18) Q2-S6(7)/PW(17)-S7(5)/PW(15) Q3-S15(8)/PW(8) Q4-S10(3)/PW(17)-S11(5)/PW(15)-S12(2)/PW(23) Q5-S15(8)/PW(8) Q6-S18(9)/PW(19)-S19(4)/PW(24)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23)-S2(7)/PW(17) Q3-S8(6)/PW(16) Q5-S16(4)/PW(14) Q6-S19(3)/PW(13)-S20(4)/PW(14)
	3	Q1-S1(10)/PW(19)-S3(3)/PW(23) Q2-S5(5)/PW(25) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(3)/PW(23)-S2(7)/PW(17)-S3(8)/PW(18) Q2-S4(9)/PW(19)-S5(8)/PW(18) Q3-S8(6)/PW(16)-S9(3)/PW(16)-S10(7)/PW(17) Q6-S19(6)/PW(16) S20(9)/PW(19)
	5	Q1-S2(7)/PW(17) Q2-S5(8)/PW(8) Q3-S9(6)/PW(16) Q6-S19(3)/PW(18)-S20(7)/PW(17)

Table A1. *Cont.*

Part	Route	Cell–Machine (Operating Time)/(Machine Power Amount)
16	1	Q4-S10(7)/PW(17)-S12(5)/PW(20) Q5-S15(8)/PW(18)
	2	Q2-S4(12)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(2)/PW(24) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(4)/PW(17)-S2(8)/PW(22)-S3(3)/PW(23) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(3)/PW(13)-S2(7)/PW(17) Q2-S4(6)/PW(18)-S5(3)/PW(18) Q3-S8(7)/PW(16)-S9(6)/PW(16) Q6-S20(7)/PW(17)
	5	Q1-S1(7)/PW(17)-S2(3)/PW(19)-S3(5)/PW(15) Q2-S5(8)/PW(18) Q3-S6(4)/PW(14)-S8(4)/PW(14)-S9(6)/PW(16) Q6-S19(5)/PW(15)-S20(2)/PW(17)
17	1	Q1-S2(6)/PW(17)-S3(5)/PW(15) Q2-S6(7)/PW(17) Q4-S10(1)/PW(17)-S12(2)/PW(22) Q5-S15(6)/PW(18)-S16(5)/PW(25) Q6-S18(6)/PW(26)-S20(5)/PW(25)
	2	Q1-S1(3)/PW(23)-S2(8)/PW(18) Q2-S4(5)/PW(15) Q3-S7(4)/PW(14)-S8(6)/PW(16) Q5-S16(11)/PW(24)-S17(7)/PW(17) Q6-S20(9)/PW(19)
	3	Q1-S1(8)/PW(19)-S3(7)/PW(14) Q2-S5(5)/PW(15)-S6(7)/PW(17) Q3-S7(6)/PW(26)-S8(5)/PW(15) Q4-S15(7)/PW(17)-S16(8)/PW(18) Q5-S18(9)/PW(19)
	4	Q1-S1(6)/PW(23)-S2(7)/PW(27) Q2-S4(1)/PW(21)-S5(8)/PW(18) Q3-S8(4)/PW(16)-S9(6)/PW(16) Q6-S20(7)/PW(17)
	5	Q1-S2(4)/PW(17) Q2-S5(8)/PW(18) Q3-S8(4)/PW(14)-S9(6)/PW(16)
18	1	Q1-S2(9)/PW(19)-S3(4)/PW(24) Q2-S6(7)/PW(17) Q4-S10(7)/PW(27)-S12(9)/PW(19) Q5-S15(8)/PW(18)-S19(4)/PW(24)-S20(5)/PW(25) Q6-S18(5)PW(15)
	2	Q1-S1(9)/PW(19)-S2(5)/PW(25) Q2-S4(4)/PW(24) Q3-S8(6)/PW(16)-S9(6)/PW(16) Q5-S16(6)/PW(16)-S17(7)/PW(17) Q6-S19(8)/PW(18)-S20(4)/PW(24)
	3	Q1-S1(9)/PW(19)-S3(7)/PW(17) Q2-S5(5)PW(15) Q3-S7(6)/PW(16)-S8(5)/PW(15) Q4-S15(9)/PW(19)-S16(4)/PW(24)
	4	Q1-S2(9)/PW(9)-S3(4)/PW(14) Q2-S5(3)/PW(13)-S6(5)/PW(15) Q3-S8(6)/PW(16) Q6-S18(3)/PW(13)-S19(8)/PW(8)-S20(4)/PW(14)
	5	Q1-S1(6)/PW(16)-S2(7)/PW(17)-S3(5)/PW(25) Q2-S5(8)/PW(8)-S8(4)/PW(14) Q3-S8(4)/PW(14)-S9(6)/PW(16)-S10(5)/PW(15) Q6-S19(5)/PW(15)-S20(7)/PW(17)
19	1	Q2-S6(4)/PW(14)-S7(8)/PW(18) Q4-S10(7)/PW(17)-S11(5)/PW(25)-S12(2)/PW(22) Q5-S15(8)/PW(18) Q6-S19(4)/PW(24)-S20(5)/PW(15)
	2	Q1-S1(6)/PW(16) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(26) Q5-S16(6)/PW(26) Q6-S19(13)/PW(13)-S20(4)/PW(14)
	3	Q1-S2(9)/PW(9)-S3(8)/PW(18) Q2-S5(5)/PW(15) Q3-S7(11)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S2(9)/PW(19) Q2-S4(7)/PW(11)-S5(8)/PW(18) Q3-S8(7)/PW(7)-S9(6)/PW(16) Q6-S19(2)/PW(22)-S20(3)/PW(3)
	5	Q2-S5(8)/PW(8) Q3-S8(4)/PW(24)-S9(6)/PW(16) Q6-S19(9)/PW(15)-S20(6)/PW(16)
20	1	Q2-S6(11)/PW(9)-S7(9)/PW(9) Q3-S9(5)PW(15) Q4-S10(6)/PW(16)-S11(8)/PW(18)-S12(2)/PW(22) Q5-S15(9)/PW(9) Q6-S18(6)/PW(16)-S19(4)/PW(24)-S20(5)/PW(25)
	2	Q1-S1(3)/PW(13)-S2(8)/PW(18) Q2-S4(9)/PW(9)-S5(6)/PW(16) Q3-S7(7)/PW(17)-S8(6)/PW(16) Q6-S20(4)/PW(14)
	3	Q1-S2(12)/PW(12) Q2-S5(9)/PW(9) Q3-S7(6)/PW(16)-S8(7)/PW(17) Q4-S15(8)/PW(8)-S16(9)/PW(9) Q6-S19(8)/PW(8)
	4	Q1-S2(7)/PW(17)-S3(8)/PW(18) Q3-S8(3)/PW(16)-S9(6)/PW(16)-S10(5)/PW(25) Q5-S17(9)/PW(9) Q6-S19(5)/PW(25)-S20(8)/PW(18)
	5	Q2-S5(8)/PW(8) Q3-S8(7)/PW(9)-S9(10)/PW(6)
21	1	Q1-S1(9)/PW(8)-S2(5)/PW(9)-S3(4)/PW(14) Q4-S10(8)/PW(15)-S11(6)/PW(16)-S12(2)/PW(22) Q6-S19(4)/PW(24)-S20(5)/PW(25)
	2	Q2-S4(9)/PW(15)-S5(8)/PW(18) Q3-S8(8)/PW(16)-S9(7)/PW(17) Q6-S19(9)/PW(9)
	3	Q1-S3(9)/PW(9) Q2-S5(5)/PW(25)-S6(7)/PW(17) Q3-S7(6)/PW(26) Q4-S15(7)/PW(17) Q6-S18(8)/PW(18)-S19(9)/PW(19)
	4	Q1-S2(7)/PW(17) Q2-S4(13)/PW(11)-S5(4)/PW(18) Q3-S8(6)/PW(16)-S9(6)/PW(16) Q6-S20(7)/PW(17)
	5	Q1-S1(4)/PW(24)-S2(6)/PW(16) Q2-S5(5)/PW(17) Q3-S8(4)/PW(14)-S9(6)/PW(16) Q4-S11(7)/PW(17)
22	1	Q1-S1(5)/PW(16)-S3(2)/PW(24) Q2-S5(5)/PW(18) Q4-S10(7)/PW(17)-S11(9)/PW(9)-S12(7)/PW(17) Q5-S15(8)/PW(8)-S16(5)/PW(15) Q6-S20(9)/PW(9)
	2	Q1-S1(5)/PW(3)-S2(9)/PW(9) Q3-S8(6)/PW(16)-S9(8)/PW(8) Q5-S16(4)/PW(14)-S17(5)/PW(15) Q6-S19(9)/PW(9)
	3	Q1-S1(8)/PW(18)-S2(2)/PW(12) Q2-S5(9)/PW(9) Q3-S7(7)/PW(16)-S8(7)/PW(17) Q4-S15(7)/PW(17)-S16(8)/PW(18)
	4	Q2-S5(8)/PW(8)-S6(7)/PW(7) Q3-S8(6)/PW(6)-S9(8)/PW(9) Q6-S18(3)/PW(3)-S20(9)/PW(9)
	5	Q1-S1(7)/PW(17)-S2(9)/PW(9) Q2-S4(2)/PW(20)-S5(8)/PW(18) Q3-S8(4)/PW(14)-S9(6)/PW(16)-S10(3)/PW(23) Q4-S16(4)/PW(14) Q5-S17(6)/PW(16)-S18(5)/PW(15) Q6-S20(7)/PW(17)
23	1	Q1-S3(3)/PW(14) Q2-S6(7)/PW(14) Q5-S15(8)/PW(18)-S16(9)/PW(9)
	2	Q1-S1(3)/PW(23)-S2(8)/PW(18) Q2-S4(5)/PW(15)-S5(6)/PW(18)-S6(7)/PW(17) Q3-S8(6)/PW(16) Q4-S15(6)/PW(16) Q6-S20(9)/PW(9)
	3	Q1-S1(9)/PW(9)-S2(8)/PW(8) Q2-S4(4)/PW(24)-S5(5)/PW(25) Q3-S7(6)/PW(26)-S8(7)/PW(17)
	4	Q2-S4(2)/PW(21)-S5(5)/PW(17)-S6(8)/PW(18) Q6-S19(3)/PW(23)-S20(9)/PW(9)
	5	Q2-S5(6)/PW(16) Q3-S9(6)/PW(6) Q6-S18(11)/PW(9)-S20(3)/PW(15)
24	1	Q1-S1(9)/PW(8)-S2(2)/PW(13)-S3(1)/PW(14) Q2-S5(6)/PW(16)-S6(7)/PW(17) Q4-S10(6)/PW(14)-S11(8)/PW(18) Q5-S14(6)/PW(16)-S15(8)/PW(18) Q6-S19(6)/PW(16)-S20(3)/PW(13)
	2	Q2-S5(7)/PW(16)-S6(7)/PW(17) Q3-S8(9)/PW(19)-S9(5)/PW(15) Q5-S16(3)/PW(23)-S17(2)/PW(22) Q6-S20(4)/PW(12)
	3	Q1-S1(6)/PW(16)-S3(8)/PW(9) Q4-S15(4)/PW(4)-S16(5)/PW(5) Q6-S19(8)/PW(8)
	4	Q1-S1(3)/PW(23)-S2(7)/PW(17)-S3(6)/PW(16) Q2-S5(8)/PW(8)-S6(5)/PW(15) Q6-S19(8)/PW(18)-S20(9)/PW(9)
	5	Q1-S2(7)/PW(17) Q2-S5(8)/PW(18)-S6(5)/PW(15) Q3-S8(4)/PW(14)

