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Task allocation planning based on hierarchical task network for national economic mobilization

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ABSTRACT

In order to cope with the task allocation in national economic mobilization, a task allocation planning method based on Hierarchical Task Network (HTN) for national economic mobilization is proposed. An HTN planning algorithm is proposed to solve and optimize task allocation, and an algorithm is designed to solve resource shortage. Finally, a case study verifies the effectiveness of the proposed method based on a real task allocation case in national economic mobilization.

Introduction

National economic mobilization is the activity of a state to activate its economic potential and social resources to cope with emergencies. In the whole process of national economic mobilization, task allocation is to distribute the mobilization tasks reasonably to enterprises and institutions, in order to achieve the goal quickly, economically, and reliably. The quality of task allocation directly determines mobilization task completion. Unreasonable task allocation may cause tasks to be unfulfilled, leading to war failure or major emergencies getting out of control.

Traditional methods of task allocation for national economic mobilization only use fixed mathematical models, while the problem of task allocation for national economic mobilization is constantly changing, and they cannot solve the changing problem. Meanwhile, task allocation for national economic mobilization requires urgency and real-time performance, but traditional methods need a long time to rebuild the model for the changing problem which cannot respond to the problem in time. Furthermore, traditional mathematical models lack specific action sequences for implementation, and cannot provide directly executable solutions for task allocation in national economic mobilization. In addition, resource shortages are widespread in task allocation in national economic mobilization. If resource shortages occur, traditional methods cannot obtain a task allocation solution because they do not satisfy the constraints.

Artificial Intelligence (AI) planning [1–5] reasons various actions and the associated resources and time, and obtains a sequence of actions that can accomplish the goal. For changing problems, AI planning reasons for each action without modifying the planning model. Meanwhile, AI planning automatically executes through planning algorithms, and can quickly respond to the task allocation[6–9]. Furthermore, AI planning outputs directly executable action sequences. Therefore, AI planning is suitable for the task allocation of national economic mobilization, which can both solve complex task constraints and obtain concrete and feasible action sequences. However, most existing planning methods cannot effectively utilize domain knowledge to optimize planning process.

Hierarchical Task Network (HTN) planning [10] is a widely used AI planning method, which performs planning according to the hierarchical decomposition of task networks. It treats abstract tasks as compound tasks and recursively decomposes compound tasks into more and more concrete subtasks until all subtasks are primitive tasks that are indivisible and executable [11]. This is very similar to the actual process of task allocation in national economic mobilization. HTN planning has rich domain knowledge representation capability and efficient reasoning ability [12–16]. It can handle complex and large-scale problems such as task allocation in national economic mobilization. Moreover, relying on domain knowledge and heuristic algorithms, it can obtain near optimal or optimal solutions. Therefore, task allocation planning based on HTN for national economic mobilization is an effective method for solving task allocation problems.

This paper focuses on the task allocation planning for national economic mobilization. The paper first models task allocation planning problem. Next, a task allocation planning algorithm based on HTN for national economic mobilization is proposed. And an algorithm to solve resource shortages is designed. Finally, the paper validates the effectiveness of the methods through a real-world case of national economic mobilization.

Task allocation planning problem modeling

Task allocation for national economic mobilization is producing and transporting mobilization materials to the assembly point under various constraints of time, resources, etc. The specific objectives are: first, to produce and transport mobilization materials to the assembly point before the deadline; second, to minimize the total cost of the tasks.

Definition 1 The task allocation planning problem can be described as $P = (s_0, \Sigma, g)$, where s_0 is the initial state, describing the state at the beginning of planning; Σ is the planning domain, indicating the domain knowledge for accomplishing the planning; g is the goal task, indicating the set of goal tasks. The planning domain can be described as $\Sigma = (O, M)$, where O is the set of operators, M is the set of methods. The definitions of operators and methods are consistent with classical HTN planning[17, 18].

