Project 4： Re-Schedule

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1. Context

a) Purpose

This application is designed to make the quickest and most convenient adjustments to people's schedule changes. And the newly generated schedule will be as similar as possible to the original schedule.

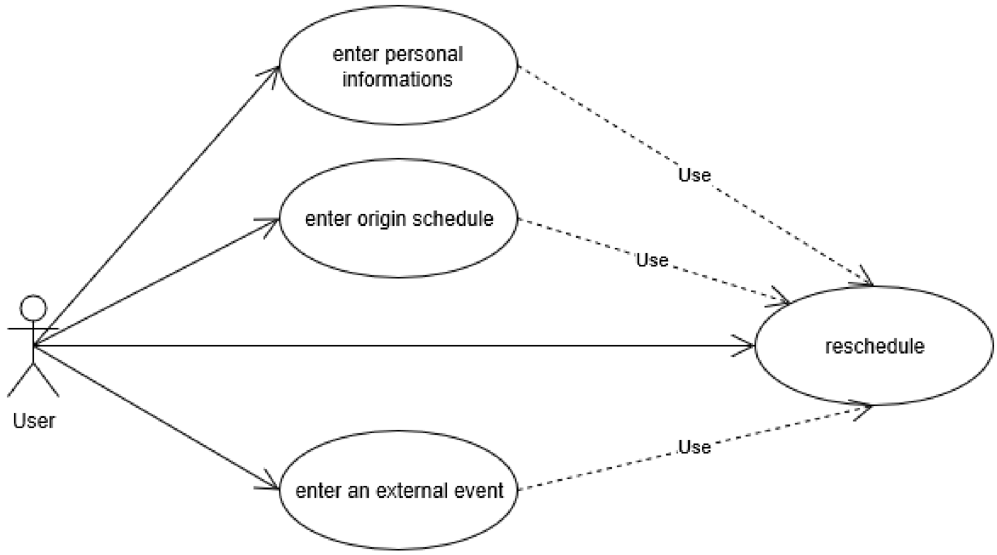
b) Research area

Currently, we only focus on individual trips for individual users. The user should be a person who does individual schedule which can't be affected by other users.
In the future, we will upgrade to a multi-person schedule for individual users. Then the agents could negotiate with each other, and the user could even be a group (family, company)

c) Function

This application permits the users to create a schedule by entering his daily activities. And once he meets some events and has to do some changes for his schedule, it can reschedule intelligently. For example, when an agent planned to go shopping, while he meets a traffic jam on his way to market, usually he has two choices. One of that is to change the start time of doing shopping, the other one is to extend the duration of shopping. What we will do is to let the application do the reschedule by itself according to the origin schedule and the favors of the agent.

d) Use case



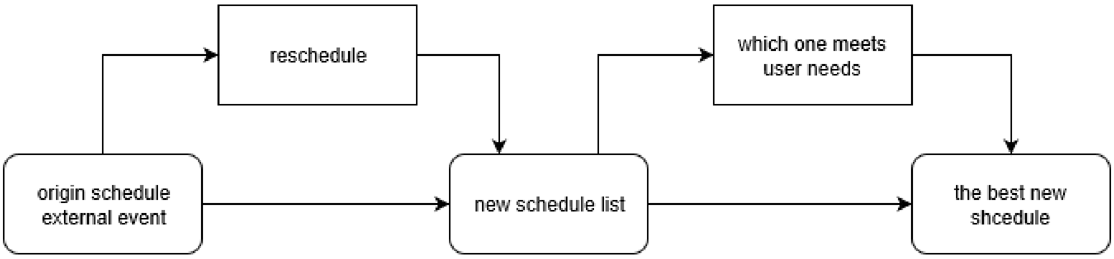
For someone who uses this application, he should at first start-up with entering his personal information such as age, sex, profession and so on. So that this application can find out the priority when it reschedules. The user could enter his planned schedule and an external event, then get the best new schedule by clicking the reschedule button.

2. Problems

Once we decide to reschedule our daily-schedule, there are several problems we need to solve. We could easily find out these problems by using the flow chart. The system will end when all the episodes in the schedule are executed, and the output is the new schedule which is performed in reality.

On conclusion, we need to solve how to do dynamically real-time rescheduling.

The following is a flow chart, then we will generally separate it into three parts:



Step 1: Input the planned schedule data, and the external events.

Step 2: Create a new set of schedules.

