MULTI-AGENT SYSTEM FOR INTELLIGENT SCHEDULING

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Model, Agent, Multi-Agent System, Dynamic Scheduling, Optimization.

ABSTRACT

This work is dedicated to the development of a multi-agent system for intelligent scheduling: to simulate, to analyze and to optimize used parameters to achieve the best performance in terms of increasing the speed of Technician agents (they provide a field service), reducing transport and time costs for their movement to Service Appointment agents (they are waiting for the Technician agent's active interaction) and Dispatcher agents (they analyze and distribute the relations between another agents. Nowadays the most of the current scheduling models on the market are centralized. This paper exposes a way to use a multi agent-based approach to shift the scheduling system from centralized control to decentralized decisions made by agents. The implemented model allows us to check the model of dynamic scheduling with the real data under a real-time environment and it allows us to test interactions between the agents of three different types.

INTRODUCTION

In a Field Service Management (FSM) system, it is necessary to simultaneously coordinate many processes: processing flows of incoming and outgoing information, tracking and distributing service resources (Technicians) and technical equipment, managing employees who are on the road, etc. The proposed modeling technique allows us to take into account various qualitative characteristics of field agents and their collective behavior, while obtaining adequate assessments of the implementation of the assigned collective task. The basis of the modeling methodology is a multi-agent simulation system for field service, which takes into account the targeted group behavior of a team of agents.

Currently, the market for modern FSM systems is growing at a significant pace (Markets and Markets; Mordor Intelligence), but the following tasks have still not been fully implemented - programming the rational behavior of an individual service resource agent, decision-making by the agent based on a collective task, assessment by the agent of the results of completing the common and his own task. The object of study is models of agents capable of functioning as part of a team. The key point is the interaction between group members, which creates a system of constant feedback, and the target function is the direction of behavior not of an individual, but of the entire group of agents within the framework of a common task.

The final result of the FSM users' work directly affects the loyalty of customers who provide direct or indirect revenue to the organization. Inconsistency between the quality of work and the current state of the market leads to customers refusing their services and deprives companies of a competitive advantage in terms of meeting customer needs and service level agreements (SLA) (Friedman, 2022; Choudhary, 2022).

When it comes to the route planning process, geographical information systems and transportation logistics always stand together. To solve operational problems and optimize internal processes, FSM system needs a scheduling methodology, which takes into account current road situation, makes a notable difference in fuel consumption, transport maintenance, time management as well as parameters of service appointments.

Off-line scheduling has attracted many researchers to find a separate schedule for operations and material handling systems or simultaneous schedule for both (Raman et al., 1986; A.I. Correa, 2007). Heuristic optimization approaches are also used for a feasible and good solution of off-line scheduling problems as most problems are np-hard in terms of computational complexity (Azamathulla et al., 2008).

Since the FSM systems do not assume the service resources to return to base(main) station after each service appointment has been completed, it causes the problem as a nonlinear mixed integer programming model (Fernandes et al., 2009). However, because of the long computation times, a heuristic-based iterative procedure could be used to build machine schedules. There are other optimization algorithms to select the optimal schedules for such types of systems (Babu et al., 2010; Jerald et al., 2006).

In FSM practice, not always exact job detail is usually known at a very late instant. This makes precise

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off-line scheduling hardly possible. Therefore, on-line scheduling or dynamic dispatching rules are necessary to mobile service resources (Khayat et al., 2006). One type of scheduling strategy is to use dynamic dispatching rules to determine which job should be processed next when a service resource becomes available. Such rules are very common in systems where many scheduling decisions should be made during the work day of the workforce.

We consider an on-line dispatching system when a remote worker completes the service appointment and then the new service appointment could appear in the system. There are two main types of on-line dispatching systems: decentralized and centralized systems. If a single control system simultaneously controls all remote workers in the system, we refer to it as a centralized system. All the information related to service appointments such as locations, duration time, needed materials and work description are stored in the controller's database. Simulation is widely used as a modeling tool to investigate many on-line dispatching rules (Singh et al., 2009; Kızıl et al., 2006; Panwalkar and Iskander, 1977).

The main objective of this research is to identify the effect that the most critical factors have on the selection of the cost effective routes for field service technicians in terms of enroute time and parameters of service appointments (location, work duration time). As another objective, a model is proposed to solve the distribution problem based on the variables derived from the model. Visualization, as the outcome of this research, will help dispatchers solve problems in the dimensions of space and time and in the form of graphs and digital maps rather than dimensionally-restricted data tables (Han, 2001).

