An AI Planning Approach to Emergency Material Scheduling Using Numerical PDDL

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Abstract. Emergency material planning and scheduling aims to schedule emergency material to destination efficiently to reduce property losses and personal casualties caused by material shortage. Existing researches usually rely on optimization of transportation routes. They ignore the rich scenarios in which human and material resources participate in scheduling simultaneously. Moreover, sudden emergencies may involve the supply of multiple material demand points. To address these issues, we propose an AI planning approach to model emergency material scheduling domain and construct a standard planning task using PDDL. Then a state-of-the-art planner is employed to solve the generated planning task. Experimental results show that the proposed approach can fit the actual situation of emergencies and give high-quality instruction to guide emergency material planning and scheduling.

Keywords: Artificial Intelligence · AI planning · Emergency Material · Material Scheduling

1 Introduction

Emergency material scheduling, which aims to regulate emergency material transportation and dispatching, has recently grown up to be a major focus on constructing a complete emergency logistics system. Scheduling in logistics transportation can achieve reasonable assembly and distribution of materials. Rahman et al. proposed a novel scheduling approach capable of ensuring integrated operations for multiple automated transport vehicles [1]. Qiao Wu et al. developed a strategy based on an improved shuffled frog-leaping algorithm for solving an integrated cross-supplier order and logistic scheduling problem [2]. Despite their success, in recent years, researchers seek to improve the efficiency of emergency material scheduling. Harzi et al. presented a mixed integer linear programming approach to schedule medical resources respecting emergency degrees of patients and the availability of resources [3]. Further, considering travel time, road capacity, and material supply and demand, Jincheng Jiang et al. designed an effective

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multi-objective multi-dynamic-constraint emergency material vehicle dispatching and routing model [4].

In this paper, we propose a multi-transportation multi-destination emergency material scheduling method based on AI planning considering traffic congestion and transportation energy consumption. The emergency material planning solution consists of problem analysis and domain modeling. In the experiment, three emergency material scheduling problems are solved. PDDL2.1 [5] will be used to describe and model the emergency material scheduling problem. To obtain planning solutions, we use a planner the Metric-FF. Our objective is to find the optimum emergency material scheduling in order to minimize the total scheduling time and transportation energy consumption.

2 Background

2.1 AI Planning

AI Planning is an artificial intelligence method that concerns the realization of strategies or action sequences, typically for execution by intelligent agents. Classical planning is an AI planning where an agent takes advantage of the problem structure to construct complex plans of an action. Concerning propositional STRIPS [6], a classical problem can be represented as a tuple $P = \langle F, A, O, G \rangle$ where F represents the set of propositions; O represents the set of actions; I represents the initial state and $I \subseteq F$; G represents the target state and $G \subseteq F$. A solution plan π can be represented in a series of action sequences $a_1, a_2, \cdots, a_n$. PDDL is a standard artificial intelligence description language based largely on concepts set out for STRIPS, which separates the model of the planning problem into domain description and the related problem description.

2.2 Emergency Material Scheduling

An emergency usually means an immediate and unforeseeable disaster including earthquake, flood, etc. In addition, COVID-19 is also a public health emergency, which requires the emergency management department to establish an effective and efficient emergency rescue system to prevent a worsening of the situation and offer palliative care for the aftermath. A strong emergency rescue system focuses on the rational scheduling of emergency material. The course of action during this scheduling covers many aspects, including emergency material demand, storage, assembly, transportation, distribution, etc.

2.3 Emergency Material Scheduling Problem

Considering the scheduling of medical supplies, food and other emergency material under COVID-19, the scene can be illustrated in Fig. 1. We must mobilize manpower and material resources, including volunteers, drones and trucks. Then they will be organized to go to the emergency materials distribution center to load the materials and transport them to the control area.