Step 3: Find out the best schedule.

a) Planned schedule and external event

In daily life, individuals generally have a schedule for a set of activities. While, academic scheduling usually assumes deterministic and known in advance data. This situation is not often met in practice, since data may be subject to uncertainty and it may change over time. This kind of change in reality is called unexpected event, and people need to make rescheduling decisions when faced with this situation. When make rescheduling decisions, there several questions we need to consider:

- Q1. Why did you decide to change the original schedule?
- Q2. When did you decide to change that activity/trip?
- Q3. Did the decision depend on change in a previous activity/trip?
- Q4. How to make the rescheduling decision?
- Q5. Will the decision have an influence on next activity?

To answer Q1, it is necessary to identify the unexpected event that may make people reschedule, if there are changes in reality environment, whether for travel or activities, they will be called as outside events. And people need to rescheduling to deal with these changes. If the rescheduling decision will have an influence on the next activity, this kind of disturbance is called as inside event. This solves the Q2.The rescheduling time depends on aware time of events and events type Q3. As for Q4, in the simulation process, we will just consider the current trip/activity and the next activities/trips, and the final rescheduling decision is made by using activity utility and rescheduling penalty. In order to solve Q5, it is necessary to analyses the rescheduling decision of the current activity, and identify it will affect the next activity or not. These questions are considered when establishing the rescheduling model.

b) Reschedule

i. Rescheduling Process

In the real world, each user will have their own preferences and habits, and depending on each specific attribute, it will result different changes.

For example, if a user wants to drive to the supermarket to shop, then episode is divided into two parts: the on-road driving and the shopping in the supermarket. At that time, an accident is found on the road, which would cause traffic jams. Then this external event will cause the original schedule to change, and there are many different solutions corresponding to this. For example, you could shorten the time of shopping, change the original driving route, and so on. So how to get to this series of new schedules, we will give detailed answers in the next section.

ii. Create internal event

Once we change the origin schedule, there is a possibility that the affected episode's change will affect the next episode. Internal event occurs during the rescheduling process. It could be classified as follows:

- the end of previous activity is later than the start time of next trip, so it will cause a delay of the next trip
- the location of previous activity is changed to a new location, so that the start of next trip is also change to this new location

So how to create an internal event which is important during the reschedule process.

c) Find out the best new schedule

There are many ways to find out the best new schedule, and what's the meaning of 'best'? Here 'best' means as similar as possible to the origin schedule. What method is used to determine whether the new one is similar to the original one? At this time, we are going to introduce a new concept, that is penalty.

3. Existing solutions

a) MATSim

MATSim (the Multi-Agent Transport Simulation Toolkit) is an open-source framework to implement large-scale agent-based transport simulations, where a large number of individuals, synthetic persons (so-called "agents") are simulated. The framework consists of several modules which can be combined or used stand-alone. Modules can be replaced by custom implementations to test single aspects of your own work.

The framework is designed for large-scale scenarios, meaning that all features of the model are stripped down to efficiently handle the targeted functionality. For the network loading simulation, for example, a queue-based model is implemented, omitting very complex and computationally expensive car-following behavior. MATSim is typically used to simulate a single day, but multi-day applications could be implemented by minor modifications to the (open) source code of the tool.

MATSim is based on the co-evolutionary principle. Every agent repeatedly optimizes its daily activity schedule while competing for space-time slots with all other agents on the transportation infrastructure. This is somewhat similar to the route assignment iterative cycle, but goes beyond route assignment by incorporating other choice dimensions like time choice, mode choice or destination choice into the iterative loop.

Currently, MATSim offers a framework for demand-modeling, agent-based mobility-simulation (traffiMc flow simulation), re-planning, a controller to iteratively run simulations as well as methods to analyze the output generated by the modules.
The re-planning algorithm was extended in MATSIM by Balac and Axhausen. It handles the adaptations to activity chains of the agents, like adding or removing an activity and swapping two activities in the current plan. While, these adaptations cannot be used at the first and last activities of the schedule. It also modifies the activity scoring function, which make performing an activity is proportional to the duration.

b) Dynamic and Individual-Centric Rescheduling

For the reason to make rescheduling decisions. Gan and Recker [12] studies the problem of adding activities to a family' schedule, it assumes that there is a known moment to change the schedule of remaining not-yet-completed activities. Based on the rule of maximizing the household utility and similarity, it tries to minimize the affected people. Knapen et al.[13]takes advantage of the output of FEATHERS, and calculates the road network load every 15 minutes. By receiving the network state evaluation, individuals have access to be aware of the incidents. And then they will adapt the activity start time or end time to reschedule, not by other ways like relocation, activity dropping etc. Balac and Axhausen [2] extends the re-planning algorithm in MATSIM. It handles the adaptations to activity chains of the agents, like adding or removing an activity and swapping two activities in the current plan. While, these adaptations cannot be used at the first and last activities of the schedule. It also modifies the activity scoring function, which make performing an activity is proportional to the duration.