Definition 2 In task allocation planning goal task $g = \{T_1, T_2, \ldots, T_n\}$ is the set of tasks assigned by the superior unit, where *T={TaskID, TaskDeadline, TaskAmount, TaskProductID, TaskDestination}, T*is a goal task, *TaskID*is a task identifier, *TaskDeadline*is the total time for completing production and transportation, *TaskProductID*is the identifier of mobilized materials for production and transportation, *TaskAmount*is the quantity of mobilized materials for production and transportation, *TaskDestination*is the assembly point of mobilized materials.

Definition 3 A planning solution π is a solution to a planning problem, expressed as $\pi = \{A_1, A_2, \ldots, A_n, R_1, R_2, \ldots, R_n\}$, where A is an action, R is a shortage report. π is a solution for solving planning problem P.

Task allocation planning

HTN-based task allocation planning algorithm

The HTN-based task allocation planning algorithm for national economic mobilization takes problem knowledge and domain knowledge as inputs, and outputs a planning solution consisting of an action sequence and resource shortage reports, as shown in Fig. 1.

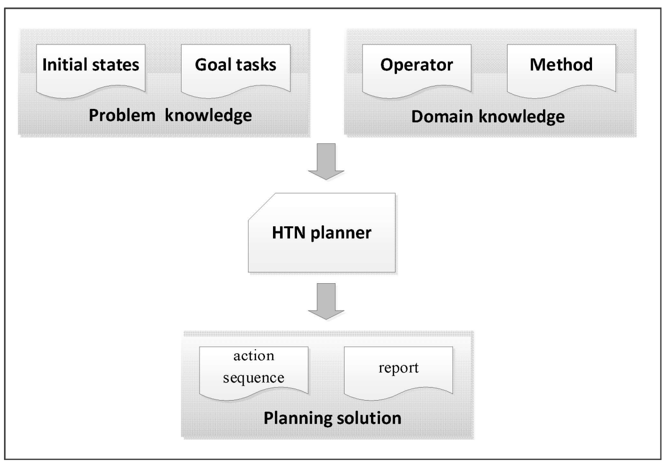

Fig. 1 The framework of the HTN-based task allocation planning for national economic mobilization

In the HTN-based task allocation planning, complex tasks are decomposed into more specific subtasks by methods under various constraints, until directly executable actions are obtained, which form the planning solution[19]. The specific planning algorithm is shown in Fig. 2.

Planning algorithm : *Plan(s,Σ, g)*

Initialize: $s \leftarrow s_0$
if $g \neq \varnothing$ **then**
pop a $T \in g$ by max $\gamma(TaskDeadline, TaskAmount)$
if T is a primitive task **then**
$Active \leftarrow \{ a \mid a$ is a ground instance of an operator in O, a is applicable to $s \}$
while $Active \neq \varnothing$ **do**
non-deterministicallypop $a \in Active$
ifResourceShortage$m$ occurs in T **then**
$R \leftarrow R \bigcup m$
disposal the ResourceShortage

10. $s' \leftarrow (s - effect^{-}(a)) \bigcup effect^{+}(a)$
11. $g' \leftarrow g - T$
12. $\pi \leftarrow Plan(s', \Sigma, g') \bigcup a$
13. **if** π is not failure **then return** π
14. **end while**
15. **if** T cannot be completed before *TaskDeadline* **then**
16. $R \leftarrow R \bigcup T$
17. **if** $Active = \varnothing$ **then return** failure
18. **else if** T is a compound task **then**
19. $Active \leftarrow \{ m \mid m$ is a ground instance of a method in M, m is applicable to s $\}$
20. **while** $Active \neq \varnothing$ **do**
21. pop $m \in Active$ by max $\gamma(\text{production}, \text{cost})$ or max $\gamma(\text{speed}, \text{cost})$
22. $g' \leftarrow g - T \bigcup subtasks$
23. $\pi \leftarrow Plan(s, \Sigma, g')$
24. **if** π is not failure **then return** π
25. **end while**
26. **if** T cannot be completed before *TaskDeadline* **then**
27. $R \leftarrow R \bigcup T$
28. **if** $Active = \varnothing$ **then return** failure
29. **else if** $g = \varnothing$ **then return** π