THE PROPOSED MODEL

Definition Of The Agents

Using the Business Process modeling technique, we created a model of a real Internet service provider in terms of providing services to end users and to the own company's existing infrastructure, geographically distributed in the city. The key roles are: Operator, Dispatcher, Technician, QA and Administrator (see Fig. 1).

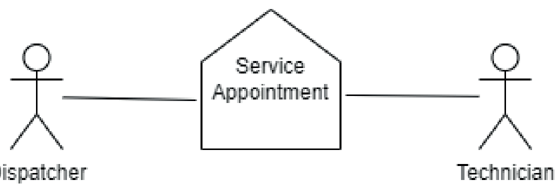

Figure 1: Definition of agent system

Dispatcher Agent (Scheduler)

This agent can create the schedule for available Technician agents by assigning them to Service Appointment agents in selected order. To perform his main job, the following criteria are used to operate the agent behavior:

- **Priority** - higher priority work orders are processed first;
- **Geolocation** - the location of the place of SA execution in relation to the place of execution of the previous SA is taken into account (to minimize travel time and distance);
- **Service Territory** - the territory to which the Technician belongs is taken into account. It is allowed to fulfill requests from another Service Territory if there is a significant difference in the workload of the Technicians. But working on 'foreign' territory is not encouraged due to the delimitation of service areas and is considered high-cost for the purposes of the algorithm;
- **Duration time** - the planned duration of the work is taken into account. Longer jobs are considered more expensive.

To develop a methodology for assessing the effectiveness of planning the Technician's working day, we introduce the initial weight of each criterion that will be using in further calculations (see table 1).

Table 1: Criteria and coefficients.

Criteria	Criterion weight coefficient	Criterion conversion factor
Priority	$p_1 = 80\%$	$p_2 = 100$
Geolocation (distance)	$l_1 = 50\%$	$l_2 = 3$
Geolocation (travel time)	$t_1 = 70\%$	$t_2 = 1$
Service Territory	$s_1 = 80\%$	$s_2 = 100$
Duration time	$d_1 = 30\%$	$d_2 = 1$

The main concept of the cost functional for moving to one object is listed in Equation (1):

$$C = f(P, L, T, S, D), \tag{1}$$

where P - Priority of the service request;
L - distance to move from the previous object to the next, km. The system receives this data from the service [Google Matrix API];
T - time to move from the previous object to the next, min. The system receives this data from the service [Google Matrix API];
S - flag that shows that Technician is not assigned to the Service Territory of current Service Appointment, 0 or 1;
D - planned duration of work, min.

When estimating costs, we use criterion weight coefficients $(p_1, l_1, t_1, s_1, d_1)$ to determine the weight of each criterion for reduction. We also introduced initial criteria conversion factors to reduce criteria values to a common unit of measurement $(p_2, l_2, t_2, s_2, d_2)$ according to the table 1.

As a result, the costs of moving to an object in a chain of movements can be calculated using the formula in Equation (2).

$$C_s = \begin{aligned} & p_1 * p_2 * P_s + l_1 * l_2 * L_s \\ & + t_1 * t_2 * T_s + s_1 * s_2 * S_s \\ & + d_1 * d_2 * D_s, s = 1..n \end{aligned} \quad (2)$$

where n - number of new service appointments.

Thus, the Dispatcher agent calculates costs parameter for all service appointments with 'New' status for each Technician agents by using

$$CV_j = C_s(j), j = 1..n \quad (3)$$

where n - number of service resources available. Then for each Technician agent it selects the next SA:

$$SA = min\{CV_j\}, j = 1..n \quad (4)$$

and assigns them to the Technicians. As a result, Technician agent is assigned to Service Appointment agent with the lowest cost parameter as the most valuable in terms of material and time costs, as well as value according to the priority. Next, the algorithm is repeated for the remaining undistributed service appointments.

For example, if there are different service appointments that differ only in priority and one more criterion like another (alien) Service Territory allocation (S.T.) or Work Time duration (W.T.), we have the value set represented in the Table 2.

Table 2: Test data

Priority and differences in Service Appointments	P	L	T	S	D	Sum, units
P1	1	5	30	0	30	120,5
P1, 2x distance	1	10	30	0	30	128,0
P1, 2x travel time	1	5	60	0	30	141,5
P1, alien S.T.	1	5	30	1	30	200,5
P1, more W.T.	1	5	30	0	50	128,5
P2	2	5	30	0	30	200,5
P2, 2x distance	2	10	30	0	30	208,0
P2, 2x travel time	2	5	60	0	30	221,5
P2, alien S.T.	2	5	30	1	30	280,5
P2, more W.T.	2	5	30	0	50	208,5

The compiled diagram shows that the 'cost' of executing the next work order is largely influenced by the priority of the application and the flag if Technician is not assigned to the Service Territory of the current Service Appointment (see Fig. 2). These parameters are needed to being adjusted on real test data for each location.

