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A GAMING MODEL OF THE HUMAN BEHAVIOR OF TAKING REFUGE IN AN EMERGENCY — A CASE STUDY OF THE COMING LARGE EARTHQUAKE IN THE TOKYO METROPOLITAN AREA

by

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ABSTRACT

The main purpose of this paper is to analyze human behavior in emergencies. Specifically we analyze the effect of information on the behavior of taking refuge in emergencies such as large earthquakes. Our goal is to determine the most effective information system for emergencies.

We adopt gaming simulation methods instead of analytical methods in our analysis of this complicated human behavior. Using gaming simulation experiments we find that there are many types of human behavior in emergencies. The particular human behavior depends on the way in which the given information is evaluated.

From this research we gain knowledge as to how we should design effective information systems for emergencies.

1. INTRODUCTION

In Japan, on September 1, 1922, there was a large earthquake, called "Kanto Dai Shinsai" ("The big disaster", hereafter, K.D.S.). This disaster meant the collapse of Tokyo, the capital of Japan. According to a recent theory, a large earthquake similar to the K.D.S. will have occurred within about sixty years of the former large earthquake.

The Japanese should be concerned with protecting themselves from the coming large earthquake. However there are few studies on this problem from the viewpoint of the social sciences. For the past few years, we have been researching this problem, one of the most important societal problems in Japan. Articles by Yasuda (7),(8),(9),(10),(11) are publications of our research written in Japanese.

In this paper, written in English for the first time, we show the features of the human behavior of taking refuge in emergencies such as the coming large earthquake in the Tokyo metropolitan area. We are concerned with the influence of information on human behavior in emergencies. Analytical methods are not effective ways to study this behavior because such behavior is too complex. Instead of analytical methods, we adopted a gaming simulation method, which is easier to use in the analysis of these kinds of complex societal problems.

There are many kinds of research in which human behavior in ordinary times is analyzed, for instance, urban games such as METRO-APEX (1),(2). Unfortunately, however, we do not know of any studies on human behavior in emergencies such as a large earthquake.

The main purpose of the present paper is to analyze the interaction between human behavior and information in emergency situations. First, we will discuss the objective of this study and the framework of the gaming simulation model. The procedure of the gaming simulation is described in the next section. We will show the main results of the simulation experiments and analyze the results from the viewpoint of the relationship between information and human behavior in an emergency. by Tversky and Kahneman (4),(5),(6). The main conclusion of this study is that human decisions are determined according to how given information is evaluated. A person's choice of a particular behavior in an emergency seems to be largely influenced by his personality. We found there exists three types of human behavior in emergencies. Last of all, we suggest directions for future research.

2. THE FRAMEWORK OF THE GAMING SIMULATION

There are many ways to model the human behavior of taking refuge in an emergency. We have chosen to use the framework of the gaming simulation model. The gaming model contains several basic elements, such as the behavioral units, the characteristics of the objective area and subareas, the delivery of information, the outcome of the action, the evaluation of the outcome etc. The structure of the gaming simulation model is described as follows.

2.1 The Behavioral Units

There are many behavioral units, or players, in the game including police departments, fire departments, the main authority for the disaster, etc. In order to simplify this study we assume that the players of the model are the only inhabitants in each area and that all other behavioral units are included in the referee group.

There are two types of inhabitants: those who reside in the area and have knowledge of the whole area, and visitors to the area, who have knowledge only about the subarea in which they are staying. The socio-economic characteristics of the players, such as location, housing type, tenure, profession, family structure, etc., are specified a priori.

After the gaming starts, only those players who enter the same subarea, or mesh, are allowed to communicate with each other.

Authorities such as police and fire departments, central and local governments, etc., are not considered as players and are therefore included in the refree group.

2.2 The Characteristics of the Objective Area and the Subareas

We take the Kohtoh ward of the Tokyo metropolitan area as the objective area of our case study. This area is considered the most dangerous one in the Tokyo metropolitan area in the event of a large earthquake.

The objective area is divided into subareas which are called meshes. A mesh consists of a 500m x 500m square. In this case study, the Kohtoh ward area is divided into 91 meshes.

The spread of fires in the subarea and the mass flow of people was obtained by using the Disaster Diffusion Computer Simulation Model, developed in Japan by our research team.

Each player cannot survey the whole area, but can survey the location and spread of fires within a circle of radius 500 meters from the centerpoint of the mesh in which he stands.

2.3 The Delivery of Information

Three kinds of information can be given to players. First, information is given to players by other players in the same subarea. Second, information is given by the mass media such as T.V. and Radio. Third, information is given by the authorities such as the fire and police departments.

In this model, information of the second and third types is diffused to players by the referee group.

The area wide information conveyed by mass media is given to all players of the objective area at the same time. Information can be exchanged only between players of the same subarea. Commands and information which are delivered to the specific subarea by the referee group are given only to the players of that subarea.

2.4 The Choice of the Action of Players

In each period , each player must choose between staying in his present mesh or moving to a neighboring mesh.

Players can move in only four possible directions; east, west, south, or north.

Each player must choose the most important reason for his action from 13 possible reasons and relay this back to the referee group.

We will now formulate the human behavior mathematically. We will use notation as follows.

x_{it}: The mesh number where player i is located at time t,

x_{ito}: The mesh number where the player i is located in the initial state at time t_o, given by the referee group a priori.

a_{it}: The action of player i at time t.

$$a_{it} = \begin{cases} 0 \text{ --- player i stays in the present mesh} \\ 1 \text{ --- player i moves to a neighboring mesh} \end{cases}$$

b_{it}: The direction in which player i moves at time t

$$b_{it} = \begin{cases} 1 \text{ --- player i moves to the east} \\ 2 \text{ --- player i moves to the west} \\ 3 \text{ --- player i moves to the south} \\ 4 \text{ --- player i moves to the north} \end{cases}$$

$b_{it} = 0$ means the player i does not move and stays in the present mesh

Then, at any time z each player i has a set of sequences of $\{x_{it}\}^{\tau}_{to}$ $\{a_{it}\}^{\tau}_{to}$ and $\{b_{it}\}^{\tau}_{to}$.