Fig.2 HTN-based Task allocation planning algorithm

Line 2 selects the current task according to the task utility function. The task utility function γ (TaskDeadline, TaskAmount)=TaskAmount/TaskDeadline indicates the urgency of the task. γ the larger, the more urgent, requiring concentrated time and resources to be satisfied first. Prioritizing urgent tasks can enable reasonable allocation of time and resources and maximize emergency needs.

When the current task is a primitive task (lines 3-17), it instantiates an operator to be an action, which changes the state. If there are insufficient resources, it reports and handles resource shortages (lines 7-9). The specific algorithm for shortage handling will be discussed in section 3.2.

When the current task is a compound task (lines 18-28), it instantiates a method and selects a subtask instance, which replaces the current task. Among them, when the compound task chooses to start a production line, it selects a subtask instance according to the production line utility function. The production line utility function γ (*production*, *cost*)=*production*/*cost*, indicates the capacity-cost ratio of the production line, the larger, the higher the efficiency of the production line. It prefers to start a production line with a high capacity-cost ratio to reduce production costs under the premise of completing the task. When the compound task chooses a transport vehicle, it selects a subtask instance according to the vehicle utility function. The vehicle utility function γ (*speed*, *cost*)=*speed*/*cost*, indicates the speed-cost ratio of the vehicle. It prefers to select a vehicle with a high speed-cost ratio to execute transport tasks.

Resource shortage

A resource shortage occurs when an enterprise analyzes that its existing resource inventory is insufficient to complete a production task and reports the amount of resources to the superior unit, requesting allocation of the resources to complete the production task[20]. Due to the uncertainty and high resource consumption of national economic mobilization tasks, resource shortages are widespread in national economic mobilization tasks, and the occurrence of shortages will directly lead to the failure of tasks. Therefore, according to the actual needs of national economic mobilization, HTN-based task allocation planning for national economic mobilization generates an executable action sequence with resource shortage reports, enhancing the practicality and robustness of the planning solution. Specifically, the task allocation planning algorithm first analyzes the goal task and corresponding resources, and if there is a resource shortage, it reports to the superior unit. Meanwhile, to ensure timely response to mobilization tasks and generate a complete task allocation solution, it virtualizes the corresponding shortage materials to satisfy the planning constraints. When the superior unit allocates the shortage resources to meet the demand, its planning solution can be executed immediately.

A resource shortage identification operation is described as O=(ResourceShortage, taskID, mtrID, lackamount), which means that to complete the task taskID, the enterprise lacks lackamount units of raw material mtrID in its current inventory. Therefore, the enterprise reports the shortage of the corresponding material to its superior unit to ensure sufficient supply. The algorithm for solving resource shortages is shown on Fig. 3.

1. **loop**
2. analyze mobilized material $M = \{M_1, M_2, \ldots, M_n\}$
3. stored material $SM = \{SM_1, SM_2, \ldots, SM_n\}$
4. **If** $M_x > SM_x$ **then**
5. report M_x
6. handle M_x, assume $M_x - SM_x$
7. **end loop**

Fig. 3 Resource shortages solving algorithm

The algorithm analyzes each type of resource used in the current task. If the usage of a certain resource exceeds its inventory level, it reports the resource shortage and creates a virtual resource to ensure the planning can continue (lines 4-6).

Case Study

This paper takes the realistic situation of national economic mobilization as a case and uses the HTN-based task allocation planning for national economic mobilization to obtain a solution to task allocation. The case study is implemented on the HTN planner SHOP2[21–23].

