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DESIGNING SUSTAINABLE SOCIETY SCENARIOS USING FORECASTING

Yuji Mizuno[1], Yusuke Kishita[1], Haruna Wada[1], Maki Hirosaki[1], Shinichi Fukushige[1], and Yasushi Umeda[1]
(1) Graduate School of Engineering, Osaka University, Japan

ABSTRACT

Environmental problems such as resource depletion and climate change are the most serious problems for society and industry. In order to deal with such problems, scenario writing is a useful methodology for envisioning ideal future, such as sustainable society. Although describing these scenarios requires a lot of time and a large amount of work, there is no computational support for it. In order to resolve this problem, this paper proposes a design methodology of scenarios based on forecasting approach, which explores future from current situation. In order to realize computational scenario design support, we formalize the design process as four steps; setting problems, constructing causal networks, describing storylines, and describing scenario texts. And we develop Scenario Design Support System for supporting the scenario design process on a computer. For testing the proposed methodology, we designed "Electric Vehicle Diffused Society Scenario" as a case study. In the case study, proposed process and design support methodology were useful for designing a forecasting scenario.

Keywords: sustainable society, scenario, scenario design, forecasting

1. INTRODUCTION

In order to deal with global environmental problems, such as resource depletion and climate change, sustainable development is becoming the most important mission for our society. For realizing sustainable development, many scenarios, such as SRES (Special Reports on Emissions Scenarios) [1] by IPCC (Intergovernmental Panel on Climate Change) and World Energy Outlook by IEA (International Energy Agency) [2] have been proposed. We call these scenarios "sustainable society scenarios." A scenario is a story that connects a description of specific future to present realities in a series of causal links that illustrate decisions and consequences [3].

Eco design does not only designs environmentally conscious products, but also their lifecycles as a whole. From broader point of view, envisioning sustainable society, especially manufacturing industry and usage of products under the sustainable society, is an important issue of eco design. For this purpose, designing scenarios is a hopeful approach.

Description of the sustainable society scenarios takes long time and requires a large amount of works. For example, Alcamo pointed out that his Story and Simulation approach [4] is a costly and time-consuming approach. However, computational support methodologies for sustainable society scenario description have not been proposed.

The authors have been proposing Sustainable Society Scenario (3S) Simulator to support designing, understanding, and archiving the sustainable society scenarios [5] [6]. Many types of users, such as policy makers, enterprise strategists, and scenario writers are expected for 3S Simulator [5]. This paper proposes a computational support methodology of sustainable society scenario design as a part of 3S Simulator.

Description processes of sustainable society scenarios are grouped into two types; namely, forecasting and backcasting. We call sustainable society scenarios designed through forecasting and backcasting processes forecasting scenarios and backcasting scenarios respectively. Forecasting explores several future visions from the current situation. Forecasting fits to usual way of thinking about future situation. Backcasting is proposed by Robinson [7], which at first set the ideal future vision and then going backwards to the present to find the pathways to realize the ideal future. Backcasting is difficult but can be useful process for describing sustainable society scenarios, because the sustainable society is distant from the current society. In these two types of processes, this paper focuses on a design methodology of forecasting scenarios.

2. DESIGNING SUSITAINABLE SOCIETY SCENARIOS

2.1. Existing Scenario Description Methodology

For describing scenarios, many methodologies have been proposed. Alcamo's Story and Simulation (SAS) approach [4] employs qualitative descriptions and quantitative simulations for describing scenarios. And its process is iterative and participative. Scenario Development and Analysis by Jäger [8] is an updated methodology of SAS. In order to describe a scenario systematically, this methodology formalizes the description process into the following four steps; (1) clarifying the purpose and structure of the scenario exercise, (2) laying the foundation for the scenario, (3) developing and testing the scenario, and (4) communication and outreach. Ward and Shriefer [9] proposed a methodology to describe a scenario as a systems dynamics model, which is a kind of causal network model.