The transportation route is described with an abstract diagram shown in Fig. 2. The circle represents the intersection, the rhombus is the emergency materials distribution

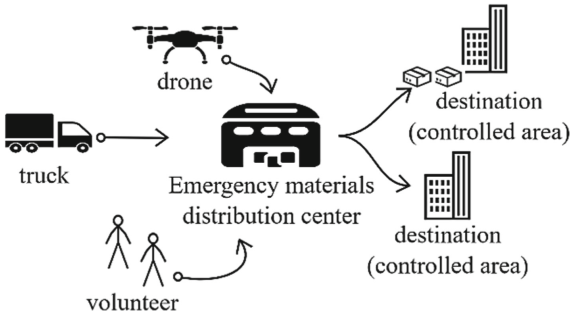

Fig. 1. Schematic diagram of emergency material scheduling

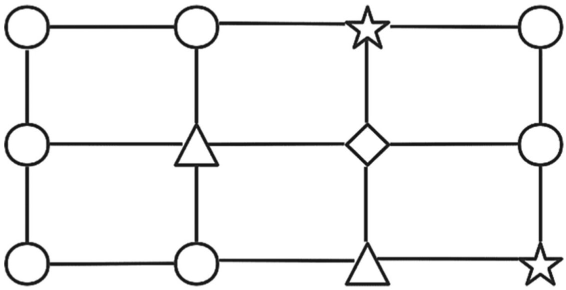

Fig. 2. An abstract representation of transportation route

center, and the star indicates the control area. Additionally, the triangle indicates the intersection with congestion and the straight line indicates that the two locations are reachable. We consider simultaneously three scheduling processes: dispatch, arriving at the distribution center, loading and transportation.

3 Planning Modeling for Emergency Material Scheduling

In this section, we will introduce our model in details. Our model is intended to extract emergency material scene based on AI planning using PDDL. Our model contains two parts: domain knowledge extraction and action modeling. We first define constant objects and predicates as templates for logical facts in every problem in emergency material scheduling domain. Then we abstract operator-schemas with parameters from state transitions for action modeling.

3.1 Domain Knowledge Extraction

In emergency material planning and scheduling, objects and predicates should be defined to express the "physics" of participants in scheduling scene. Type of objects dictates that things can play different roles in emergency material scheduling scene. We define three main types, namely transport, location and goods. Considering volunteers, drones, and trucks can assemble and deliver emergency supplies, we set volunteer, drone, and truck as sub-types of transport. Besides, according to the weight of emergency material, light, moderate and severe are identified as the sub-types of goods. Transportation route is a channel for the directional movement of transportation tools depending on the relative position between waypoints, so we define assembly-area, destination and route-area as the sub-types of location. Details of other predicates are presented in Fig. 3.

Domain knowledge extraction need to be driven by properties of objects. We build some predicates which describe loading condition of transportation tools and volunteers, the orientation of each location, real-time traffic information, etc. Table 1 shows the PDDL predicate carry with two parameters from emergency material scheduling, which means transportation tools are loaded with emergency material. Apart from carry, the PDDL definition of the domain includes other predicates: located-north for describing the orientation relationship between different areas, **linked** for denoting there exists drone routes between two locations, **jam** for representing congestion somewhere, **free** and **non-empty** for signifying whether emergency material is carried by transport tools, and **at** and **at-loc**, for indicating location of transport tools and goods.

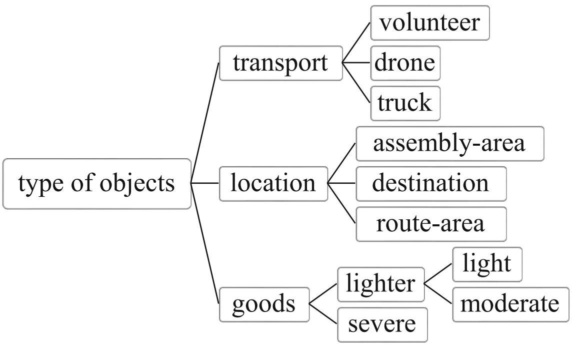

Fig. 3. Type of object structure diagram

Table 1. The definition of types

Predicates
(located-west ?l1 ?l2 - location)
(located-east ?l1 ?l2 - location)
(located-north ?l1 ?l2 - location)
(located-south ?l1 ?l2 - location)
(carry ?g - goods ?t - transport)
(free ?t - transport)
(non-empty ?t - transport)
(at ?t - transport ?loc - location)
(at-loc ?g - goods ?loc - location)
(linked ?l1 ?l2 - location)
(jam ?l1 - location)

