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Research on Conflict Resolution Method of Production Evaluation Index in Flexible Manufacturing Field Based on Multiplayer Cooperative Game

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ABSTRACT Multiple local assignment rules are common in production lines with complex production elements to direct the production process. Different local assignment rules have different degrees of impact on each production evaluation index, which aggravates the conflict between each production evaluation index. In order to solve the problem of increasing conflict among multiple production evaluation indexes in complex production scheduling process, based on the mathematical model of flexible flow shop with limited buffer and public buffer (FFSP-PB), game elements such as game player, game strategy and game order are established according to the idea of multiplayer cooperative game, and design the corresponding game strategy selection method to predict and control the game behavior of each player in the problem. Then a conflict resolution method of production evaluation index based on multiplayer cooperative game is proposed to solve the conflict between multiple production evaluation indexes, and then improve each production evaluation index. Finally, according to the actual production data of a bus manufacturing enterprise based on flexible manufacturing mode, several simulation schemes are designed to analyze and verify the effectiveness and practicability of the proposed method in resolving the conflicts between production evaluation indexes, and provides a reliable new solution for the conflict resolution of production evaluation index in the field of flexible manufacturing.

INDEX TERMS Flexible flow shop, limited buffer, public buffer, multiplayer cooperative game, conflict resolution, local assignment rules.

I. INTRODUCTION

With the rapid development and application of cloud technology, artificial intelligence technology and intelligent manufacturing technology, Germany took the lead in proposing "Industry 4.0" national strategy in the "high tech Strategy 2020". Subsequently, the United States, Japan, China and other countries successively put forward the " Advanced Manufacturing Partnership Program", "Manufacturing White Paper", "Made in China 2025" and other national strategies, which promoted the process of upgrading and transformation of the manufacturing industry [1], [2]. In the production process of heavy machinery assembly, vehicle production, semiconductor packaging and other complex production industries, in order to meet the needs of customers, the customized production mode with multiple varieties and small batch characteristics has been transformed into the mainstream production mode of today's manufacturing enterprises, and the variety of products has become more diversified [3]–[7]. With the popularization of customized production mode, the production structure and process of the production line have been gradually changed, complex production elements such as public buffer, sequence buffer, routing buffer, re-entrant process and variable-time process

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are added, which leads to a variety of local assignment rules for special production elements. In the process of production scheduling, different local assignment rules have different degrees of influence on production evaluation indexes, and there are certain conflicts among production evaluation indexes, which makes it difficult to get better scheduling results in the process of production scheduling, thus increasing the matching complexity of demand and supply capacity. Due to the introduction of local assignment rules for special production elements, the conflict among production evaluation indexes in complex production scheduling process is further aggravated, which further increases the production operation cost and production control difficulty of enterprises, and reduces the production efficiency and production resource utilization rate of enterprises. Therefore, it is necessary to explore more effective methods for aggravating the conflicts among multiple production evaluation indexes in the process of complex production scheduling, so as to effectively resolve the conflicts among various production evaluation indexes, inhibit the influence of various local assignment rules on various production evaluation indexes, and improve all production evaluation indexes. As a result, the research on the optimization methods and techniques of production scheduling for resolving the conflict of production evaluation indexes in the complex production scheduling process has important theoretical value and wide application prospect, it will further enhance the intelligent level of manufacturing automation technology.

The conflict of production evaluation index is a problem that may seriously affect the production results. It may make the actual production results greatly different from the expected results, thus making the production results unable to meet the customized demands of customers and reducing the market competitiveness of production enterprises. In recent years, many scholars have paid attention to the causes and solutions of evaluation index conflicts in different fields. Li *et al.* studied conflict resolution among multiple Unmanned Aerial Vehicles (UAVs) and proposed a conflict resolution method based on satisfactory game theory [11]. Bettinelli *et al.* proposed a fast algorithm for solving scheduling conflicts in train traffic management in real time [12]. Li *et al.* optimized concurrent engineering by means of row-column transformation, and proposed a task scheduling and conflict solution to eliminate or weaken the resource conflict in concurrent engineering [13]. Du *et al.* used the hybrid method of ant colony algorithm and Shapley value in decision support system to solve the conflicts between production plans in complex product system [14]. Liang *et al.* proposed a hybrid solution strategy based on rules, constraints, and examples, which was used to solve various conflict problems in the process of manufacturing system operation [15]. Through the research and analysis of the above related literature, it can be known that only a few scholars have studied the conflict of production evaluation indexes in the field of manufacturing. And the research direction is more about resolving conflicts from the perspectives of resources and costs. Meanwhile, the conflict resolution methods adopted are mostly improved heuristic algorithm and bionic algorithm. These methods will lose their feasibility with the increase of data scale and the difficulty of solving the problem, and will increase the computational cost of solving the problem, which is not easy to be applied in practical engineering projects. In order to solve the problem of aggravating the conflict among several production evaluation indexes studied in this paper, it is necessary to consider how to restrain the influence of a variety of complex local assignment rules on each production evaluation index, so as to resolve the conflict among various production evaluation indexes. All production evaluation indexes are improved, which plays a certain role in guiding the circulation of the actual production and manufacturing process.

As the problem studied in this paper is difficult to solve, it is necessary to explore an effective method to solve the problem of aggravating the conflict among multiple production evaluation indexes in the complex production scheduling process. Bionic algorithms and heuristic algorithms have good effects on solving optimization problems, but they cannot play a more effective role in resolving conflicts between multiple production evaluation indexes in the complex scheduling process. The multiplayer cooperative game method in Game Theory has a better performance in solving the conflicts among multiple players and obtaining a better overall income. It is often used in finance, economics, politics, military strategy, and many other disciplines, but in the field of manufacturing applications is low. Therefore, based on the mathematical model of the limited buffer problem of flexible flow shop with public buffer (FFSP-PB), this paper establishes the game elements such as game side, game strategy and game order according to the idea of multiplayer cooperative game, designs the corresponding game strategy selection method, predicts the game behavior of each player in FFSP-PB, and puts forward a conflict resolution method of production evaluation index based on multiplayer cooperative game. Finally, adopted the actual production data of the workshop based on the flexible production mode, a multi-group simulation scheme is designed, and the conflict resolution method of the production evaluation index based on the multiplayer cooperative game is compared and analyzed to resolve the conflict among the various production evaluation indexes, the effect of restraining the influence of various local assignment rules on various production evaluation indexes, and verify the effectiveness of this method as a new method of conflict resolution in the field of flexible manufacturing.

II. MATHEMATICAL MODEL OF FLEXIBLE FLOW SHOP WITH LIMITED BUFFER AND PUBLIC BUFFER

In the conventional production line, the local assignment rules in the production process are not enough and complicated because the production process is simple and the production elements are few, it cannot fully reflect the conflict of production evaluation indexes caused by local assignment rules and the application value of multiplayer cooperative game.

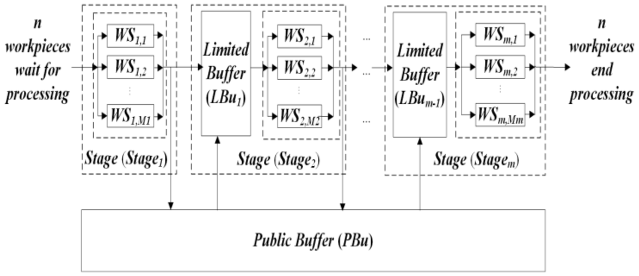

FIGURE 1. **Mathematical model of flexible flow shop with limited buffer and public buffer.**

In order to get closer to the complex actual manufacturing process, the FFSP-PB mathematical model in previous studies was adopted as the basis for studying the conflict enhancement among multiple production evaluation indexes and the application object of conflict resolution method of production evaluation indexes based on multiplayer cooperative game, The model parameters, constraints and production evaluation indexes in this section have some changes compared with my previous studies [16]–[18].

A. MODEL DESCRIPTION

Figure 1 is a mathematical model of flexible flow shop with limited buffer and public buffer, which can be described as follows: the production workshop contains m stages, and the processing queue of n workpieces needs to complete the processing tasks of m stages in turn. At least one of m stages consists of two or more parallel workstations, and the processing times of the workpiece at different parallel workstations are the same in the same stage. A buffer with limited capacity is set up between each stage, and when the limited buffer capacity between each stage reaches the upper limit, it is easy to cause production blockage. In order to alleviate the production blockage, a public buffer is set up in the production workshop. If the limited buffer capacity between each stage reaches the upper limit, the workpiece can be moved into the public buffer for temporary storage. All workpieces are processed online from the first stage, and all workpieces are processed sequentially. When the capacity of the limited buffer between stages reaches the upper limit, newly completed workpieces are transferred to the public buffer. Under certain conditions, the workpiece during transport can also be retraced back to the limited buffer. When the workpiece in the limited buffer is moved, an idle position will appear in the limited buffer, and then the workpiece in the public buffer that should enter the limited buffer needs to be transferred back to the limited buffer. The transfer time between the workpiece in the limited buffer and the public buffer cannot be ignored. The online sequence of the workpieces, the standard transfer time of the workpiece and the standard processing time of the workpiece in each stage, the local assignment rules are used to control the moving process of the workpiece between the workstation, the limited buffer and the public buffer is given. The workstation state, start time and end time of all the workpieces in each stage are obtained, and the scheduling results of the transfer process information.