As mentioned in section 1, scenario description, both forecasting and backcasting, takes a long time and requires a lot of work, because scenarios require collecting and organizing plenty of information and several times of revision to make scenarios consistent. In spite of this problem, there is no computational support for scenario description in existing methodologies. There are three difficulties for realizing computational scenario description support. Firstly, there is no methodology and environment for conducting scenario description process as a whole on computers. Secondly, scenarios are usually described in the text format so their logical structures are not clarified and not computer-readable. Thirdly, there is no computer-readable format for expressing medieval state of scenario description. These two problems about scenario expression make difficulties in understanding and reviewing scenarios rationally. Therefore, this study proposes a computational support methodology for designing forecasting scenarios, by dealing with these three problems.

2.2. Requirements for Forecasting Scenario Design

In this study, based on the general design process model [10], we define a design process for sustainable society scenarios as an iterative process consists of the following four steps:

1. Problem setting of the scenario
2. Describing the scenario
3. Reviewing the scenario
4. Feedback the review result

We identify the following four requirements for computational support of forecasting scenario design:

1. Constructing clear insights into the current situation of scenarios' object worlds before describing scenario texts, in order to describe consistent forecasting scenarios.
2. Collecting plenty of information related to the theme of the scenario, because sustainable development is related to many aspects of society.
3. Describing several sub scenarios, each of which indicates specific future, for tackling with uncertain future situations.
4. Clarifying the logical structures of scenarios for enabling us to rationally understand and review scenarios.

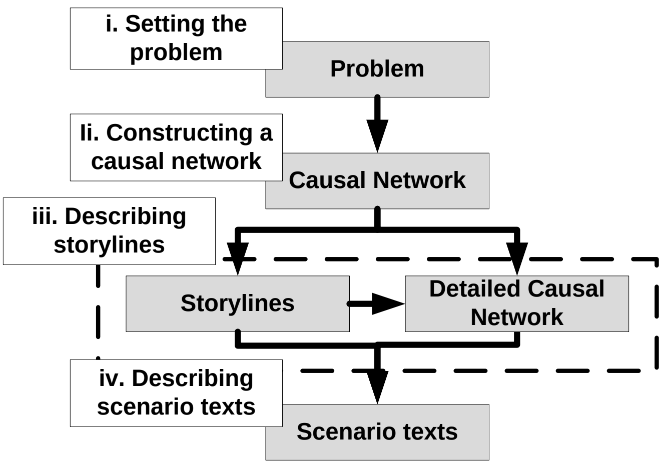

Figure 1 Design process of forecasting scenarios

3. FORECASTING SCENARIO DESIGN METHODOLOGY

3.1. Approach

In order to propose the forecasting scenario design methodology, we take the following two approaches to meet the requirements identified in section 2.2;

1. Formalizing the design process into the four steps shown in Figure 1, in order to enable the scenario designer making clear insights and then describing scenario texts.
2. Represent a scenario using Structural Scenario Description method [6] for clarifying logical structures of the scenario.

3.2. Model of Scenario Design Process

As a result of our preliminary study, we found out that it is difficult to describe scenario texts directly after problem setting. Rather, our scenario design process supports a scenario designer in detailing the scenario gradually. For this purpose, two steps, *i.e.* "constructing a causal network" and "describing storylines", are added into our design process between the "setting the problem" and "describing scenario texts" (see Figure 1).

Causal network is used for clarifying the current situation of the scenario's object world. It supports the scenario designer to understand, analyze, and communicate about how changes of elements have impact on the whole object world. In this method we use two kinds of causal networks in terms of abstraction level. The causal network constructed at first is detailed to fit to each storyline; in other words, each storyline has its own causal network. We call the former causal network and storyline's causal network as a rough causal network and a detailed causal network, respectively.

Forecasting explores several future visions from the current. We defined the second additional constituent, storyline, as critical hypotheses for a sub scenario. A storyline indicates the outline of a specific future description by describing the direction of change from the current situation to the future. In this methodology, storylines are derived from causal network by picking up key drivers, which are uncertain elements have high impacts on the future states of the scenario's object world.

