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Quantitative scenario-based simulation of global business models for manufacturers

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ABSTRACT

Manufacturers expanding their business globally need to understand and analyze long-term trends of technology innovation relevant to their products as well as future socio-economic development of the target markets. Qualitative scenario modeling methods can evaluate opportunities and risks of their products in a specific market. To obtain quantitative evaluation results, however, just qualitative scenario models do not suffice. This paper proposes a new method for scenario modeling and simulation that integrates numerical data from various available scenarios and analyzes the compatibility between the product and the market. A simulation case study of the dissemination of electric vehicles is illustrated.

1. Introduction

The growing global environmental concerns have expanded the market of electric vehicles (EVs), whose physical mechanisms are far less complex than those of vehicles with an internal combustion engine (ICE). This lowers the entry barrier for manufacturers with less expertize in automotive design to the industry, which threatens traditional car manufacturers.

Manufacturers of EVs have been facing difficulties in selling EVs due to several disadvantages compared with ICE vehicles, such as higher car price, expensive maintenance cost of the batteries, and insufficient cruising distances. The difficulties depend on technological, social, economic, and environmental conditions of the market, because every market has its own business models, or Product-Service Systems (PSS) [1,2]. For instance, some of the manufacturers facilitate popularization of EVs by introducing PSS (e.g., car-sharing services) and by installing charging infrastructures [3].

In designing such business models, manufacturers utilize scenarios to understand the future situation of the target market from various viewpoints. These scenarios are often offered by the governments and research institutions. Examples of scenarios include a technology roadmap [4], an outlook of population [5], of economy [6], and of energy policy [7]. They are considered useful to identify the characteristics of target markets during product development process [8].

Scenario-based simulation methods (e.g., [9]) can be used in the product development process to clarify causal relations between assumptions and consequences derived in the business model. Unfortunately since such causal relations are sometimes qualitative (e.g., roadmaps), it is difficult to numerically compute and compare influences of various business models. In addition, even if these scenarios are computable, they assume different data granularity and resolution, which make direct comparisons among them difficult when multiple scenarios are utilized.

This paper proposes a new method for scenario-based simulation of multiple business models. The method allows mixing both qualitative and quantitative scenarios and fusing simulation results that have different precisions and resolutions.

The proposed method is currently used for the simulation-based evaluation of the pervasion of EVs, including hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs), while benchmarking them against the continuous development of ICE vehicles (ICEVs). The simulation model is based on scenarios published by the governments and research institutions about demographics [5], economics [6,7], and user preferences [10]. The outputs of the study include not only the developed simulation model but also a generic method for scenario simulation development, which can deal with frequent scenario update, extension, and integration. To the best of the authors' knowledge, related work about future market introduction of EVs (e.g., [11–13]) has not addressed the need of systematic methods for scenario update, extension, and integration. The paper describes the scenario-based simulation method along with the development of the scenario.

The paper explains the proposed scenario modeling and scenario simulation in Sections 2 and 3, respectively. Section 4 summarizes and concludes the paper.

2. Scenario modeling for scenario simulation

2.1. The definition of scenario models

Scenario modeling following the proposed method starts with the collection of publically available scenarios listed in Table 1. Among them, scenarios SW1–SW6 are concerned with the

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Table 1
Property of collected scenarios.

Scenario index	Content and information source	Resolution	Coverage
SW1	Population progress [5]	Country	High
SW2	Economic development in GDP per capita [6]	Country	High
SW3	Life cycle scenario in terms of e.g., use life time [14]	Country	Low
SW4	Fuel and electricity prices [7]	Region	Low
SW5	Preferences of potential EV users [10] (regarding cruising distance, life cycle costs)	Country	Low
SW6	Sales volume of vehicles	Country	High
SW7	Performance progress of vehicles [4] and market data	Individual	Low

behavior of the markets of EVs, while scenario SW7 is concerned with the performance progress of EVs to be introduced to the markets. In the study, the sales of EVs defined in SW6 are obtained as a result of scenario simulation (see Section 3). These scenarios consist of numerical data from a specific aspect (e.g., SW1, SW2) or mathematical models derived from such numerical data (e.g., SW3). The scenarios are classified in terms of the resolution and coverage. The resolution indicates the degree of the scenario description, at which the corresponding numerical data is available. The coverage is the degree of the completeness of the description of numerical data at the given resolution. For instance, the UN's demographic information [5] provides the population of most of countries. Thus, the resolution and coverage of SW1 shown in Table 1 are *Country* and *High*. The resolution and coverage of SW5 are *Country* and *Low*, as the study about the preferences of potential users of EVs [10] focuses on several countries. In case of a scenario with low coverage, missing numerical data is complemented by the data at the same resolution in the scenario. The resolution of SW7 is set to *Individual*, because the scenario contains the publically available information of some EVs in addition to the target performance of EVs introduced in the future.