2.5 The Outcome of the Action

The possible ways of moving are determined by the referee group. The referee group gives commands such that no player can move to a mesh which is more than one-half covered by fires or in a direction where the mass flow of people from the neighboring mesh is very large (this information is obtained from the results of the Disaster Diffusion Computer Simulation Model).

Each player can find himself in one or more of the following three situations.

(1) The player is injured. He cannot move and must stay in the present mesh for one period.

(2) If the player has a family, there is a possibility he will become separated from it. In this case, if he stays in the present mesh, he can meet his family again with probability 1/2. If he moves to a neighboring mesh, he does not have a chance of meeting his family again.

(3) The player meets an injured person. If he decides to help the injured person, then he must stay in the present mesh. If he decides not to help the injured person, then he can move to a neighboring mesh.

We will use the following notation for the player's choice of action when he encounters one of the above three situations.

The information on the situations is given to the players by the referee group.

y_{it}: The situation that player i encounters at time t

$$y_{it} = \begin{cases} 1 \text{ --- player i is injured} \\ 2 \text{ --- player i loses his family} \\ 3 \text{ --- player i meets an injured person} \end{cases}$$

y_{it} = 0 means that the player i does not encounter any of the above three situations

If player i is injured, then he must stay in the present mesh, that is, $y_{it} = 1$ implies $a_{it} = 0$.

c_{it}: The i-th player's decision to look for his family or not.

$$c_{it} = \begin{cases} 0 \text{ --- player i decides not to look for his family} \\ 1 \text{ --- player i decides to look for his family} \end{cases}$$

If the player decides to look for his family, then he must move to a neighboring mesh, that is $c_{it} = 1$ implies $a_{it} = 1$. However if the player decides not to look for his family, then he does not necessarily stay in the present mesh, that is, $c_{it} = 0$ does not necessarily imply $a_{it} = 0$.

d_{it}: The decision of the i-th player to help the injured person or not.

$$d_{it} = \begin{cases} 0 \text{ --- player i decides to help the injured person} \\ 1 \text{ --- player i decides not to help the injured person} \end{cases}$$

If the player decides to help the injured person, then he must stay in the present mesh, that is, $d_{it} = 0$ implies $a_{it} = 0$.

At any time τ each player i has a set of actions $\{x_{it}\}_{to}^{\tau}$ and $\{y_{it}\}_{to}^{\tau}$ and a set of decisions $\{a_{it}\}_{to}^{\tau}$, $\{b_{it}\}_{to}^{\tau}$, $\{c_{it}\}_{to}^{\tau}$ and $\{d_{it}\}_{to}^{\tau}$.

The referee group judges whether a player can move to the mesh where he would like to move.

α_{it}: The judgement given to player i by the referee group at time t

$$\alpha_{it} = \begin{cases} 0 \text{ --- player i must stay in his present mesh} \\ 1 \text{ --- player i can move to the mesh where he would like to move.} \end{cases}$$

z_t^m: the proportion of the area covered by fires to the total area of mesh m (m = 1,2, ---, 91) at time t.

If $z_t^m > 1/2$, then the player who would like to move to mesh m cannot move and must stay in the present mesh.

u_t^{mn}: The mass flow of people from mesh n to mesh m at time t

If $u_t^{mn} > \overline{u}$, then the player i who would like to move from mesh m to mesh n cannot move and must stay in the present mesh n, where $\overline{u}$ is given a priori.

Both z_t^m and u_t^{mn} are given from the results of the Diaster Diffusion Computer Simulation Model.

If $z_t^m > 1/2$ or $u_t^{mn} > \overline{u}$, then the referee group gives the judgement that the player who would like to move to the mesh n from the present mesh m cannot move and must stay in the present mesh, that is, $\alpha_{it} = 0$.

2.6 The Evaluation of the Outcome of the Player's Action

Each player gives an evaluation of the outcome of his action in the past turn to the referee group so that the referee group can give qualitative comments from the following points of view after the gaming experiment is finished.

(1) Whether the player has survived at the end of the experiment

(2) Whether the player has reached a safe refuge place

(3) Whether the direction and timing of the movement of the player were appropriate in order to survive.

(4) Whether the player was confused by rumors or false information.

(5) Whether the player protected the lives of his family

(6) Whether the player helped an injured person

In business games it is meaningful to make quantitative indicators for evaluation such as revenues, earning per share, etc. However, it is not meaningful to make a comprehensive evaluation indicator for emergency problems.

We want to find out what the minimum essential information is so that each player can decide how to act wisely.

3. THE PROCEDURE TO IMPLEMENT THE GAMING SIMULATION

Let us describe the systems and the equipment to implement the gaming simulation experiments.

The information diffused from the referee group to the players is given by the visual media such as television. Other information is conveyed by language through speech or printed matter.

Information about the spread of fires is delivered to the players by the referee group through visual media.