B. MODEL PARAMETERS

C. RESTRICTIONS

1) HYPOTHETICAL VARIABLE

$$At_{i,j,l}=\begin{cases}1 & \text{Workpiece } Wp_i \text{ is assigned to be processed on workstation} WS_{j,l}\\ 0 & \text{Workpiece } Wp_i \text{ isn't assigned to be processed on workstation } WS_{j,l}\end{cases} \tag{1}$$

$$OAl_{i,j}\left(t\right)=\begin{cases}1 & \text{At time } t\text{, workpiece } Wp_i \text{ is in limited buffer } LBu_j\\ 0 & \text{At time } t\text{, workpiece } Wp_i \text{ isn't in limited buffer } LBu_j\end{cases} \tag{2}$$

$$OAp_{i,j}\left(t\right)=\begin{cases}1 & \text{At time } t\text{, workpiece } Wp_i \text{ that should have entered limited buffer } LBu_j \text{ is in public buffer}\\ 0 & \text{At time } t\text{, workpiece } Wp_i \text{ that should have entered limited buffer } LBu_j \text{ isn't in public buffer}\end{cases} \tag{3}$$

$$OAt_{i,j}\left(t\right)=\begin{cases}1 & \text{At time } t\text{, workpiece } Wp_i \text{ that should have entered limited buffer } LBu_j \text{ is in transit}\\ 0 & \text{At time } t\text{, workpiece } Wp_i \text{ that should have entered limited buffer } LBu_j \text{ isn't in transit}\end{cases} \tag{4}$$

$$Pan\_Car\left(t\right)=\begin{cases}0 & \text{At time } t\text{, electric flat carriage is on workstation}\\ 1 & \text{At time } t\text{, electric flat carriage is in limited buffer}\\ 2 & \text{At time } t\text{, electric flat carriage is in public buffer}\\ 3 & \text{At time } t\text{, electric flat carriage is in transit from workstation to public buffer}\\ 4 & \text{At time } t\text{, electric flat carriage is in transit from public buffer to limited buffer}\end{cases} \tag{5}$$

2) GENERAL CONSTRAINT OF FLEXIBLE FLOW SHOPS SCHEDULING

$$\sum_{l=1}^{M_j} At_{i,j,l}=1,\quad i\in\{1,\ldots,n\},\ j\in\{1,\ldots,m\},\ l\in\left\{1,\ldots,M_j\right\} \tag{6}$$

$$Tc_{i,j}=Ts_{i,j}+Tb_{i,j},\quad i\in\{1,\ldots,n\},\ j\in\{1,\ldots,m\} \tag{7}$$

TABLE 1. Model parameters.

Parameters	Description
n	Total number of workpieces to be processed
m	Total number of stages to be processed
$Stage_j$	Stage j , $j\in$ 1,...,m
M_j	Total number of parallel workstations in stage $Stage_j$, $j\in$ 1,...,m
l	Workstation, $l\in$ 1,...,M_j
$WS_{j,l}$	Workstation l of stage $Stage_j$, $j\in$ 1,...,m , $l\in$ 1,...,M_j
LBu_j	Limited buffer of stage $Stage_j$, $j\in$ 2,...,m
Kl_j	Maximum buffer capacity in the limited buffer LBu_j of stage $Stage_j$, $j\in$ 1,...,m
$Bl_{j,k}$	Buffer position k of limited buffer LBu_j , $j\in$ 2,...,m , $k\in$ 1,...,Kl_j
$WAl_j\ t$	At the t time, the workpieces in the limited buffer LBu_j , $j\in$ 2,...,m
PBu	Public buffer
Kp	Maximum buffer capacity in the public buffer PBu , $1\leq Kp\leq n-\min\ Kl_j$
$Ts_{i,j}$	The start time of workpiece Wp_i at stage $Stage_j$, $j\in$ 1,...,m
$Tc_{i,j}$	The completion time of workpiece Wp_i at stage $Stage_j$, $j\in$ 1,...,m
$Tb_{i,j}$	The standard processing time of workpiece Wp_i at stage $Stage_j$, $j\in$ 1,...,m
$Ti_{i,j}$	The entry time of workpiece Wp_i into stage $Stage_j$, $j\in$ 1,...,m
$To_{i,j}$	The departure time of workpiece Wp_i out of stage $Stage_j$, $j\in$ 1,...,m
$Tli_{i,j}$	The entry time of workpiece Wp_i into limited buffer LBu_j , $j\in$ 2,...,m
$Tlo_{i,j}$	The departure time of workpiece Wp_i out of limited buffer LBu_j , $j\in$ 2,...,m
$Tpi_{i,j}$	The entry time of workpiece Wp_i into public buffer PBu at stage $Stage_j$, $j\in$ 2,...,m
$Tpo_{i,j}$	The departure time of workpiece Wp_i out of public buffer PBu at stage $Stage_j$, $j\in$ 2,...,m
Tbt	The standard processing time for transferring workpiece
Rp_i	The workpiece Wp_i is on the way from workstation to the public buffer
Rl_i	The workpiece Wp_i is on the way from public buffer to the limited buffer
Rr_i	The workpiece Wp_i is on the way return to the limited buffer
Cfp	The time for electric flat carriage to finish the current task and return to the public buffer
$Ttw_{i,j}(t)$	At the t time, The transit time of workpiece Wp_i from the workstation of stage $Stage_j$ to the public buffer, $j\in$ 1,...,m

$$Tc_{i,j-1} \leq Ts_{i,j}, \quad i \in \{1, \ldots, n\}, j \in \{2, \cdots, m\} \tag{8}$$

Formula (6) expresses the constraint that the workpiece Wp_i can only be processed at one workstation of the stage during the processing. Formula (7) indicates the constraint that the completion time of workpiece Wp_i in the stage $Stage_j$ is equal to the sum of the start time and standard processing time in the stage $Stage_j$ and this constraint guarantees the close machining between the workpieces. Formula (8) indicates the constraint that workpiece Wp_i needs to complete the processing task of the current stage before the processing task of the next stage. This constraint limits the processing sequence of each workpiece in all stages. Constraint (6), (7), and (8) ensure that the entire processing is in accordance with the processing characteristics of the flexible flow shop.

3) CONSTRAINTS OF LIMITED BUFFERS

$$Tli_{i,j} \geq Tc_{i,j-1}, \quad j \in \{2, \ldots, m\} \tag{9}$$

Formula (9) indicates the constraint that time $Tli_{i,j}$ for the workpiece to enter the limited buffer LBu_j cannot be less than the completion time $Tc_{i,j-1}$ of this workpiece processed at the previous stage $Stage_{j-1}$.

$$Tlo_{i,j} = Ts_{i,j}, \quad j \in \{2, \ldots, m\} \tag{10}$$

Formula (10) indicates that the time for the workpiece to leave the limited buffer LBu_j is equal to the start time of the stage $Stage_j$

$$WAl_j\,(t) = \left\{Wp_i | OAl_{i,j}\,(t) = 1\right\} \tag{11}$$

Formula (11) indicates the constraint and the workpieces in the limited buffer LBu_j at the t time.

$$card\,\left(WAl_j\,(t)\right) \leq Kl_j \tag{12}$$

Formula (12) indicates the constraint that at any time, the total number of workpieces in the collection WAl_j waiting to be processed cannot be greater than the maximum buffer capacity Kl_j in the limited buffer. This constraint guarantees that the characteristics of the limited buffer correspond to the actual processing.

$$Tlo_{i,j} \geq Tli_{i,j}, \quad j \in \{2, \ldots, m\} \tag{13}$$

Formula (13) denotes that time for the workpiece to leave the limited buffer LBu_j cannot be less than the time for the workpiece to enter limited buffer LBu_j.

4) CONSTRAINTS OF PUBLIC BUFFER

$$Tpo_{i,j} \geq Tpi_{i,j}, \quad j \in \{2, \ldots, m\} \tag{14}$$

Formula (14) indicates the time for the workpiece in public buffer PBu that should have entered the limited buffer LBu_j to leave the public buffer PBu should not be less than the time for it to enter the public buffer PBu. This constraint ensures that the moving in and out of the public buffer conforms to the actual processing.

$$WAp_j\,(t) = \left\{Wp_i | OAp_{i,j}\,(t) = 1\right\} \tag{15}$$

Formula (15) represents the collection of all workpieces contained in public buffer PBu at time t.

$$card\,\left(WAp_j\,(t)\right) \leq Kp \tag{16}$$

Formula (16) indicates the constraint that at any time, the sum of workpieces contained in the to-be-processed collection WAp_j is less than or equal to the maximum buffer capacity Kp of the public buffer. This constraint guarantees that the characteristics of the public buffer conform to the actual processing.

$$Ttw_{i,j}(t) = \left(t - To_{i,j}\right) \tag{17}$$

Formula (17) shows that at time t, the time for the workpiece Wp_i to be transferred from the workstation of the stage $Stage_j$ to the public buffer is equal to the difference between the time for the workpiece Wp_i to leave the workstation of stage $Stage_j$ at time t.

$$Ttw_{i,j}(t) \leq Tbt \tag{18}$$

Formula (18) indicates the constraint that at time t, the time for the workpiece Wp_i to be transferred from the workstation of the stage $Stage_j$ to the public buffer should be less than the standard processing time for transferring workpiece.