Table A1. *Cont.*

Part	Route	Cell–Machine (Operating Time)/(Machine Power Amount)
25	1	Q1-S1(5)/PW(15)-S2(6)/PW(16)-S3(5)/PW(14) Q2-S5(8)PW(18)-S6(7)/PW(17)-S7(5)/PW(15) Q3-S8(5)/PW(23) Q4-S12(9)/PW(9) Q5-S15(8)/PW(18)
	2	Q1-S1(3)/PW(3)-S2(1)/PW(5) Q2-S4(4)/PW(24)-S5(7)/PW(17) Q3-S8(5)/PW(15)-S9(4)PW(24) Q5-S16(3)/PW(8) Q6-S19(9)/PW(9)-S20(6)/PW(6)
	3	Q1-S2(8)/PW(18)-S3(9)/PW(9) Q2-S5(5)/PW(15) Q3-S6(4)/PW(10)-S7(6)/PW(16)
	4	Q1-S1(6)/PW(16)-S2(7)/PW(17)-S3(8)/PW(18) Q2-S4(2)/PW(12)-S5(8)/PW(18)-S6(3)/PW(11) Q3-S8(6)/PW(16)-S9(6)/PW(16) Q6-S19(8)/PW(18)-S20(7)/PW(17)
	5	Q1-S2(9)/PW(17) Q2-S4(4)/PW(14)-S5(8)/PW(8) Q3-S8(4)/PW(14)-S9(6)/PW(16) Q6-S19(9)/PW(16)-S20(7)/PW(17)
26	1	Q1-S3(4)/PW(14) Q2-S6(10)/PW(17)-S7(8)/PW(18) Q4-S10(7)/PW(17) Q5-S15(8)/PW(8)-S16(8)/PW(8) Q6-S18(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(7)/PW(17)-S2(8)/PW(18) Q2-S4(2)/PW(21)-S5(3)/PW(13)-S6(4)/PW(24) Q3-S7(5)/PW(15)-S8(6)/PW(16)-S9(7)/PW(17) Q5-S16(4)/PW(14)-S17(5)/PW(15) Q6-S18(7)/PW(17)S20(4)/PW(24)
	3	Q1-S1(10)/PW(18)-S2(9)/PW(19) Q2-S5(5)/PW(15)-S6(6)/PW(16) Q3-S7(6)/PW(16)-S8(7)/PW(17) Q4-S14(7)/PW(17)-S15(8)/PW(18)
	4	Q2-S4(8)/PW(18)-S5(8)/PW(18) Q3-S8(9)/PW(19)
	5	Q1-S2(4)/PW(14) Q2-S5(6)/PW(16)-S6(7)/PW(17) Q3-S8(5)/PW(15)-S9(7)/PW(17) Q5-S16(6)/PW(16)-S17(3)/PW(23) Q6-S18(2)/PW(14)-S19(8)/PW(18)
27	1	Q1-S1(7)/PW(9)-S2(1)/PW(21)-S3(4)/PW(14) Q2-S4(3)/PW(23)-S6(5)/PW(15) Q4-S10(5)/PW(15)-S11(6)/PW(16)-S12(2)/PW(12) Q6-S19(7)/PW(17)
	2	Q1-S1(15)/PW(13)-S2(5)/PW(15)-S3(1)/PW(16) Q2-S5(5)/PW(15)-S6(2)/PW(2) Q3-S7(3)/PW(17)-S8(6)/PW(16) Q5-S6(4)/PW(4)-S17(5)PW(5)
	3	Q1-S1(6)/PW(16)-S3(3)/PW(23) Q2-S5(8)/PW(18)-S6(9)/PW(9) Q3-S7(7)/PW(17)-S8(5)/PW(15) Q4-S14(6)/PW(26)-S15(7)/PW(7) Q6-S19(8)/PW(18)-S20(4)/PW(14)
	4	Q1-S1(3)/PW(3)-S2(8)/PW(6)-S3(4)/PW(4) Q4-S5(7)/PW(8) Q6-S20(7)/PW(7)
	5	Q1-S1(4)/PW(24)-S2(7)/PW(17)-S3(8)/PW(18) Q2-S4(5)/PW(25)-S5(8)/PW(18) Q3-S8(4)/PW(24)-S9(6)/PW(16) Q5-S17(6)/PW(16) Q6-S19(5)/PW(17)-S20(7)/PW(17)
28	1	Q1-S1(4)/PW(15)-S3(6)/PW(16) Q2-S6(9)/PW(9) Q4-S10(6)/PW(16)-S12(3)/PW(13) Q5-S15(8)/PW(18) Q6-S19(6)/PW(16)-S20(8)/PW(18)
	2	Q1-S1(3)/PW(16) Q2-S4(12)/PW(22)-S5(8)/PW(18) Q3-S8(7)/PW(17) Q5-S16(6)/PW(6) Q6-S19(5)/PW(15)-S20(1)/PW(23)
	3	Q1-S1(9)/PW(19)-S3(6)/PW(26) Q2-S5(5)/PW(5) Q3-S7(7)/PW(7) Q4-S15(8)/PW(8)
	4	Q1-S1(4)/PW(14)-S2(8)/PW(18) Q2-S4(3)/PW(13)-S5(7)/PW(11) Q3-S8(9)PW(19)-S9(6)/PW(26) Q6-S19(4)/PW(14)-S20(8)/PW(18)
	5	Q1-S1(6)/PW(16)-S2(8)/PW(18) Q2-S5(8)(PW(18) Q3-S8(9)/PW(19)-S9(5)/PW(15) Q6-S19(3)/PW(23)-S20(6)/PW(16)
29	1	Q1-S1(3)/PW(15)-S3(3)/PW(13) Q2-S6(8)/PW(8) Q4-S12(9)/PW(9) Q6-S20(6)/PW(16)
	2	Q2-S4(5)/PW(9)-S5(6)/PW(16)-S6(5)/PW(15) Q3-S7(7)/PW(17)-S8(8)/PW(8) Q4-S9(9)/PW(9) Q5-S16(3)/PW(23)-S17(2)/PW(20) Q6-S20(4)/PW(14)
	3	Q1-S2(6)/PW(9)-S3(3)/PW(13) Q3-S7(7)/PW(17)-S8(8)/PW(18) Q6-S18(9)/PW(9)
	4	Q1-S2(7)/PW(17) Q2-S5(8)/PW(18)-S6(4)/PW(14) Q3-S7(5)/PW(15)-S8(4)/PW(16)-S9(6)/PW(16) Q6-S19(5)/PW(15)-S20(6)/PW(16)
	5	Q1-S2(7)/PW(17) Q2-S5(8)/PW(18) Q3-S8(4)/PW(14)-S9(6)/PW(16) Q5-S16(4)/PW(14)-S17(5)PW(15) Q6-S19(3)/PW(13)-S20(6)/PW(9)
30	1	Q1-S1(9)/PW(9)-S2(1)/PW(13)-S3(5)/PW(15) Q2-S5(6)/PW(16)-S7(7)/PW(17) Q3-S8(5)/PW(15)-S9(4)/PW(24) Q5-S15(6)/PW(16) Q6-S20(9)/PW(19)
	2	Q1-S1(9)/PW(13)-S2(5)/PW(15)-S3(8)/PW(18) Q2-S4(7)/PW(14)-S5(3)/PW(13) Q3-S7(9)/PW(13)-S8(9)/PW(9) Q5-S16(6)/PW(6)-S17(7)/PW(7)
	3	Q1-S2(7)/PW(17)-S3(3)PW(13) Q2-S5(6)/PW(16)-S6(7)/PW(17) Q3-S7(11)/PW(11) Q4-S15(3)/PW(23)-S16(4)/PW(14) Q6-S18(5)/PW(15)-S19(6)/PW(16)
	4	Q1-S1(9)/PW(9)-S2(7)/PW(17) Q2-S5(8)/PW(8) Q3-S8(5)/PW(15)-S9(4)/PW(14) Q6-S19(8)/PW(8)-S20(9)/PW(9)
	5	Q1-S2(9)/PW(9)-S3(7)/PW(17) Q2-S4(6)/PW(16)-S5(5)/PW(15) Q3-S8(4)/PW(14)-S9(6)/PW(16) Q4-S11(6)/PW(16)-S12(8)/PW(8) Q5-S16(9)/PW(9)-S17(8)/PW(8)
31	1	Q1-S1(5)/PW(18)-S3(5)PW(15) Q2-S6(6)/PW(16) Q4-S10(6)/PW(16)-S12(3)/PW(23) Q5-S15(9)/PW(19) Q6-S19(7)-S20(3)
	2	Q1-S1(6)/PW(16) Q2-S4(7)/PW(17)-S5(8)/PW(18) Q3-S8(9)/PW(19) Q5-S16(5)/PW(25) Q6-S19(4)/PW(24)-S20(5)/PW(15)
	3	Q1-S1(6)/PW(16)-S2(3)/PW(13)-S3(5)/PW(15) Q2-S5(9)/PW(19) Q3-S7(7)/PW(17) Q4-S15(9)/PW(19)
	4	Q1-S1(9)/PW(17)-S2(3)/PW(23) Q2-S4(2)/PW(20)-S5(4)/PW(14) Q3-S8(9)/PW(19)-S9(3)/PW(23) Q6-S20(8)/PW(18)
	5	Q1-S1(3)/PW(25)-S2(9)/PW(19) Q2-S5(4)/PW(24) Q3-S8(6)/PW(23)-S9(2)/PW(17) Q6-S20(8)/PW(18)
32	1	Q3-S7(6)/PW(16) Q4-S10(8)/PW(18)-S11(7)/PW(17)-S12(1)/PW(23) Q5-S15(4)/PW(14) Q6-S20(5)/PW(15)
	2	Q1-S1(13)/PW(13)-S2(8)/PW(18)-S3(4)/PW(24) Q2-S5(3)/PW(13) Q3-S7(5)/PW(13)-S8(7)/PW(18) Q5-S16(6)/PW(16)-S17(7)/PW(17) Q6-S19(8)/PW(18)
	3	Q1-S1(9)/PW(9) Q3-S7(6)/PW(16)-S8(9)/PW(9) Q4-S14(6)/PW(16)-S15(7)/PW(17) Q5-S16(9)/PW(9)-S17(3)/PW(13) Q6-S18(8)/PW(8)-S19(9)/PW(9)
	4	Q1-S1(6)/PW(16)-S2(10)/PW(17)-S3(5)/PW(10) Q2-S4(2)/PW(5) Q3-S8(3)/PW(13)-S9(7)/PW(7) Q5-S16(5)/PW(15) Q6-S18(5)/PW(15)-S19(9)/PW(9)
	5	Q1-S2(9)/PW(9) Q3-S8(6)/PW(13)-S9(2)/PW(21) Q6-S19(3)/PW(16)-S20(7)/PW(7)

Table A1. *Cont.*

Part	Route	Cell–Machine (Operating Time)/(Machine Power Amount)
33	1	Q1-S1(3)/PW(9)-S2(3)/PW(12)-S3(9)/PW(23) Q2-S5(9)/PW(15)-S6(7)/PW(17) Q3-S7(6)/PW(16)-S8(5)/PW(20) Q4-S10(7)/PW(17)-S11(3)/PW(13)-S12(2)/PW(21) Q5-S15(8)/PW(18)-S16(4)/PW(18) Q6-S18(6)/PW(16)-S19(4)/PW(24)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(13)-S2(8)/PW(18) Q2-S4(5)/PW(13)-S5(8)/PW(18) Q3-S8(6)/PW(16)-S9(7)/PW(17) Q5-S16(4)/PW(14)-S17(5)/PW(23) Q6-S18(5)/PW(15)-S20(4)/PW(14)
	3	Q1-S1(7)/PW(16)-S3(10)/PW(23) Q2-S5(6)/PW(16) Q3-S7(3)/PW(19) Q4-S15(8)/PW(18)-S16(9)/PW(19)
	4	Q1-S2(9)/PW(19)-S3(5)/PW(15) Q2-S4(3)/PW(11)-S5(3)/PW(9) Q3-S7(4)/PW(14) Q4-S10(5)/PW(15)-S11(3)/PW(16)
	5	Q1-S2(8)/PW(18)-S3(9)/PW(19) Q2-S4(4)/PW(24)-S5(5)/PW(12) Q3-S8(3)PW(13)-S9(6)/PW(16)-S10(2)/PW(14) Q5-S16(2)/PW(20)-S17(3)/PW(13) Q6-S18(4)/PW(15)-S19(3)/PW(16)-S20(7)/PW(17)
34	1	Q4-S10(6)/PW(16)-S11(5)/PW(18)-S12(2)PW(22) Q5-S15(6)/PW(18)-S16(8)/PW(18) Q6-S19(5)/PW(15)
	2	Q1-S1(3)/PW(23)-S2(8)/PW(18) Q2-S5(6)/PW(18)-S6(7)/PW(21) Q3-S8(5)/PW(22)-S9(4)/PW(18)-S10(3)/PW(13) Q5-S16(4)/PW(14)-S17(5) Q6-S18(7)/PW(17)-S20(4)/PW(20)
	3	Q1-S1(8)/PW(9)-S3(5)/PW(15) Q2-S5(5)/PW(15)-S6(6)/PW(16) Q3-S7(6)/PW(16)-S8(8)/PW(18) Q4-S15(7)/PW(17)-S16(8)/PW(18)
	4	Q1-S1(3)/PW(23)-S2(7)/PW(17)-S3(4)/PW(24) Q2-S5(8)/PW(18) Q3-S8(6)/PW(16)-S9(5)/PW(15) Q6-S19(8)/PW(8)
	5	Q1-S1(6)/PW(16)-S2(3)/PW(23)-S3(5)/PW(15) Q2-S5(8)/PW(18)-S6(4)/PW(24) Q3-S8(9)/PW(14)-S9(6)/PW(15)-S10(3)/PW(23) Q6-S18(6)/PW(14)-S19(5)/PW(15)-S20(7)/PW(17)
35	1	Q2-S6(8)/PW(18)-S7(9)/PW(19) Q4-S10(7)/PW(17)-S12(2)/PW(22) Q5-S15(8)/PW(18)
	2	Q1-S1(3)/PW(23) Q2-S4(6)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(4)/PW(14) Q6-S19(3)/PW(23)-S20(4)/PW(14)
	3	Q1-S1(7)/PW(17)-S2(2)/PW(20)-S3(3)/PW(15) Q2-S5(5)/PW(5) Q3-S7(6)/PW(6) Q4-S15(7)/PW(7)
	4	Q1-S1(10)/PW(23)-S2(7)/PW(17) Q2-S4(3)/PW(21)-S5(9)/PW(18) Q3-S8(6)/PW(6)-S9(6)/PW(6) Q6-S20(7)/PW(17)
	5	Q1-S1(6)/PW(11)-S2(7)/PW(17) Q2-S5(8)/PW(8) Q3-S8(1)/PW(15)-S9(6)/PW(16) Q6-S20(2)/PW(17)
36	1	Q1-S1(3)/PW(12) Q2-S4(5)/PW(17) Q3-S7(3)/PW(13) Q4-S11(3)/PW(14)-S12(7)/PW(17) Q5-S14(8)/PW(18)-S15(4)/PW(14) Q6-S20(8)/PW(18)
	2	Q1-S2(3)/PW(23)-S3(5)/PW(18) Q2-S5(7)/PW(17) Q4-S11(9)/PW(19)-S12(6)/PW(17)-S13(5)/PW(15) Q5-S14(8)/PW(18)-S15(4)/PW(14) Q6-S18(4)/PW(14)-S20(8)/PW(18)
	3	Q1-S1(6)/PW(16)-S2(9)/PW(19)-S3(1)/PW(14) Q3-S8(2)/PW(22) Q4-S12(9)/PW(19)-S13(6)/PW(26) Q5-S14(8)/PW(18)-S15(4)/PW(24) Q6-S18(9)/PW(19)-S20(8)/PW(18)
	4	Q1-S1(9)/PW(21)-S2(7)/PW(18)-S3(5)/PW(25) Q2-S5(5)/PW(25) Q4-S11(9)/PW(19)-S12(4)/PW(24)-S13(5)/PW(15) Q5-S14(3)/PW(23)-S15(4)/PW(24) Q6-S20(8)/PW(18)
	5	Q1-S1(9)/PW(20)-S2(9)/PW(23)-S3(4)/PW(24) Q3-S8(6)/PW(14) Q4-S12(9)/PW(15)-S13(6)/PW(16) Q5-S14(4)/PW(11)-S15(4)/PW(24) Q6-S18(3)/PW(17)-S20(8)/PW(16)
37	1	Q1-S3(8)/PW(15) Q2-S6(5)/PW(24) Q3-S7(4)/PW(14) Q4-S9(4)PW(20)-S10(5)/PW(18) Q5-S13(8)/PW(18)-S14(9)/PW(19) Q6-S19(4)/PW(24)
	2	Q1-S1(2)/PW(20) Q2-S6(8)/PW(28) Q4-S11(8)/PW(18)-S13(3)/PW(23) Q5-S14(7)/PW(27) Q6-S18(8)/PW(18)-S19(2)/PW(22)
	3	Q1-S2(9)/PW(25)-S3(3)/PW(23) Q2-S6(6)/PW(16) Q3-S7(4)/PW(24)-S8(7)/PW(17) Q4-S8(3)/PW(8) Q5-S16(4)/PW(14) Q6-S20(7)/PW(17)
	4	Q1-S1(5)/PW(18)-S2(7)/PW(17)-S3(3)/PW(23) Q2-S6(8)/PW(8) Q4-S11(8)/PW(8)-S13(3)/PW(23) Q5-S14(7)/PW(17) Q6-S18(8)/PW(18)-S19(2)/PW(22)
	5	Q1-S2(5)/PW(25)-S3(3)/PW(23) Q3-S7(4)/PW(24)-S8(7)/PW(17) Q4-S8(8)/PW(20) Q5-S15(5)/PW(22)-S16(4)/PW(24) Q6-S20(7)/PW(27)
38	1	Q1-S1(2)/PW(19)-S3(14)/PW(17) Q2-S6(7)/PW(19) Q4-S10(7)/PW(20)-S12(2)/PW(22) Q5-S15(8)/PW(18) Q6-S19(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(5)/PW(25)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(4)/PW(24) Q6-S19(3)/PW(13)-S20(4)/PW(24)
	3	Q1-S1(3)/PW(19)-S2(2)/PW(11)-S3(13)/PW(13) Q2-S5(5)/PW(15) Q3-S7(6)/PW(17) Q4-S15(7)/PW(19)
	4	Q1-S1(3)/PW(23)-S2(7)/PW(17) Q2-S4(1)/PW(19)-S5(8)/PW(18) Q3-S8(6)/PW(16)-S9(6)/PW(19) Q6-S20(7)/PW(24)
	5	Q1-S1(3)/PW(10)-S2(7)/PW(17) Q2-S5(8)/PW(18) Q3-S8(4)/PW(19)-S9(6)/PW(16) Q6-S20(10)/PW(21)
39	1	Q1-S1(1)/PW(24)-S2(8)/PW(26)-S3(4)/PW(14) Q2-S4(5)/PW(18)-S6(7)/PW(17) Q4-S10(7)/PW(17)-S12(2)/PW(18) Q5-S15(8)/PW(18) Q6-S19(4)/PW(19)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(5)/PW(22)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(4)/PW(14) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(3)/PW(17)-S2(2)/PW(22)-S3(3)/PW(23) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(3)/PW(23)-S2(7)/PW(17) Q2-S4(3)/PW(21)-S5(5)7PW(18) Q3-S8(6)/PW(16)-S9(6)/PW(26) Q6-S20(7)/PW(17)
	5	Q1-S1(4)/PW(21)-S2(9)/PW(27) Q2-S5(8)/PW(18) Q3-S8(4)/PW(24)-S9(6)/PW(26) Q6-S20(5)/PW(27)
40	1	Q1-S1(2)/PW(14)-S2(5)/PW(15)-S3(4)/PW(19) Q2-S6(8)/PW(18)-S7(9)/PW(19) Q4-S10(5)/PW(15)-S12(2)/PW(12) Q5-S15(6)/PW(16)-S16(5)/PW(15) Q6-S20(5)/PW(15)
	2	Q1-S1(13)/PW(23)-S2(7)/PW(27) Q2-S4(9)/PW(19)-S5(8)/PW(18)-S6(6)/PW(16) Q3-S8(6)/PW(26)-S9(7)/PW(7) Q5-S16(4)/PW(24)-S17(5)/PW(25) Q6-S18(5)/PW(15)-S19(3)/PW(23) S20(4)/PW(14)
	3	Q1-S1(8)/PW(18)-S3(3)/PW(28) Q2-S5(9)/PW(19) Q3-S7(7)/PW(17) Q4-S15(9)/PW(19)-S16(8)/PW(18)
	4	Q1-S1(3)/PW(19)-S2(8)/PW(18)-S3(5)/PW(25) Q2-S4(4)/PW(21)-S5(7)/PW(17)-S6(6)/PW(26) Q3-S8(4)/PW(16)-S9(5)/PW(25) Q6-S19(4)/PW(24)-S20(7)/PW(17)
	5	Q1-S1(5)/PW(15)-S2(6)/PW(16) Q2-S5(8)/PW(28) Q3-S8(8)/PW(18)-S9(6)/PW(16) Q6-S19(9)/PW(17)