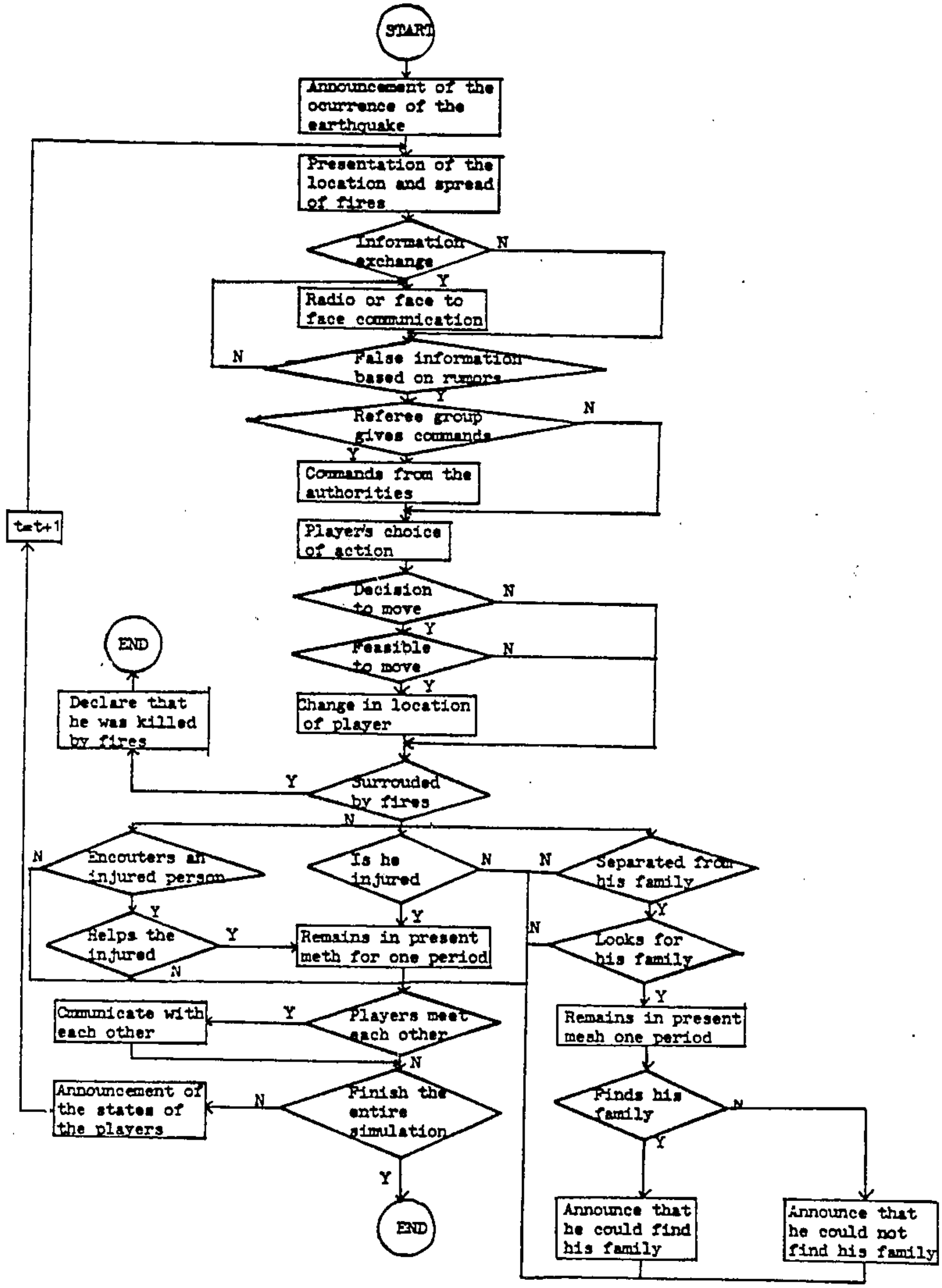
In order to achieve the above conditions, we used the SOBES (Social Behavioral Experimental Systems) in the University of Tsukuba in Japan.

The procedure used to carry out the gaming simulation experiment is given in Table 1. The flow chart of the gaming simulation is shown in Figure 1.

TABLE 1. The Procedure of the Gaming Simulation

STEP	ITEM	SENDER	RECEIVER	MEDIA	FORMAT
0	Announcement of the occurence of the earthquake	Referee group	All players	Language	Speech
1	Presentation of the location and spread of fires in the subareas	Referee group	Players of each subarea	Visual Media such as T.V., and pictures.	Visual Media
2	Information exchanges by Radio, T.V. or face to face communication	Referee group	All Players	Language	Speech
3	Commands from the authorities	Referee group	All Players	Language	Speech
4	The choice of the action	Each Player	Referee group	Language	Printed matter
5	The outcome of the action	Referee group	Each Player	Language	Printed matter

FIGURE1. The Flow Chart of the Gaming Simulation



Step 1, the announcement of the occurence of the earthquake, to step 5, the outcome of the action, corresponds to one period. This period lasts for twenty minutes in the real world; however, each period must be no more than a few minutes in the gaming simulation in order to finish the experiment quickly.

At the end of each period each player must send an account of his actions and reasoning to the referee group, and the referee group must give a letter with the action's outcome to each player.

4. RESULTS OF A GAMING SIMULATION EXPERIMENT

In a gaming simulation experiment, six graduate students of the University of Tsukuba acted as players of the game. The referee group consisted of members of the research team.

We assumed that the Tokyo metropolitan area was hit by a large earthquake similar to the last large earthquake that occured at noon on Saturday, September 1, 1922. These are the conditions of the hypothetical earthquake:

(1) The time of occurrence of the large earthquake is Sunday, March 2, 1980.

(2) Weather is Sunny; Wind direction from south to north; Wind speed 10 meters/second.

(3) Each player is in his house with his family.

The simulation experiment is divided into periods that correspond to twenty minute periods in the real world, for a total of 50 and 1/2 hours, the actual expected time that the diaster will last.

The results of the experiment are described as follows.