5) OTHER CONSTRAINTS

① Continuous processing constraint: If the workpiece has started the processing task of a certain stage, it cannot be interrupted until the task is completed.

② Workstation uniqueness constraint: A workstation can only process one workpiece simultaneously.

③ Workstation availability constraint: All workstations are available at the scheduling time.

④ Time simplification constraint: Irrespective of the transit time of the workpiece between the limited buffer and workstation, only the processing time of the workpiece at each stage and the transit time of the workpiece on the electric flat carriage are considered.

D. PRODUCTION EVALUATION INDEX FOR FFSP-PB SCHEDULING OPTIMIZATION PROBLEM

In order to better analyze and study the results of production scheduling simulation, it is necessary to establish a number of production evaluation indexes related to the actual production process, including the makespan C_{max}, the total workpiece waiting time $TWWT$, the total workstation idle time $TWIT$, the total plant factor TPF, the total workpiece blockage time $TWBT$, the total workpiece transport time $TWTT$, the total workpiece temporary storage time in public buffer $TWTST\text{-}PB$. Except for the TPF, other production evaluation index values are the smaller the better.

1) MAKESPAN

$$C_{max} = \max\left\{Tc_{i,m}\right\}, \quad i \in \{1, \ldots, n\} \tag{19}$$

In formula (19), makespan C_{max} indicates the maximum value of all workpieces that completed processing at the last stage.

2) TOTAL WORKPIECE WAITING TIME

$$TWWT = \sum_{j=2}^{m}\left(\sum_{i=1}^{n}\left(Ts_{i,j} - Tc_{i,j-1}\right)\right) \tag{20}$$

In formula (20), total workpiece waiting time $TWWT$ indicates the sum of the waiting time of all workpieces in all stages and between each stage.

3) TOTAL WORKSTATION IDLE TIME

$$TWIT = \sum_{j=1}^{m}\sum_{l=1}^{M_j}\begin{pmatrix}\left(\max\left\{To_{i,j}\cdot At_{i,j,l}\right\}\right. \\ \left. -\ \min\left\{Ts_{i,j}\cdot At_{i,j,l}\right\}\right) \\ -\sum_{i=1}^{n}\left(Tb_{i,j}\cdot At_{i,j,l}\right)\end{pmatrix} \tag{21}$$

In formula (21), $TWIT$ represents the sum of the idle time for the workstation between the start time of the first processed workpiece and the completion time of the last processed workpiece.

4) TOTAL PLANT FACTOR

$$TPF = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\left(Tb_{i,j}\right)}{\sum_{j=1}^{m}\sum_{l=1}^{M_j}\left(\max\left\{To_{i,j}\cdot At_{i,j,l}\right\} - \min\left\{Ts_{i,j}\cdot At_{i,j,l}\right\}\right)} \tag{22}$$

In formula (22), TPF represents the total plant factor of all workstations, which is the ratio of the effective processing time of all workstations to the occupied period of all workstations. This period starts from the first workpiece processed on the workstation at each stage to the last workpiece that leaves the workstation after completion [19].

5) TOTAL WORKPIECE BLOCKAGE TIME

$$TWBT = \sum_{i=1}^{n}\sum_{j=2}^{m}\left(To_{i,j-1} - Tc_{i,j-1}\right) \tag{23}$$

In formula (23), $TWBT$ indicates the sum of blockage time of all workpieces stuck on the workstations since the limited buffer is full and the electric flat carriage is in transit during the production.

6) TOTAL WORKPIECE TRANSPORT TIME

$$TWTT = \sum_{i=1}^{n}\sum_{j=2}^{m}\begin{pmatrix}\left(Tctg_{i,j-1} - Tstg_{i,j-1}\right) \\ +\left(Tctb_{i,j-1} - Tstb_{i,j-1}\right) \\ +\left(Tctr_{i,j-1} - Tstg_{i,j-1}\right)\end{pmatrix} \tag{24}$$

In the formula (2.24), $TWTT$ indicates the sum of the time during the entire production and processing process that the electric flat carriage drives each workpiece between the workstation, the limited buffer and the public buffer.

7) TOTAL WORKPIECE TEMPORARY STORAGE TIME IN PUBLIC BUFFER

$$TWTST\text{-}PB = \sum_{i=1}^{n}\sum_{j=2}^{m}\left(Tstb_{i,j-1} - Tctg_{i,j-1}\right) \tag{25}$$

In the formula (2.25), *TWTST-PB* indicates the sum of the temporary storage time of each workpiece in the public buffer during the entire production and processing process.

In order to make a better comparison of production evaluation indexes, formula (26) is established.

$$IR(A/B) = |[(A - B)/B]| \times 100\% \tag{26}$$

In the formula (26), $IR(A/B)$ indicates the improvement range of A with respect to the designated evaluation index of B, and the meanings of A and B would be modified according to the actual situation.

III. RESEARCH ON THE CONFLICT RESOLUTION METHOD OF PRODUCTION EVALUATION INDEX

Game theory is a mathematical theory and method with the nature of struggle or competition. This method holds that the game side is rational, that is, each player will maximize their own payoff under certain constraints. At the same time, the payoff of each player in the communication and cooperation are in conflict, the behaviors influence each other, and the information is often asymmetric. Therefore, the game theory often studies people's decisions during interaction and the balance between decisions, while the multi-player cooperative game method in game theory has a better effect in resolving conflicts between multiplayers and optimizing each player [20], [21]. In the production scheduling process of FFSP-PB, due to the introduction of the special production element of the public buffer, it brings many local assignment rules, further increases the conflict of multiple production evaluation indexes, and affects the production efficiency of the production workshop. Therefore, it is feasible to solve the problem of the conflict between multiple production evaluation indexes in FFSP-PB by using the multiplayer cooperative game method.

A. ANALYSIS OF MULTIPLAYER COOPERATIVE GAME METHOD

In the process of multiplayer cooperative game, all players need to maximize their own payoff, which has some similarities with most optimization methods. The optimization method belongs to the single person decision-making method. In the decision-making process, all the variables affecting the final result are controlled in the hands of the decision-maker. Moreover, the overall optimization process of the optimization method is deterministic, and the initial decision can directly determine the final result. However, a multiplayer cooperative game is a multiplayer decision-making method, in which all the variables affecting the final result are controlled by multiple players themselves. The whole optimization process of multiplayer cooperative game has both certainty and uncertainty. After the decision of each player is made, the profit of each player can be determined. However, after each player makes a decision, the variables that affect the final result are the decisions of other players. If the players do not know the decisions of other players, the final result will be inaccurate Qualitative. In the process of cooperative game among multiple players, the players may not cooperate with each other, but there will be an external binding agreement to punish the non-cooperative players. Finally, all players adopt the game behavior of obeying the agreement, reduce the uncertainty of the final result, and then increase the profits of the whole game process.

In recent years, many scholars have applied the multiplayer cooperative game method to solve various complex problems. Aiming at the operation mode of distributed energy storage system in solving the load balance problem in power network, Han *et al.* constructed an energy alliance based on cooperative game theory to optimize the operation of distributed energy storage system and reduce the energy cost of the alliance to the greatest extent [22]. For the problem of multiple-in multiple-out (MIMO) cognitive radio network, Liu *et al.* modeled the secondary user transmission problem through a cooperative game, and developed an effective distributed algorithm to maximize the total rate of the cognitive radio network [23]. Liu *et al.* for resource-constrained project scheduling problem, by using cooperative game theory to design a kind of negotiation mechanism to allocation of global resources, through experiments show that using cooperative game consultation mechanism can effectively reduce the total delay cost several purposes, and the solving mechanism of the change of the scale and intensity of resource conflict problem has good adaptability [24]. Wang *et al.* aiming at the problem that it is difficult for enterprises to give full play to their production capacity due to their own technical limitations in the actual collaborative development process of industrial clusters, established a restricted cooperative game model with grey authorization mechanism to improve the production capacity of enterprises [25]. Through the analysis of the research results of many scholars above, it can be seen that the multiplayer cooperative game method in game theory has better performance in solving the conflicts between multiple players and obtaining better overall payoff. Therefore, the multiplayer cooperative game method is adopted to solve the conflict of production evaluation indexes in FFSP-PB production scheduling process, so as to resolve the conflict among multiple production evaluation indexes, all production evaluation indexes are optimized.