Technician Agent

The Technician agent represents the remote worker, who receives the service appointment request, analyzes the details, accepts the service appointment, moves to the place where it will be performed and carries it out.

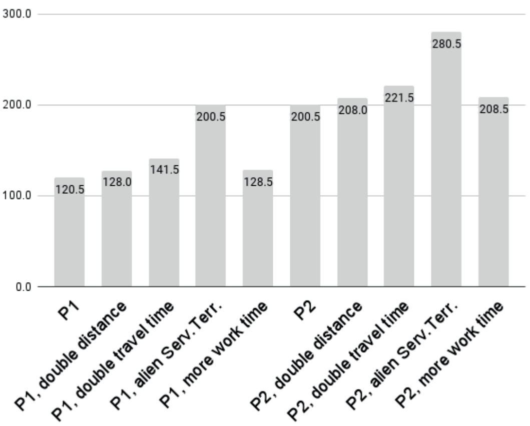

Figure 2: Diagram of the dependence of 'costs'.

Each step of the technician reflects on an assigned service appointment status. For example, above mentioned steps set the status to Accepted, Enroute, In Progress. When Technician finishes his work, he can change the service appointment status to 'Complete', 'Incomplete' or 'Cannot Complete'. In the current realization of the model we use 'Complete' finish status only. After all, he creates a report on the work done and materials used, signs it with the service customer (if the order came from the customer, and not from the company itself) and sends it to the dispatcher.

Service Appointment Agent

To simplify the model we use only Service Appointment as an agent who Technician-agent interacts with. Service Appointment (SA) is used to represent the entity of the work performed as part of work order. For one work order, there may be several service appointments for different Technicians, if the work cannot be done completely in one visit of a specialist. Main properties for the current model:

- Scheduled Date/Time - to store a date when the SA is due;
- Duration time - planned time to complete SA, min;
- Status - to store the current status of the SA. The value is assigned by Operator, Dispatcher or Technician agents.

THE MODEL RESULTS

When testing the model in practice, it proved that the proposed algorithm makes the order of service appointments according to the rule of placing the lowest cost service appointments first for execution. Costs include not only real material and time costs, but the number of appointments can be done during the day (e.g. two short service appointments have less costs than one during the same time). A schedule of all active Technician is displayed on the Dispatcher panel in FSM software as a set of graphs (Fig. 3).

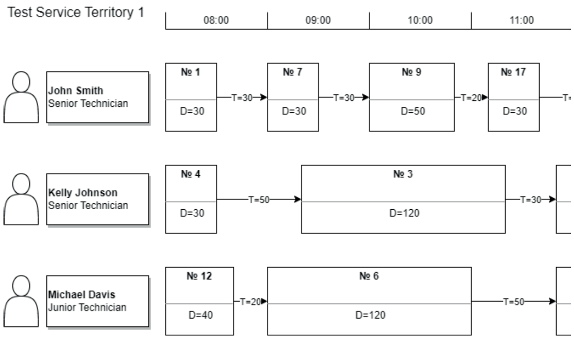

Figure 3: The graph with schedule for many Technicians.

The figure schematically shows the work schedule of technicians belonging to the 'Test Service Territory 1' Service Territory.

When the Technician agent has the current service appointment finished, the Dispatcher agent recalculates all the schedule to take into account new service appointments appearing in the system and possible changes on location and travel time parameters.

MODEL TESTING

The model was implemented and tested in NetLogo software Vidal (2010). The model allows to simulate the work of Dispatchers and Technicians interacting with service appointments,

When running manually created test data, 10 Technician agents were created in random locations as a setup of the system. Then service resources have been created in random locations with random parameters. The Dispatcher agent (Scheduler) iterates through available technicians and calculates cost parameters (2) for each service appointment. Summarizing and finding the best values by (3)(4), The Dispatcher agent assigns available Technician agents to Service Appointment agents. Technician agents accept the assignment and move to Service Appointment agent location. When he arrives, he interacts with the assigned Service Appointment agent until work duration time has finished (Fig. 4).

