Development of a Multi-agent Simulator of Electric Power Distribution Equipment Damage Restoration Process

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ABSTRACT:

We propose a multi-agent simulator of an electric power distribution equipment damage restoration process due to a disaster. In the proposed simulator, the agents, who imitate the restorer, are modeled by extracting main work steps of the actual restoration process. The major functions of the proposed simulator are 1) to imitate the restoration process, 2) to estimate the alternative strategy, and 3) to improve the restoration time estimation by adding the damage information reported by the inspector. In this paper, we show an outline of the prototype and demonstrate numerical examples to confirm the effectiveness.

KEYWORDS: Restoration, Multi-agent, Simulation

1. PREFACE

In Japan, it has been pointed out that some megacities are threatened by not only a low frequency large-scale earthquake [Japan Meteorological Agency (2007)] but also high frequency high-scale weather hazards included typhoons [Central Disaster Prevention Council (2005)]. Since these natural hazards also cause damage to electric power distribution equipment, and their damage in recent years has tended to increase, the reasonable countermeasures against such natural hazards are needed for the electric power companies.

The Japanese electric power companies need to rationalize the restoration process and shorten the emergency restoration time after natural hazards. The purpose of this study is to develop a system that can simulate the emergency restoration process for electric power distribution equipment using a multi-agent based technology. In order to simulate the emergency restoration process, it is necessary to model the complicated factors for emergency restoration of the electric power distribution equipment. The multi-agent based system can easily simulate such complicated factors. Since there are few public information and statistical records related to such an emergency restoration process, however, the information associated with the process is very limited. Thus, the necessary functions and the strategies that can be achieved are discussed with practitioners in order to design the simulator. During the design process, we performed some questionnaire surveys to practitioners of an actual electric power company. On the basis of these surveys, we developed a prototype simulator.

In this paper, Chapter 2 describes the outline of the restoration simulator. Chapter 3 illustrates some numerical examples. The proposed simulator is applied to a hypothetical electric power distribution system and its effectiveness was discussed. Chapter 4 summarizes the concluding remarks and futures subjects.

2. THE OUTLINE OF THE RESTORATION SIMULATOR

2.1. The design policy of the restoration simulator

The emergency restoration of electric power distribution equipment is a process that is accomplished by the cooperation of many restorers. In order to program a human collaborative relationship naturally, the multi-agent technology is applicable. Furthermore, during an emergency restoration, it is usually operation for the restorer to start the restoration activities from an uncertain situation in which the equipment damage condition is unknown. Therefore, the decision-making during the restoration process is usually performed with incomplete and unreliable damage information. The multi-agent based technology enables us to easily simulate such uncertain situations.

Moreover, since it is not easy to collect the actual statistical data associated with equipment damage or its restoration time, there have been few studies to simulate the restoration process of electric power distribution equipment. However, Shumuta (2000) statistically analyzed the relationship between the restoration time and its correlated factors including the number of damaged high voltage distribution lines in order to propose a restoration time estimation for the electric power distribution equipment. Shumuta (2000) clarified that the time for detecting the damaged points and the number of damaged high-voltage lines were major factors for estimating the total restoration time. However, in general, the restoration time is highly affected by not only the above factors but also other local facility damage conditions including the roads, residential and commercial buildings. Therefore, the applicable condition for the estimation function by Shumuta (2000) is very limited. .

Our research group proposed a multi-agent based simulation system to simultaneously consider the many factors associated with the emergency restoration process for the electric power distribution equipment. Compared with different restoration strategies, it enables us to prioritize some emergency restoration processes. It can also consider not only equipment damage but also other facility damage in an object area due to large-scale natural hazards.

2.2. The Constitution of the Restoration Simulator

2.2.1 The Elements of the Restoration Simulator

In order to determine the constituent factors of the simulator, some questionnaire surveys were conducted to understand the high prioritized equipment for restoration, actual restoration plans, and existing records associated with the restoration process. On the basis of the survey, a primary model of the restoration process was proposed. The primary model was improved one by one based on the discussion with actual restorer of the electric power companies. The final model of the simulator is shown in Fig. 1. The proposed simulator consists of three computer based modules.