Table A1. *Cont.*

Part	Route	Cell–Machine (Operating Time)/(Machine Power Amount)
41	1	Q1-S1(8)/PW(16) Q2-S4(5)/PW(18) Q3-S7(3)/PW(13) Q4-S11(4)/PW(14)-S12(7)/PW(17) Q5-S14(8)/PW(18)-S15(4)/PW(14) Q6-S20(8)/PW(18)
	2	Q1-S2(3)/PW(23)-S3(5)/PW(15) Q2-S5(7)/PW(17) Q4-S11(9)/PW(19)-S12(7)/PW(19)-S13(5)/PW(15) Q5-S14(8)/PW(18)-S15(4)/PW(14) Q6-S18(4)/PW(24) Q6-S20(8)/PW(18)
	3	Q1-S1(6)/PW(16)-S2(5)/PW(19)-S3(4)/PW(14) Q3-S8(2)/PW(22) Q4-S12(9)/PW(17)-S13(6)/PW(26) Q5-S14(8)/PW(18)-S15(4)/PW(21) Q6-S18(9)/PW(19)-S20(8)/PW(18)
	4	Q1-S1(9)/PW(19)-S2(8)/PW(18)-S3(5)PW(25) Q2-S5(5)/PW(25) Q4-S11(9)/PW(18)-S12(4)/PW(24)-S13(5)/PW(15) Q5-S14(13)/PW(23)-S15(4)/PW(24) Q6-S20(8)/PW(18)
	5	Q1-S1(6)/PW(19)-S2(9)/PW(19)-S3(4)/PW(24) Q3-S8(6)/PW(26) Q4-S12(11)/PW(19)-S13(6)/PW(16) Q5-S14(8)/PW(18)-S15(4)/PW(24) Q6-S18(3)/PW(14)-S20(8)/PW(18)
42	1	Q1-S3(8)/PW(19) Q2-S6(5)/PW(25) Q3-S7(4)/PW(14) Q4-S9(4)PW(14)-S10(5)/PW(15) Q5-S13(8)/PW(18)-S14(7)/PW(19) Q6-S19(4)/PW(24)
	2	Q1-S1(8)/PW(20) Q2-S6(8)/PW(18) Q4-S11(8)/PW(18)-S13(3)/PW(23) Q5-S14(7)/PW(27) Q6-S18(8)/PW(18)-S19(2)/PW(22
	3	Q1-S2(7)/PW(25)-S3(3)/PW(23) Q2-S6(3)/PW(16) Q3-S7(4)/PW(24)-S8(7)/PW(17) Q4-S8(8)/PW(8) Q5-S16(4)/PW(14) Q6-S20(7)/PW(17)
	4	Q1-S1(6)/PW(18)-S2(7)/PW(17)-S3(3)/PW(23) Q2-S6(8)/PW(8) Q4-S11(8)/PW(8)-S13(3)/PW(23) Q5-S14(7)/PW(17) Q6-S18(8)/PW(18)-S19(2)/PW(22)
	5	Q1-S2(5)/PW(15)-S3(3)/PW(23) Q3-S7(4)/PW(24)-S8(7)/PW(17) Q4-S8(8)/PW(18) Q5-S15(5)/PW(25)-S16(4)/PW(24) Q6-S20(5)/PW(17)
43	1	Q1-S1(8)/PW(19)-S3(4)/PW(14) Q2-S6(7)/PW(17) Q4-S10(7)/PW(17)-S12(1)/PW(22) Q5-S15(8)/PW(18) Q6-S19(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(13) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(26) Q5-S16(4)/PW(14) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(2)/PW(17)-S2(2)/PW(21)-S3(3)/PW(15) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(3)/PW(23)-S2(7)/PW(17) Q2-S4(5)/PW(19)-S5(3)/PW(18) Q3-S8(3)/PW(19)-S9(6)/PW(16) Q6-S20(7)/PW(27)
	5	Q1-S1(4)/PW(21)-S2(2)/PW(17) Q2-S5(8)/PW(18) Q3-S8(3)/PW(15)-S9(9)/PW(16) Q6-S20(2)/PW(27)
44	1	Q1-S1(1)/PW(20)-S2(5)/PW(22)-S3(4)/PW(14) Q2-S4(5)/PW(15)-S6(7)/PW(27) Q4-S10(7)/PW(17)-S12(2)/PW(12) Q5-S15(8)/PW(18) Q6-S19(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(4)/PW(14) Q6-S19(3)/PW(13)-S20(4)/PW(24)
	3	Q1-S1(4)/PW(17)-S2(2)/PW(12)-S3(3)/PW(23) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(3)/PW(25)-S2(5)/PW(17) Q2-S4(1)/PW(21)-S5(3)PW(18) Q3-S8(6)/PW(16)-S9(6)/PW(26) Q6-S20(7)/PW(17)
	5	Q1-S1(3)/PW(16)-S2(5)/PW(17) Q2-S5(8)/PW(18) Q3-S8(3)/PW(24)-S9(6)/PW(26) Q6-S20(3)/PW(17)
45	1	Q1-S1(9)/PW(14)-S2(5)/PW(15)-S3(4)/PW(13) Q2-S6(8)/PW(18)-S7(6)/PW(12) Q4-S10(5)/PW(15)-S12(2)/PW(12) Q5-S15(6)/PW(16)-S16(5)/PW(15) Q6-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23)-S2(7)/PW(17) Q2-S4(6)/PW(19)-S5(8)/PW(18)-S6(6)/PW(16) Q3-S8(6)/PW(16)-S9(9)/PW(7) Q5-S16(4)/PW(24)-S17(5)/PW(25) Q6-S18(5)/PW(15)-S19(3)/PW(23)-S20(4)/PW(14)
	3	Q1-S1(8)/PW(18)-S3(3)/PW(23) Q2-S5(6)/PW(19) Q3-S7(7)/PW(17) Q4-S15(9)/PW(19)-S16(8)/PW(18)
	4	Q1-S1(6)/PW(16)-S2(8)/PW(18)-S3(5)/PW(25) Q2-S4(4)/PW(24)-S5(3)/PW(17)-S6(6)/PW(26) Q3-S8(6)/PW(16)-S9(5)/PW(25) Q6-S19(4)/PW(24)-S20(5)/PW(17)
	5	Q1-S1(5)/PW(15)-S2(6)/PW(16) Q2-S5(8)/PW(18) Q3-S8(8)/PW(21)-S9(6)/PW(16) Q6-S19(9)/PW(20)
46	1	Q1-S1(4)/PW(17)-S2(2)/PW(15)-S3(8)/PW(18) Q2-S6(7)/PW(17)-S7(5)/PW(26) Q4-S10(7)/PW(17)-S12(2)/PW(22) Q5-S15(8)/PW(28) Q6-S19(4)/PW(24)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(4)/PW(14) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(5)/PW(19)-S2(2)/PW(22)-S3(3)/PW(23) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(14)
	4	Q1-S1(4)/PW(19)-S2(7)/PW(17) Q2-S4(2)/PW(19)-S5(8)/PW(18) Q3-S8(3)/PW(16)-S9(6)/PW(16) Q6-S20(7)/PW(17)
	5	Q1-S1(3)/PW(18)-S2(7)/PW(17) Q2-S5(8)/PW(8) Q3-S8(12)/PW(4)-S9(6)/PW(6) Q6-S20(3)/PW(16)
47	1	Q1-S3(4)/PW(24) Q2-S5(8)/PW(8)-S6(7)/PW(17) Q4-S10(7)/PW(17)-S12(2)/PW(12) Q5-S15(8)/PW(18) Q6-S19(14)/PW(4)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(5)/PW(5)-S5(8)/PW(8) Q3-S8(6)/PW(6) Q5-S16(4)/PW(14) Q6-S19(3)/PW(13)-S20(4)/PW(14)
	3	Q1-S1(7)/PW(17)-S2(9)/PW(18)-S3(3)/PW(13) Q2-S5(5)/PW(5) Q3-S7(6)/PW(6) Q4-S15(7)/PW(17)
	4	Q1-S1(6)/PW(13)-S2(7)/PW(17) Q2-S4(1)/PW(11)-S5(5)/PW(8) Q3-S8(3)/PW(16)-S9(6)/PW(21) Q6-S20(7)/PW(22)
	5	Q1-S1(3)/PW(12)-S2(7)/PW(17) Q2-S5(9)/PW(18) Q3-S8(4)/PW(14)-S9(6)/PW(16) Q6-S20(4)/PW(11)
48	1	Q1-S1(6)/PW(19)-S3(8)/PW(18) Q2-S6(4)/PW(14) Q4-S10(7)/PW(17)-S12(2)/PW(12) Q5-S15(8)/PW(8) Q6-S19(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(6)/PW(21) Q2-S4(6)/PW(16)-S5(8)/PW(18) Q3-S8(6)/PW(19) Q5-S16(4)/PW(14) Q6-S19(3)/PW(13)-S20(4)/PW(14)
	3	Q1-S1(7)/PW(17)-S2(5)/PW(15)-S3(3)/PW(23) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(3)PW(13)-S2(7)/PW(17) Q2-S4(10)/PW(11)-S5(8)/PW(19) Q3-S8(4)/PW(16)-S9(6)/PW(16) Q6-S20(11)/PW(16)
	5	Q1-S1(4)/PW(14)-S2(7)/PW(17) Q2-S5(8)/PW(22) Q3-S8(6)/PW(14)-S9(3)/PW(16) Q6-S20(8)/PW(21)