Scenario texts in this methodology are grouped into sub scenarios, each of which represents a transition from the current situation to a future image. A sub scenario's critical hypotheses are described in a storyline and each description in a sub scenario represents situations of elements in the storyline's detailed causal network, namely, scenario texts correspond to causal networks.

The detail of each step is discussed in section 3.4.

3.3. Structural Scenario Description Method

Structural Scenario Description Method is a method for describing logical structure of scenarios clearly on computers [5] [6]. A scenario described with this method is named "a structured scenario." In order to comprehend a scenario from the macroscopic and microscopic viewpoints, a structured scenario consists of the following four levels:

1. Scenario Level: expresses the relations among sub scenarios
2. Expression Level: expresses the relations among clauses in a sub scenario
3. Word Level: expresses the relations among words and phrases in a sub scenario
4. Data Level: expresses relations between the scenario and simulation conducted for the scenario

In this methodology, we extend Scenario Structural Description Method for forecasting scenario design. Three constituents, *i.e.* problem, causal networks, and storylines are added to the method. They are defined for representing the result of steps i, ii, and iii in Figure 1.

In these four levels, Scenario, Expression, and Data Levels are defined in [6]. In our method, these three levels are used for representing scenario texts.

Word Level is used for expressing causal networks. Nodes in Word Level express elements of the scenario's object world and links express causal relations between two nodes (see Table 1). The types of links are defined according to the polarity of causal relation. "Positive (A,B)" means that when the state of node A increases the state of node B also increases. "Negative (A,B)" means reversed causal relation and "related (A,B)" has no or un known polarity. Each node contain additional information to support design team; "category" for grouping nodes and "impact" and "uncertainty" for supporting to select key drivers (see section 3.4). Each link has "weight" to evaluate "impact" of each node. In addition, we define a new kind of link, "deploy" link between Word and Expression Levels for

expressing derivation of scenario texts from the detailed causal network in step iv in Figure 1 (see Table 2).
For problem settings, we determine the items shown in Table 3 to classify design teams' ideas. These items are intended for the scenario designer to clarify what to write in the scenario.
Storylines are represented by three constituents; key drivers, names, and contents. Key drivers are selected from the rough causal network. Each storyline has name and contents and they are described by combining the situations of key drivers, how they changes into the futures. The name of a storyline is same as the name of corresponding sub scenario. Contents of storylines consist of the situations of key drivers and nodes related to them (see Table 4) and they are transformed into the descriptions in the scenario texts and used as the starting point to describe sub scenarios.

3.4. Design Process of Forecasting Scenarios

As mentioned in section 3.2, following four steps are set in the design process of forecasting scenarios

i. Setting the problem

In this step, a scenario design team identifies motivation and objectives for designing a scenario as problem setting. The team set the problem through brainstorming and classifying their ideas into the items shown in Table 3.

i. Constructing a causal network

In step ii, the team constructs a causal network as an expression of the current situation of the object world in the scenario. The team brainstorms about the elements included in the object world and then connecting them with causal links. In this methodology, the causal network supports the team in three ways, *i.e.* clarifying common understanding about the object world of the scenario, communicating about it among members, and working as a guide to describe storylines and scenario texts.

Table 1 Types of nodes and links in Word Level

Type		Definition
Node	element	A constituent of the object world of the scenario.
Link	positive (*A*,*B*)	Node *A* causes a positive (+) effect on node *B*.
	negative (*A*,*B*)	Node *A* causes a negative (-) effect on node *B*.
	related (*A*,*B*)	Node *A* causes an effect on node *B*, where the polarity is undetermined.

Table 2 A type of link between Expression and Word Levels

Type	Definition
deploy (*A*,*B*)	Node *A* (Word level node, i.e., a node of a causal network) is deployed to a description of node *B* (Expression Level node).