The paths of players 1-6 are shown in Figure 2-7, respectively. In Figure 2-7, the number of concentric circles shows the number of periods that the player stayed in the same mesh.

The path of the information, the action, the reason for the action, and the outcome of the action for each player was obtained from the experiment (not shown).

From these results we obtained the final outcome of each player shown in Table 2.

TABLE 2. The Final Outcome of Each Player

Number of the Player	The final outcome of the player
Player 1	covered by fires and killed
Player 2	surrounded by fires but has good chance of surviving
Player 3	surrounded by fires but survived
Player 4	reached a safe place
Player 5	reached an approved refuge place and survived
Player 6	far from fires but may be dangerous in the future

As shown in the Table 2, only players 4 and 5 could reach safe places. They stayed in the initial mesh in the first stages of the disaster, and then went to southern refuge places, which is the direction from which the wind comes.

Players 1 and 2 spent much time moving to the east and the west in order to look for the nearest refuge place. Player 3 moved in the direction which the wind blows in order to take refuge, and as a result was in a dangerous mesh at the final state.

Player 6 moved very little, and not until it became dangerous to stay where he was; in the future, therefore, his mesh has the potential to become dangerous.

Let us clarify the relation between decision making and information in emergencies by analyzing the results of each player's actions.

We found that there are three types of human behavior that show the relationship between the information obtained and the choice of an action.

The first type of human behavior is conservative, where people tend to neither believe other people nor to follow their advice, preferring to remain in their own subarea and move as little as possible and only when they themselves see that it is necessary.

People of the second type act immediately according to any information which they receive.

Finally, there are people who accept information, but then evaluate it according to their own knowledge of the situation and then act rationally.

The behavioral type into which a specific person falls may be caused by the person's personality.

It was often disastrous for the inhabitants to act only on information from the authorities, since this information was often incomplete and unreliable.

Moreover, we found that in the case when the player did not move, the main reason was often the need to wait for the correct information.

It is necessary to build an effective information system which can obtain correct, precise, and complete information, and then diffuse it back to the inhabitants.

From this research we can analyze the features of human behavior that imply the relationship between decision-making and information in emergencies. We can propose a more effective information system than the present information system for emergency situations.