1. Geographical areas
2. Electric power distribution equipment
3. Agents

Each module is designed as follows:

2.2.2 Geographical Areas

The Geographical areas indicate a model territory that agents can move in. They consist of roads and geographical blocks. The geographical blocks are divided by the roads. The agents, which indicate the restorers, can move on the roads in the simulator. The roads also have some road obstacles caused by building collapses according to the simulated damaged conditions in the geographical areas. In addition, it is assumed that the moving speed of the agents on the road changes according to the road obstruction rate. To estimate the road obstruction rate, the number and installed year of the frame homes in each block are collected on the basis of census data [Statistics Bureau (2003)] and the damage rates of the frame homes are estimated as the road obstruction rates for each earthquake scenario.

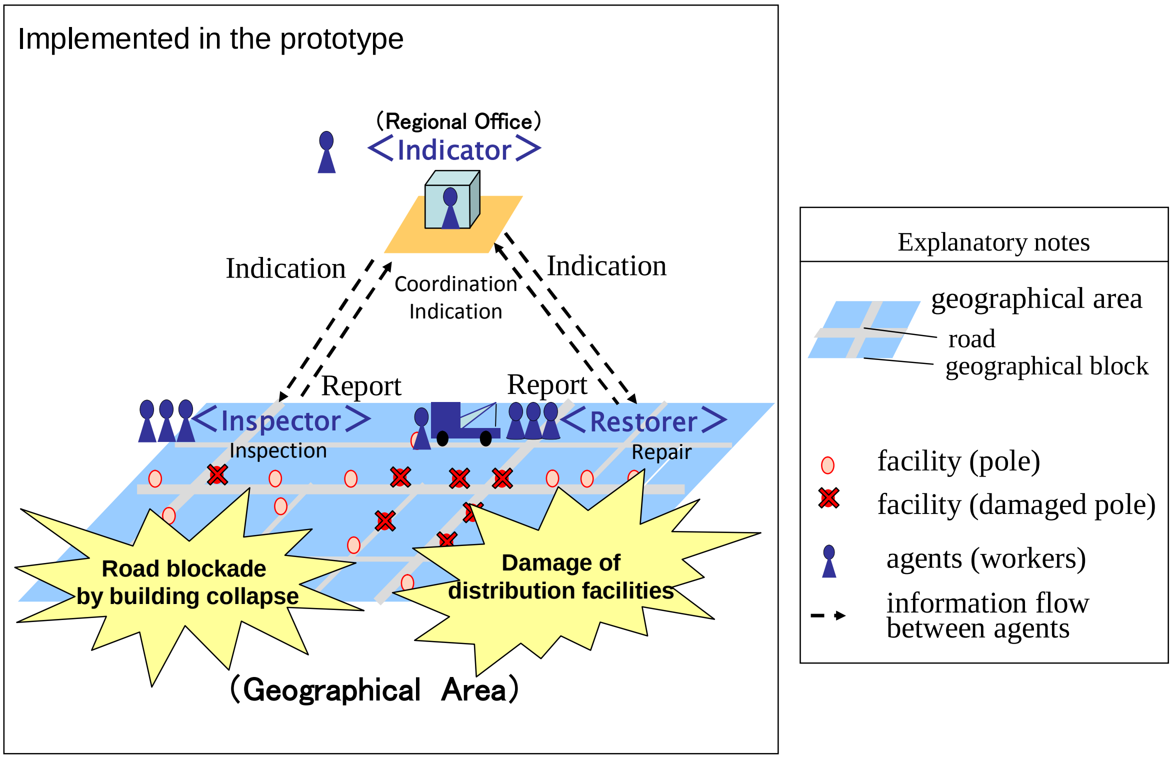

Fig. 1 Overview of the Restoration Simulator

2.2.3 Electric Power Distribution Equipment

The electric power distribution equipment consists of distribution poles, switches, transformers, and high-voltage lines, which are modeled as installed equipment in the geographical area. In an earthquake event, diversified damage occurs to this equipment. Thus, major damage modes of the equipment are assumed on the basis of the questionnaire surveys from practitioners of the electric power company. Table 1 shows their major damage modes for four pieces of equipment. For the simulator, the restoration time is estimated for each damage mode in Table 1 based on the actual records associated with existing restoration processes for existing disasters.