Table A1. *Cont.*

Part	Route	Cell–Machine (Operating Time)/(Machine Power Amount)
49	1	Q1-S3(6)/PW(11) Q2-S5(8)/PW(18)-S6(7)/PW(17)-S7(9)/PW(19) Q4-S11(6)/PW(9)-S12(4)/PW(12) Q5-S15(8)/PW(18) Q6-S19(5)/PW(13)-S20(5)/PW(11)
	2	Q1-S1(6)/PW(8)-S2(9)/PW(9) Q2-S4(5)/PW(15)-S5(8)/PW(8) Q3-S7(7)/PW(7)-S8(6)/PW(6) Q5-S16(4)/PW(14)-S17(6)/PW(6) Q6-S20(4)/PW(14)
	3	Q1-S1(6)/PW(17)-S3(3)/PW(13) Q2-S5(5)/PW(15)-S6(8)/PW(18) Q3-S7(6)/PW(22)-S8(8)/PW(8) Q4-S15(7)/PW(17)-S16(9)/PW(9)
	4	Q1-S1(3)/PW(21)-S2(7)/PW(17)-S3(4)/PW(18) Q2-S4(3)/PW(11)-S5(6)/PW(18) Q3-S8(6)/PW(14)-S9(6)/PW(13) Q6-S20(7)/PW(17)
	5	Q1-S1(1)/PW(15)-S2(7)/PW(11)-S3(7)/PW(17) Q2-S5(8)/PW(8) Q3-S8(4)/PW(22)-S9(6)/PW(16) Q6-S19(8)/PW(18)-S20(7)/PW(21)
50	1	Q2-S5(4)/PW(14)-S6(5)/PW(15) Q4-S10(7)/PW(17)-S11(8)/PW(18)-S12(2)/PW(22) Q5-S15(8)/PW(21)-S17(9)/PW(19) Q6-S19(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(7)/PW(23)-S2(5)/PW(25) Q2-S4(5)/PW(25)-S5(7)/PW(28)-S6(4)/PW(24) Q3-S8(4)/PW(14) Q5-S16(2)/PW(14)-S17(5)/PW(15) Q6-S19(3)/PW(13)-S20(4)/PW(14)
	3	Q1-S1(6)/PW(16)-S2(8)/PW(18)-S3(3)/PW(13) Q2-S5(5)/PW(15)-S6(7)/PW(17) Q3-S7(6)/PW(16)-S8(8)/PW(18) Q4-S15(7)/PW(17)
	4	Q1-S1(4)/PW(15)-S2(7)/PW(17) Q2-S4(4)/PW(14)-S5(8)/PW(21) Q3-S8(5)/PW(16)-S9(6)/PW(16) Q6-S18(5)/PW(18)-S20(7)/PW(17)
	5	Q1-S1(4)/PW(14)-S2(6)/PW(17)-S3(8)/PW(18) Q2-S5(8)/PW(18) Q3-S8(5)/PW(14)-S9(6)/PW(26) Q6-S19(7)/PW(17)
51	1	Q1-S2(9)/PW(18) Q2-S5(4)/PW(14)-S6(7)7PW(17) Q4-S10(4)/PW(14)-S11(8)/PW(18)-S12(5)/PW(15) Q5-S15(8)/PW(8)-S16(7)/PW(7) Q6-S18(6)/PW(16)-S19(8)/PW(18)-S20(9)/PW(21)
	2	Q1-S1(8)/PW(10)-S2(8)/PW(12) Q2-S4(5)/PW(17)-S5(8)/PW(20)-S6(9)/PW(19) Q3-S8(6)/PW(16) Q5-S16(3)/PW(14) Q6-S19(3)/PW(11)-S20(4)/PW(14)
	3	Q1-S2(5)/PW(15) Q2-S6(6)/PW(15)-S7(7)/PW(17) Q4-S15(7)/PW(16)
	4	Q1-S1(8)/PW(17)-S2(4)/PW(19)-S3(9)/PW(9) Q2-S4(8)/PW(21)-S5(5)/PW(10) Q3-S8(5)/PW(15)-S9(6)/PW(16) Q5-S18(4)/PW(14) Q6-S19(8)/PW(18)-S20(7)/PW(17)
	5	Q1-S1(5)/PW(16)-S2(7)/PW(17) Q2-S4(7)/PW(17)-S5(8)/PW(12) Q3-S7(5)/PW(15)-S8(4)/PW(24)-S9(6)/PW(16) Q6-S19(8)/PW(20)-S20(6)/PW(16)
52	1	Q1-S3(8)/PW(23) Q2-S6(6)/PW(16)-S7(5)/PW(15) Q4-S10(3)/PW(14)-S11(3)/PW(13)-S12(2)/PW(12) Q5-S15(8)/PW(18) Q6-S20(5)/PW(15)
	2	Q1-S1(5)/PW(21)-S2(6)/PW(18) Q2-S4(6)/PW(24)-S5(7)/PW(17) Q3-S8(7)/PW(14) Q5-S16(5)/PW(15)-S17(4)/PW(14) Q6-S19(7)/PW(17)-S20(8)/PW(18)
	3	Q1-S1(4)/PW(22)-S2(6)/PW(18) Q2-S5(7)/PW(17)-S6(5)/PW(24) Q3-S7(6)/PW(11)-S8(5)/PW(15) Q4-S15(7)/PW(19)-S16(8)/PW(18)
	4	Q1-S1(4)/PW(18)-S2(6)/PW(16) Q2-S4(5)/PW(15)-S5(4)/PW(24) Q3-S8(7)/PW(24) Q6-S20(7)/PW(21)
	5	Q1-S2(8)/PW(8) Q2-S5(7)/PW(18) Q3-S8(4)/PW(24)-S9(6)/PW(16) Q6-S19(9)/PW(19)
53	1	Q1-S2(9)/PW(18)-S3(3)/PW(12) Q2-S4(6)/PW(16)-S6(7)/PW(17) Q4-S10(6)/PW(20)-S11(8)/PW(18)-S12(2)/PW(12) Q5-S15(7)/PW(18)-S16(9)/PW(9) Q6-S18(7)/PW(17)-S19(6)/PW(16)-S20(5)/PW(20)
	2	Q1-S1(8)/PW(15)-S2(6)/PW(26) Q2-S4(5)/PW(15)-S5(8)/PW(18)-S6(7)/PW(17) Q3-S8(6)/PW(24)-S9(7)/PW(17) Q5-S16(4)/PW(24)-S17(5)/PW(15) Q6-S19(6)/PW(16)
	3	Q1-S3(3)/PW(13) Q2-S5(5)/PW(15)-S6(7)/PW(17) Q3-S7(6)/PW(16)-S8(7)/PW(17) Q4-S15(7)/PW(17)-S16(6)/PW(16)
	4	Q1-S2(7)/PW(17) Q2-S5(8)/PW(18) Q3-S8(5)/PW(15)-S9(6)/PW(16)-S10(4)/PW(24) Q6-S19(8)/PW(18)
	5	Q1-S1(1)/PW(24)-S2(7)/PW(17) Q2-S5(3)/PW(21) Q3-S8(4)/PW(24)-S9(6)/PW(16) Q6-S18(4)/PW(22)-S19(8)/PW(19)
54	1	Q2-S6(9)/PW(17) Q4-S10(7)/PW(21)-S12(1)/PW(22) Q5-S15(10)/PW(18) Q6-S19(11)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(4)/PW(24) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(4)/PW(17)-S2(2)/PW(22)-S3(3)/PW(13) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(3)/PW(12)-S2(6)(PW(14) Q2-S4(2)/PW(11)-S5(8)/PW(18) Q3-S8(6)/PW(23)-S9(6)/PW(16) Q6-S20(7)/PW(17)
	5	Q1-S1(1)/PW(21)-S2(5)/PW(17) Q2-S5(3)/PW(18) Q3-S8(4)/PW(14)-S9(6)/PW(16) Q6-S20(7)/PW(22)
55	1	Q1-S1(5)/PW(18) Q2-S6(7)/PW(17)-S7(5)/PW(15) Q3-S15(8)/PW(8) Q4-S10(4)/PW(17)-S11(5)/PW(15)-S12(2)/PW(23) Q5-S15(8)/PW(8) Q6-S18(9)/PW(19)-S19(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23)-S2(7)/PW(17) Q3-S8(6)/PW(16) Q5-S16(4)/PW(14) Q6-S19(3)/PW(13)-S20(4)/PW(14)
	3	Q1-S1(11)/PW(19)-S3(3)/PW(23) Q2-S5(5)/PW(25) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(6)/PW(26)-S2(7)/PW(11)-S3(8)/PW(18) Q2-S4(9)/PW(15)-S5(8)/PW(18) Q3-S8(8)/PW(16)-S9(6)/PW(19)-S10(7)/PW(17) Q6-S19(6)/PW(16)-S20(9)/PW(16)
	5	Q1-S2(7)/PW(17) Q2-S5(8)/PW(8) Q3-S9(6)/PW(16) Q6-S19(9)/PW(24)-S20(7)/PW(17)
56	1	Q4-S10(7)/PW(15)-S12(9)/PW(20) Q5-S15(8)/PW(18)
	2	Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(5)/PW(24) Q6-S19(3)/PW(13)-S20(4)/PW(24)
	3	Q1-S1(9)/PW(18)-S2(2)/PW(24)-S3(3)/PW(23) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(3)/PW(18)-S2(7)/PW(17) Q2-S4(3)/PW(19)-S5(8)/PW(21) Q3-S8(10)/PW(21)-S9(6)/PW(15) Q6-S20(7)/PW(18)
	5	Q1-S1(4)/PW(13)-S2(9)/PW(20)-S3(9)/PW(15) Q2-S5(8)/PW(19) Q3-S6(4)/PW(16)-S8(7)/PW(18)-S9(6)/PW(16) Q6-S19(5)/PW(17)-S20(4)/PW(21)

Table A1. *Cont.*

Part	Route	Cell–Machine (Operating Time)/(Machine Power Amount)
57	1	Q1-S2(9)/PW(21)-S3(5)/PW(15) Q2-S6(4)/PW(17) Q4-S10(7)/PW(17)-S12(5)/PW(22) Q5-S15(8)/PW(18)-S16(5)/PW(25) Q6-S18(6)/PW(26)-S20(5)/PW(25)
	2	Q1-S1(3)/PW(23)-S2(8)/PW(18) Q2-S4(5)/PW(15) Q3-S7(4)/PW(14)-S8(6)/PW(16) Q5-S16(4)/PW(24)-S17(3)/PW(17) Q6-S20(9)/PW(19)
	3	Q1-S1(8)/PW(19)-S3(4)/PW(14) Q2-S5(5)/PW(15)-S6(7)/PW(17) Q3-S7(6)/PW(26)-S8(5)/PW(15) Q4-S15(7)/PW(17)-S16(8)/PW(18) Q5-S18(9)/PW(19)
	4	Q1-S1(3)/PW(23)-S2(7)/PW(17) Q2-S4(1)/PW(21)-S5(4)/PW(8) Q3-S8(6)/PW(13)-S9(6)/PW(19) Q6-S20(7)/PW(22)
	5	Q1-S2(9)/PW(21) Q2-S5(8)/PW(18) Q3-S8(4)/PW(14)-S9(6)/PW(16)
58	1	Q1-S2(9)/PW(18)-S3(4)/PW(14) Q2-S6(7)/PW(17) Q4-S10(7)/PW(27)-S12(9)/PW(19) Q5-S15(8)/PW(18) Q6-S18(5)PW(15)-S19(4)/PW(24)-S20(5)/PW(25)
	2	Q1-S1(8)/PW(19)-S2(5)/PW(25) Q2-S4(9)/PW(24) Q3-S8(6)/PW(26)-S9(6)/PW(16) Q5-S16(6)/PW(16)-S17(7)/PW(17) Q6-S19(8)/PW(18)-S20(4)/PW(24)
	3	Q1-S1(9)/PW(19)-S3(7)/PW(17) Q2-S5(5)PW(15) Q3-S7(6)/PW(16)-S8(5)/PW(15) Q4-S15(9)/PW(19)-S16(4)/PW(24)
	4	Q1-S2(9)/PW(9)-S3(4)/PW(14) Q2-S5(3)/PW(13)-S6(5)/PW(15) Q3-S8(6)/PW(16) Q6-S18(3)/PW(13)-S19(8)/PW(18)-S20(4)/PW(14)
	5	Q1-S1(6)/PW(19)-S2(7)/PW(16)-S3(5)/PW(15) Q2-S5(8)/PW(8)-S8(4)/PW(14) Q3-S8(4)/PW(14)-S9(6)/PW(26)-S10(5)/PW(15) Q6-S19(9)/PW(18)-S20(7)/PW(13)
59	1	Q2-S6(3)/PW(14)-S7(8)/PW(18) Q4-S10(7)/PW(17)-S11(5)/PW(25)-S12(2)/PW(22) Q5-S15(8)/PW(18) Q6-S19(4)/PW(24)-S20(5)/PW(15)
	2	Q1-S1(6)/PW(16) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(26) Q5-S16(5)/PW(26) Q6-S19(13)/PW(13)-S20(4)/PW(14)
	3	Q1-S2(9)/PW(9)-S3(7)/PW(18) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S2(9)/PW(19) Q2-S4(11)/PW(11)-S5(8)/PW(18) Q3-S8(4)/PW(7)-S9(6)/PW(16) Q6-S19(2)/PW(22)-S20(3)/PW(14)
	5	Q2-S5(8)/PW(8) Q3-S8(4)/PW(24)-S9(6)/PW(16) Q6-S19(5)/PW(15)-S20(6)/PW(19)
60	1	Q2-S6(7)/PW(11)-S7(9)/PW(9) Q3-S9(8)PW(15) Q4-S10(3)/PW(19)-S11(8)/PW(18)-S12(2)/PW(22) Q5-S15(9)/PW(9) Q6-S18(6)/PW(16)-S19(4)/PW(14)-S20(5)/PW(25)
	2	Q1-S1(3)/PW(23)-S2(8)/PW(18) Q2-S4(9)/PW(9)-S5(6)/PW(16) Q3-S7(7)/PW(17)-S8(6)/PW(16) Q6-S20(4)/PW(14)
	3	Q1-S2(12)/PW(12) Q2-S5(8)/PW(9) Q3-S7(6)/PW(16)-S8(7)/PW(17) Q4-S15(8)/PW(19)-S16(9)/PW(9) Q6-S19(8)/PW(18)
	4	Q1-S2(7)/PW(17)-S3(8)/PW(18) Q3-S8(6)/PW(16)-S9(6)/PW(16)-S10(5)/PW(25) Q5-S17(9)/PW(19) Q6-S19(5)/PW(25)-S20(8)/PW(18)
	5	Q2-S5(3)/PW(18) Q3-S8(5)/PW(21)-S9(6)/PW(16)
61	1	Q1-S1(6)/PW(21)-S2(5)/PW(19)-S3(4)/PW(14) Q4-S10(5)/PW(15)-S11(7)/PW(16)-S12(8)/PW(22) Q6-S19(4)/PW(24)-S20(5)/PW(15)
	2	Q2-S4(5)/PW(25)-S5(8)/PW(18) Q3-S8(6)/PW(26)-S9(7)/PW(17) Q6-S19(9)/PW(9)
	3	Q1-S3(5)/PW(9) Q2-S5(5)/PW(25)-S6(7)/PW(17) Q3-S7(6)/PW(26) Q4-S15(7)/PW(17) Q6-S18(8)/PW(18)-S19(9)/PW(19)
	4	Q1-S2(7)/PW(17) Q2-S4(11)/PW(11)-S5(8)/PW(18) Q3-S8(6)/PW(19)-S9(6)/PW(18) Q6-S20(7)/PW(20)
	5	Q1-S1(4)/PW(24)-S2(5)/PW(16) Q2-S5(8)/PW(27) Q3-S8(4)/PW(22)-S9(6)/PW(16) Q4-S11(4)/PW(17)
62	1	Q1-S1(8)/PW(18)-S3(7)/PW(24) Q2-S5(6)/PW(18) Q4-S10(7)/PW(17)-S11(8)/PW(9)-S12(5)/PW(17) Q5-S15(9)/PW(8)-S16(3)/PW(15) Q6-S20(7)/PW(9)
	2	Q1-S1(6)/PW(3)-S2(8)/PW(9) Q3-S8(4)/PW(16)-S9(5)/PW(8) Q5-S16(8)/PW(14)-S17(5)/PW(15) Q6-S19(7)/PW(9)
	3	Q1-S1(6)/PW(18)-S2(7)/PW(12) Q2-S5(7)/PW(9) Q3-S7(8)/PW(16)-S8(4)/PW(19) Q4-S15(7)/PW(27)-S16(6)/PW(18)
	4	Q2-S5(9)/PW(8)-S6(3)/PW(7) Q3-S8(9)/PW(6)-S9(5)/PW(9) Q6-S18(3)/PW(3)-S20(9)/PW(9)
	5	Q1-S2(5)/PW(17)-S3(9)/PW(9) Q2-S4(2)/PW(20)-S5(8)/PW(18) Q3-S8(5)/PW(21)-S9(6)/PW(16)-S10(3)/PW(13) Q4-S16(4)/PW(14) Q5-S17(3)/PW(18)-S18(5)/PW(15) Q6-S20(9)/PW(21)
63	1	Q1-S3(9)/PW(24) Q2-S6(7)/PW(17) Q5-S15(8)/PW(18)-S16(9)/PW(9)
	2	Q1-S1(7)/PW(23)-S2(3)/PW(18) Q2-S4(5)/PW(15)-S5(8)/PW(18)-S6(7)/PW(17) Q3-S8(6)/PW(16) Q4-S15(6)/PW(16) Q6-S20(9)/PW(19)
	3	Q1-S1(7)/PW(9)-S2(8)/PW(8) Q2-S4(4)/PW(24)-S5(5)/PW(25) Q3-S7(6)/PW(26)-S8(9)/PW(17)
	4	Q2-S4(3)/PW(23)-S5(7)/PW(17)-S6(3)/PW(18) Q6-S19(9)/PW(23)-S20(7)/PW(11)
	5	Q2-S5(7)/PW(19) Q3-S9(6)/PW(6) Q6-S18(8)/PW(9)-S20(5)/PW(15)
64	1	Q1-S1(9)/PW(14)-S2(3)/PW(20)-S3(2)/PW(14) Q2-S5(9)/PW(16)-S6(7)/PW(17) Q4-S10(2)/PW(19)-S11(8)/PW(18) Q5-S14(6)/PW(16)-S15(8)/PW(18) Q6-S19(6)/PW(16)-S20(3)/PW(13)
	2	Q2-S5(6)/PW(16)-S6(7)/PW(17) Q3-S8(9)/PW(19)-S9(5)/PW(15) Q5-S16(7)/PW(23)-S17(2)/PW(22) Q6-S20(4)/PW(12)
	3	Q1-S1(6)/PW(16)-S3(9)/PW(9) Q4-S15(7)/PW(21)-S16(5)/PW(15) Q6-S19(8)/PW(18)
	4	Q1-S1(3)/PW(13)-S2(7)/PW(17)-S3(6)/PW(16) Q2-S5(8)/PW(8)-S6(5)/PW(15) Q6-S19(8)/PW(18)-S20(9)/PW(9)
	5	Q1-S2(3)/PW(17) Q2-S5(9)/PW(14)-S6(5)/PW(15) Q3-S8(7)/PW(21)
65	1	Q1-S1(7)/PW(15)-S2(4)/PW(16)-S3(5)/PW(14) Q2-S5(8)PW(18)-S6(7)/PW(17)-S7(5)/PW(15) Q3-S8(3)/PW(23) Q4-S12(9)/PW(9) Q5-S15(8)/PW(18)
	2	Q1-S1(9)/PW(9)-S2(5)/PW(15) Q2-S4(4)/PW(24)-S5(7)/PW(17) Q3-S8(5)/PW(15)-S9(4)PW(24) Q5-S16(8)/PW(8) Q6-S19(9)/PW(9)-S20(6)/PW(6)
	3	Q1-S2(7)/PW(18)-S3(9)/PW(9) Q2-S5(5)/PW(15) Q3-S6(4)/PW(10)-S7(6)/PW(16)
	4	Q1-S1(5)/PW(16)-S2(7)/PW(17)-S3(8)/PW(18) Q2-S4(9)/PW(12)-S5(8)/PW(18)-S6(3)/PW(11) Q3-S8(6)/PW(16)-S9(6)/PW(16) Q6-S19(8)/PW(18)-S20(7)/PW(17)
	5	Q1-S2(8)/PW(17) Q2-S4(5)/PW(14)-S5(3)/PW(8) Q3-S8(7)/PW(14)-S9(6)/PW(16) Q6-S19(6)/PW(16)-S20(7)/PW(17)