FIGURE 2. The Path of the Player 1

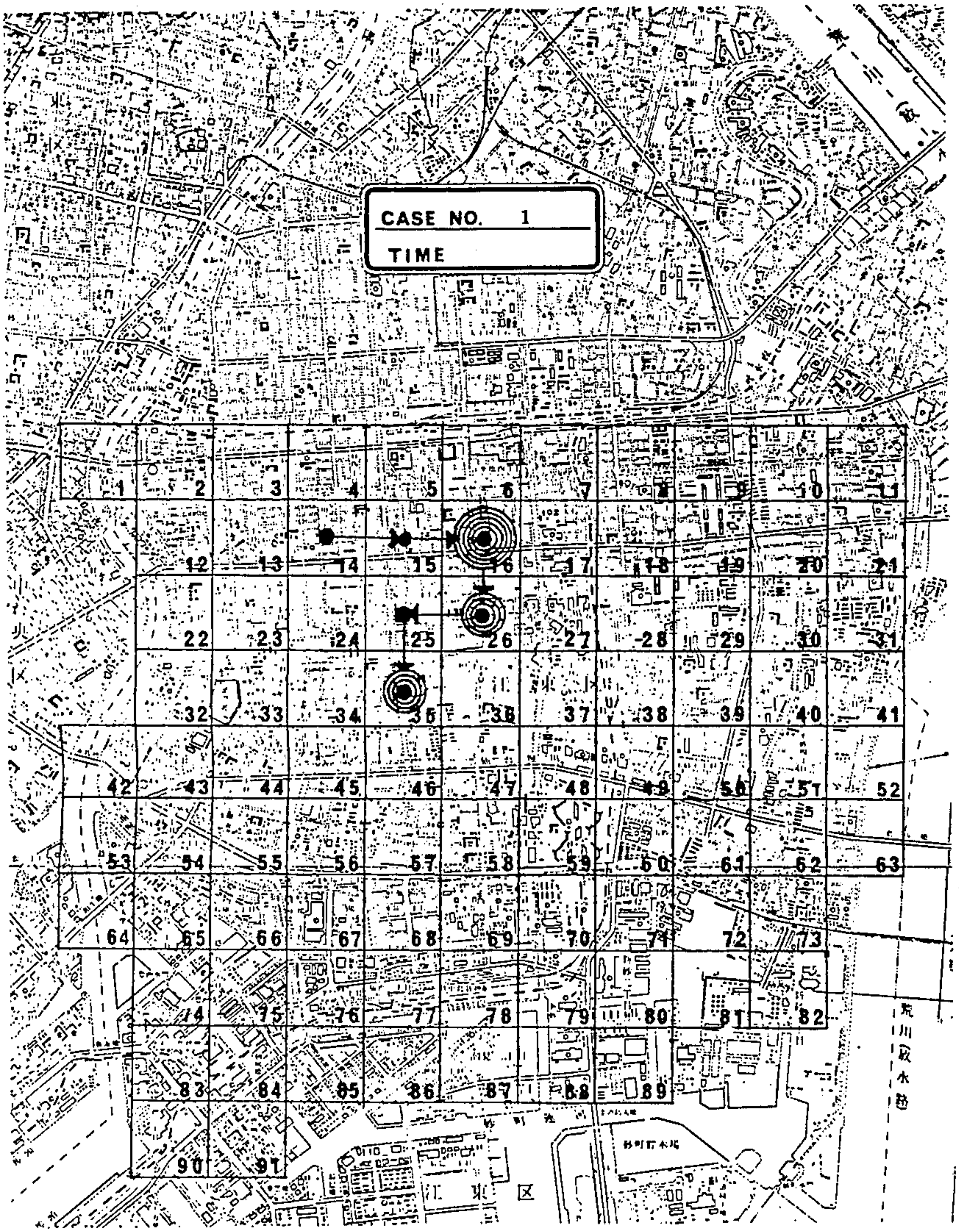


FIGURE 3. The Path of the Player 2

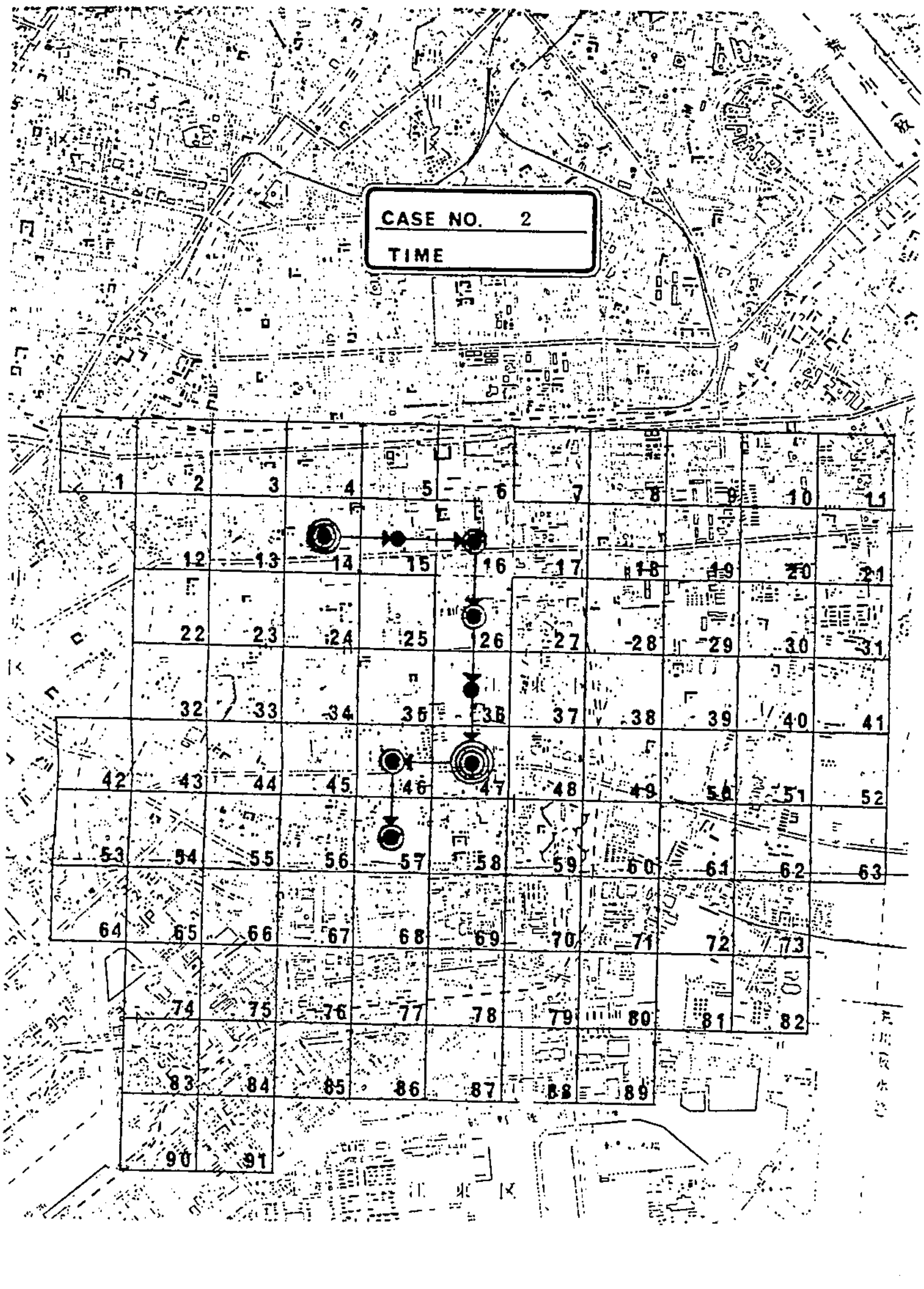