Table 1 Distribution Equipment and Damage Modes in the Restoration Simulator

Equipment	Damage Modes
Pole	breakage, inclination, other failure
Switch	failure
Transformer	failure
High-voltage line	disconnection, crossing

2.2.4 Agents

The agents, who indicate the restorers modeled in the simulator, consist of three types; i.e., the Indicators, Inspectors, and restorers. Table 2 shows the functions of the three agents. Each agent has the following roles:

Table 2 Agents and Their Actions

Agent	Actions of Agents(Work Items)				
Indicators	plan	indicate	−	−	−
Inspectors	move	inspect	−	stand−by	wait at office
Restorers	move	repair	check damage	stand−by	wait at office

Indicators:
Indicators are the agents who make an initial restoration plan. On the basis of the initial restoration plan, they give other function agents including the inspectors and restorers the instruction for the restoration actions. They also collect damage information from inspectors/restorers. In addition, they revise the restoration plan one by one based on the updated damage information. They estimate the work completion time of the other agents in order to revise the restoration plan.

Inspectors:
Inspectors are the agents who inspect the equipment. The inspectors go along the feeders[1] inspecting the facilities. When they detect damaged equipment, they report the damage mode to the indicators.

Restorers:
The inspectors complete the inspection and report it to the indicators. After the indicators make the decision of strategy, they order the repair plan to restorer. They head for the detected damaged points and perform the repair work at the damaged points. Note that in an actual situation, the repair work is usually conducted by several restorers working as a restoration working party. However, in the proposed simulator, one real restoration working party is treated as one restorer agent.

2.3. The Behavior of the Restoration Simulator

The behavior of the simulator is divided into three phases; initialization phase, first action phase, and restoration phase. The behavior of the restoration simulator is shown in Fig. 2.

During the initialization phase, the simulator reads various important data for execution of the simulation. After completing the initialization phase, the simulator shifts to the first action phase. In the first action phase, the simulator imitates the initial actions of the restorer just after an earthquake. The indicators make an initial restoration plan based on a manual and estimates damage condition. Then they dispatch the inspectors and restorers. The restoration phase is a main phase of this simulation. The simulator simulates the repair action of the restorers. As for the restoration phase, it continues until all the damaged equipment has been repaired.

During the restoration phases, the inspectors and restorers report the damage condition to the indicators. Thus, unknown or uncertain damage condition of the object area gradually becomes clear during the phase. The indicators direct the inspectors and restorers while revising the initial restoration plan using the updated damage information. In this way, collection of the damage information, the revision of the restoration plan, and the execution of the repairs are repeated until all the damaged equipment are repaired in the simulation.

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[1] A feeder is a large current power line from the switchboard of a transformation room of a substation to distribute electricity.

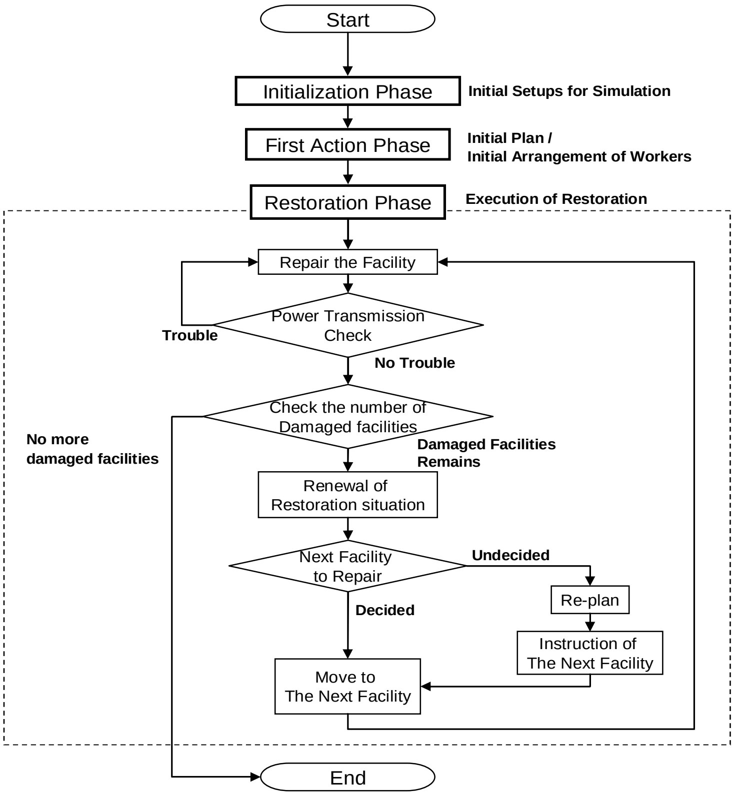

Fig. 2 The behavior of the restoration simulator.