Some researchers focus on rescheduling decisions. Clark[8] explores rescheduling process based on the rescheduling data collected through interviews. Activities with a time difference less than 15 minutes were not discussed in the interview, and modifications of in-home activities were not discussed. It found that the vast majority were adding an activity, deleting an activity, and modifying the time of an activity (start time, end time, or both). Other changes such as modifying location, activity type, and involved persons were very rarely.

What is more, it concluded that socio-demographic variables appear to have a limited impact on rescheduling decisions, but the type of activities that are rescheduled seem to have a great deal of importance. Nijland et al. [16] puts forward that changing the duration of an activity is most frequent way. People will consider other choice facets only if the resulting duration reduces utility too much, and other options is depending on their substitutability degree. Weis and Axhausen [20] concludes that people are very reluctant to change their daily activity patterns when faced with changes in transportation systems.

When the travel times change between -30 minutes and +90 minutes. Almost, 90 percent of the surveyed people decide not to change the number of activities in their daily schedule. Sun et al. [19] analyses the heterogeneous risk attitudes under uncertainty and information in an activity-travel context. It uses decision tree to analyze individual's options. Allahviranloo et al. [1] uses data obtained from a detailed survey performed in Belgium, and then analyses the differences between the stated preferences of individuals in terms of their planned and their actual (realized) activity participation. It analyses the flexibility of travelers in making changes in their mental plans in reaction to the external events impacting them. Through using penalty function, it finds that rescheduling mandatory activity has a high cost, and rescheduling flexible activity has a low cost.

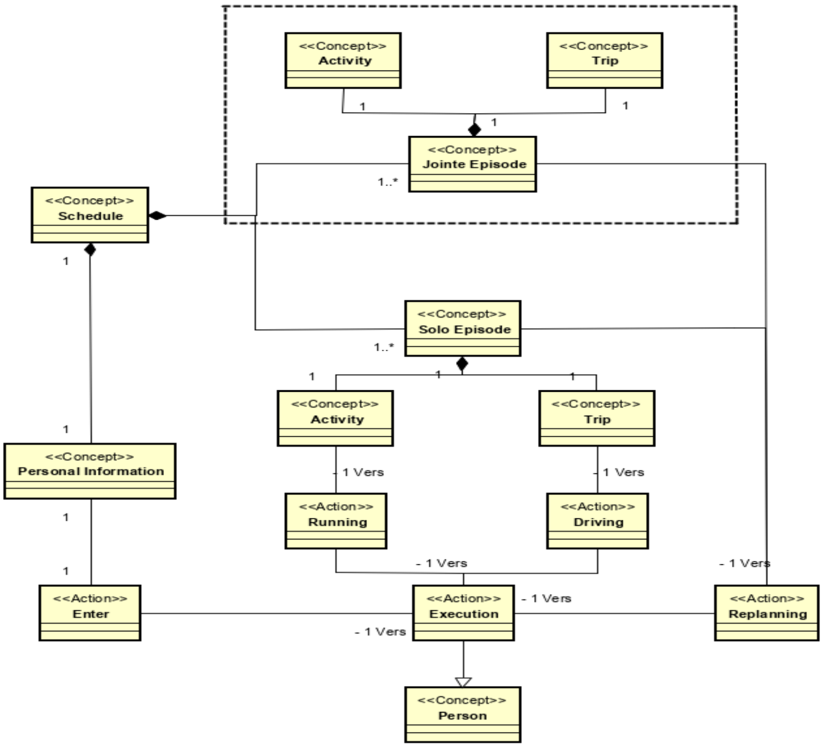
c) Penalty

We could use 'Penalty Genetic Algorithm'(PGA) to estimate the penalty values for replacing a planned schedule in the new schedule, inserting an external event. Then it could measure the dissimilarity between planned and performed schedule. The sequence alignment technique is used to measure the distance between ant pair of texting string by finding the minimum number of steps required to align two sequences.