Table 2. Definition of partial actions

(:action pick-up :parameters (?v - volunteer ?l - light ?assembling - assembly-area) :precondition (and (at ?v ?assembling) (at-loc ?l ?assembling) (free ?v)) :effect (and (carry ?l ?v) (non-empty ?v) (not (at-loc ?l ?assembling)) (not (free ?v)) (increase (total-time) 1)))
(:action move-north :parameters (?v - volunteer ?from - location ?to - location) :precondition (and (at ?v ?from) (located-north ?from ?to)) :effect (and (at ?v ?to) (not (at ?v ?from)) (increase (total-time) 1)))
(:action fly :parameters (?d - drone ?from - location ?to - location) :precondition (and (at ?d ?from) (linked ?from ?to)) :effect (and (at ?d ?to) (not (at ?d ?from)) (increase (total-time) 1) (increase (energy) 5)))

3.2 Action Modeling

We design action schemas for reasoning about actions in AI planning, namely pick-up, put-down, grab, put, load, unload, fly, move-north, drive-north, etc. **Pick-up**, **grab** and **load** represent volunteer, drone and truck are loaded with emergency material respectively. **Put-down**, **put** and **unload** are opposite action schemas, whose effect is to unload emergency material from transportation tools or volunteers. Furthermore, there are some actions representing movement of transportation tools and volunteers, which contain **fly**, the moving action and driving action. They depend on the relative positions of their starting position and target position. Table 2 shows definition of partial actions. When volunteer *v* is at emergency material assembly-area and there exists light goods *l*, the goods *l* can be picked up at assembly-area assembling. In addition, function *total-time* associate scheduling time with numeric values in order to choose an effective plan. Effects can make use of a selection of assignment operations in order to update the values of primitive numeric expressions. The literal *(increase (total-time) 1)* indicates total scheduling time will increase one unit when performing the **pick-up** action.

4 Experiments

In this part, we build a domain file and problem file based on emergency material scheduling model. All experiments were conducted on operating system Ubuntu18 with CPU(Intel(R) Core(TM) i7-8700 CPU @ 3.20 GHz). We use Metric-FF planner to solve these problems.

In order to solve different emergency material scheduling problems on the complicated ground, we consider the following two scenes: (1) Emergency material is delivered to a control area. (2) Emergency material is transported to multiple control areas with traffic congestion somewhere.

Referring to the traffic route in Fig. 2, in scene.1, we set an emergency material demand point to *loc3*, 5 volunteers to *v1*, *v2*, *v3*, *v4*, *v5*, 2 drones to *d1*, *d2*, and 2 trucks