3. THE PRELIMINARY ANALYSIS USING PROTOTYPE SIMULATOR

3.1. The Purpose And The Functions Of The Prototype

The purpose of the prototype simulator is

1) Confirmation of the feasibility of the restoration simulator,
2) Collecting opinion from the on-site person in charge for the development of the main body of the restoration simulator, by introducing the real movement of the prototype simulator.

In the prototype, we took a simple implementation and restricted the functions compared to the full-functional restoration simulator in the following two points in order to attain the two above-mentioned objectives.

a. Planning function of the indicator

The work instruction of the indicator includes a process to determine the order and route of the repair work, taking into account the complicated on-site conditions. In order to implement the logic on a computer, we need to extract both the situation recognition and the logic of the indicator. We decided to first develop a working prototype for all the people of the electric power company who will be users of the simulator to get the image of the simulator’s behavior. We wanted an easy extraction of the logic and information about the work instructions using the questionnaire surveys from practitioners with the working image of the simulator.

b. Size of the geographical area

The geographical area of the prototype was restricted to a supply area of 4 feeders, which are connected to one bank of an imaginary substation. This objective area of the prototype is relatively small in order to follow the actions of each agent. We can easily detect the difference from actions of an actual restorer by pursuing the actions of the agents.

Other basic functions of the prototype are made as same as possible with the full-functional restoration simulator. For example, the prototype has an animated display of the restoration actions of the agents, and has a logging function of the agents' actions.

3.2. The Conditions of the Test Simulation

The test simulation was performed for the following two purposes.
1) To check that the prototype shows the reaction corresponding to the setup of a condition change,
2) To create an analysis example using the prototype for easy understanding of the actual use of the restoration simulator.

The parameters that define the cases of the test simulation are shown in Table 3. Two cases were assumed in the test simulation. One is the "standard" case that virtually imitated the present restoration process. The other is the "information support" case that will obtain information about a damage situation as well as the speed on a road with support by information technology during the restoration process.

The damage assumption of the distribution equipment by a disaster is a very difficult problem. Therefore, we did not examine damage assumptions in detail. Alternatively, we use the following two damage assumptions for the prototype,
1) **Uniform damage data**: damage to the equipment that randomly occurred in the objective geographical area
2) **Concentrated damage data**: damage to the equipment that occurred only in a particular part of the objective geographical area

We created ten sets of damage data based on two kinds of the above-mentioned damage assumptions at a time, and they were used as the simulation data. The spatial distribution of the damaged equipment differs in each data set. However, all of the numbers of the damaged equipment and its classification were made the same. Therefore, at this test simulation, the time for the physical repair operations of the equipment is the same at any trial, but the total restoration time changes because of the time requirement by the other item.

Table 3. The Parameter Setting of Each Case of the Test Simulation

Case	Setting of the Case	
Parameters	Accuracy of Inspaction*1	Supply of Road Information*2
Standard	mistake rate is 5%	not supplied
Information Support	no mistake	supplied

Standard	The case is similar to the present conditions.
Information Support	The case information service is carried out for the agent's movement during restoration.
*1:Accuracy of Inspection	The parameter which indicates whether or not an inspection has an error.
*2:Supply of Road Information	The parameter which indicates whether or not the road information is supplied.

With the combination of the situation and data, four cases occur. In the information support case, since the road information is acquired in advance, the inspectors/restorers are considered to be able to move in a shorter time compared with the standard case. Moreover, when the concentrated damage data is used, the damage part is concentrated and the migration length is short. Therefore, when these data are used, it is thought that the restoration is completed in a short time as compared with the case when the uniform damage data are used.

The number of restorer agents was changed to 4, 8, and 12 in each case for the test simulation. The time to each restoration completion was then totaled. Therefore, it means that a total of 120 simulations of 4 (case) x 10 (data) x 3 were performed. Common setups used for the test simulation are summarized in Table 4.

In addition, various data used for this test simulation are set up only for the behavior check of this prototype. Some data have not been obtained by actual data. In order to obtain reasonable results, a detailed investigation to get the correct data should be separately conducted and the data should be set up based on these results. We recognize this problem to be a future subject.