Table 3 Items of problem setting

Type		Definition
Title		Title of the scenario, e.g. EV (Electric Vehicle) Diffused Society Scenario
Objective		Objective for describing the scenario, e.g. To discuss change of automotive industry. To calculate CO2 emissions when EV is diffused.
Background		Motivation for describing the scenario, e.g. For achieving the low carbon society, EVs will be diffused. Policy makers want to look ahead how this diffusion changes structure of automotive industry.
Time horizon	Start year	Starting year of the scenario, e.g. 2010
	End year	End year of the scenario, e.g. 2030
Region		Targeted region in the scenario, e.g. Japan
Main actors		Main stakeholders of in the scenario, e.g. Policy makers of the Japanese government
Actors		Stakeholders involved in the scenario, besides the main actor e.g. Japanese automotive companies, Japanese electric and electronics manufacturers, automotive companies in developing countries

Table 4 Constituents of storylines (example: "EV Diffused Society Scenario")

Constituent		Storylines	
Key driver		"Form of Cities"	
Name		Urban Centralization sub scenario	Compact City sub scenario
Contents	Situation of key driver	There are some metropolitan areas, in which 10 million people live.	There are many compact cities spread all around Japan, in which 300 thousand people live.
	Situation of elements related to key drivers (transportation)	In cities: public transportation Between cities and rural areas: cars and public transportation In rural area: cars and community buses	In cities: LRTs, bikes and small EVs at low speed Between cities: public transportation and cars Cars are used on park-and-ride basis

ii. Describing storylines

In this step, the team describes storylines by referring the causal network. The methodology systematically supports the team to describe storylines by identifying key drivers and elements related to them in the causal network and describing changes of these elements. Here, a key driver is an uncertain element that has high impact on the future state of the object world. For supporting to determine key drivers, we build a model for evaluating uncertainty and impact of each element. The model regards impact on the future state of object world as impact on a specific element highly related to the objective of scenario (this element is called "goal element"). Uncertainty is regarded as relative uncertainty among elements in the causal network. This evaluation is conducted as follows:

- The team picks up one element as goal element
- The team set uncertainty on each element and weight on each causal link in the causal network.
- The method calculates impact of each node to the goal element.

In this way, the team can evaluate how well the elements fit to the key drivers, which is product of uncertainty and impact. The algorithm of calculating impacts is as follows (see Figure 2):

1. In this algorithm, the impact of the goal element is determined as 1.
2. The algorithm regards each closed loop in the causal network as one node, in other words, nodes in a closed loop has the same value of impacts.
3. When n nodes (node N-1 to N-n) are related by links $L_{N-j,\,N}$ ($0 \leq j \leq n$) to node N, the impact $i_{N-j,\,N}$ transferred by $L_{N-j,\,N}$ from node N is calculated by equation (1) using the weight $w_{N-j,\,N}$ of link and the impact I_N of node N.
4. The impact of a node is defined as the sum of the impacts transferred by links connected from the node. When m nodes (node N+1 to N+m) are related by links L_{N+l} ($0 \leq l \leq m$) from node N, I_N is calculated by equation (2), using $i_{N,\,N+l}$. Step 3 and 4 are started from goal element and iterated.