Scenario Description

An Enterprise accepts the task assigned by its superior unit. The enterprise has production and transportation capabilities and has some inventory of raw materials. The following is an introduction to the relevant information of the scenario. For simplicity, we ignore the units of quantity in the following description. The total amount of resources is shown in Table 1. The information of raw materials is shown in Table 2. The production capacity and cost of production lines are shown in Table 3. The resource consumption of production lines is shown in Table 4. The information of transportation vehicles is shown in Table 5. The transportation distance is shown in Table 6. The loading and unloading speed is shown in Table 7.

Table 1 Total amount of resources

	Water	Electricity	Steam	Worker
Total amount	80000	80000	80000	1000

Table 2 Raw materials

Raw material inventory		m001	m002	m003	m004	m005	m006
		10000	10000	10000	10000	10000	10000
Required raw materials	p001	2	3	5	-	-	-
	p002	1	2	-	3	-	-
	p003	-	-	5	-	3	1

Table 3 Production capacity and cost of production lines

		p001	p002	p003
Production capacity	l001	20	25	30
	l002	-	40	-
	l003	30	-	-
Cost		p001	p002	p003
	l001	10	20	20
	l002	-	50	-
	l003	40	-	-

Table 4 Resource consumption of production lines

Production line	l001			l002			l003		
Material	p001	p002	p003	p001	p002	p003	p001	p002	p003
Water	50	40	20	-	90	-	50	-	-
Electricity	60	30	30	-	60	-	40	-	-
Steam	60	50	50	-	60	-	40	-	-
Worker	30	30	40	-	30	-	20	-	-

Table 5 Transportation vehicles

		c001	c002	c003	c004	c005	c006	c007	c008
Speed		70	90	70	90	90	70	70	70
Transportation capability		c001	c002	c003	c004	c005	c006	c007	c008
	p001	60	50	60	20	20	-	-	-
	p002	60	50	-	-	60	50	50	-
	p003	60	50	-	-	-	-	60	50

Table 6 Transportation distance

	b1	b2	b3
a1	100	120	80

Table 7 Loading and unloading speed

	p001	p002	p003
Loading speed	50	60	50
Unloading speed	50	50	60

Case of optimized planning

The goal task g=Task1, where Task1={t001, 9, 200, p001, b1}, that is, the task t001 of producing and transporting 200 units of mobilization material p001 to the assembly point b1 within 9 hours.

Task1	Task2, Task3
(!start l003 0.0 t001)	(!start l003 0.0 t002)
(!start l001 0.0 t001)	(!start l001 0.0 t002)
(!load c001 t001 p001 60.0 1.2)	(!load c001 t002 p001 60.0 1.2)
(!transport c001 t001 p001 60.0 2.4)	(!transport c001 t002 p001 60.0 2.4)
(!unload c001 t001 p001 60.0 3.8)	(!unload c001 t002 p001 60.0 3.8)
(!back c001 t001 p001 5.0)	(!back c001 t002 p001 5.0)
(!load c003 t001 p001 60.0 2.4)	(!load c003 t002 p001 40.0 2.0)
(!transport c003 t001 p001 60.0 3.6)	(!transport c003 t002 p001 40.0 2.8)
(!unload c003 t001 p001 60.0 5.0)	(!unload c003 t002 p001 40.0 4.2)
(!back c003 t001 p001 6.2)	(!back c003 t002 p001 5.0)
(!load c002 t001 p001 50.0 3.4)	(!ResourceShortage t003 m001 100.0)
(!transport c002 t001 p001 50.0 4.4)	(!start l002 0.0 t003)
(!unload c002 t001 p001 50.0 5.5)	(!load c006 t003 p002 50.0 1.2)
(!back c002 t001 p001 6.5)	(!transport c006 t003 p002 50.0 2.1)
(!load c001 t001 p001 30.0 6.5)	(!unload c006 t003 p002 50.0 3.5)
(!transport c001 t001 p001 30.0 7.1)	(!back c006 t003 p002 4.5)
(!unload c001 t001 p001 30.0 8.5)	(!load c006 t003 p002 50.0 5.9)
(!back c001 t001 p001 9.1)	(!transport c006 t003 p002 50.0 6.8)
	(!unload c006 t003 p002 50.0 8.2)
	(!back c006 t003 p002 9.2)
	(!start l001 2.5 t003)
	(!load c006 t003 p002 50.0 10.6)
	(!transport c006 t003 p002 50.0 11.5)
	(!unload c006 t003 p002 50.0 12.9)
	(!back c006 t003 p002 13.9)