B. OTHER RECOMMENDATIONS ANALYSIS OF PRODUCTION EVALUATION INDEX CONFLICT IN FFSP-PB PRODUCTION SCHEDULING PROCESS

In ordinary flexible flow shop scheduling process, due to the existence of limited buffer, many local assignment rules about limited buffer are established and the problem of production blockage is also caused. However, different local assignment rules have different degrees of influence on each production evaluation index, so there are certain conflicts among production evaluation indexes. When the production element of public buffer is added to the flexible flow shop with limited buffer to solve the problem of production congestion, several local assignment rules are added to control the movement of workpieces between the workstation, the limited buffer and the public buffer, thus increasing the scheduling complexity. At the same time, due to the increase of the public buffer, several local assignment rules designed for the public buffer are brought, which makes the production scheduling process more complex and further aggravates the conflicts among various production evaluation indexes. For example, when the limited buffer LBu_{j+1} of the next stage $Stage_{j+1}$ reaches its capacity limit, the completed workpiece of the current stage $Stage_j$ will not be able to enter the limited buffer, then the workpiece will start to transfer to the public buffer. This local assignment rule designed for the public buffer will make the completed workpiece of the current process $Stage_j$ not have to stay at its workstation, so that the workstation can continue to process the remaining processing workpiece, thus improving the total equipment utilization rate TPF, and reducing the total workpiece blocking time $TWBT$ and the total workstation idle time $TWIT$. However, under the effect of this local assignment rule, the total workpiece waiting time $TWWT$ and the total workpiece transfer time $TWTT$ will increase, which will cause conflicts between multiple production evaluation indexes. When an idle position appears in the limited buffer LBu_{j+1} of the next stage $Stage_{j+1}$ and the workpiece that should enter the next stage $Stage_{j+1}$ is in the public buffer $Pan\_Car(t) = 2$, the workpiece will be transferred back to the idle position in the limited buffer LBu_{j+1} of the next stage $Stage_{j+1}$ for temporary storage. The local assignment rule designed for the public buffer will enable the workpieces in the public buffer to be transferred back to the idle position of the limited buffer in time, so that the workpiece can continue to complete its subsequent processing tasks, so as to reduce the temporary storage time of workpieces in the public buffer $TWTST\text{-}PB$. But with the effect of this local assignment rule, the total workpiece waiting time $TWWT$ and the total workpiece transfer time $TWTT$ will increase, which will lead to the conflict between the production evaluation indexes.

Because many local assignment rules for limited buffer and public buffer is existed in the process of FFSP-PB scheduling, the conflict among production evaluation indexes in the whole scheduling process will become more prominent, resulting in multiple production evaluation indexes cannot get their optimal solution. If the conflict of production evaluation index in FFSP-PB scheduling process is not solved, it will affect the production efficiency and production resource utilization ratio of the whole production line. Therefore, the study of conflict of production evaluation index in FFSP-PB scheduling process has important theoretical and engineering application value.

C. APPLICATION PROCESS ANALYSIS OF CONFLICT RESOLUTION METHOD OF PRODUCTION EVALUATION INDEX BASED ON MULTIPLAYER COOPERATIVE GAME

1) GAME ELEMENTS DESIGN

When the multiplayer cooperative game method is used to solve the conflict of production evaluation index in the process of FFSP-PB scheduling, the corresponding game elements should be designed to solve the problem, which mainly includes five game elements: player, information, points & strategies, order, and payoff. And since the idea of multiplayer cooperative game in game theory itself does not have controlling parameters, the conflict resolution method of production evaluation index based on multiplayer cooperative game does not have controlling parameters.

a: PLAYER

The player refers to the decision-maker who chooses the game strategy by maximizing his own payoff in the whole game process. When solving the conflict problem of multiple production evaluation indexes in FFSP-PB scheduling process, the player includes six production evaluation indexes, namely, the makespan C_{max}, the total workpiece waiting time $TWWT$, the total processing idle time $TWIT$, the total plant factor TPF, the total workpiece blockage time $TWBT$, the total workpiece transport time $TWTT$, the total workpiece temporary storage time in public buffer $TWTST\text{-}PB$.

b: INFORMATION

Information refers to the information that each player has in the whole game process, which is helpful to his decision-making, including the information of other players. Because the multiplayer cooperative game method is used to solve the conflict of production evaluation index in the process of FFSP-PB scheduling, based on the concept of cooperation, the information of each player needs to be exactly the same, that is, each production evaluation index fully understands and has the information of production elements such as workstation information, workpiece information, limited buffer information and so on.

c: POINTS & STRATEGIES

Strategy refers to what kind of behavior the players should choose under different preconditions, that is, the method set that each player can choose when making decisions. Under different game prerequisites, most of the strategies available to each player are different. Under the same game premise, the strategies available to different players can be the same or different. The points refer to the prerequisite for each player to make a game strategy. In general, all players need to make a game at all the points. According to the conflict of production evaluation index in the process of FFSP-PB scheduling studied in this paper, the design of game points and game strategies are as follows:

Point 1: When the workpiece completes the processing task of current stage and there is no idle position in the limited buffer of the next stage:

a. The workpiece is transferred to the public buffer by the electric flat carriage.

b. The workpiece remains in its workstation.

Point 2: When the workpiece completes the processing task of current stage and there is idle position in the limited buffer of the next stage:

a. The idle position of the workpiece in the limited buffer of the next stage.

b. The workpiece is transferred to the public buffer by the electric flat carriage.

c. The workpiece remains in its workstation.

Point 3: When an idle position is existed in the limited buffer of the next stage, and there is no workpiece in the completed state on current stage and there is a workpiece in the public buffer that should enter the limited buffer of the next stage:

a. The workpiece in the public buffer that is supposed to enter the limited buffer of the next stage is transferred to the idle position in the limited buffer of the next stage.

b. The workpiece remains in its workstation.

Point 4: When the workpiece is transferred from the workstation of current stage to the public buffer and there is an idle position in the limited buffer of the next stage:

a. The workpiece returns to the idle position in the limited buffer of the next stage.

b. The workpiece remains in the current transfer state and continues to transfer to the public buffer.

d: ORDER

The order refers to the sequence of strategies adopted by each player at each point. The multiplayer cooperative game method used in the actual production scheduling process of FFSP-PB belongs to a static game method. Each player has no order in the points, that is, when each player chooses its own dominant strategy at each point, all players need to make decisions at the same point, so as to ensure the fairness and rationality of the whole game process.

e: PAYOFF

The payoff refers to the gain and loss of each player after making decisions according to the strategy at each point. It is a function of the strategy of the player. Generally, the game process is analyzed by the quantitative relationship of the payoff. Payoff can be positive or negative, which is the standard and basis for analyzing the advantages and disadvantages of strategies.

D. DESIGN OF STRATEGY SELECTION METHOD

At each point, different players need to choose the dominant strategy in their strategies to play the game, so as to maximize their own payoff. Therefore, it is necessary to determine a strategy selection method to select the dominant strategy among the multiple strategies of each player at each point. Since the multiplayer cooperative game method is used to solve the conflict of production evaluation indexes in the process of FFSP-PB production scheduling, the binding contract in the multiplayer cooperative game method that restricts the behavior of each player is the game strategy selection method to force the strategy choice behavior of each player. The optimal method of the designed strategy is as follows:

When starting a game, that is, when it reaches a point, by calculating and comparing the sum of the payoff per unit point of the strategies under this point to the next point reached by each strategy, and then judge the pros and cons of each strategy. At the same point, because of the limitation of FFSP-PB studied in this paper, point 3 and point 4 cannot be triggered continuously in the same stage, that is, the next point after point 3 of this stage cannot also be point 3 of this stage. The formula for judging the advantages and disadvantages of strategies is shown in (27), in which X represents game strategies, g_a and g_b represent points.

$$\begin{aligned}\sum CR_X &= \frac{C_{max}(g_a)-C_{max}(g_b)}{g_a-g_b}+\frac{TWIP(g_a)-TWIP(g_b)}{g_a-g_b}\\ &\quad+\frac{TWIT(g_a)-TWIT(g_b)}{g_a-g_b}+\frac{TPF(g_b)-TPF(g_a)}{g_b-g_a}\\ &\quad+\frac{TWBT(g_a)-TWBT(g_b)}{g_a-g_b}+\frac{TWTT(g_a)-TWTT(g_b)}{g_a-g_b}\\ &\quad+\frac{TWIST\text{-}PB(g_a)-TWIST\text{-}PB(g_b)}{g_a-g_b}\end{aligned}\tag{27}$$

Suppose $g1$ is the first point, under which each player has two strategies A and B, $g2$ is the second point of strategy A, $g3$ is the second point of strategy B, and the sum of unit point change ranges of game returns is $\sum CR$. according to (27), the sum of unit point change ranges of strategies A and B are shown in formula (28) and (29)

$$\begin{aligned}\sum CR_A &= \frac{C_{max}(g_2)-C_{max}(g_1)}{g_2-g_1}+\frac{TWIP(g_2)-TWIP(g_1)}{g_2-g_1}\\ &\quad+\frac{TWIT(g_2)-TWIT(g_1)}{g_2-g_1}+\frac{TPF(g_1)-TPF(g_2)}{g_2-g_1}\\ &\quad+\frac{TWBT(g_2)-TWBT(g_1)}{g_2-g_1}+\frac{TWTT(g_2)-TWTT(g_1)}{g_2-g_1}\\ &\quad+\frac{TWIST\text{-}PB(g_2)-TWIST\text{-}PB(g_1)}{g_2-g_1}\end{aligned}\tag{28}$$

$$\begin{aligned}\sum CR_B &= \frac{C_{max}(g_3)-C_{max}(g_1)}{g_3-g_1}+\frac{TWIP(g_3)-TWIP(g_1)}{g_3-g_1}\\ &\quad+\frac{TWIT(g_3)-TWIT(g_1)}{g_3-g_1}+\frac{TPF(g_1)-TPF(g_3)}{g_3-g_1}\\ &\quad+\frac{TWBT(g_3)-TWBT(g_1)}{g_3-g_1}+\frac{TWTT(g_3)-TWTT(g_1)}{g_3-g_1}\\ &\quad+\frac{TWIST\text{-}PB(g_3)-TWIST\text{-}PB(g_1)}{g_3-g_1}\end{aligned}\tag{29}$$

Since the production evaluation indexes except the total plant factor are the smaller the better, so the sum of the payoff returns per unit time are the smaller the better. Comparing the value of $\sum CR_A$ and $\sum CR_B$, if $\sum CR_A$ is less than $\sum CR_B$, it means that the payoff per unit time of strategy A is greater than that of strategy B. It also represents that strategy A is the dominant strategy under point $g1$, otherwise, strategy B is the dominant strategy under point $g1$. If $\sum CR_A$ is equal to $\sum CR_B$, then the values of the expressions in (28) and (29) are judged respectively. If there are a larger number of numerical values in the two formulas than the smaller ones, which formula represents the dominant strategy at the $g1$ point. If the two formulas have the same number of terms with relatively small values, then there is no dominant strategy under the $g1$ point, then a new point should be selected according to their respective strategies for comparison.