$$i_{N-j,N} = I_N \times \frac{w_{N-j,N}}{\sum_{k=1}^{n} w_{N-k,N}} \tag{1}$$

$$I_N = \sum_{l=1}^{m} i_{N,N+l} \tag{2}$$

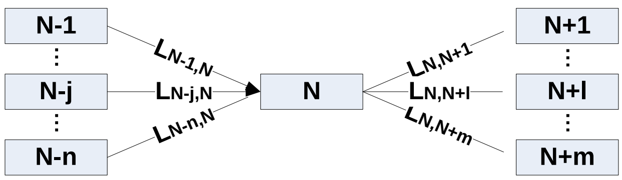

Figure 2 Calculation of impact of node N

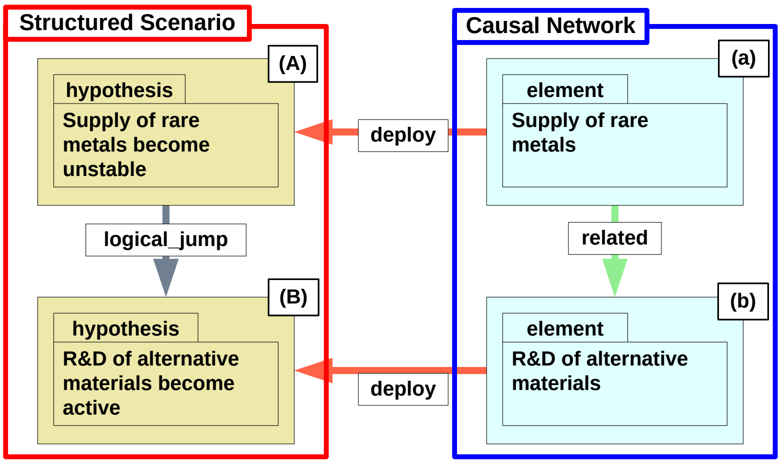

Figure 3 Deploying scenario text form causal network

The team should determine key drivers subjectively by considering broad range of interactions in the scenario's object world. The result of the evaluation can be a reason for determining key drivers. After selecting key drivers, the team briefly describes the changes of the key drivers. A storyline is made by combining these changes and situations of respective key drivers. The team determines the name of storylines and describes the contents of them by detailing the situations of the key drivers and elements related to the key drivers. After describing storylines, the team constructs detailed causal networks of storylines by detailing the rough causal network.

iii. Describing scenario texts

In this step, the team describes texts of sub scenarios. As mentioned in section 3.3, this methodology uses Scenario, Expression, Data and Word Levels of Structural Scenario Description Method for describing scenario texts. When describing a sub scenario, its related storyline, and its detailed causal network are used. The team uses descriptions of each storyline as starting point of the equivalent sub scenario. Typically, state or change of an element in the causal network is deployed to a clause in the scenario text, which is an Expression Level node in a structured scenario. Links between two Expression Level nodes are made by referring the causal links between two elements corresponding to the two Expression Level nodes.

For example, when the team describes scenario texts, nodes "(a) Supply of rare metals" and "(b) R&D of alternative materials" in the causal network (see Figure 3) and the causal link between them are used as guidelines. The change of these elements in the scenario deployed as Expression Nodes "(A) Supply of rare metals become unstable" and "(B) R&D of alternative materials become active." "Deploy" links connects these Word Nodes with Expression Nodes for expressing this deployment. Referring the "related" link between (a) and (b), (A) and (B) are connected by "logical_jump" link. The type of this Expression Link is determined by the team, in this case, the relationship between (A) and (B) is judged as logically weak.

4. SCENARIO DESIGN SUPPORT SYSTEM

For supporting forecasting scenario design process proposed in Section 3, we developed Scenario Design Support System. The structure of the system is shown in Figure 4. It is composed of five components; Scenario Design Manager, Problem Editor, Causal Network Editor, Storyline Editor, and Scenario Structural Description Support System. The scenario design team uses Problem Editor, Causal Network Editor, and Storyline Editor respectively for setting problems, constructing causal networks, and describing storylines. Scenario Structural Description Support System [6] is extended and used for describing scenario texts from storylines and causal networks. These tools exchange data to support the scenario design process. Scenario Design Manager manages these four tools and structured scenarios, which is implemented as XML documents [11].