Table A1. *Cont.*

Part	Route	Cell–Machine (Operating Time)/(Machine Power Amount)
66	1	Q1-S3(4)/PW(14) Q2-S6(7)/PW(17)-S7(8)/PW(18) Q4-S10(7)/PW(17) Q5-S15(8)/PW(8)-S16(8)/PW(8) Q6-S18(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(7)/PW(17)-S2(8)/PW(18) Q2-S4(2)/PW(21)-S5(3)/PW(13)-S6(4)/PW(24) Q3-S7(5)/PW(15)-S8(6)/PW(16)-S9(7)/PW(17) Q5-S16(4)/PW(14)-S17(5)/PW(15) Q6-S18(7)/PW(17)-S20(4)/PW(24)
	3	Q1-S1(8)/PW(18)-S2(9)/PW(19) Q2-S5(5)/PW(15)-S6(6)/PW(16) Q3-S7(6)/PW(16)-S8(7)/PW(17) Q4-S14(7)/PW(17)-S15(8)/PW(18)
	4	Q2-S4(7)/PW(18)-S5(8)/PW(18) Q3-S8(9)/PW(19)
	5	Q1-S2(5)/PW(14) Q2-S5(8)/PW(16)-S6(7)/PW(17) Q3-S8(5)/PW(15)-S9(7)/PW(17) Q5-S16(6)/PW(16)-S17(3)/PW(23) Q6-S18(4)/PW(14)-S19(8)/PW(18)
67	1	Q1-S1(7)/PW(19)-S2(1)/PW(21)-S3(4)/PW(14) Q2-S4(3)/PW(23)-S6(5)/PW(15) Q4-S10(7)/PW(15)-S11(6)/PW(16)-S12(2)/PW(12) Q6-S19(7)/PW(17)
	2	Q1-S1(11)/PW(13)-S2(5)/PW(15)-S3(5)/PW(16) Q2-S5(9)/PW(15)-S6(7)/PW(8) Q3-S7(4)/PW(17)-S8(5)/PW(16) Q5-S6(6)/PW(4)-S17(8)PW(5)
	3	Q1-S1(6)/PW(16)-S3(8)/PW(23) Q2-S5(8)/PW(18)-S6(9)/PW(9) Q3-S7(7)/PW(17)-S8(8)/PW(19) Q4-S14(6)/PW(26)-S15(7)/PW(7) Q6-S19(8)/PW(18)-S20(6)/PW(14)
	4	Q1-S1(3)/PW(3)-S2(6)/PW(6)-S3(4)/PW(4) Q4-S5(8)/PW(8) Q6-S20(7)/PW(7)
	5	Q1-S1(6)/PW(24)-S2(7)/PW(17)-S3(8)/PW(18) Q2-S4(5)/PW(25)-S5(8)/PW(18) Q3-S8(3)/PW(24)-S9(6)/PW(16) Q5-S17(6)/PW(16) Q6-S19(4)/PW(21)-S20(7)/PW(17)
68	1	Q1-S1(7)/PW(22)-S3(6)/PW(14) Q2-S6(9)/PW(9) Q4-S10(6)/PW(16)-S12(3)/PW(13) Q5-S15(8)/PW(18) Q6-S19(6)/PW(16)-S20(8)/PW(18)
	2	Q1-S1(6)/PW(16) Q2-S4(6)/PW(22)-S5(8)/PW(18) Q3-S8(9)/PW(17) Q5-S16(6)/PW(6) Q6-S19(7)/PW(15)-S20(3)/PW(23)
	3	Q1-S1(9)/PW(19)-S3(6)/PW(26) Q2-S5(5)/PW(5) Q3-S7(7)/PW(7) Q4-S15(8)/PW(8)
	4	Q1-S1(4)/PW(14)-S2(8)/PW(18) Q2-S4(3)/PW(16)-S5(11)/PW(11) Q3-S8(9)PW(19)-S9(6)/PW(26) Q6-S19(4)/PW(14)-S20(8)/PW(18)
	5	Q1-S1(6)/PW(16)-S2(8)/PW(18) Q2-S5(8)(PW(18) Q3-S8(9)/PW(11)-S9(5)/PW(15) Q6-S19(3)/PW(23)-S20(6)/PW(16)
69	1	Q1-S1(7)/PW(17)-S3(5)/PW(13) Q2-S6(9)/PW(8) Q4-S12(9)/PW(9) Q6-S20(6)/PW(16)
	2	Q2-S4(9)/PW(11)-S5(6)/PW(16)-S6(5)/PW(15) Q3-S7(7)/PW(17)-S8(8)/PW(8) Q4-S9(9)/PW(9) Q5-S16(3)/PW(23)-S17(2)/PW(20) Q6-S20(4)/PW(9)
	3	Q1-S2(6)/PW(9)-S3(3)/PW(13) Q3-S7(7)/PW(17)-S8(8)/PW(18) Q6-S18(9)/PW(9)
	4	Q1-S2(9)/PW(17) Q2-S5(7)/PW(18)-S6(4)/PW(14) Q3-S7(6)/PW(15)-S8(6)/PW(16)-S9(6)/PW(16) Q6-S19(5)/PW(15)-S20(6)/PW(16)
	5	Q1-S2(7)/PW(17) Q2-S5(8)/PW(18) Q3-S8(4)/PW(14)-S9(6)/PW(16) Q5-S16(4)/PW(14)-S17(5)PW(15) Q6-S19(3)/PW(13)-S20(8)/PW(19)
70	1	Q1-S1(10)/PW(17)-S2(2)/PW(11)-S3(4)/PW(15) Q2-S5(6)/PW(16)-S7(7)/PW(17) Q3-S8(5)/PW(15)-S9(4)/PW(24) Q5-S15(6)/PW(16) Q6-S20(9)/PW(19)
	2	Q1-S1(3)/PW(14)-S2(5)/PW(15)-S3(8)/PW(18) Q2-S4(4)/PW(19)-S5(3)/PW(13) Q3-S7(3)/PW(23)-S8(9)/PW(9) Q5-S16(6)/PW(16)-S17(7)/PW(17)
	3	Q1-S2(13)/PW(17)-S3(3)PW(13) Q2-S5(6)/PW(16)-S6(7)/PW(17) Q3-S7(11)/PW(11) Q4-S15(3)/PW(23)-S16(4)/PW(14) Q6-S18(5)/PW(15)-S19(6)/PW(16)
	4	Q1-S1(9)/PW(9)-S2(7)/PW(17) Q2-S5(8)/PW(8) Q3-S8(5)/PW(15)-S9(4)/PW(14) Q6-S19(8)/PW(8)-S20(9)/PW(9)
	5	Q1-S2(8)/PW(9)-S3(7)/PW(17) Q2-S4(6)/PW(16)-S5(5)/PW(15) Q3-S8(4)/PW(24)-S9(3)/PW(16) Q4-S11(7)/PW(16)-S12(8)/PW(8) Q5-S16(10)/PW(19)-S17(8)/PW(18)
71	1	Q1-S1(7)/PW(18)-S3(5)PW(25) Q2-S6(6)/PW(16) Q4-S10(6)/PW(16)-S12(3)/PW(23) Q5-S15(9)/PW(19) Q6-S19/PW(17)-S20(3)/PW(13)
	2	Q1-S1(6)/PW(16) Q2-S4(9)/PW(17)-S5(8)/PW(18) Q3-S8(5)/PW(19) Q5-S16(5)/PW(25) Q6-S19(4)/PW(24)-S20(5)/PW(15)
	3	Q1-S1(6)/PW(16)-S2(3)/PW(13)-S3(5)/PW(15) Q2-S5(8)/PW(19) Q3-S7(3)/PW(17) Q4-S15(9)/PW(19)
	4	Q1-S1(7)/PW(17)-S2(3)/PW(23) Q2-S4(2)/PW(20)-S5(4)/PW(14) Q3-S8(7)/PW(22)-S9(3)/PW(23) Q6-S20(10)/PW(18)
	5	Q1-S1(3)/PW(25)-S2(3)/PW(19) Q2-S5(5)/PW(24) Q3-S8(6)/PW(23)-S9(8)/PW(17) Q6-S20(8)/PW(26)
72	1	Q3-S7(9)/PW(16) Q4-S10(8)/PW(18)-S11(6)/PW(17)-S12(3)/PW(23) Q5-S15(5)/PW(14) Q6-S20(5)/PW(15)
	2	Q1-S1(8)/PW(19)-S2(8)/PW(18)-S3(4)/PW(24) Q2-S5(3)/PW(13) Q3-S7(5)/PW(23)-S8(7)/PW(18) Q5-S16(6)/PW(16)-S17(7)/PW(17) Q6-S19(8)/PW(18)
	3	Q1-S1(7)/PW(9) Q3-S7(6)/PW(16)-S8(9)/PW(19) Q4-S14(6)/PW(26)-S15(7)/PW(17) Q5-S16(9)/PW(9)-S17(3)/PW(13) Q6-S18(8)/PW(8)-S19(9)/PW(9)
	4	Q1-S1(10)/PW(16)-S2(3)/PW(17)-S3(5)/PW(10) Q2-S4(2)/PW(5) Q3-S8(3)/PW(13)-S9(7)/PW(7) Q5-S16(5)/PW(15) Q6-S18(5)/PW(15)-S19(9)/PW(9)
	5	Q1-S2(9)/PW(9) Q3-S8(3)/PW(13)-S9(2)/PW(21) Q6-S19(5)/PW(16)-S20(3)/PW(27)
73	1	Q1-S1(6)/PW(23)-S2(2)/PW(19)-S3(4)/PW(13) Q2-S5(5)/PW(15)-S6(7)/PW(17) Q3-S7(3)/PW(16)-S8(5)/PW(20) Q4-S10(4)/PW(17)-S11(3)/PW(13)-S12(2)/PW(21) Q5-S15(8)/PW(18)-S16(4)/PW(24) Q6-S18(6)/PW(16)-S19(4)/PW(24)-S20(5)/PW(15)
	2	Q1-S1(5)/PW(13)-S2(8)/PW(18) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(16)-S9(7)/PW(17) Q5-S16(4)/PW(14)-S17(5)/PW(23) Q6-S18(5)/PW(15)-S20(4)/PW(24)
	3	Q1-S1(7)/PW(16)-S3(13)/PW(23) Q2-S5(6)/PW(16) Q3-S7(9)/PW(19) Q4-S15(8)/PW(18)-S16(9)/PW(19)
	4	Q1-S2(9)/PW(19)-S3(5)/PW(15) Q2-S4(3)/PW(11)-S5(9)/PW(9) Q3-S7(4)/PW(14) Q4-S10(5)/PW(15)-S11(6)/PW(16)
	5	Q1-S2(8)/PW(19)-S3(8)/PW(19) Q2-S4(4)/PW(22)-S5(8)/PW(12) Q3-S8(3)PW(13)-S9(9)/PW(16)-S10(2)/PW(14) Q5-S16(8)/PW(20)-S17(3)/PW(13) Q6-S18(7)/PW(15)-S19(6)/PW(11)-S20(3)/PW(27)