E. DETAILED DESIGN OF CONFLICT RESOLUTION METHOD OF PRODUCTION EVALUATION INDEX BASED ON MULTIPLAYER COOPERATIVE GAME

In this paper, the detailed implementation process of solving the conflict of production evaluation index in the process of FFSP-PB scheduling by multiplayer cooperative game method is as follows, and the flowchart of this method is shown in Figure 2:

Step 1: Obtain the production data of the manufacturing workshop, including the estimated number of workpieces, the number electric flat carriage, the standard processing time of the workpiece in each stage, the standard transfer time between the workstation of the electric flat carriage in the stage and the public buffer and the standard transfer time between the electric flat carriage in the limited buffer and the public buffer. The standard transfer time between the workstation and the public buffer of the electric flat carriage in the stage is equal to the standard transfer time of the electric flat carriage between the limited buffer and the public buffer.

Step 2: The workpieces, the positions in the limited buffer, the positions in the public buffer and the parallel workstations of the stage are abstracted as points on the two-dimensional plane, and the mathematical model of flexible flow shop with limited buffer and public buffer is established.

Step 3: Determine if there is a workpiece ready for on-line processing in the limited buffer LBu_{j+1} of stage $Stage_{j+1}$. If it exists, continue with step 4. If not, stop the scheduling work of the production workshop until there are workpieces ready for online processing in the limited buffer LBu_{j+1} of stage $Stage_{j+1}$.

Step 4: Determine whether there is an idle position in the limited buffer LBu_{j+1} of stage $Stage_{j+1}$. If not, continue step 5, if yes, continue step 8.

Step 5: Judge whether there is a workpiece in stage $Stage_j$. If yes, continue with step 6, if not, return to step 3.

Step 6: According to the formula for judging the advantages and disadvantages of strategies, respectively calculate the change range of the payoff per unit time of the two strategies with the transfer of the workpiece to the public buffer and the retention of the workpiece in its workstation from the current point to their next point. And then give which game strategy is the dominant strategy under the current point. When the dominant strategy is the transfer of the workpiece to the public buffer, continue step 7; when the dominant policy is that the workpiece is stranded in its workstation, continue the step 8.

Step 7: Judge the position of the electric flat carriage. If the electric flat carriage is at the workstation of the current stage $Stage_j$ of the workpiece, the electric flat carriage will immediately drive the workpiece to be transferred, and then continue step 8; If the electric flat carriage is in the public buffer, the electric flat carriage immediately moves to the workstation where the workpiece is currently located. After the standard transfer time Tbt, it moves to the workstation in the stage $Stage_j$ where the workpiece is currently located, and returns step 4. If the electric flat carriage is in the process of moving, wait for the electric flat carriage to finish the work it is performing, and then return to step 4.

Step 8: Determine whether there is a finished workpiece in stage $Stage_j$. If it exists, continue with step 9; if not, continue with step 10.

Step 9: According to the formula for judging the advantages and disadvantages of strategies, the limited buffer of the workpiece entering into stage $Stage_{j+1}$ is calculated respectively three strategies, namely, the transfer of workpieces to the public buffer and the workpieces staying in their workstations, are used to calculate the change range of the payoff per unit time of the six players who arrive at their respective next point from the current point. And then the paper gives which strategy is the dominant strategy under the current point. When the dominant strategy is that the workpiece enters the limited buffer LBu_{j+1} of stage $Stage_{j+1}$ or the workpiece is detained in its workstation, continue with step 16. when the dominant strategy is that the workpiece is transferred to the public buffer, return to step 8.

Step 10: Determine whether there is an electric flat carriage transporting the workpiece from stage $Stage_j$ to the public buffer. If yes, continue with step 11, if not, continue with step 12.

Step 11: According to the formula for judging the advantages and disadvantages of strategies, respectively calculate the idle position in the limited buffer LBu_{j+1} corresponding to the workpiece return stage $Stage_{j+1}$ and the transfer to the existing public buffer. The change range of the payoff per unit time of the six players from the current point to their next point is given, and then which game strategy is the dominant strategy under the current point, continue step 16.

Step 12: Determine whether there is a workpiece in the public buffer that should have entered the limited buffer LBu_{j+1}. If yes, continue with step 13; if not, return to step 3.

Step 13: Determine whether the electric flat carriage is in a public buffer. If yes, continue with step 14; if not, continue with step 15.

Steps 14: According to the formula for judging the advantages and disadvantages of strategies, the transfer of workpieces in the public buffer which should have entered the limited buffer LBu_{j+1} of stage $Stage_{j+1}$ to the idle position in the limited buffer LBu_{j+1} of stage $Stage_{j+1}$ and

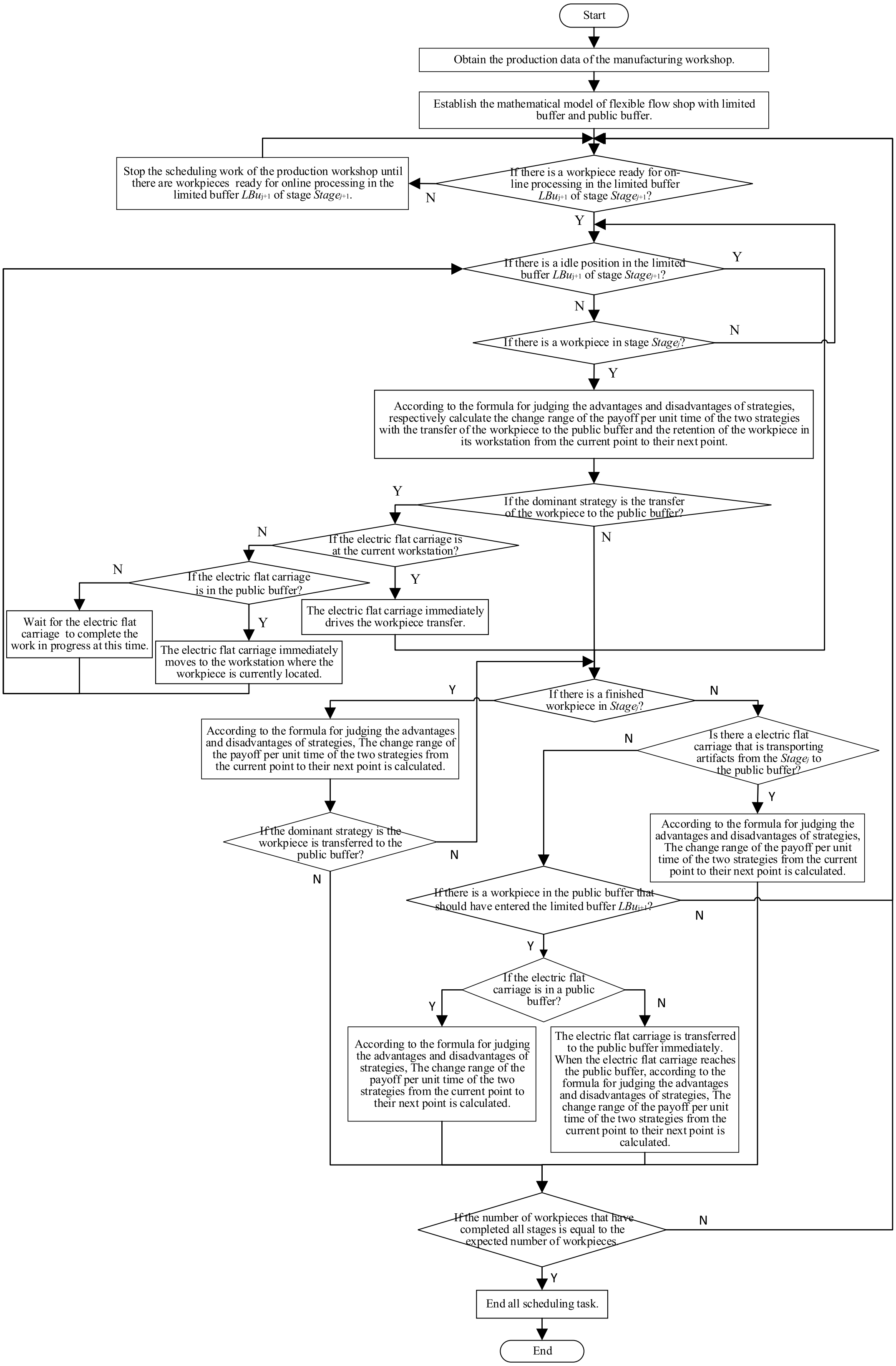

FIGURE 2. **Flowchart of conflict resolution method of production evaluation index based on multiplayer cooperative game.**

the workpieces remaining in the public buffer until a new idle position appears in the limited buffer LBu_{j+1} of stage $Stage_{j+1}$ is calculated. The change range of the payoff per unit time of the two strategies from the current point to their next point, and then gives which strategy is the dominant strategy at the current point, continue step 16.