The collected and classified scenarios are analyzed for the formalization of scenario model. Each scenario model consists of *world* and *action*. Fig. 1 depicts the models of scenarios SW1–SW7 defined on the simulation environment. The world of each scenario is defined by a number of world elements, which have common parameters. These world elements are unique in terms of the value of parameters. For instance, each world element of SW1 has population and country code (Area in Fig. 1) as parameters, while all vehicle models in SW7 has such parameters as type (e.g., HEV, PHEV), model year, purchase price, and energy consumption rate. Each country and vehicle model is unique in terms of the parameter values. An action of a scenario is described by a program code that defines the initial state of the world of the corresponding scenario and its changes with respect to time. The code includes numerical data and/or mathematical formula. For instance, the action of SW1 includes the numerical data about the current population and its progress of every country. Similarly, the action of SW7 includes the progress of vehicle performance with respect to time.

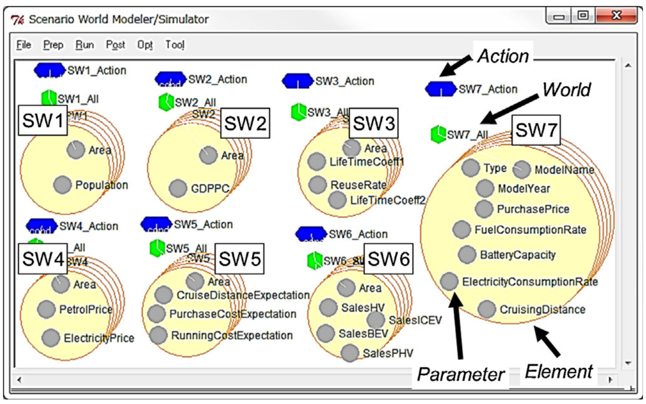

Fig. 1. Definition of scenario models.

2.2. Integration of scenario models

The scenario models SW1–SW6 shown in Section 2.1 are used to build an integrated scenario model concerned with the market behavior (SW8). The parameters of SW8 are defined by the union of the parameter sets defined in SW1–SW6. In Fig. 2, the integrated scenario model SW8 is shown alongside SW7. The actions for SW1–SW6 are inherited as actions for SW8.

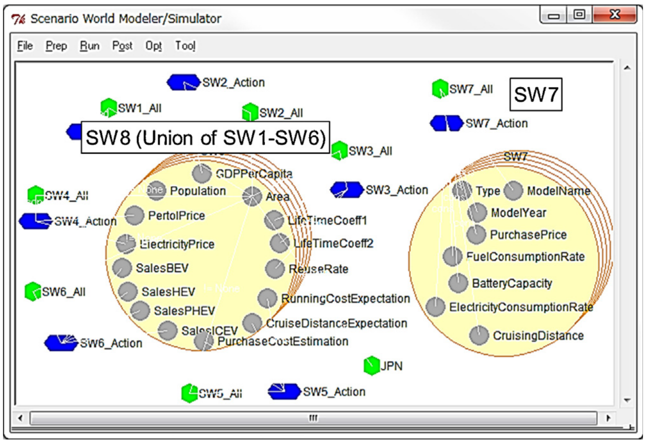

Fig. 2. The integrated scenario world model.

In order to integrate scenario models with different resolutions, parameters common in these models are identified first. In the study, the parameter *Area* is a common parameter defined for SW1–SW6. The parameter stores a country code (e.g., *JPN* and *FRA*) in SW1–3, 5, 6, while it stores a region code (e.g., *Asia* and *Europe*) in SW4. Then, the membership of country codes to region codes is defined. Once they are defined, these scenario models as well as such membership descriptions are reusable to integrate other scenario models.

Fig. 3 depicts the overview of the procedure to calculate the sales volume of vehicles. This overview shows the dependency among the parameters of the integrated scenario model SW8. The parameters framed by dotted lines are additionally defined for the calculation. The procedure starts with the calculation of the total number of owned vehicles based on SW1 and SW2. Second, the sales volume of vehicles, as a whole, is calculated based on the calculated total volume in the present and previous years and the number of the retired vehicles in the present year based on SW3. Third, the sales volume is divided with respect to the vehicle types (i.e., ICEV, HEV, PHEV, and BEV). As shown in Fig. 3, the sales volume depends on the performances of the vehicles (SW7), the economic state (SW2, SW4), and user preferences (SW5).

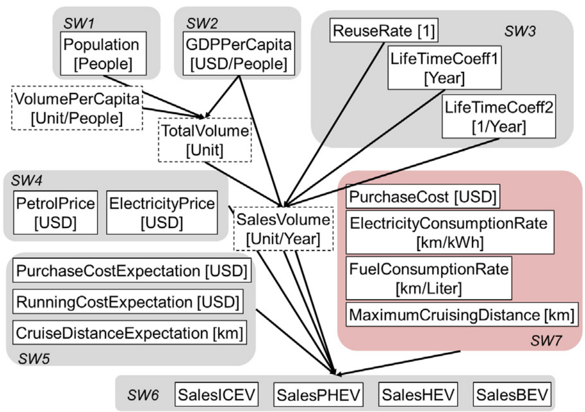

Fig. 3. Calculation procedure of the sales volume of vehicles.