We could use decision tree to simulate the re-routing when receiving an external event. It calculates the utility of each decision node. And it can choose to believe the information or not. Id it accepts the information, and then it goes to the next decision node. Il also classifies the users as three type of risk takers. People with different risk will have different utility functions.

4. Model and Solutions

a) Ontologie Diagram



An agent can enter his personal information and execute the original schedule. A schedule is composed by several episode (solo-episode, joint-episode). An episode consists of one trip and one activity which could be run and driven by the agent.

b) Definition

i. Event

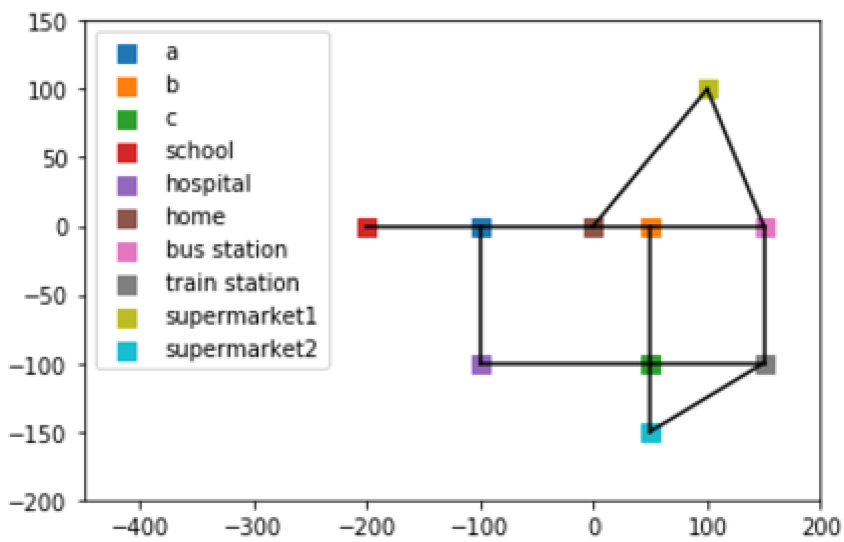
To solve the problem of rescheduling, we have created a very original and useful solution. In the class <<Event>>, there is not only the event but also the solution to solve this event.

```
class Event extends Object {

    public var trip_or_activity : int //0 trip 1 activity
    public var type_of_event : int // 0 1 2
    public var time_event : int // the awareness time of the event
    public var time_start: int // the start time of the event
    public var affect_id : int // which episode will be affected by the event


    public var travel_new_mode : Transport_Mode // no change
    public var path_non_congested : Path
    public var delta_start_time_trip : int
    public var delta_start_time_activity : int
    public var delta_duration_time_activity : int
    public var new_location : Location

    public var new_endtime_activity : int
```

For instance, if the there is a traffic jam, when we create the object of external event <<traffic_jam>>, we also put the solutions like the new path we choose, and the new transportation mode like bicycle. Therefore, when we do the rescheduling, the incoming parameters are the original schedule and the event, then we find the episode affected by the event, and we can directly assign the episode with the solutions. So that we get a new schedule if the next episode is not affected. If not, we can create an intern event with the new solutions obtained by the modules to do the recurrence. However, not all the attributes in this class are used. It depends on the activity in the episode affected. For example, if the activity is work, we can have 3 solutions: new mode, new path and the new time. If the activity is social visit, we can have 4 solutions. So, the package module is very important to create the (internal) events. We think it's the best way to define the class <<Event>> and it can reduce the difficulty of the whole project.

ii. Map

We create a simple map for better understanding the routing module. (python)