Step (15): The electric flat carriage is transferred to the public buffer immediately. When the electric flat carriage reaches the public buffer, according to the formula for judging the advantages and disadvantages of strategies, respectively calculate the transfer of the workpiece which should have entered the limited buffer LBu_{j+1} of stage $Stage_{j+1}$ to the idle position in the limited buffer LBu_{j+1} of stage $Stage_{j+1}$ and that the workpiece continues to remain in the public buffer until a new idle position appears in the limited buffer LBu_{j+1} of stage $Stage_{j+1}$. The change range of the payoff per unit time of the two strategies from the current point to their next point, and then gives which strategy is the dominant strategy at the current point, continue step 16.

Step 16: Judge whether the number of workpieces that have completed all stages is equal to the expected number of workpieces. If yes, end all scheduling task; otherwise, return to step 3.

Through the multiplayer cooperative game method to resolve the conflict between multiple production evaluation indexes in the process of FFSP-PB, an effective game strategy for multiple workpieces in and out of workstations, limited buffers and public buffer in the process of local assignment based on public buffer is established. And a strategy selection method is designed to select the dominant strategy under each point among the multiple strategies. And then restrain the impact of a variety of complex local assignment rules on each production evaluation index and improve the utilization rate of production resources, so that each production evaluation index can be optimized.

IV. SIMULATION TEST ON CONFLICT RESOLUTION METHOD OF PRODUCTION EVALUATION INDEX BASED ON MULTIPLAYER COOPERATIVE GAME

In order to more effectively verify the effectiveness of the multiplayer cooperative game method proposed in this paper for solving the conflict problem of production evaluation index in FFSP-PB scheduling process, the simulation data close to the actual production process of bus manufacturing enterprises are constructed by taking bus manufacturing enterprises in actual large equipment manufacturing enterprises as an example.

The simulation data consists of three stages, namely $\{Stage_1, Stage_2, Stage_3\}$, the number of parallel workstations of the three stages $\left\{M_j\right\} = \{3, 3, 3\}$, a limited buffer is set up between each stage, the maximum buffer capacity of the limited buffer $\{LBu_2, LBu_3\} = \{2, 2\}$, the standard transfer time of the workpiece $Tbt = 5$, and the maximum buffer capacity of the public buffer $Kp = 3$. The total number of workpieces is adjusted according to the scale of simulation data. This paper selects three kinds of data: small-scale data, medium-scale data and large-scale data for testing.

A. DESIGN OF SIMULATION SCHEMES

In order to better verify the effectiveness of solving the conflict of production evaluation indexes in the process of FFSP-PB scheduling by means of multiplayer cooperative game, and further analyze the function of the strategy selection method designed in this paper, three groups of simulation schemes are designed to solve the problem of conflict of production evaluation indexes in the process of FFSP-PB scheduling. The specific information of the simulation scheme is shown in table 2. Among them, the reentrant rules of electric flat carriage and workpiece transfer rules in public buffer of scheme 2 have been proposed in previous studies [16]–[18].

TABLE 2. Simulation schemes information.

Simulation schemes	Scheduling model	Information
Scheme 1	Mathematical model of flexible flow shop with limited buffer and public buffer	Regular local assignment rules
Scheme 2		Improved local assignment rules (the reentrant rules of electric flat carriage and the workpiece transfer rules in public buffer)
Scheme 3		Regular local assignment rules and the conflict resolution method of production evaluation index based on multiplayer cooperative game

B. ANALYSIS OF PRODUCTION SCHEDULING RESULTS BASED ON PRODUCTION EVALUATION INDEXES

In order to obtain better evaluation results of production scheduling, the three schemes are tested under small-scale data, medium-scale data and large-scale data respectively. The total number of workpieces n in small-scale data is set to 12, the total number of workpieces n in medium-scale data is set to 40, and the total number of workpieces n in large-scale data is set to 80. Based on the production data of three examples with different data sizes, 30 different online sequences are randomly generated, the production evaluation index values are obtained through simulation tests, and the average value of each production evaluation index of each simulation scheme under 30 different online sequences is calculated. The production evaluation indexes include the makespan C_{max}, the total workpiece waiting time $TWWT$, the total processing idle time $TWIT$, the total plant factor TPF, the total workpiece blockage time $TWBT$, the total workpiece transport time $TWTT$, and the total workpiece temporary storage time in public buffer $TWTST\text{-}PB$.

1) SMALL-SCALE DATA

The three schemes run 30 times for small-scale data, and the average values of evaluation indexes obtained from 30 simulations are summarized in Table 3.

The analysis of the small-scale data simulation results in Table 3 shows that when solving the FFSP-PB scheduling problem, the scheme 3 which adopts the conflict resolution method of production evaluation index based on multiplayer cooperative game, reduces the makespan C_{max} of the main production evaluation index by 22.66 and 11.78 in comparison to scheme 1 and scheme 2, respectively, and

TABLE 3. Comparison of production evaluation indexes of three simulation schemes' scheduling results (small-scale data).

Simulation schemes	Production evaluation indexes						
	$\overline{C_{max}}$	$\overline{TWWT}$	$\overline{TWIT}$	$\overline{TPF}$	$\overline{TWBT}$	$\overline{TWTT}$	$\overline{TWTST\text{-}PB}$
Scheme 1	238.31	339.54	31.87	0.941	18.31	17.51	15.32
Scheme 2	227.43	319.33	28.51	0.967	14.19	26.29	18.35
Scheme 3	215.65	296.10	24.22	0.979	8.77	8.86	12.01
$IR(\frac{Scheme\ 3}{Scheme\ 1})$	9.51%	12.79%	24.00%	4.04%	52.10%	49.40%	21.61%
$IR(\frac{Scheme\ 3}{Scheme\ 2})$	2.18%	7.27%	15.05%	1.24%	38.20%	66.30%	34.55%

the improvement was 9.51% and 2.18%, respectively. Moreover, the total workpiece blockage time $TWBT$, compared with scheme 1 and scheme 2, scheme 3 decreased by 9.61% and 5.42%, respectively, and improved by 52.10% and 38.20%, respectively. The total workpiece waiting time $TWWT$, the total plant factor TPF, the total workpiece transport time $TWTT$ and the total workpiece temporary storage time in public buffer $TWTST\text{-}PB$ also improves. At the same time, it can be seen from the above table that scheme 2, which only uses the improved local assignment rules, has improved the makespan C_{max}, the total workpiece blockage time $TWBT$, the total plant factor TPF and the total workpiece transport time $TWTT$ compared with scheme 1, but the total workpiece transport time $TWTT$ and the total workpiece temporary storage time in public buffer $TWTST\text{-}PB$ in the public buffer are worse than those in scheme 1. Through the above analysis, it can be concluded that in the process of small-scale data simulation, only using the improved local assignment rules cannot resolve the conflicts between the production evaluation indexes, but the conflict resolution method of production evaluation index based on multiplayer cooperative game can effectively resolve each conflict between the production evaluation indexes and improve the production evaluation indexes.

2) MEDIUM-SCALE DATA AND LARGE-SCALE DATA

The four algorithms run 30 times under for medium-scale and large-scale data, respectively, and the average values of the evaluation indexes obtained from 30 simulations under the two data scales are listed in Tables 4 and 5.

The analysis of the simulation results in Table 4 and Table 5 shows that under the medium-scale data, the scheme 3 which adopts the conflict resolution method of production evaluation index based on multiplayer cooperative game, compared with scheme 1 and scheme 2, the makespan C_{max} of the main production evaluation indexes is reduced by 115.71 and 40.33 respectively, and the improvement is 17.31% and 10.83%, respectively. Under large-scale data, the makespan C_{max} of the main production evaluation indexes of scheme 3 compared with scheme 1 and scheme 2 is reduced by 177.91 and 112.29 respectively, and the improvement is 9.55% and 6.25%, respectively. Under medium-scale data and large-scale data, Scheme 3 of the conflict resolution method of production evaluation index based on multiplayer cooperative game have been improved slightly of other production evaluation indexes. It shows that under medium-scale data and large-scale data, conflict resolution method of production evaluation index based on multiplayer cooperative game still maintains a good ability to resolve conflicts and has good applicability.