FIGURE 4. The Path of the Player 3

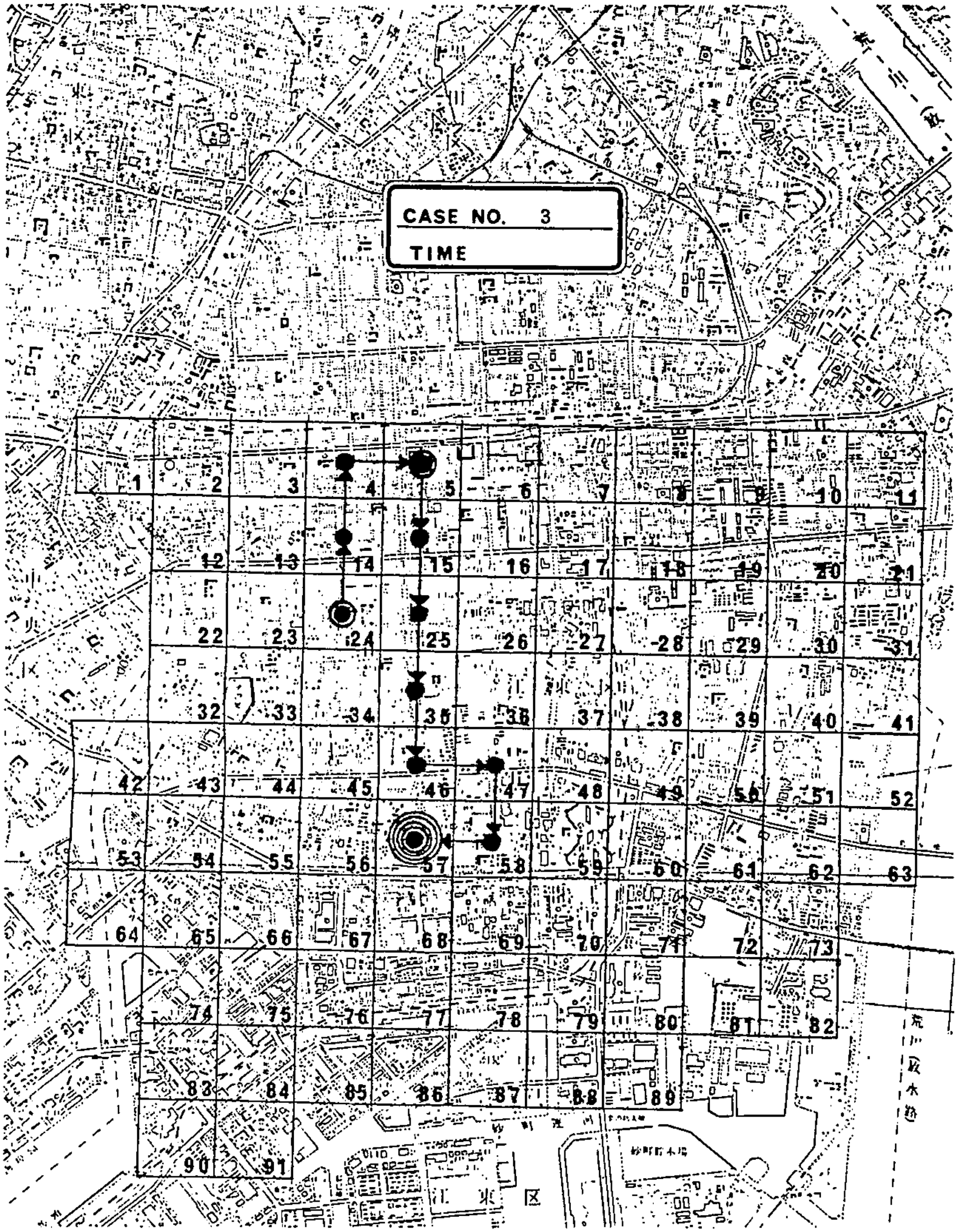


FIGURE 5. The Path of the Player 4