c) Reschedule

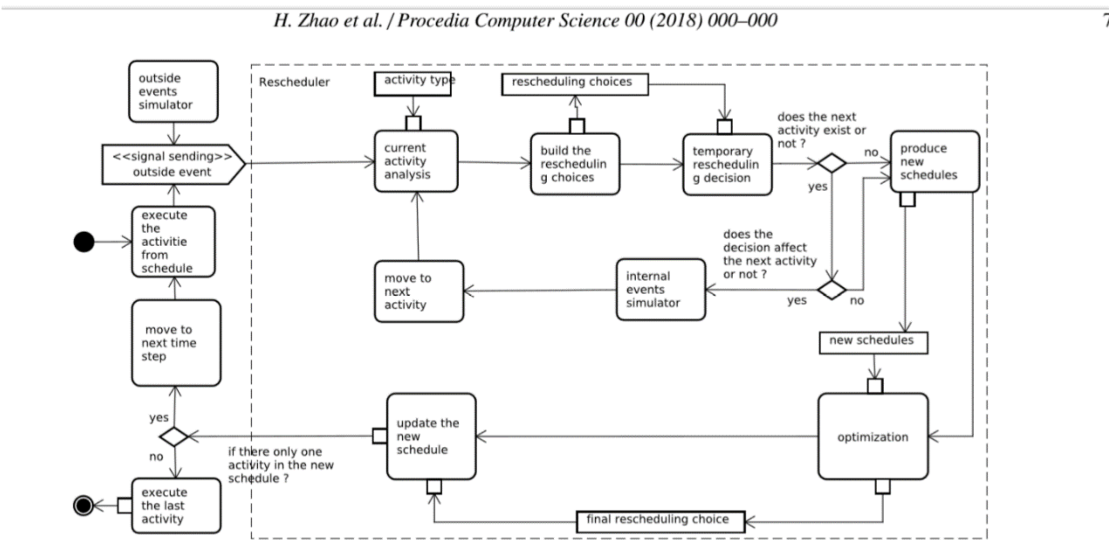
We use a recursive approach to reschedule, once we find the next episode would be affected by the change of temporary schedule, we would create the internal event.

i. Rescheduling Process

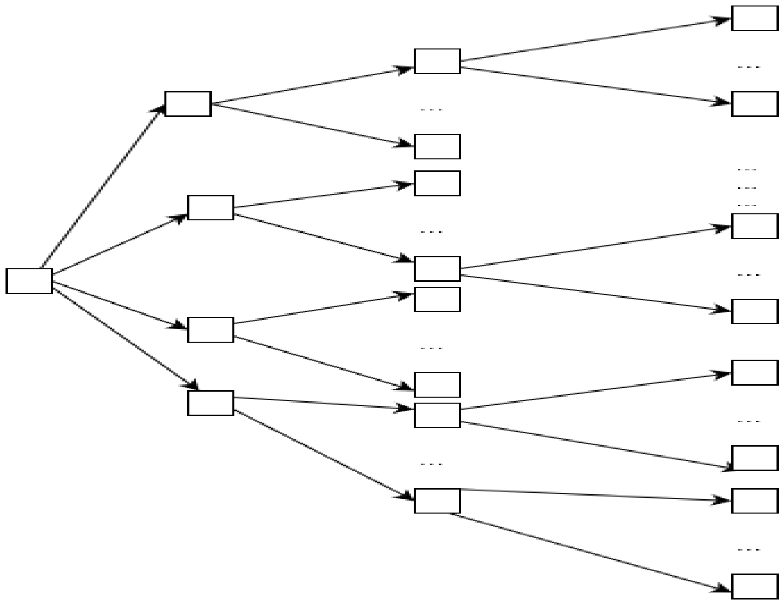
Algorithm 1 Core Re-scheduling Algorithm

Input: an $externalEvent$ and an original schedule
Output: a new schedule

while simulation end not reached **do**
  $Event \longleftarrow externalEvent$
  $newschedule \longleftarrow schedule$
  for all $episodes$ not being executed **do**
    $Event$ affect $currenEpisode$
    $choiceSet(currentEpisode) \longleftarrow choiceCustomized$
    $execute(agent, currentEpisode)$
    if $nextEpisode$ be $Affected$ **then**
      $currentEpisode \longleftarrow nextEpisode$
      $Event \longleftarrow internalEvent$
    end if
  end for
  $Calculate$ cost C of all the $temporaryscheduleset$
  $newschedule \longleftarrow MinimizeC(temporaryscheduleset)$
end while



- Change time: It could be separated into: trip change start time, activity change start time and activity change duration.
- Change mode: Change only the mode of trip.
- Change path: Trip changes path.
- Cancel episode: Drop the episode affected by the unexpected events.