C. ANALYSIS OF GAME PROCESS BASED ON GANTT CHART

Figure 3 shows the Gantt chart of the scheduling result of Scheme 2. Figure 4 shows the Gantt chart of the scheduling result of Scheme 3. The line sequence of the workpieces in the two Gantt charts is the same, which is $\{Wp_3, Wp_8, Wp_{10}, Wp_{11}, Wp_7, Wp_6, Wp_4, Wp_5, Wp_2, Wp_9, Wp_{12}, Wp_1\}$. The abscissa in the figure is the time axis, and the ordinate represents the workstation of each stage, limited buffer and public buffer.The dotted part in the figure represents the time for the workpiece that is temporarily stored in the limited buffer; the red part indicates that the electric flat carriage transfers the workpiece from workstation to public buffer; the blue part indicates the time for electric flat carriage that transfers the workpiece back to the limited buffer when transporting the workpiece from the workstation to the public buffer; the yellow part denotes that the workpiece is stored temporarily in public buffer; the green part denotes that the electric flat carriage transports the workpiece from the public buffer to the limited buffer; the orange part in the figure represents the blockage time of the workpiece in the stage. It can be seen intuitively from Figure 3 that the processing route of workpiece Wp_5 is $\left\{WS_{1,1}, Rp_5, Rr_5, Bl_{2,2}, WS_{2,3}, Bl_{3,1}, WS_{3,3}\right\}$. It can be seen intuitively from Figure 4 that the processing route of workpiece Wp_5 is $\left\{WS_{1,1}, Rp_5, Rl_5, Bl_{2,2}, WS_{2,3}, Bl_{3,1}, WS_{3,3}\right\}$. At the time of $t = 67$, the workpiece Wp_5 in scheme 2 and scheme 3 completes the processing task on the workstation $WS_{1,1}$ of the stage $Stage_1$, and there is no idle position

TABLE 4. Comparison of production evaluation indexes of three simulation schemes' scheduling results (medium-scale data).

Simulation schemes	Production evaluation indexes						
	$\overline{C_{max}}$	$\overline{TWWT}$	$\overline{TWIT}$	$\overline{TPF}$	$\overline{TWBT}$	$\overline{TWTT}$	$\overline{TWTST\text{-}PB}$
Scheme 1	899.67	1049.62	288.65	0.896	96.54	46.58	89.68
Scheme 2	854.29	1001.88	261.44	0.917	50.29	49.55	95.93
Scheme 3	813.96	987.25	207.53	0.952	43.58	29.64	75.28
$IR(\frac{Scheme\ 3}{Scheme\ 1})$	12.86%	5.94%	28.10%	6.25%	54.86%	36.37%	16.06%
$IR(\frac{Scheme\ 3}{Scheme\ 2})$	4.72%	1.46%	20.62%	3.82%	13.34%	40.18%	21.53%

TABLE 5. Comparison of production evaluation indexes of three simulation schemes' scheduling results (large-scale data).

Simulation schemes	Production evaluation indexes						
	$\overline{C_{max}}$	$\overline{TWWT}$	$\overline{TWIT}$	$\overline{TPF}$	$\overline{TWBT}$	$\overline{TWTT}$	$\overline{TWTST\text{-}PB}$
Scheme 1	1862.17	2158.73	716.97	0.882	186.32	442.31	289.68
Scheme 2	1796.55	2095.64	661.29	0.925	130.59	501.60	265.83
Scheme 3	1684.26	1996.47	577.38	0.947	92.55	389.41	215.54
$IR(\frac{Scheme\ 3}{Scheme\ 1})$	9.55%	7.52%	19.47%	7.37%	50.33%	11.96%	25.59%
$IR(\frac{Scheme\ 3}{Scheme\ 2})$	6.25%	4.78%	12.69%	2.38%	29.13%	22.37%	18.92%

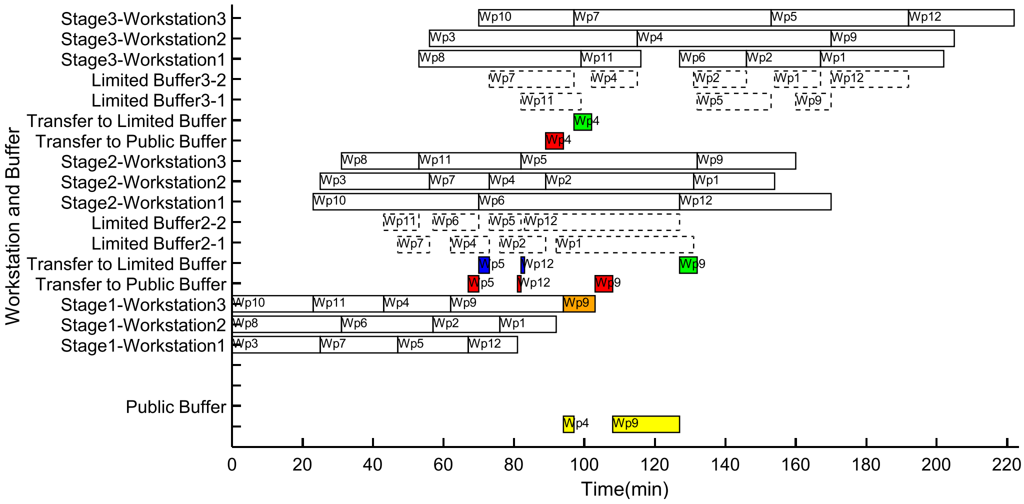

FIGURE 3. Gantt chart of scheduling results for scheme 2.

WAl_2 (67) = $\{Wp_4, Wp_6\}$ in the limited buffer LBu_2, and the electric flat carriage is at the workstation Pan_Car (67) = 0, so the workpiece Wp_5 begins to transfer to the public buffer, and the electric flat carriage state becomes Pan_Car (67) = 3. At the time of $t = 70$, the position $Bl_{2,2}$ in the limited buffer LBu_2 is idle and the workpiece Wp_5 is still in the transfer state Pan_Car (67) = 3, at this time in scheme 2, the reentrant rules of electric flat carriage takes effect, and the spent transfer time $Ttw_{5,1}(70) = 3$ of the workpiece Wp_5 transferred from the workstation of the stage $Stage_1$ to the public buffer is compared with the shortest estimated end processing time $min\{(Tc_{i,1} - 70)\big|(Ts_{i,1} - 70) \leq 0, (Tc_{i,1} - 70) > 0, i \in \{2, 9, 12\}\} = 6$ of all the workpieces on the stage $Stage_1$. Because the transfer time spent by the workpiece Wp_5 is

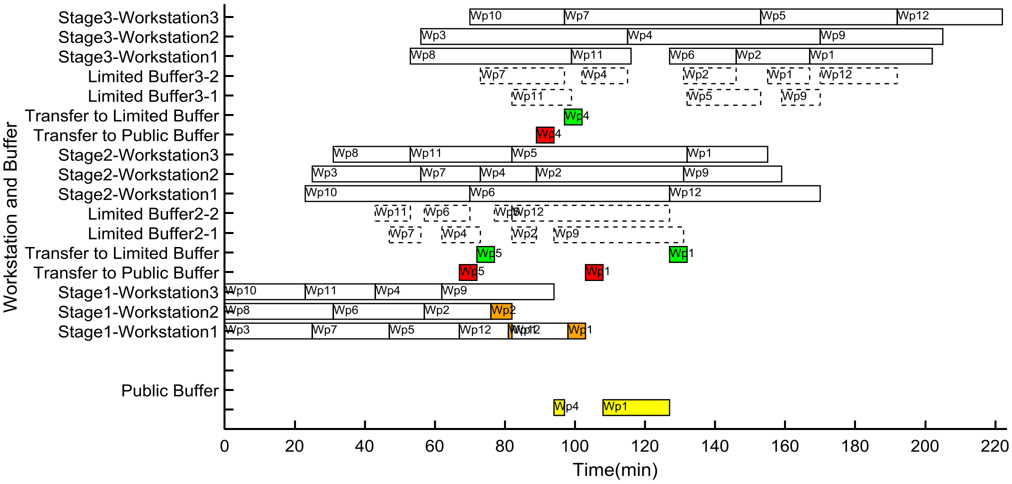

FIGURE 4. Gantt chart of scheduling results for scheme 3.

less than the minimum estimated end processing time of all workpieces in the stage, when the electric flat carriage transports the workpiece Wp_5 back to the location $Bl_{2,2}$ in the limited buffer LBu_2. When $t = 73$, the workpiece Wp_5 enters the location $Bl_{2,2}$ of the limited buffer LBu_2. In the scheme 3, the time of $t = 70$ is regarded as a point, and the point accords with point 4. Therefore, the strategy is that the workpiece returns to the idle position in the limited buffer of the next stage and the workpiece remains in the current transfer state and continues to transfer to the public buffer. The workpiece returns to the idle position in the limited buffer of the next stage is set as strategy A, and the workpiece remains in the current transfer state and continues to transfer to the public buffer is set as strategy B. According to the strategy selection method, the sum of the payoff per unit time of the two strategies at this point to the next point through each strategy is calculated and compared. The next point of the two strategies is $t = 76$. At this time, the workpiece Wp_2 completes the processing task on the workstation $WS_{1,2}$ of stage $Stage_1$ and is ready to be offline, and the position $Bl_{2,1}$ in the limited buffer LBu_2 is idle, which conforms to the description of point 2. The sum of the game return per unit time change range of strategy A is $\sum CR_A = 2.4189$ and the game return per unit time change range of strategy B is $\sum CR_B = 2.2215$, so the dominant strategy is strategy B at the moment of $t = 70$, that is, the workpiece remains in the current transfer state and continues to transfer to the public buffer. At the time of $t = 75$, the workpiece Wp_5 reaches the public buffer. After the whole production scheduling process of scheme 2 and scheme 3, the $C_{max} = 223$ of scheme 3 is smaller than the $C_{max} = 225$ of scheme 2, the $TWIP = 336$ of scheme 3 is less than the $TWIP = 342$ of scheme 2, the $TWIT = 20$ of scheme 3 is smaller than the $TWIT = 23$ of scheme 2, the $TPF = 0.9823$ of scheme 3 is larger than the $TPF = 0.9797$ of scheme 2, the $TWBT = 9$ of scheme 3 is less than the $TWTT = 23$ of scheme 2, and the $TWTST\text{-}PB = 22$ of scheme 3 is less than the $TWTST\text{-}PB = 24$ of scheme 2. According to the above final production scheduling results, it is obvious that the production evaluation indexes in scheme 3 have been optimized in varying degrees compared with scheme 2.