Table A1. *Cont.*

Part	Route	Cell–Machine (Operating Time)/(Machine Power Amount)
74	1	Q4-S10(8)/PW(16)-S11(8)/PW(18)-S12(2)PW(22) Q5-S15(9)/PW(18)-S16(3)/PW(18) Q6-S19(5)/PW(15)
	2	Q1-S1(3)/PW(23)-S2(8)/PW(18) Q2-S5(8)/PW(18)-S6(7)/PW(21) Q3-S8(5)/PW(22)-S9(4)/PW(18)-S10(3)/PW(13) Q5-S16(4)/PW(14)-S17(5) Q6-S18(5)/PW(17)-S20(4)/PW(20)
	3	Q1-S1(9)/PW(9)-S3(5)/PW(15) Q2-S5(5)/PW(15)-S6(6)/PW(16) Q3-S7(6)/PW(16)-S8(8)/PW(18) Q4-S15(7)/PW(17)-S16(8)/PW(18)
	4	Q1-S1(8)/PW(23)-S2(7)/PW(17)-S3(4)/PW(24) Q2-S5(8)/PW(18) Q3-S8(6)/PW(16)-S9(5)/PW(15) Q6-S19(9)/PW(8
	5	Q1-S1(6)/PW(16)-S2(7)/PW(23)-S3(6)/PW(15) Q2-S5(7)/PW(18)-S6(8)/PW(24) Q3-S8(4)/PW(14)-S9(6)/PW(25)-S10(8)/PW(23) Q6-S18(4)/PW(14)-S19(6)/PW(15)-S20(8)/PW(17)
75	1	Q2-S6(4)/PW(18)-S7(9)/PW(19) Q4-S10(6)/PW(17)-S12(5)/PW(22) Q5-S15(8)/PW(18)
	2	Q1-S1(7)/PW(23) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(16) Q5-S16(5)/PW(14) Q6-S19(6)/PW(23)-S20(4)/PW(14)
	3	Q1-S1(6)/PW(17)-S2(2)/PW(22)-S3(5)/PW(15) Q2-S5(4)/PW(5) Q3-S7(3)/PW(6) Q4-S15(5)/PW(7)
	4	Q1-S1(4)/PW(23)-S2(7)/PW(17) Q2-S4(5)/PW(21)-S5(6)/PW(18) Q3-S8(8)/PW(6)-S9(6)/PW(6) Q6-S20(6)/PW(17)
	5	Q1-S1(1)/PW(11)-S2(4)/PW(17) Q2-S5(3)/PW(18) Q3-S8(5)/PW(15)-S9(6)/PW(16) Q6-S20(9)/PW(25)
76	1	Q1-S1(7)/PW(24) Q2-S4(7)/PW(15) Q3-S7(4)/PW(13) Q4-S11(6)/PW(14)-S12(7)/PW(17) Q5-S14(5)/PW(18)-S15(4)/PW(14) Q6-S20(8)/PW(18)
	2	Q1-S2(3)/PW(13)-S3(5)/PW(15) Q2-S5(7)/PW(17) Q4-S11(5)/PW(19)-S12(4)/PW(17)-S13(3)/PW(15) Q5-S14(8)/PW(18)-S15(4)/PW(14) Q6-S18(4)/PW(14)-S20(8)/PW(18)
	3	Q1-S1(5)/PW(16)-S2(7)/PW(19)-S3(4)/PW(14) Q3-S8(8)/PW(22) Q4-S12(9)/PW(19)-S13(8)/PW(26) Q5-S14(8)/PW(18)-S15(4)/PW(24). Q6-S18(9)/PW(19)-S20(8)/PW(18)
	4	Q1-S1(9)/PW(19)-S2(8)/PW(18)-S3(5)/PW(25) Q2-S5(5)/PW(25) Q4-S11(9)/PW(19)-S12(4)/PW(24)-S13(5)/PW(15) Q5-S14(3)/PW(23)-S15(4)/PW(24) Q6-S20(8)/PW(28)
	5	Q1-S1(7)/PW(16)-S2(8)/PW(19)-S3(4)/PW(24) Q3-S8(6)/PW(16) Q4-S12(7)/PW(19)-S13(6)/PW(16) Q5-S14(8)/PW(18)-S15(4)/PW(24) Q6-S18(10)/PW(19)-S20(6)/PW(28)
77	1	Q1-S3(7)/PW(18) Q2-S6(5)/PW(15) Q3-S7(4)/PW(14) Q4-S9(6)PW(24)-S10(5)/PW(15) Q5-S13(7)/PW(18)-S14(9)/PW(19) Q6-S19(6)/PW(24)
	2	Q1-S1(5)/PW(20) Q2-S6(8)/PW(18) Q4-S11(8)/PW(18)-S13(3)/PW(23) Q5-S14(7)/PW(27) Q6-S18(8)/PW(18)-S19(5)/PW(22)
	3	Q1-S2(3)/PW(25)-S3(6)/PW(23) Q2-S6(4)/PW(19) Q3-S7(7)/PW(24)-S8(8)/PW(17) Q4-S8(5)/PW(8) Q5-S16(5)/PW(14) Q6-S20(7)/PW(17)
	4	Q1-S1(8)/PW(21)-S2(7)/PW(17)-S3(3)/PW(23) Q2-S6(8)/PW(8) Q4-S11(9)/PW(8)-S13(2)/PW(23) Q5-S14(7)/PW(17) Q6-S18(8)/PW(28)-S19(2)/PW(22)
	5	Q1-S2(5)/PW(15)-S3(3)/PW(23) Q3-S7(7)/PW(24)-S8(7)/PW(17) Q4-S8(8)/PW(18) Q5-S15(3)/PW(25)-S16(6)/PW(24) Q6-S20(7)/PW(24)
78	1	Q1-S1(8)/PW(22)-S3(4)/PW(14) Q2-S6(6)/PW(17) Q4-S10(8)/PW(17)-S12(2)/PW(22) Q5-S15(8)/PW(18) Q6-S19(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(5)/PW(15)-S5(8)/PW(18) Q3-S8(6)/PW(26) Q5-S16(4)/PW(18) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(6)/PW(17)-S2(2)/PW(21)-S3(3)/PW(13) Q2-S5(5)/PW(15) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(8)/PW(23)-S2(7)/PW(17) Q2-S4(6)/PW(19)-S5(6)/PW(18) Q3-S8(5)/PW(16)-S9(6)/PW(16) Q6-S20(3)/PW(17)
	5	Q1-S1(3)/PW(11)-S2(7)/PW(17) Q2-S5(8)/PW(18) Q3-S8(8)/PW(24)-S9(6)/PW(16) Q6-S20(5)/PW(26)
79	1	Q1-S1(5)/PW(11)-S2(2)/PW(22)-S3(4)/PW(14) Q2-S4(1)/PW(25)-S6(7)/PW(17) Q4-S10(7)/PW(17)-S12(2)/PW(12) Q5-S15(8)/PW(18) Q6-S19(4)/PW(14)-S20(5)/PW(15)
	2	Q1-S1(3)/PW(23) Q2-S4(5)/PW(19)-S5(8)/PW(18) Q3-S8(6)/PW(26) Q5-S16(5)/PW(14) Q6-S19(3)/PW(23)-S20(4)/PW(24)
	3	Q1-S1(7)/PW(17)-S2(6)/PW(22)-S3(3)/PW(23) Q2-S5(4)/PW(19) Q3-S7(6)/PW(16) Q4-S15(7)/PW(17)
	4	Q1-S1(3)/PW(23)-S2(7)/PW(17) Q2-S4(3)/PW(21)-S5(8)7PW(18) Q3-S8(2)/PW(16)-S9(6)/PW(26) Q6-S20(11)/PW(17)
	5	Q1-S1(4)/PW(21)-S2(6)/PW(17) Q2-S5(8)/PW(18) Q3-S8(5)/PW(24)-S9(6)/PW(26) Q6-S20(8)/PW(27)
80	1	Q1-S1(8)/PW(19)-S2(5)/PW(25)-S3(4)/PW(19) Q2-S6(8)/PW(18)-S7(9)/PW(19) Q4-S10(5)/PW(15)-S12(2)/PW(12) Q5-S15(6)/PW(16)-S16(5)/PW(15) Q6-S20(5)/PW(15)
	2	Q1-S1(7)/PW(23)-S2(4)/PW(17) Q2-S4(5)/PW(19)-S5(7)/PW(18)-S6(6)/PW(16) Q3-S8(5)/PW(16)-S9(7)/PW(7) Q5-S16(4)/PW(24)-S17(3)/PW(25) Q6-S18(5)/PW(25)-S19(6)/PW(23)-S20(4)/PW(14)
	3	Q1-S1(6)/PW(18)-S3(7)/PW(23) Q2-S5(7)/PW(19) Q3-S7(5)/PW(17) Q4-S15(6)/PW(25)-S16(8)/PW(18)
	4	Q1-S1(6)/PW(16)-S2(8)/PW(18)-S3(5)/PW(25) Q2-S4(4)/PW(24)-S5(7)/PW(17)-S6(6)/PW(26) Q3-S8(6)/PW(16)-S9(5)/PW(25) Q6-S19(5)/PW(24)-S20(7)/PW(19)
	5	Q1-S1(7)/PW(15)-S2(6)/PW(20) Q2-S5(7)/PW(21) Q3-S8(4)/PW(18)-S9(6)/PW(16) Q6-S19(8)/PW(19)

Table A2. Part demands and movement costs between cells.

Part	Part Demands					Movement Costs between Cells				
	1. Period	2. Period	3. Period	4. Period	5. Period	1. Period	2. Period	3. Period	4. Period	5. Period
1	150	90	80	70	65	45	40	35	30	40
2	80	75	70	75	70	35	50	45	40	45
3	40	35	30	50	45	30	47	40	37	47
4	75	70	65	85	80	34	48	40	38	48
5	80	75	70	100	95	52	40	55	40	45
6	120	100	90	85	80	55	50	55	50	55
7	60	55	50	65	60	37	45	40	35	45
8	50	45	40	55	50	36	45	35	35	40
9	85	75	70	85	75	33	50	44	40	45
10	90	70	65	90	85	40	35	30	30	35
11	90	75	70	45	40	55	43	40	33	38
12	60	55	50	50	45	32	52	50	36	42
13	50	45	40	40	35	35	45	45	40	45
14	55	50	45	55	50	38	40	50	48	55
15	70	60	55	65	60	45	45	40	39	49
16	110	90	85	70	65	47	42	40	32	45
17	100	80	75	55	50	45	55	50	45	48
18	50	45	40	40	38	40	38	35	32	38
19	65	50	45	55	50	33	45	40	39	42
20	80	75	70	80	75	52	45	40	35	45
21	70	65	60	60	55	40	50	55	50	55
22	100	95	85	90	75	45	55	50	50	55
23	60	55	50	50	45	40	37	35	33	38
24	55	50	45	55	50	43	38	35	30	35
25	70	60	55	65	60	40	30	35	32	38
26	50	45	40	40	35	45	45	40	36	40
27	90	85	80	90	80	55	55	50	48	55
28	45	40	35	70	65	40	45	45	43	53
29	55	50	45	80	75	33	40	40	38	45
30	90	80	75	90	85	40	45	45	40	45
31	120	85	80	60	55	45	38	30	29	45
32	90	85	80	100	95	46	55	50	48	52
33	100	75	70	85	80	32	52	50	45	55
34	85	70	65	80	70	35	48	45	40	45
35	80	70	65	80	70	52	45	35	30	40
36	150	125	115	105	100	41	38	50	45	55
37	90	85	80	80	75	37	52	40	35	45
38	40	35	30	65	60	33	45	45	40	45
39	45	40	35	40	35	43	40	40	35	48
40	90	80	75	60	55	40	43	40	39	42
41	90	65	60	60	50	47	38	35	30	35
42	70	65	60	65	60	45	43	40	35	38
43	60	55	50	75	70	40	45	40	35	40
44	95	60	55	65	60	42	48	45	40	45
45	70	60	50	65	60	51	50	55	50	55
46	150	115	105	75	70	43	35	35	30	39
47	70	65	55	80	70	37	40	40	35	42
48	60	55	45	75	65	33	42	45	42	45
49	75	70	60	80	70	35	46	50	46	50
50	80	70	50	90	80	48	43	45	43	53
51	120	115	95	75	70	43	35	30	30	45
52	70	65	60	60	55	37	53	55	53	55
53	50	45	40	40	35	30	45	45	40	45

Table A2. *Cont.*

Part	Part Demands					Movement Costs between Cells				
	1. Period	2. Period	3. Period	4. Period	5. Period	1. Period	2. Period	3. Period	4. Period	5. Period
54	65	60	55	55	50	34	40	40	35	45
55	70	60	55	55	55	52	45	55	45	50
56	50	45	40	40	37	45	48	40	38	40
57	90	70	60	80	75	34	48	45	44	45
58	70	65	60	75	73	40	45	55	45	48
59	65	60	55	65	64	38	40	35	30	35
60	70	65	60	60	58	52	45	40	38	42
61	130	105	100	95	90	47	36	40	36	40
62	80	65	60	60	55	30	47	45	43	45
63	80	70	60	75	70	35	39	35	33	35
64	70	60	55	70	65	30	41	40	31	35
65	85	70	65	75	70	50	45	45	40	45
66	130	85	80	80	75	40	52	50	42	48
67	80	75	65	70	65	38	55	55	50	55
68	70	65	60	85	80	37	45	40	38	42
69	85	80	70	90	85	40	40	45	40	45
70	90	80	70	75	70	45	50	55	50	55
71	110	95	90	70	65	40	45	50	45	48
72	90	85	80	65	60	35	52	55	52	55
73	70	65	60	60	55	30	45	40	38	42
74	85	50	45	40	35	38	44	45	40	45
75	80	70	60	60	55	55	43	40	38	42
76	60	55	50	65	60	40	50	50	45	55
77	70	65	60	95	90	30	55	55	50	55
78	80	75	70	105	100	40	39	35	36	40
79	65	60	55	70	65	35	49	45	42	45
80	70	55	50	55	45	40	50	50	45	55

Appendix B

Table A3. Optimal routes for the goal programming, ε-constraint, and AUGMECON methods.