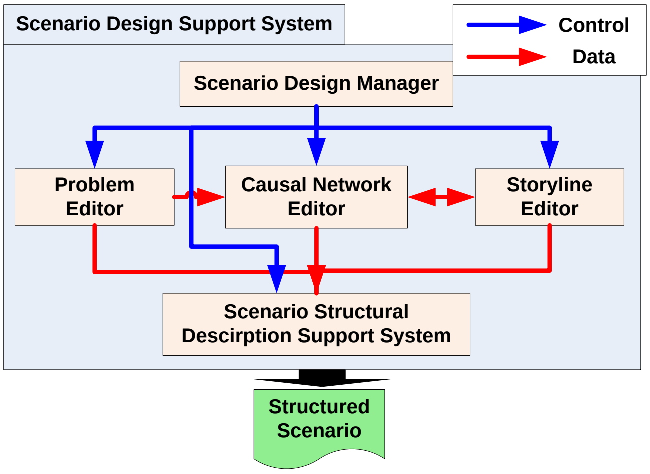

Figure 4 The structure of Scenario Design Support System

5. CASE STUDY

In order to confirm the effectiveness of this methodology, we designed "EV (Electric Vehicle) Diffused Society Scenario" as a case study. Our scenario design team consists of three students in our research group and they used Scenario Design Support System for this case study.

5.1. Design process of "EV Diffused Society Scenario"

i. Setting the problem

The problem setting of this scenario is brainstormed and determined as shown in Table 3. Normally, the main actor and other actors of the scenario are well related to, in some case involved in the scenario design team [4]. In this case, we set policy makers of the Japanese government as the main actor, because they are thought to have motivation for designing a scenario about diffusion of EVs, future situations of automotive industry, and CO2 reduction. And we picked up Japanese electric and electronics manufacturers and automotive companies in Japan and automotive manufacturers from developing and developed countries as actors, because they have great impact on the future of Japanese automotive industry.

ii. Constructing a causal network

When constructing a rough causal network with referring the problem setting, we brainstormed and picked up 20 elements related to the theme and objective of the scenario, *e.g.* "energy supply for vehicles," "share of EVs in the whole automotive market," and "automotive companies."

iii. Describing storylines

For determining key drivers, we evaluated the impact and uncertainty of each element in the rough causal network. An element "Automotive Company" was picked up as the goal element and the weight of links and uncertainty of elements were assigned based on the result of brainstorming. Then our system calculated impacts to the goal element "Automotive Company." The top five elements out of 20 elements ranked by products of their impacts and uncertainties are shown in Table 5. Referring the result of this evaluation, "Form of City" is selected as the key driver of this scenario, because it has high score and is judged to diversify the future situation of car usage and EV diffusions.
Then, we described two storylines "Urban Centralization sub scenario" and "Compact City sub scenario" by brainstorming and describing about the future situations of "Form of City" and related elements. The storylines of this scenario are shown in Table 4.
After that, the rough causal network was detailed into two detailed causal networks for two storylines. For example, in "Compact City Sub Scenario," an element "public transport" in the initial network was detailed into two elements; "train" and "bus." In this way, from 20 elements in the initial causal network, 66 elements were made in the detailed causal network of "Urban Centralization Sub Scenario" and 96 elements in that of "Compact City Sub Scenario".

Table 5 Candidates for key driver in the rough causal network

Rank	Element	Impact	Uncertainty	Product of Impact and Uncertainty
1	Global Political Cooperation	6.4	2	12.8
2	Global Economic Cooperation e.g. ETA	6.2	2	12.4
3	Energy Supply for Vehicles	1.4	5	7.0
4	Form of City	1.3	4	5.2
5	Energy price	1.4	2	2.8

iv. Describing scenario texts

For each storylines, we detailed the scenario texts as a structured scenario. Detailed causal networks are used as guides for describing scenario texts. For example, when describing scenario texts in “Compact City sub scenario,” the detailed causal network was used as shown in Figure 5. The starting point was a description in the storyline, “(A) Many cities become compact cities, which are 20 ~ 30 km dia..”, and it was expressed as an Expression Level node (A). The “deploy” link from node (A)was traced to “(a) Compact city.” From node (a), another description about the compact cities was deployed as “(B) The density in cities is high, so roads and passages in them are narrow.” Nodes (A) and (B) were linked with “logical_jump” Expression Level link, because they are deployed from the same element but the relation between them was not logical enough. In this causal network, element (a) was connect to “(b) Needs for cars” with a “negative“ link. Based on this link, “(C) Mid-sized cars are not useful in narrow roads and passages in cities” was derived from (B) and (C) with “logical_jump” links. Through these discussions about the usability of EVs in compact cities, the hypothesis about EVs used in this sub scenario, “(D) In this sub scenario, small EVs will only be used as EV” was determined.