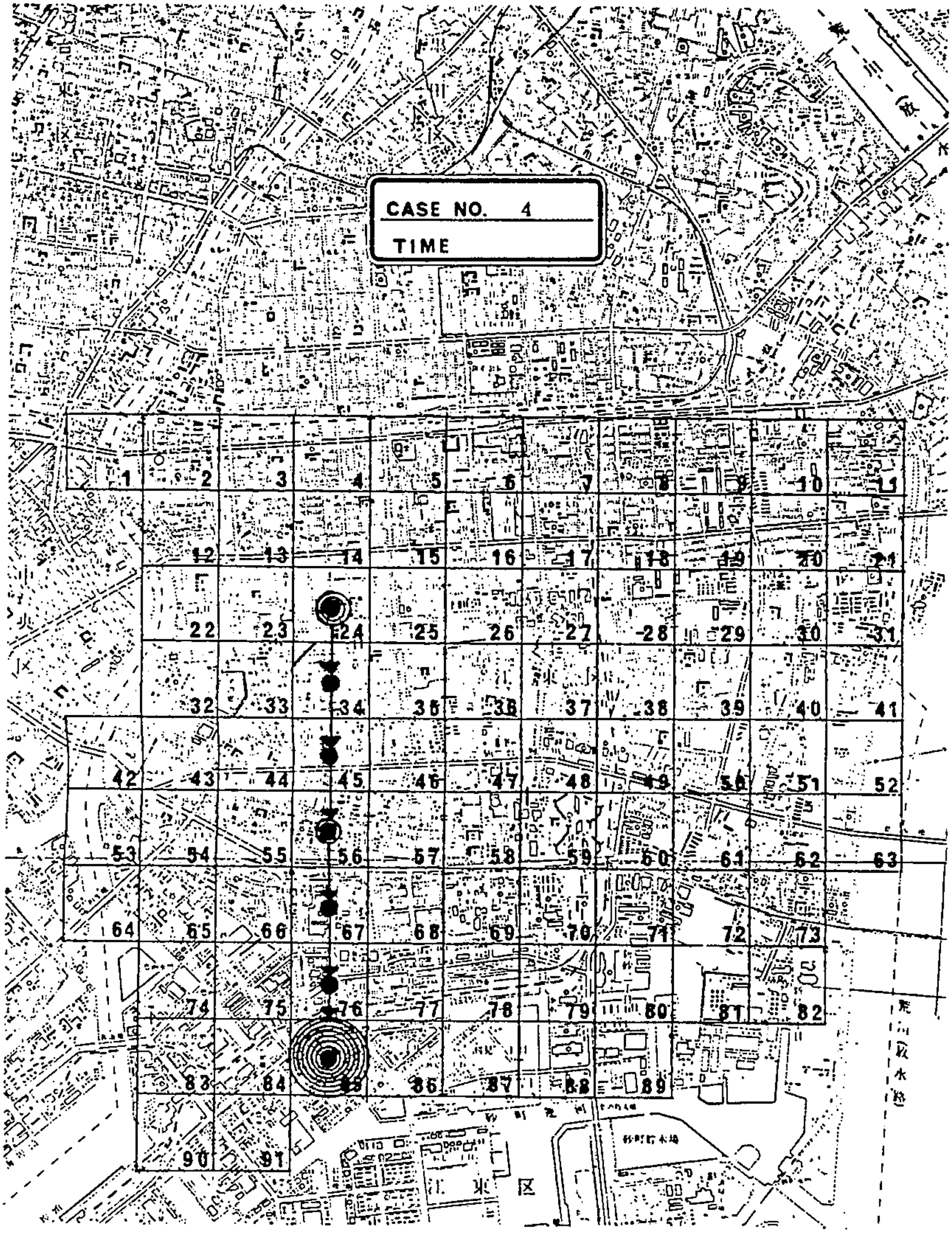


FIGURE 6. The Path of the Player 5

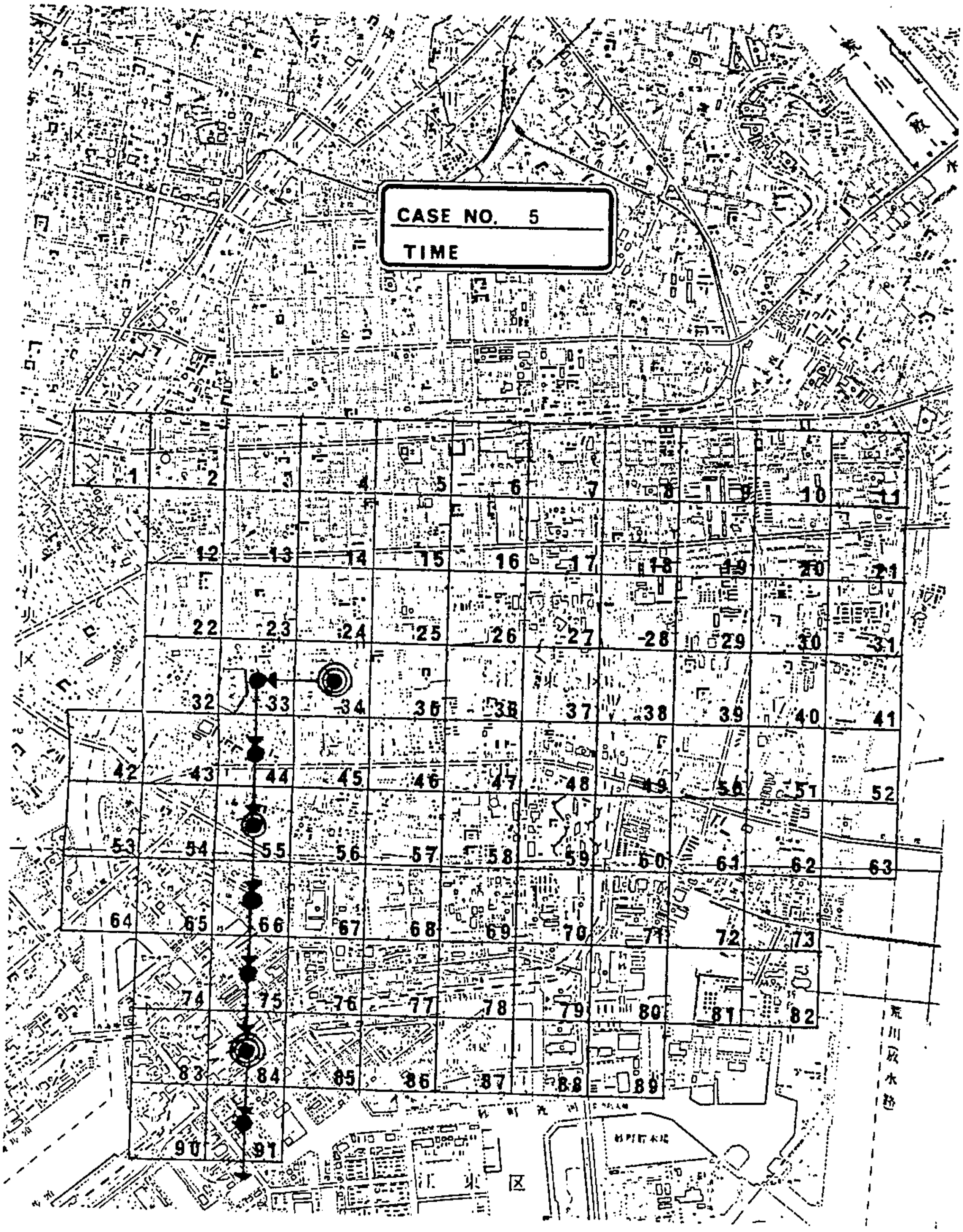
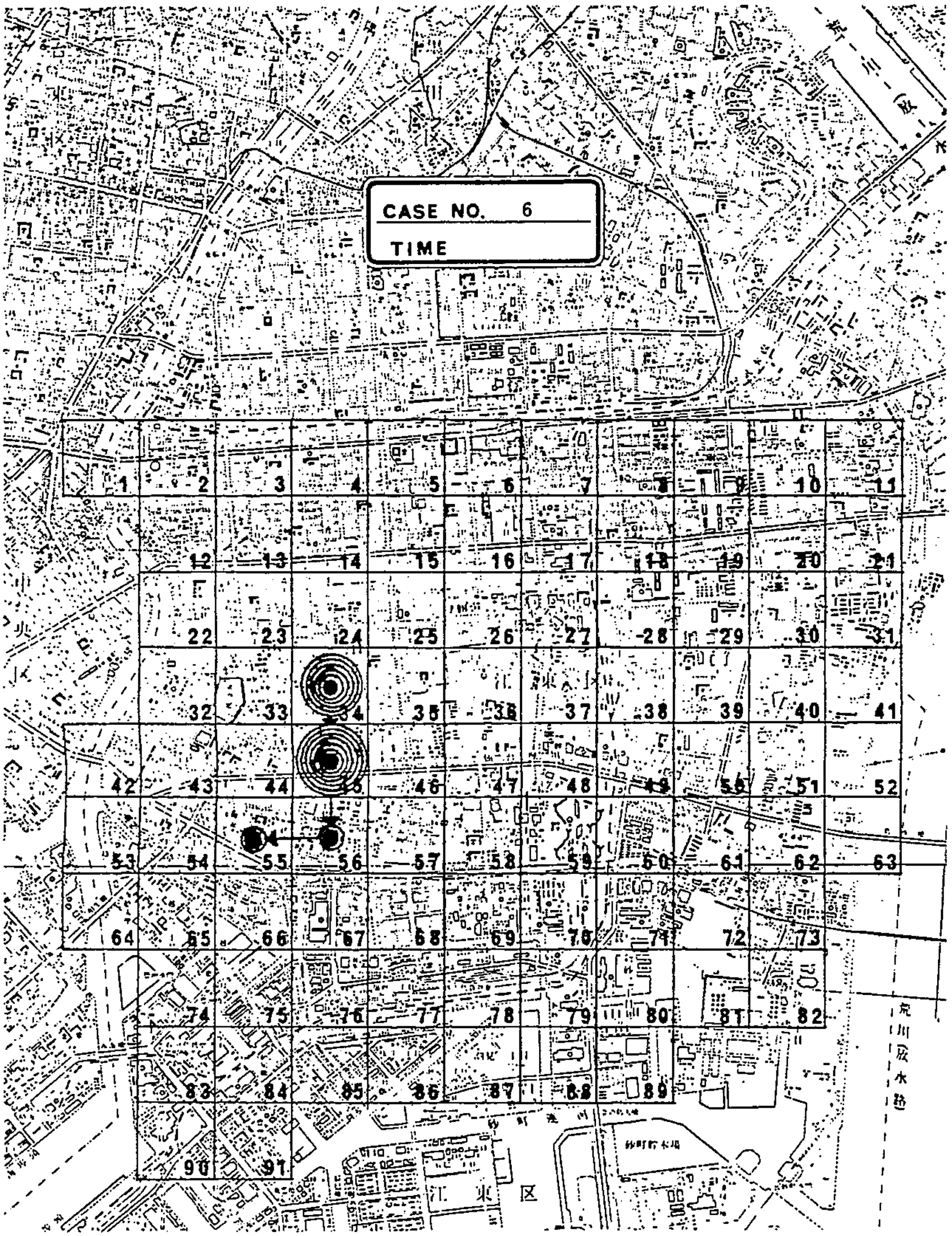