Parts	Optimal Route for Goal Programming	Optimal Route for ε-Constraint	Optimal Route for AUGMECON
1	$x_{111}, x_{211}, x_{311}, x_{411}, x_{511}$	$x_{111}, x_{211}, x_{311}, x_{411}, x_{511}$	$x_{111}, x_{211}, x_{311}, x_{411}, x_{511}$
2	$x_{123}, x_{222}, x_{323}, x_{422}, x_{523}$	$x_{122}, x_{222}, x_{323}, x_{422}, x_{523}$	$x_{122}, x_{222}, x_{323}, x_{423}, x_{523}$
3	$x_{135}, x_{235}, x_{335}, x_{435}, x_{535}$	$x_{135}, x_{235}, x_{335}, x_{435}, x_{535}$	$x_{135}, x_{235}, x_{335}, x_{435}, x_{535}$
4	$x_{142}, x_{242}, x_{342}, x_{443}, x_{542}$	$x_{142}, x_{242}, x_{342}, x_{443}, x_{542}$	$x_{142}, x_{242}, x_{342}, x_{443}, x_{542}$
5	$x_{155}, x_{255}, x_{355}, x_{455}, x_{555}$	$x_{155}, x_{255}, x_{355}, x_{455}, x_{555}$	$x_{155}, x_{255}, x_{355}, x_{455}, x_{555}$
6	$x_{165}, x_{265}, x_{365}, x_{465}, x_{565}$	$x_{165}, x_{265}, x_{365}, x_{465}, x_{565}$	$x_{165}, x_{265}, x_{365}, x_{465}, x_{565}$
7	$x_{173}, x_{273}, x_{373}, x_{473}, x_{573}$	$x_{173}, x_{273}, x_{373}, x_{473}, x_{573}$	$x_{173}, x_{273}, x_{373}, x_{473}, x_{573}$
8	$x_{185}, x_{285}, x_{385}, x_{483}, x_{585}$	$x_{185}, x_{285}, x_{385}, x_{483}, x_{585}$	$x_{185}, x_{285}, x_{385}, x_{483}, x_{585}$
9	$x_{192}, x_{295}, x_{395}, x_{492}, x_{592}$	$x_{195}, x_{295}, x_{395}, x_{494}, x_{592}$	$x_{195}, x_{295}, x_{395}, x_{494}, x_{592}$
10	$x_{1,10,4}, x_{2,10,1}, x_{3,10,1}, x_{4,10,1}, x_{5,10,5}$	$x_{1,10,5}, x_{2,10,5}, x_{3,10,1}, x_{4,10,1}, x_{5,10,5}$	$x_{1,10,5}, x_{2,10,5}, x_{3,10,1}, x_{4,10,1}, x_{5,10,5}$
11	$x_{1,11,3}, x_{2,11,3}, x_{3,11,3}, x_{4,11,3}, x_{5,11,3}$	$x_{1,11,3}, x_{2,11,3}, x_{3,11,3}, x_{4,11,3}, x_{5,11,3}$	$x_{1,11,3}, x_{2,11,3}, x_{3,11,3}, x_{4,11,3}, x_{5,11,3}$
12	$x_{1,12,5}, x_{2,12,5}, x_{3,12,5}, x_{4,12,5}, x_{5,12,5}$	$x_{1,12,5}, x_{2,12,5}, x_{3,12,5}, x_{4,12,5}, x_{5,12,5}$	$x_{1,12,5}, x_{2,12,5}, x_{3,12,5}, x_{4,12,5}, x_{5,12,5}$
13	$x_{1,13,5}, x_{2,13,5}, x_{3,13,5}, x_{4,13,5}, x_{5,13,5}$	$x_{1,13,5}, x_{2,13,5}, x_{3,13,5}, x_{4,13,5}, x_{5,13,5}$	$x_{1,13,5}, x_{2,13,5}, x_{3,13,5}, x_{4,13,5}, x_{5,13,5}$
14	$x_{1,14,3}, x_{2,14,3}, x_{3,14,3}, x_{4,14,3}, x_{5,14,3}$	$x_{1,14,3}, x_{2,14,3}, x_{3,14,3}, x_{4,14,3}, x_{5,14,3}$	$x_{1,14,3}, x_{2,14,3}, x_{3,14,3}, x_{4,14,3}, x_{5,14,3}$
15	$x_{1,15,5}, x_{2,15,5}, x_{3,15,2}, x_{4,15,2}, x_{5,15,2}$	$x_{1,15,5}, x_{2,15,5}, x_{3,15,2}, x_{4,15,2}, x_{5,15,2}$	$x_{1,15,5}, x_{2,15,5}, x_{3,15,2}, x_{4,15,2}, x_{5,15,2}$

Table A3. *Cont.*

Parts	Optimal Route for Goal Programming	Optimal Route for ε-Constraint	Optimal Route for AUGMECON
16	$x_{1,16,2}, x_{2,16,1}, x_{3,16,1}, x_{4,16,1}, x_{5,16,3}$	$x_{1,16,2}, x_{2,16,1}, x_{3,16,1}, x_{4,16,1}, x_{5,16,3}$	$x_{1,16,2}, x_{2,16,1}, x_{3,16,1}, x_{4,16,1}, x_{5,16,3}$
17	$x_{1,17,5}, x_{2,17,5}, x_{3,17,5}, x_{4,17,5}, x_{5,17,5}$	$x_{1,17,5}, x_{2,17,5}, x_{3,17,5}, x_{4,17,5}, x_{5,17,5}$	$x_{1,17,5}, x_{2,17,5}, x_{3,17,5}, x_{4,17,5}, x_{5,17,5}$
18	$x_{1,18,4}, x_{2,18,4}, x_{3,18,4}, x_{4,18,4}, x_{5,18,4}$	$x_{1,18,4}, x_{2,18,4}, x_{3,18,4}, x_{4,18,4}, x_{5,18,4}$	$x_{1,18,4}, x_{2,18,4}, x_{3,18,4}, x_{4,18,4}, x_{5,18,4}$
19	$x_{1,19,5}, x_{2,19,5}, x_{3,19,5}, x_{4,19,5}, x_{5,19,5}$	$x_{1,19,5}, x_{2,19,5}, x_{3,19,5}, x_{4,19,5}, x_{5,19,5}$	$x_{1,19,5}, x_{2,19,5}, x_{3,19,5}, x_{4,19,5}, x_{5,19,5}$
20	$x_{1,20,5}, x_{2,20,5}, x_{3,20,5}, x_{4,20,5}, x_{5,20,5}$	$x_{1,20,5}, x_{2,20,5}, x_{3,20,5}, x_{4,20,5}, x_{5,20,5}$	$x_{1,20,5}, x_{2,20,5}, x_{3,20,5}, x_{4,20,5}, x_{5,20,5}$
21	$x_{1,21,5}, x_{2,21,5}, x_{3,21,5}, x_{4,21,5}, x_{5,21,5}$	$x_{1,21,5}, x_{2,21,5}, x_{3,21,5}, x_{4,21,5}, x_{5,21,5}$	$x_{1,21,5}, x_{2,21,5}, x_{3,21,5}, x_{4,21,5}, x_{5,21,5}$
22	$x_{1,22,4}, x_{2,22,4}, x_{3,22,4}, x_{4,22,4}, x_{5,22,4}$	$x_{1,22,4}, x_{2,22,4}, x_{3,22,4}, x_{4,22,4}, x_{5,22,4}$	$x_{1,22,4}, x_{2,22,4}, x_{3,22,4}, x_{4,22,4}, x_{5,22,4}$
23	$x_{1,23,5}, x_{2,23,5}, x_{3,23,5}, x_{4,23,5}, x_{5,23,5}$	$x_{1,23,5}, x_{2,23,5}, x_{3,23,5}, x_{4,23,5}, x_{5,23,5}$	$x_{1,23,5}, x_{2,23,5}, x_{3,23,5}, x_{4,23,5}, x_{5,23,5}$
24	$x_{1,24,5}, x_{2,24,5}, x_{3,24,5}, x_{4,24,5}, x_{5,24,5}$	$x_{1,24,5}, x_{2,24,5}, x_{3,24,5}, x_{4,24,5}, x_{5,24,5}$	$x_{1,24,5}, x_{2,24,5}, x_{3,24,5}, x_{4,24,5}, x_{5,24,5}$
25	$x_{1,25,3}, x_{2,25,3}, x_{3,25,3}, x_{4,25,3}, x_{5,25,3}$	$x_{1,25,3}, x_{2,25,3}, x_{3,25,3}, x_{4,25,3}, x_{5,25,3}$	$x_{1,25,3}, x_{2,25,3}, x_{3,25,3}, x_{4,25,3}, x_{5,25,3}$
26	$x_{1,26,4}, x_{2,26,4}, x_{3,26,4}, x_{4,26,4}, x_{5,26,4}$	$x_{1,26,4}, x_{2,26,4}, x_{3,26,4}, x_{4,26,4}, x_{5,26,4}$	$x_{1,26,4}, x_{2,26,4}, x_{3,26,4}, x_{4,26,4}, x_{5,26,4}$
27	$x_{1,27,4}, x_{2,27,4}, x_{3,27,4}, x_{4,27,4}, x_{5,27,4}$	$x_{1,27,4}, x_{2,27,4}, x_{3,27,4}, x_{4,27,4}, x_{5,27,4}$	$x_{1,27,4}, x_{2,27,4}, x_{3,27,4}, x_{4,27,4}, x_{5,27,4}$
28	$x_{1,28,3}, x_{2,28,3}, x_{3,28,3}, x_{4,28,3}, x_{5,28,3}$	$x_{1,28,3}, x_{2,28,3}, x_{3,28,3}, x_{4,28,3}, x_{5,28,3}$	$x_{1,28,3}, x_{2,28,3}, x_{3,28,3}, x_{4,28,3}, x_{5,28,3}$
29	$x_{1,29,1}, x_{2,29,1}, x_{3,29,1}, x_{4,29,1}, x_{5,29,1}$	$x_{1,29,1}, x_{2,29,1}, x_{3,29,1}, x_{4,29,1}, x_{5,29,1}$	$x_{1,29,1}, x_{2,29,1}, x_{3,29,1}, x_{4,29,1}, x_{5,29,1}$
30	$x_{1,30,4}, x_{2,30,4}, x_{3,30,4}, x_{4,30,4}, x_{5,30,4}$	$x_{1,30,4}, x_{2,30,4}, x_{3,30,4}, x_{4,30,4}, x_{5,30,4}$	$x_{1,30,4}, x_{2,30,4}, x_{3,30,4}, x_{4,30,4}, x_{5,30,4}$
31	$x_{1,31,5}, x_{2,31,3}, x_{3,31,3}, x_{4,31,3}, x_{5,31,5}$	$x_{1,31,5}, x_{2,31,3}, x_{3,31,3}, x_{4,31,3}, x_{5,31,5}$	$x_{1,31,5}, x_{2,31,3}, x_{3,31,3}, x_{4,31,3}, x_{5,31,5}$
32	$x_{1,32,5}, x_{2,32,5}, x_{3,32,5}, x_{4,32,5}, x_{5,32,5}$	$x_{1,32,5}, x_{2,32,5}, x_{3,32,5}, x_{4,32,5}, x_{5,32,5}$	$x_{1,32,5}, x_{2,32,5}, x_{3,32,5}, x_{4,32,5}, x_{5,32,5}$
33	$x_{1,33,2}, x_{2,33,4}, x_{3,33,4}, x_{4,33,4}, x_{5,33,2}$	$x_{1,33,2}, x_{2,33,4}, x_{3,33,4}, x_{4,33,4}, x_{5,33,2}$	$x_{1,33,2}, x_{2,33,4}, x_{3,33,4}, x_{4,33,4}, x_{5,33,2}$
34	$x_{1,34,4}, x_{2,34,1}, x_{3,34,1}, x_{4,34,1}, x_{5,34,4}$	$x_{1,34,4}, x_{2,34,1}, x_{3,34,1}, x_{4,34,1}, x_{5,34,4}$	$x_{1,34,4}, x_{2,34,1}, x_{3,34,1}, x_{4,34,1}, x_{5,34,4}$
35	$x_{1,35,3}, x_{2,35,3}, x_{3,35,3}, x_{4,35,3}, x_{5,35,3}$	$x_{1,35,3}, x_{2,35,3}, x_{3,35,3}, x_{4,35,3}, x_{5,35,3}$	$x_{1,35,3}, x_{2,35,3}, x_{3,35,3}, x_{4,35,3}, x_{5,35,3}$
36	$x_{1,36,1}, x_{2,36,1}, x_{3,36,1}, x_{4,36,1}, x_{5,36,1}$	$x_{1,36,1}, x_{2,36,1}, x_{3,36,1}, x_{4,36,1}, x_{5,36,1}$	$x_{1,36,1}, x_{2,36,1}, x_{3,36,1}, x_{4,36,1}, x_{5,36,1}$
37	$x_{1,37,2}, x_{2,37,4}, x_{3,37,3}, x_{4,37,4}, x_{5,37,3}$	$x_{1,37,2}, x_{2,37,2}, x_{3,37,3}, x_{4,37,2}, x_{5,37,3}$	$x_{1,37,2}, x_{2,37,2}, x_{3,37,3}, x_{4,37,3}, x_{5,37,3}$
38	$x_{1,38,3}, x_{2,38,3}, x_{3,38,3}, x_{4,38,3}, x_{5,38,3}$	$x_{1,38,3}, x_{2,38,3}, x_{3,38,3}, x_{4,38,3}, x_{5,38,3}$	$x_{1,38,3}, x_{2,38,3}, x_{3,38,3}, x_{4,38,3}, x_{5,38,3}$
39	$x_{1,39,3}, x_{2,39,3}, x_{3,39,3}, x_{4,39,3}, x_{5,39,3}$	$x_{1,39,3}, x_{2,39,3}, x_{3,39,3}, x_{4,39,3}, x_{5,39,3}$	$x_{1,39,3}, x_{2,39,3}, x_{3,39,3}, x_{4,39,3}, x_{5,39,3}$
40	$x_{1,40,5}, x_{2,40,5}, x_{3,40,5}, x_{4,40,1}, x_{5,40,5}$	$x_{1,40,5}, x_{2,40,5}, x_{3,40,5}, x_{4,40,5}, x_{5,40,5}$	$x_{1,40,5}, x_{2,40,5}, x_{3,40,5}, x_{4,40,5}, x_{5,40,5}$
41	$x_{1,41,1}, x_{2,41,1}, x_{3,41,1}, x_{4,41,1}, x_{5,41,1}$	$x_{1,41,1}, x_{2,41,1}, x_{3,41,1}, x_{4,41,1}, x_{5,41,1}$	$x_{1,41,1}, x_{2,41,1}, x_{3,41,1}, x_{4,41,1}, x_{5,41,1}$
42	$x_{1,42,3}, x_{2,42,4}, x_{3,42,3}, x_{4,42,4}, x_{5,42,3}$	$x_{1,42,4}, x_{2,42,4}, x_{3,42,3}, x_{4,42,4}, x_{5,42,3}$	$x_{1,42,4}, x_{2,42,4}, x_{3,42,3}, x_{4,42,3}, x_{5,42,3}$
43	$x_{1,43,3}, x_{2,43,3}, x_{3,43,3}, x_{4,43,3}, x_{5,43,3}$	$x_{1,43,3}, x_{2,43,3}, x_{3,43,3}, x_{4,43,3}, x_{5,43,3}$	$x_{1,43,3}, x_{2,43,3}, x_{3,43,3}, x_{4,43,3}, x_{5,43,3}$
44	$x_{1,44,3}, x_{2,44,3}, x_{3,44,3}, x_{4,44,3}, x_{5,44,3}$	$x_{1,44,3}, x_{2,44,3}, x_{3,44,3}, x_{4,44,3}, x_{5,44,3}$	$x_{1,44,3}, x_{2,44,3}, x_{3,44,3}, x_{4,44,3}, x_{5,44,3}$
45	$x_{1,45,5}, x_{2,45,5}, x_{3,45,5}, x_{4,45,1}, x_{5,45,5}$	$x_{1,45,5}, x_{2,45,5}, x_{3,45,5}, x_{4,45,5}, x_{5,45,5}$	$x_{1,45,5}, x_{2,45,5}, x_{3,45,5}, x_{4,45,5}, x_{5,45,5}$
46	$x_{1,46,5}, x_{2,46,5}, x_{3,46,5}, x_{4,46,5}, x_{5,46,5}$	$x_{1,46,5}, x_{2,46,3}, x_{3,46,5}, x_{4,46,5}, x_{5,46,5}$	$x_{1,46,5}, x_{2,46,3}, x_{3,46,5}, x_{4,46,5}, x_{5,46,5}$
47	$x_{1,47,2}, x_{2,47,2}, x_{3,47,2}, x_{4,47,2}, x_{5,47,2}$	$x_{1,47,2}, x_{2,47,2}, x_{3,47,2}, x_{4,47,2}, x_{5,47,2}$	$x_{1,47,2}, x_{2,47,2}, x_{3,47,2}, x_{4,47,2}, x_{5,47,2}$
48	$x_{1,48,3}, x_{2,48,3}, x_{3,48,3}, x_{4,48,3}, x_{5,48,3}$	$x_{1,48,3}, x_{2,48,3}, x_{3,48,3}, x_{4,48,3}, x_{5,48,3}$	$x_{1,48,3}, x_{2,48,3}, x_{3,48,3}, x_{4,48,3}, x_{5,48,3}$
49	$x_{1,49,2}, x_{2,49,2}, x_{3,49,2}, x_{4,49,2}, x_{5,49,2}$	$x_{1,49,2}, x_{2,49,2}, x_{3,49,2}, x_{4,49,2}, x_{5,49,2}$	$x_{1,49,2}, x_{2,49,2}, x_{3,49,2}, x_{4,49,2}, x_{5,49,2}$
50	$x_{1,50,4}, x_{2,50,4}, x_{3,50,4}, x_{4,50,3}, x_{5,50,4}$	$x_{1,50,4}, x_{2,50,5}, x_{3,50,4}, x_{4,50,3}, x_{5,50,4}$	$x_{1,50,4}, x_{2,50,5}, x_{3,50,4}, x_{4,50,3}, x_{5,50,4}$
51	$x_{1,51,3}, x_{2,51,3}, x_{3,51,3}, x_{4,51,3}, x_{5,51,3}$	$x_{1,51,3}, x_{2,51,3}, x_{3,51,3}, x_{4,51,3}, x_{5,51,3}$	$x_{1,51,3}, x_{2,51,3}, x_{3,51,3}, x_{4,51,3}, x_{5,51,3}$
52	$x_{1,52,5}, x_{2,52,5}, x_{3,52,5}, x_{4,52,5}, x_{5,52,5}$	$x_{1,52,5}, x_{2,52,5}, x_{3,52,5}, x_{4,52,5}, x_{5,52,5}$	$x_{1,52,5}, x_{2,52,5}, x_{3,52,5}, x_{4,52,5}, x_{5,52,5}$
53	$x_{1,53,5}, x_{2,53,5}, x_{3,53,5}, x_{4,53,5}, x_{5,53,5}$	$x_{1,53,5}, x_{2,53,5}, x_{3,53,5}, x_{4,53,5}, x_{5,53,5}$	$x_{1,53,5}, x_{2,53,5}, x_{3,53,5}, x_{4,53,5}, x_{5,53,5}$
54	$x_{1,54,5}, x_{2,54,3}, x_{3,54,3}, x_{4,54,3}, x_{5,54,3}$	$x_{1,54,5}, x_{2,54,3}, x_{3,54,3}, x_{4,54,3}, x_{5,54,3}$	$x_{1,54,5}, x_{2,54,3}, x_{3,54,3}, x_{4,54,3}, x_{5,54,3}$
55	$x_{1,55,2}, x_{2,55,2}, x_{3,55,2}, x_{4,55,2}, x_{5,55,2}$	$x_{1,55,2}, x_{2,55,2}, x_{3,55,2}, x_{4,55,2}, x_{5,55,2}$	$x_{1,55,2}, x_{2,55,2}, x_{3,55,2}, x_{4,55,2}, x_{5,55,2}$
56	$x_{1,56,2}, x_{2,56,1}, x_{3,56,1}, x_{4,56,1}, x_{5,56,2}$	$x_{1,56,2}, x_{2,56,1}, x_{3,56,1}, x_{4,56,1}, x_{5,56,3}$	$x_{1,56,2}, x_{2,56,1}, x_{3,56,1}, x_{4,56,1}, x_{5,56,3}$
57	$x_{1,57,5}, x_{2,57,5}, x_{3,57,5}, x_{4,57,5}, x_{5,57,5}$	$x_{1,57,5}, x_{2,57,5}, x_{3,57,5}, x_{4,57,5}, x_{5,57,5}$	$x_{1,57,5}, x_{2,57,5}, x_{3,57,5}, x_{4,57,5}, x_{5,57,5}$
58	$x_{1,58,4}, x_{2,58,4}, x_{3,58,4}, x_{4,58,4}, x_{5,58,4}$	$x_{1,58,4}, x_{2,58,4}, x_{3,58,4}, x_{4,58,4}, x_{5,58,4}$	$x_{1,58,4}, x_{2,58,4}, x_{3,58,4}, x_{4,58,4}, x_{5,58,4}$
59	$x_{1,59,5}, x_{2,59,5}, x_{3,59,5}, x_{4,59,5}, x_{5,59,5}$	$x_{1,59,5}, x_{2,59,5}, x_{3,59,5}, x_{4,59,5}, x_{5,59,5}$	$x_{1,59,5}, x_{2,59,5}, x_{3,59,5}, x_{4,59,5}, x_{5,59,5}$
60	$x_{1,60,5}, x_{2,60,5}, x_{3,60,5}, x_{4,60,5}, x_{5,60,5}$	$x_{1,60,5}, x_{2,60,5}, x_{3,60,5}, x_{4,60,5}, x_{5,60,5}$	$x_{1,60,5}, x_{2,60,5}, x_{3,60,5}, x_{4,60,5}, x_{5,60,5}$
61	$x_{1,61,2}, x_{2,61,2}, x_{3,61,5}, x_{4,61,5}, x_{5,61,5}$	$x_{1,61,5}, x_{2,61,2}, x_{3,61,5}, x_{4,61,5}, x_{5,61,5}$	$x_{1,61,5}, x_{2,61,2}, x_{3,61,5}, x_{4,61,5}, x_{5,61,5}$
62	$x_{1,62,4}, x_{2,62,4}, x_{3,62,4}, x_{4,62,4}, x_{5,62,4}$	$x_{1,62,4}, x_{2,62,4}, x_{3,62,4}, x_{4,62,4}, x_{5,62,4}$	$x_{1,62,4}, x_{2,62,4}, x_{3,62,4}, x_{4,62,4}, x_{5,62,4}$
63	$x_{1,63,5}, x_{2,63,5}, x_{3,63,5}, x_{4,63,5}, x_{5,63,5}$	$x_{1,63,5}, x_{2,63,5}, x_{3,63,5}, x_{4,63,5}, x_{5,63,5}$	$x_{1,63,5}, x_{2,63,5}, x_{3,63,5}, x_{4,63,5}, x_{5,63,5}$