In this way, sub scenarios were logically described with Structural Scenario Description method. Based on these qualitative descriptions, CO2 emissions from automobiles, total automobile numbers, and distribution rate of car types were evaluated. External literatures were referred for the basis of this evaluation, *e.g.* World Energy Outlook [2] was referred for determining future oil prices. After that, the future situation of automotive companies, power generation, material supply, and automobile parts and components suppliers was analyzed. The conclusions of this scenario are mentioned in Section 5.2.

5.2. Conclusions of “EV Diffused Society Scenario”

In “Urban Centralization sub scenario,” we assumed the same situation in car usage as today and dominancy of Japanese automotive companies in 2030. Current gasoline vehicles (GVs) are gradually

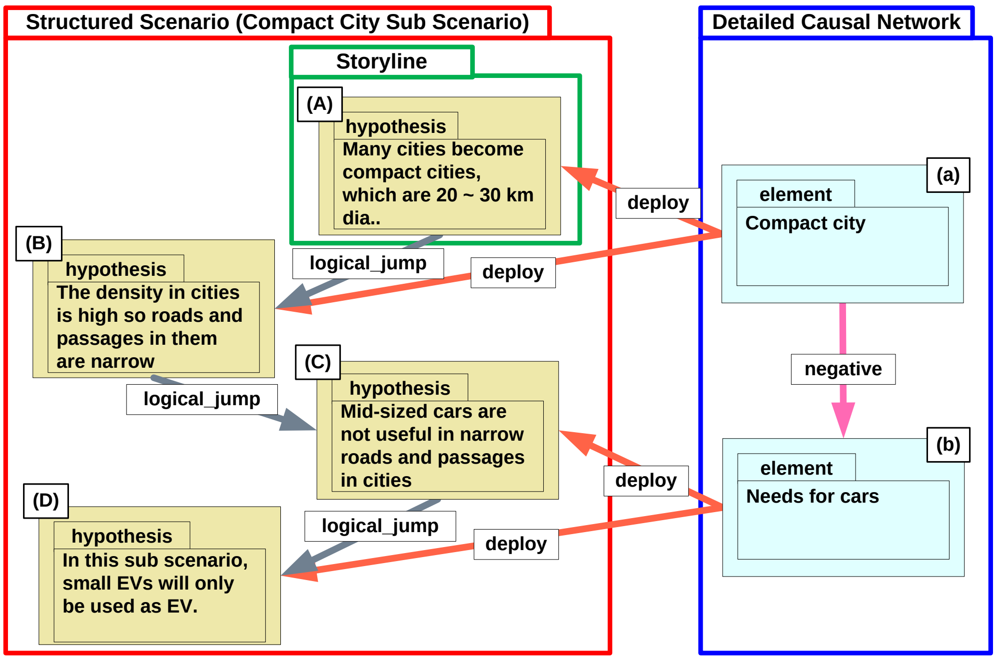

Figure 5 Describing Compact City Sub Scenario (partially)

replaced with EVs and the total number of automobiles will not change until 2030. This replacement decreases CO2 emissions from automobiles because carbon intensity of power generation is lower than that of gasoline engines in automobiles.

In “Compact City sub scenario,” we presumed very different situation about future automobile usage because of drastic change in the form of city. As discussed in iv in section 5, low speed small EVs for one or two persons will be mainly used. The total number of automobile increases in this sub scenario because mini EVs are more personalized and a family will own several EVs. Distribution of EVs is more rapid than “Urban Centralization sub scenario” and half of total automobiles in 2030 are EVs in this scenario. These small EVs are produced by many manufacturers, *i.e.* Japanese electric manufacturers and foreign automotive manufacturers. CO2 emissions from automobiles are lower than that of “Urban Centralization sub scenario.”