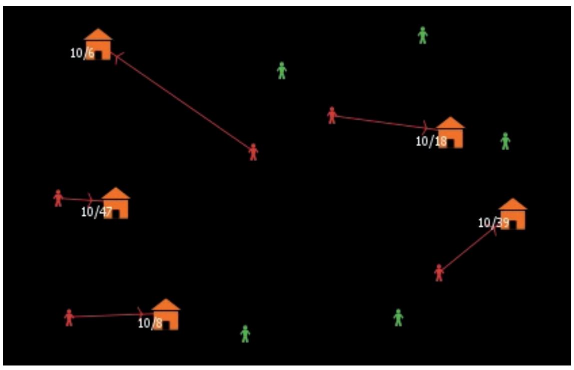

Figure 4: NetLogo interface with model workspace.

The main statistical data is showing on the graphs (Fig. 5). The maximal and sum of waiting times from all Service Appointment agents are the subject to cut down during the optimization: we adjust the initial model parameters to minimize these sums to find the best result.

Figure 5: NetLogo interface with model graph output.

MODEL TESTING IN PRACTICE

Current model was also tested using the real Internet service provider (ISP) data (ATEK Research page). Its service appointments included maintenance of client equipment and modernization of the core hardware owned by ISP. The model allows to leverage Criterion weight coefficients and Criterion conversion factors to adjust the model to real work situations.

As a result of testing, it was found that for high-quality implementation of the system it is necessary to carefully analyze the division of the city into service areas and empirically (from the model run) select the coefficients of the dispatcher module. The latter is necessary due to various dependencies not taken into account in the current model, for example, the presence of traffic jams and their dependence on the time of the day, the density of urban development and parking restrictions in the city streets for official vehicles. There is a need to add the breaks for Technicians for lunch and the rest during the day in future modeling.

CONCLUSIONS

Obviously Agent Based Model Scheduling has an application in different industry sectors today: in the agricultural system, to efficiently utilize costly equipment (harvesters, tractor, trucks, etc.), owners rent them out to farmers (Jayawant et al., 2016), in dynamic rescheduling decision making systems for flexible flow line manufacturing systems that work under dynamic customer demand (Roudi et al., 2015), in aviation industry, where time and safety are the two most important factors and a lot of machinery like vehicles are involved and lots of communication are involved (Ip et al., 2010), in the logistics industry for quality logistics solutions to achieve high levels of service (Tse et al., 2009).

In the present paper, we show the research on simulation of multi-agent system for dynamic and simultaneous scheduling of Technicians' work. This scheduling solution was tested practically in the Field Service Management system for the Internet Service Provider to dispatch the work force in the city to work with customer issues.

The solution is based on the model of agents, which interact and produce the vital statistical information. System allows to enter the real data and adjust the parameters of the model to obtain the best result like cutting such expenses as Technician travel time and travel costs. Using the system to find the best coefficients allows customer to cut the time and costs of manual adjustment of the scheduler parameters based on the location and task specifics.

Currently we are on the testing stage, but regarding the current practical testing result, we can confidently say, that we made a right model and the software system to use this model.

The FSM system, developed on the basis of the proposed model, made it possible to bring FSM service to a qualitatively new level. The analysis of system data within the framework of the model allowed us to note the following positive achievements: automated dispatch of the service requests has been implemented, the deadlines for completing service appointments have been reduced, the places (equipment) that most often require technical intervention have been identified.

Our model was also compared with the proposed model with classical dispatching rules. As a result, we found that the proposed system outperforms the traditional dispatching rules in most simulation tests. These rules are mostly for deterministic cases and usually not able to handle dynamic situations. However, we consider their results as snapshots in time and we used them as the upper bounds on the makespan in order to assess the outcome of the proposed agent-based system.

Nowadays the task of mobile workforce scheduling optimization and dispatching is a part of the FSM systems. They are mostly commercial projects and therefore there is no open information about their structure and used parameters. Currently there are more than 10 systems on the market to manage service resources (TrustRadius page). Competition and corporate rules do not allow sharing the science part of the work they implement. Researches based on the agent-based models of the workers' behavior investigate only the interaction between workers and the world, but not the workers and their service appointments they need to do (Binhomaid and Hegazy, 2021a,b).

Although there have been some studies for the remote workers control by using multi-agent approaches, none of them presents a simultaneous scheduling solution for remote service resources and their planned service appointments. Moreover, the execution of the job assignments through the dynamical scheduling with many parameters was not described explicitly in these previous studies that are currently available.

FURTHER RESEARCH

The proposed model has a good performance, but we consider refactoring it to provide optimization using the neural network to reduce the time to market of the FSM system. Also we plan to use simulation system with the opportunity to make real-time integration to have the online data about the road traffic for making dynamic scheduling depending on the actual data.

Next plans are related to extend the Technician agent properties like skills (qualifications) and available materials to make more precice association between Technician agents and Service Appointment agents. It will be significantly close to the real technicians work and their action on their duties.

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