From the above specific analysis of the gantt chart of the simulation results, compared with the improved local assignment rule designed for the public buffer, the conflict resolution method of production evaluation index based on multiplayer cooperative game is adopted to solve the problem of production evaluation index conflict in the process of FFSP-PB scheduling, which can give full play to the role of public buffer to reduce production congestion. It can restrain the influence of many complicated local assignment rules on each production evaluation index, and effectively resolve the conflict between each production evaluation index, so that each production evaluation index can be optimized to a certain extent.

D. ANALYSIS OF PAYOFF BASED ON OPTIMIZATION PROCESS

The relationship between the total workpiece waiting time $TWWT$, the total plant factor TPF and the total workpiece blockage time $TWBT$ under the actual production data of schemes 2 and 3 is drawn. The relationship between the total workpiece transport time $TWWT$ and the production time is shown in Figure 5. The relationship between the total plant factor TPF and the production time is shown in Figure 6. The relationship between the total workpiece blockage time $TWBT$ and the production time is shown in Figure 7.

The * symbol on the solid line in figure5, figure 6, and figure 7 is marked as a point. It can be seen from figure 5 that the total workpiece waiting time of scheme 3 is 336, which is less than that of scheme 2 is 342. The growth trend of scheme 3 is slower than that of scheme 2. And the total workpiece waiting time of scheme 3 is lower than that of scheme 2 for most of the production time. It can be seen from figure 6 that the total plant factor of scheme 3 is 0.9823,

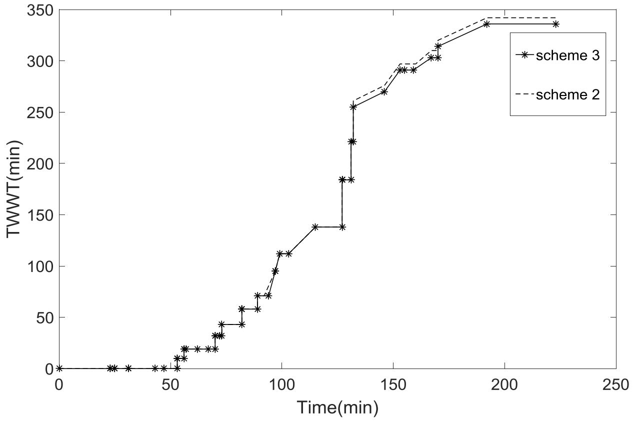

FIGURE 5. **Gantt chart of scheduling results for scheme 3 the relationship between the total workpiece waiting time and the production time.**

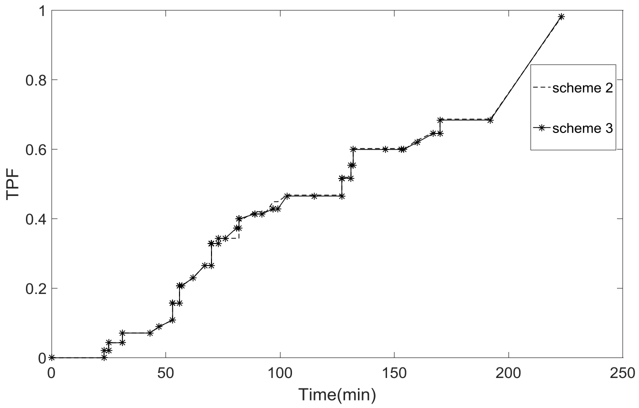

FIGURE 6. **The relationship between the total plant factor and the production time.**

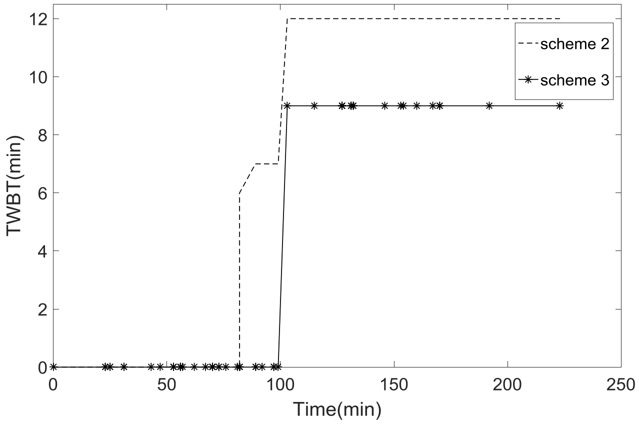

FIGURE 7. **The relationship between the total workpiece blockage time and the production time.**

which is larger than that of scheme 2 is 0.9797. The growth trend of scheme 3 is better than that of scheme 2. The total plant factor at all points keeps increasing or flat. In figure 7, the total workpiece blockage time of scheme 3 is 9, which is less than that of scheme 2 is 12. The workpiece blockage time of the workpiece in scheme 3 at each point is basically the same trend with less increase times and increasing range.

Through the above analysis, we can know that the conflict resolution method of production evaluation index based on multiplayer cooperative game can well resolve the conflict of production evaluation index in the process of FFSP-PB scheduling, restrain the influence of a variety of complex local assignment rules on each production evaluation index, and optimize each production evaluation index on the premise of giving full play to the role of public buffer in reducing production blockage. Finally, the conflict resolution method of production evaluation index based on multiplayer cooperative game can improve the production efficiency and the utilization rate of production resources.

Through the above analysis of production scheduling results based on production evaluation indexes analysis, analysis of game process based on gantt chart, and analysis of payoff based on optimization process of the results obtained from the game payoff analysis, the method of conflict resolution method of production evaluation index based on multiplayer cooperative game compared with the traditional FFSP-PB scheduling optimization method and the FFSP-PB scheduling optimization method with improved local assignment rules, it has the following three advantages:

- The conflict resolution method of production evaluation index based on multiplayer cooperative game can improve several production evaluation indexes, while the comparison method can only improve the set optimization index, and cannot improve the other production evaluation indexes purposeful.
- The overall optimization of the conflict resolution method of production evaluation index based on multiplayer cooperative game is faster, and the optimization results can be obtained without many local iterations of the conventional optimization algorithms.
- The conflict resolution method of production evaluation index based on multiplayer cooperative game uses the multi-player cooperative game method which is seldom used and studied in the field of production manufacturing, which provides a new method to resolve the conflict of multiple production evaluation indexes in the field of production manufacturing.

V. CONCLUSION

This paper studies the problem of aggravating the conflict among several production evaluation indexes in the process of complex production scheduling. Aiming at the conflict of production evaluation indexes in the process of FFSP-PB scheduling, and the corresponding game strategy selection method is designed. So as to predict and control the behavior of each player in the problem. Then a conflict resolution method of production evaluation index based on multiplayer cooperative game is proposed to resolve the conflict between multiple production evaluation indexes, so that each production evaluation index can be improved, and provides a novel and efficient solution for the conflict resolution of production evaluation index in the field of flexible manufacturing. These research results would guide the production process for the related enterprises, meet a number of daily production requirements of enterprises, and then improve the market competitiveness of enterprises.

Compared with the problems studied in this paper, the local assignment rules in the actual production process are more complex, which will further aggravate the conflict of various production evaluation indexes, and even make some production requirements of enterprises unable to meet, then reduce the competitiveness of enterprises. In order to solve the problem that the conflicts between multiple production evaluation indexes are aggravated in these larger and more complex production processes, the relationship and influence between multiple production evaluation indexes are more difficult to measure and determine, so it is difficult to accurately establish the corresponding game strategy selection method. Simultaneously because too many game points and game strategies established for the problem, the conflict resolution method of production evaluation index based on multiplayer cooperative game proposed in this paper cannot quickly provide the scheduling results after the game. Therefore, the main direction of future work is divided into the following two aspects:

① To understand and study the ideas and methods in the field of assessing system risk conflict and conflict data fusion in uncertain environment, so as to better measure and determine the relationship and impact between multiple conflicts in complex problem environment [26], [27].

② Use the artificial intelligence such as reinforcement learning method to optimize the conflict resolution method of production evaluation index based on multiplayer cooperative game. Through the accumulation of experience and training way of learning, makes the improvement method can quickly and effective production solutions, further improve the intelligent level of the conflict resolution method of production evaluation index based on multiplayer cooperative game.

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