Fig.4 Planning solution

The planning solution is shown on Fig. 4. At time 0, the enterprise starts production lines l003 and l001 to produce the mobilization material p001 for task t001. At time 1.2, vehicle c001 is selected to transport 60 units of mobilization material p001. At time 2.4, vehicle c003 is selected to transport 60 units of mobilization material p001. At time 3.4, vehicle c002 is selected to transport 50 units of mobilization material p001. At time 6.5, vehicle c001 is selected to transport 30 units of mobilization material p001.

Since the task goal time is sufficient, the transportation tasks choose vehicles that have lower costs but slower driving speeds, under the precondition of completing the task within the goal time, a low-cost transportation plan is obtained. By carefully analyzing the planning solution, it can be known that under the current situation enterprise, the planning solution obtained in this task is the optimal solution under these conditions. That is, it satisfies the task requirements with the lowest cost of production and transportation. This plan shows that under some conditions, optimal solutions can be obtained with the guidance of planning algorithms.

Case of resource shortage

The goal tasks are g={Task2, Task3}, where Task2={t002, 7, 100, p001,b1}, Task3={t003, 20, 150, p002, b1}, that is, task t002 produces and transports 100 units of mobilization material p001 to assembly point b1 within 7 hours, and task t003 produces and transports 150 units of mobilization material p002 to assembly point b1 within 20 hours. The initial raw material inventory is shown in Table 8, and other environmental information is consistent with Section 4.1.

Table 8 Material inventory

m001	m002	m003	m004	m005	m006
250	1000	1000	1000	1000	1000

The planning solution is shown on Fig. 4. The planning solution respectively achieves Task2 (lines 1-10) and Task3 (lines 11-25). The planning algorithm reasons the raw materials and finds that task t003 lacks 100 units of raw material m001. Accordingly, the shortage is reported to the superior unit (line 11).

At time 0, the enterprise starts production lines l003 and l001 to produce mobilization material p001 for task t002. At time 1.2, vehicle c001 is selected to transport 60 units of mobilization material p001. At time 2.0, vehicle c003 is selected to transport 40 units of mobilization material p001.

At time 0, production line l002 starts to produce mobilization material p002 for task t003. At time 1.2, vehicle c006 is selected to transport 50 units of mobilization material p002. At time 2.5, production line l001 finishes producing mobilization material p001 for task t002 and switches to produce mobilization material p002 for task t003. At time 5.9, vehicle c006 is selected to transport another 50 units of mobilization material p002 At time 10.6, vehicle c006 is selected to evacuate 50 units of mobilization material p002.

In this case study, the resource shortage for Task3 is caused by the production consumption of Task2. If Task2 is canceled or the superior unit allocates the corresponding shortage of raw materials, then Task3 can be executed immediately according to the planning solution. The planning solutionshows that the coupling between multiple tasks makes Task2's consumption of raw materials cause a shortage for Task3, and that the proposed resource shortage solving algorithm can dynamically cope with resource shortages under multiple tasks.

Conclusion

This paper proposes an HTN-based task allocation planning algorithm for national economic mobilization, which solves and optimizes the mobilization task allocation, and presents an algorithm for solving resource shortage. Finally, the validity of the proposed methods is verified by a practical case of national economic mobilization task allocation.

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