Table A3. *Cont.*

Parts	Optimal Route for Goal Programming	Optimal Route for ε-Constraint	Optimal Route for AUGMECON
64	$x_{1,64,5}, x_{2,64,5}, x_{3,64,5}, x_{4,64,5}, x_{5,64,5}$	$x_{1,64,5}, x_{2,64,5}, x_{3,64,5}, x_{4,64,5}, x_{5,64,5}$	$x_{1,64,5}, x_{2,64,5}, x_{3,64,5}, x_{4,64,5}, x_{5,64,5}$
65	$x_{1,65,3}, x_{2,65,3}, x_{3,65,3}, x_{4,65,3}, x_{5,65,3}$	$x_{1,65,3}, x_{2,65,3}, x_{3,65,3}, x_{4,65,3}, x_{5,65,3}$	$x_{1,65,3}, x_{2,65,3}, x_{3,65,3}, x_{4,65,3}, x_{5,65,3}$
66	$x_{1,66,4}, x_{2,66,4}, x_{3,66,4}, x_{4,66,4}, x_{5,66,4}$	$x_{1,66,4}, x_{2,66,4}, x_{3,66,4}, x_{4,66,4}, x_{5,66,4}$	$x_{1,66,4}, x_{2,66,4}, x_{3,66,4}, x_{4,66,4}, x_{5,66,4}$
67	$x_{1,67,4}, x_{2,67,4}, x_{3,67,4}, x_{4,67,4}, x_{5,67,4}$	$x_{1,67,4}, x_{2,67,4}, x_{3,67,4}, x_{4,67,4}, x_{5,67,4}$	$x_{1,67,4}, x_{2,67,4}, x_{3,67,4}, x_{4,67,4}, x_{5,67,4}$
68	$x_{1,68,3}, x_{2,68,3}, x_{3,68,3}, x_{4,68,3}, x_{5,68,3}$	$x_{1,68,3}, x_{2,68,3}, x_{3,68,3}, x_{4,68,3}, x_{5,68,3}$	$x_{1,68,3}, x_{2,68,3}, x_{3,68,3}, x_{4,68,3}, x_{5,68,3}$
69	$x_{1,69,3}, x_{2,69,1}, x_{3,69,3}, x_{4,69,1}, x_{5,69,3}$	$x_{1,69,3}, x_{2,69,1}, x_{3,69,3}, x_{4,69,1}, x_{5,69,3}$	$x_{1,69,3}, x_{2,69,1}, x_{3,69,3}, x_{4,69,1}, x_{5,69,3}$
70	$x_{1,70,4}, x_{2,70,4}, x_{3,70,4}, x_{4,70,4}, x_{5,70,4}$	$x_{1,70,4}, x_{2,70,4}, x_{3,70,4}, x_{4,70,4}, x_{5,70,4}$	$x_{1,70,4}, x_{2,70,4}, x_{3,70,4}, x_{4,70,4}, x_{5,70,4}$
71	$x_{1,71,3}, x_{2,71,3}, x_{3,71,3}, x_{4,71,3}, x_{5,71,3}$	$x_{1,71,3}, x_{2,71,3}, x_{3,71,3}, x_{4,71,3}, x_{5,71,3}$	$x_{1,71,3}, x_{2,71,3}, x_{3,71,3}, x_{4,71,3}, x_{5,71,3}$
72	$x_{1,72,5}, x_{2,72,5}, x_{3,72,5}, x_{4,72,5}, x_{5,72,5}$	$x_{1,72,5}, x_{2,72,5}, x_{3,72,5}, x_{4,72,5}, x_{5,72,5}$	$x_{1,72,5}, x_{2,72,5}, x_{3,72,5}, x_{4,72,5}, x_{5,72,5}$
73	$x_{1,73,2}, x_{2,73,4}, x_{3,73,4}, x_{4,73,4}, x_{5,73,2}$	$x_{1,73,2}, x_{2,73,4}, x_{3,73,4}, x_{4,73,4}, x_{5,73,2}$	$x_{1,73,2}, x_{2,73,4}, x_{3,73,4}, x_{4,73,4}, x_{5,73,2}$
74	$x_{1,74,4}, x_{2,74,1}, x_{3,74,1}, x_{4,74,1}, x_{5,74,4}$	$x_{1,74,4}, x_{2,74,1}, x_{3,74,1}, x_{4,74,1}, x_{5,74,4}$	$x_{1,74,4}, x_{2,74,1}, x_{3,74,1}, x_{4,74,1}, x_{5,74,4}$
75	$x_{1,75,3}, x_{2,75,3}, x_{3,75,3}, x_{4,75,3}, x_{5,75,3}$	$x_{1,75,3}, x_{2,75,3}, x_{3,75,3}, x_{4,75,3}, x_{5,75,3}$	$x_{1,75,3}, x_{2,75,3}, x_{3,75,3}, x_{4,75,3}, x_{5,75,3}$
76	$x_{1,76,1}, x_{2,76,1}, x_{3,76,1}, x_{4,76,1}, x_{5,76,1}$	$x_{1,76,2}, x_{2,76,1}, x_{3,76,1}, x_{4,76,1}, x_{5,76,1}$	$x_{1,76,2}, x_{2,76,1}, x_{3,76,1}, x_{4,76,1}, x_{5,76,1}$
77	$x_{1,77,3}, x_{2,77,2}, x_{3,77,3}, x_{4,77,2}, x_{5,77,3}$	$x_{1,77,2}, x_{2,77,2}, x_{3,77,3}, x_{4,77,2}, x_{5,77,3}$	$x_{1,77,2}, x_{2,77,2}, x_{3,77,3}, x_{4,77,3}, x_{5,77,3}$
78	$x_{1,78,3}, x_{2,78,3}, x_{3,78,3}, x_{4,78,3}, x_{5,78,3}$	$x_{1,78,3}, x_{2,78,3}, x_{3,78,3}, x_{4,78,3}, x_{5,78,3}$	$x_{1,78,3}, x_{2,78,3}, x_{3,78,3}, x_{4,78,3}, x_{5,78,3}$
79	$x_{1,79,3}, x_{2,79,3}, x_{3,79,3}, x_{4,79,3}, x_{5,79,3}$	$x_{1,79,3}, x_{2,79,3}, x_{3,79,3}, x_{4,79,3}, x_{5,79,3}$	$x_{1,79,3}, x_{2,79,3}, x_{3,79,3}, x_{4,79,3}, x_{5,79,3}$
80	$x_{1,80,5}, x_{2,80,5}, x_{3,80,5}, x_{4,80,5}, x_{5,80,5}$	$x_{1,80,5}, x_{2,80,5}, x_{3,80,5}, x_{4,80,5}, x_{5,80,5}$	$x_{1,80,5}, x_{2,80,5}, x_{3,80,5}, x_{4,80,5}, x_{5,80,5}$

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