Table. 4 The Conditions of the Test Simulation

Component		Details of Settting
Geographical Area		a supply area of 4 feeders under an imaginary substaion.
Facilities		865 Poles, 596 transformers, 111 switches.
Agents	Indicator	1 .
	Inspector	4 , Maximum(when there is no road blockage) movable speed is set 4[km/h].
	Restorer	4, 8, 12, Maximum(when there is no road blockage) movable speed is set 4[km/h].
Damage of Facilities	Uniform damage	30 breaks of Pole, 8 disconnections of high-voltage line, 47 failures of transformer.
	Concentrated damage	30 breaks of Pole, 8 disconnections of high-voltage line, 47 failures of transformer.

3.3. The Results of the Test Simulation

The time of each work item in the standard case with the uniform damage data was set to 100. The ratio of the time of each item of other cases compared to the standard case with the uniform damage data is shown in Table 5-(a). Moreover, the ratio of each work item over the total working hours at each case is shown in Table 5-(b). The value of each case in Table 5 is the average of the simulations changing restorer agent number of 4, 8, and 12 in each case.

Table 5-(a) shows that an information support case with the concentrated damage data can complete the work in the shortest time. Moreover, when the influence of the data at each case is compared, it turns out that the travel time of the cases with the concentrated damage data are shorter, and work is completed in a short time as a result. According to Table 5-(b), it turns out that 20% or more of the working time of the restorers is required for movement.

Table 5. The Results of the Test Simulation

Table 5-(a) comparison of work time rate to the standard case with uniform data

Case	Data	Total	Move	Repair Work	Damage Check	Stand-by	Wait at Office
Standard	Uniform	100	100	100	100	100	100
	Concentrated	94	84	100	99	91	90
Information support	Uniform	93	79	100	93	93	98
	Concentrated	88	65	100	93	85	76

The ratio of each work item time in case of the time of each work item for the standard case with the uniform data is assumed to be 100.
Each figure is the average of all cases to which the number of groups of restorers was changed to 4, 8, and 12.

Table 5-(b) the breakdown rate of each work item

Case	Data	Total	Move	Repair Work	Damage Check	Stand-by	Wait at Office
Standard	Uniform	100	32	62	2	1	3
	Concentrated	100	29	66	2	1	3
Information support	Uniform	100	27	67	2	1	4
	Concentrated	100	24	71	2	1	3

The breakdown rate of each work item in case of the total time of each case is set to 100.
Each figure is the average of all cases to which the number of groups of restorers was changed to 4, 8, and 12.

3.4. Discussion

Though some data for the test simulation are based on a hypothetical setup, the effect on the total restoration time by the difference among the damage conditions, or by the support of road information is also reproduced in the test simulation. Based on these results, we think that the prototype is properly working as the restoration simulator. We also confirm that we have good prospects for estimating the restoration time in the emergency restoration process of the distribution equipment using the restoration simulation.

We need to care about the fact that each agent’s speed is set up as same as on foot in this setup. As for the speed of the agents, since this speed is quite slow compared with the speed of vehicles, the rate of time for the movement might seem high. Though we can expect high-speed movements by using vehicles, a road move with vehicles may be limited and the average movement speed may be slowed at the time of the disaster, such as an earthquake. It is necessary to conduct a prudent analysis to estimate the effect of the movable speed at the disaster to the total restoration time.

In order to improve the prototype to be effectively applicable for an actual analysis, we need to investigate the actual work process of the restoration in detail. It is necessary to analyze the actual data so that the accuracy of a simulation result may be as high as possible.

4. CONCLUSIONS

This paper reported the prototype of a restoration simulator of an emergency restoration process, when the damage situations of the distribution equipment during a large-scale disaster, such as an earthquake, were given. Moreover, we carried out test simulations to check whether the differences among the conditions were reflected in the difference of the simulation results, or whether operations of this prototype were correctly performed. From the result of the test simulation, the difference among conditions was reflected in the merits and demerits of the restoration time, and we confirmed that the prototype was working properly as expected.

We continue to upgrade the prototype in order to improve the accuracy of the estimated restoration time. We would like to accumulate knowledge that can support the emergency restoration processes of the electric power distribution equipment at the time of disaster through the simulations, and to contribute to speeding up the restoration processes.

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