Table 3. Plans for the two scenes

Scene	Scene.1	Scene.2
Problem	init: (linked loc1 loc7) (linked loc7 loc3) …… (located-east loc1 loc2) (located-south loc1 loc5) …… (located-west loc12 loc11) (at c1 loc5) (at c2 loc5) …… (at v5 loc7) (free c1) …… (at-loc l1 loc7) …… (at-loc s3 loc7) (= (total-cost) 0) (= (energy) 0) goal: (at-loc l1 loc3) (at-loc l2 loc3) …… (at-loc s2 loc3) (:metric minimize (+ (energy) (total-cost)))	init: (linked loc1 loc7) (linked loc7 loc3) …… (located-east loc1 loc2) (located-south loc1 loc5) …… (located-west loc12 loc11) (at c1 loc5) …… (at v5 loc7) (free c1) …… (free v5) (at-loc l1 loc7) …… (at-loc s3 loc7) (jam loc6) (jam loc11) (= (total-cost) 0) (= (energy) 0) goal: (at-loc l1 loc3) (at-loc l2 loc3) …… (at-loc s2 loc3) (at-loc s3 loc12) (:metric minimize (+ (energy) (total-cost)))
Plan	0: DRIVE-EAST C1 LOC5 LOC6 1: FLY D1 LOC1 LOC7 2: DRIVE-EAST C1 LOC6 LOC7 3: GRAB D1 M1 LOC7 4: FLY D1 LOC7 LOC3 …… 46: DRIVE-NORTH C1 LOC7 LOC3 47: UNLOAD C1 S1 LOC3 48: DRIVE-SOUTH C1 LOC3 LOC7 49: LOAD C1 S2 LOC7 50: DRIVE-NORTH C1 LOC7 LOC3 51: UNLOAD C1 S2 LOC3	0: DRIVE-NORTH C1 LOC5 LOC1 1: FLY D1 LOC1 LOC7 2: DRIVE-EAST C1 LOC1 LOC2 3: DRIVE-EAST C1 LOC2 LOC3 4: DRIVE-SOUTH C1 LOC3 LOC7 …… 60: DRIVE-NORTH C1 LOC7 LOC3 61: UNLOAD C1 S2 LOC3 62: DRIVE-SOUTH C1 LOC3 LOC7 63: LOAD C1 S3 LOC7 64: DRIVE-EAST C1 LOC7 LOC8 65: DRIVE-SOUTH C1 LOC8 LOC12 66: UNLOAD C1 S3 LOC12
Total-time	98	177
Nodes expanded	348	618
Plan time	0.02 s	0.06 s

to *c1*, *c2*. Initially, volunteers are located in the emergency supplies distribution center *loc7*, drones are at *loc1*, and trucks are at *loc5*. We implement the planner to deliver emergency material from materials distribution center *loc7* to control area *loc3* to meet the needs of emergency material. Additionally, scene.2 sets up two emergency material

Table 4. Emergency material scheduling problem with power depletion

(:action drive-north
:parameters (?t - truck ?from - location ?to - location)
:precondition (and (at ?t ?from) (located-north ?from ?to) (not (jam ?to)) (> (power ?t) 0))
:effect (and (at ?c ?to) (not (at ?t ?from)) (increase (total-time) 1) (decrease (power ?c) 1)))
0: DRIVE-EAST C1 LOC5 LOC6
1: FLY D1 LOC1 LOC7
2: DRIVE-EAST C1 LOC6 LOC7
……
46: DRIVE-EAST C2 LOC6 LOC7
47: LOAD C2 S1 LOC7
48: DRIVE-NORTH C2 LOC7 LOC3
49: UNLOAD C2 S1 LOC3
50: DRIVE-SOUTH C2 LOC3 LOC7
51: LOAD C2 S2 LOC7
52: DRIVE-NORTH C2 LOC7 LOC3
53: UNLOAD C2 S2 LOC3

demand points *loc3* and *loc12*. At the same time, delivery may pass through location *loc6* and *loc11* with traffic jam. The transportation tools should complete all emergency supplies avoiding congestion to ensure total delivery time. Details are shown in Table 3. According to the results of Table 3, we can deal with emergency material scheduling problems in a short time which guide us in emergency material distribution.

Taking into account some exceptional cases, drones and trucks cannot perform transportation tasks with power depletion because they are powered by electricity. Therefore, we need to modify the driving action and the action fly. Taking drive-north as an example shown in Table 4, we add predicate *(power ?t)* to ensure that each truck's power is greater than 0 when driving. We construct a problem file according to scene.1, and add proposition *(= (power c1) 6) (= (power c2) 30)* to the initial state as descriptions of trucks' remaining power. The planning solution is shown in Table 4.

5 Conclusion

In this paper, we propose an AI planning method to solve emergency material planning and scheduling problems which contain many factors corresponding to multi-transport, traffic congestion and multi-destination scene. Our model makes full use of numeric expressions in PDDL2.1 and takes energy consumption into account. In particular, we show that transport tools cannot move forward to deliver emergency material without energy. We run our experiments in Metric-FF planner and obtain plans. The solution sequence is applied to emergency material scheduling management system, which has the characteristics of short scheduling time, low energy and optimal plan. AI planning provides a novel direction for the research on emergency material scheduling.

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