During this process, there are many optional temporary new schedules. The user needs to find the best one.

ii. Create internal event

Internal event could only be created during the reschedule process. It is related to Module which is composed by several different modules:

- Routing module: Update the trip time on each edge, minimize the total trip time. To find the minimal trip time from current point to the location, A* algorithm is used. In order to get the new path.
- Time module: Time allocation is a module to re-planning the trip start time, activity duration time end time. Under this situation, both mode and not be changed. Type of event mainly affect the rescheduling of time module. Here we can get the new end time of the affected episode.
- Location module: In the location module, all the location known by the individual are considered. "Known" in this context means that the agent not only knows the physical location but also the attributes that are potentially relevant for evaluation utility values for the planned activities. (which is related to the definition of<<Location>>) Nevertheless, the location module is dynamic.
- Mode module: It is related to the travel time, travel cost and individual's preference to the corresponding mode. According to the definition of <<Event>>, we can get the new mode of the internal event.

By using these modules, we can get the internal event, and send the internal event and the result of i-th schedule to the Reschedule Module, then get a sequence of new schedules.

d) Cost and Penalty

Whenever there are attributes changed in an episode, there will be penalty for this change.

And if the change is caused by changes of previous episode, an extra penalty is used for this operation. Therefore, the relations between a pair of episodes can be captured. This parameter is determined by the activity type of two connected episodes.

i. Utility

For each episode, there is a parameter named utility, which is related to the activity type, activity duration, and so on.

ii. Probability

For each schedule, there is a parameter named probability, which is related to the attributes of trip and activity.

iii. Penalty

Penalty is the changes about path, time, and locations:

$$P_i = P_{path} + P_{time} + P_{location}$$

iv. Cost

The optimization function is to minimize the penalty of attributes changing between the original schedule and the new schedule, and the function is as follows:

$$minC = \sum_{s}^{K_s}(\sum_{k=1}^{K_i}\{P_i \times x_{ik} + \sum_{i+1}^{N}\sum_{k=1}^{k_{i+1}} w_{i+1} \times P_{i+1} \times x_{(i+1)k}\}) \times r_s$$

5. Example

Here is a simple example of rescheduling.

- Original schedule:

Episode 1:

Trip:

start time: 9H00

duration: 0H20

Mode: Car

Path: Highway

Activity:

start time: 9H20

duration: 1H10

Type: Leisure

Location: Swimming pool

Episode 2:

Trip:

start time: 10H40

duration: 0H20

Mode: walk

Path: Sidewalk cross a business center

Activity:

start time: 11H00

duration: 2H00

Type: work

Location: School

For example, when we are swimming, we are so relaxed that we forget the time. And when we leave the swimming pool, it's already 10H45. So, the next episode has been affected. The type of the activity of the episode affected is work, as we have defined, so there are 3 ways to treat this event: change the mode of transportation, change the start time of working and change the path to the destination. So, the event is defined as followed:

Event e:

time_event = 10H50

affect_id = 2

travel_new_mode = Bike //obtained from the mode module

delta_start_time_activity = 0H10 //10 minutes late compared with expected

new_path = the shortest path to the school //obtained from the routing module

- Rescheduling Set are as followed:

Reschedule 1:

Episode 1:

Trip:

start time: 9H00

duration: 0H20

Mode: Car

Path: Highway

Activity:

start time: 9H20

duration: 1H10

Type: Leisure

Location: Swimming pool

Episode 2:

Trip:

start time: 10H50

duration: 0H10

Mode: Bike

Path: Sidewalk cross a business center

Activity:

start time: 11H00

duration: 2H00

Type: work

Location: School

Reschedule 2:

Episode 1:

Trip:

start time: 9H00
duration: 0H20
Mode: Car
Path: Highway

Activity:
start time: 9H20
duration: 1H10
Type: Leisure
Location: Swimming pool

Episode 2:

Trip:
start time: 10H50
duration: 0H10
Mode: walk
Path: the shortest path to the school

Activity:
start time: 11H00
duration: 2H00
Type: work
Location: School

Reschedule 3:

Episode 1:

Trip:
start time: 9H00
duration: 0H20
Mode: Car
Path: Highway

Activity:
start time: 9H20
duration: 1H10
Type: Leisure
Location: Swimming pool

Episode 2:

Trip:
start time: 10H50
duration: 0H20
Mode: walk
Path: Sidewalk cross a business center

Activity:
start time: 11H10
duration: 2H00
Type: work
Location: School

We get 3 rescheduling, and each one has its own penalty. According to the penalty, we can calculate the possibility of choosing. But pay attention, if we choose the Reschedule 3, which means the end time of the activity is 13H10, 10 minutes later than expected, and if there is episode 3, which starts at 13H00, it will be conflict. In this case, we have to create an internal event to handle this problem. If there is an internal event, we use the recurrence to traverse all the possible reschedule until there is no more internal event.

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