FIGURE 7. The Path of the Player 6



5. THEORETICAL CONSIDERATIONS OF MODELS OF HUMAN BEHAVIOR IN EMERGENCIES

Generally speaking, it is very difficult to formulate a theoretical model of human behavior or decision-making in emergencies. There are few studies which theoretically analyze human behavior or decision-making in unusual situation such as emergencies.

Economists have rarely treated the theory of human behavior in unusual situations in which people violate the consistency and conherence of their decisions.

Some psychologists have tried to formulate theoretical models of human behavior in unusual situations. For example, Tversky and Kahmeman (4),(5), and (6) made contributions to the theory of decision-making in situations where the requirements of consistency and coherence are violated.

There are three types of uncertainty. First is "risk", in which the states and the probability distribution of the states are known to the decision maker. Second is "uncertainty", in which the states are known but the probability distribution of the states are unknown to the decision maker. Third is "ignorance" in which both the states and the probability distribution of the states are unknown to the decision maker.

The major theory of decision-making under risk is expected utility theory. In this theory there is a general agreement that rational choices should satisfy some elementary requirements of consistency and coherence. This theory is based on a set of axioms, for example, transitivity of preferences, which provide criteria for rational decision-making. The choices of a decision-maker who conforms to these axioms can be described in terms of the utilities of various outcomes for that decision maker. The utility of a risky prospect is equal to the expected utility of its outcomes, obtained by weighting the utility by its probability. When faced with a choice, a rational decision-maker will prefer the prospect that offers the highest expected utility.

Tversky and Kahneman (5) developed a prospect theory using two concepts of hypotehtical value function and hypothetical weighting function. A hypothetical function is a function from Gains (Losses) to Value. A hypothetical weighting function is a function from a stated probability to a decision weight.

Prospect theory, a theory which is modified and extended from expected utility theory, can be used to develop a behavioral model for decision problems without consistency and coherence.

However, decision problems of human behavior in emergencies are more complicated. First, these kinds of decision problems fall into the category of ignorance. That is, almost all of the states are unknown to the decision maker. Second, the decision maker can change his decision according to new information. Third, the decision-maker's evaluation of a given piece of information depends on his personality.

It is not easy to formulate a theory of decision-making which satisfies the above requirements. In the near future, we have to attack this problem.

6. CONCLUDING REMARKS

We have researched the human behavior of taking refuge in an emergency with a case study of the coming large earthquake in the Tokyo metropolitan area. The main purpose of this paper was to analyze the relationship between information and human behavior in emergencies.

Our main conclusion is that human behavior is determined by the way i which the player (decision maker) evaluates a given piece of information. We found that there are three types of human behavior in emergencies. The type of behavior chosen by a person seems to be determined by his personality.

There is much work to be done in this field. It would be both interesting and important to develop a theoretical model analytically and to compare it with the results from gaming simulation experiments.

From the viewpoint of psychology, it is necessary to study both the analytical and gaming approaches.

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