Based on these assumptions we analyzed and concluded the future situation as follows. Especially in “Compact City sub scenario,” Japanese automotive companies need to be more competitive and more rapidly adapt to the market change. This is the same to the automobile parts and components suppliers, because EVs and GVs have different structures. Material suppliers need to keep security about rare metals and rare earths supply. About energy industries, distribution of EVs will cause changes in electricity demands and demand patterns, so developing more robust and low-carbon power generation is important for CO2 emission reduction through EV distribution.

6. DISCUSSIONS

Using this methodology, two different future societies are envisioned in the sub scenarios of the case study, as mentioned in the previous section. “EV Diffused Society Scenario” was gradually detailed through the proposed design process, *i.e.* setting the problems, constructing a causal network, storylines, and describing scenario texts.

Especially, these two sub scenarios are made through describing different future situations of the key making and sharing understanding about the current and future situations of EV usage and diffusion. Determining this key driver is supported by the evaluation of uncertainties and impacts of elements in the causal network. This evaluation provides the design team with reasons to determine key drivers.

In this method, Structural Scenario Description Method is used for expressing medieval state of scenario design process and describing scenario texts. Four medieval states *i.e.* problem settings, causal networks, storylines, and scenario texts are related with each other in this description method. This method supports a scenario design team to describe consistent scenarios. Using Structural Scenario Description Method, the team can easily trace the rationale of descriptions in scenario texts. For example, in Figure 5, the team easily finds the rationale of hypothesis (D) by tracing “logical_jump” links and “deploy” links, the rationales of (D) are nodes (A) ~ (C) in Expression Level and elements (a) and (b) in Word Level.

When describing scenario texts, detailed causal networks are used as guides. Table 6 shows the number and rate of Expression Nodes related/not related to Word Nodes in each correspondent detailed causal networks. This can be seen as how systematically scenario text was described in the proposed methodology. In “Urban Centralization Sub Scenario,” 94 Expression Nodes out of 104 nodes (90%) are related to the Word Nodes. In “Compact City Sub Scenario,” 103 Expression Nodes out of 113 nodes (91%) are related. In both sub scenarios, non-related nodes mean external literatures used for the basis of evaluation of CO2 emissions and number of automobiles. This means scenarios can be described systematically using the causal network.

Table 6 Expression Nodes related to Word Nodes

	Nodes in Expression Level			
	“Urban Centralization sub scenario”		“Compact City sub scenario”	
Expression Nodes related to Word Nodes	94	90%	103	91%
Expression Nodes not related to Word Nodes	10	10%	10	9%
Total	104	100%	113	100%

However, this methodology cannot support designing good scenarios, *e.g.* a scenario ought to be based on deep insights into some topics and have creative and fruitful future visions. The quality of scenarios depends on the capability of the design team.

As mentioned in Section 1, forecasting scenario is based on the current situation of the object world. So scenarios contain quantum leaps from today, are difficult to design using this methodology.

7. CONCLUSIONS

In this paper, we proposed a methodology to design forecasting scenarios. We formalized the design process of forecasting scenarios into four steps; setting problems, constructing a causal network, describing storylines, and describing scenario texts. And we developed Scenario Design Support System for supporting the design process on a computer. We designed "EV Diffused Society Scenario" as a case study. In the case study, we succeeded in designing two different future visions and they are systematically described. The support system supported the design process. The future work is backcasting scenario design methodology, which set ideal futures and their requirements.

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Contact: Yuji Mizuno
Graduate School of Engineering, Osaka University
Department of Mechanical Engineering
2-1, Yamada-Oka, Suita, Osaka 565-0871, Japan
Tel & Fax: Int +81 6 6879 7262
Email: mizuno@lce.mech.eng.osaka-u.ac.jp
URL: http://www-lce.mech.eng.osaka-u.ac.jp/mizuno

Yuji is a Ph. D student in Department of Mechanical Engineering at the Graduate School of Engineering, Osaka University. His research interest is eco design, especially design methodology of sustainable society scenarios.