10-8-2018

Framework for Building Integrative Scenarios of Autonomous Vehicle Technology Application and Impacts, Using Fuzzy Cognitive Maps (FCM)

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Citation Details
P. Zhang and A. Jetter, "A Framework for Building Integrative Scenarios of Autonomous Vehicle Technology Application and Impacts, using Fuzzy Cognitive Maps (FCM)," 2018 Portland International Conference on Management of Engineering and Technology (PICMET), Honolulu, HI, 2018, pp. 1-14.

A Framework for Building Integrative Scenarios of Autonomous Vehicle Technology Application and Impacts, Using Fuzzy Cognitive Maps (FCM)

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Abstract—**Currently, Autonomous Vehicle (AV) technology is considered a potentially life-changing new technology that brings science fiction to life and can fundamentally impact how and where people live and work. As is the case with any new technology, it is unknown how the future will unfold. Instead, ideas about the future can be captured through scenario planning and used to develop a range of plausible, alternative futures (or scenarios). These scenarios can be used for strategic decision-making in technology and urban planning, transportation and business. Because policy makers, technology developers, and end-users all need to make assumptions about future AV technology, there is a growing number of research on possible future developments, that each represent the unique perspective of the different stakeholder groups. However, an integration of these pieces of the puzzle into a holistic view of alternatives futures (i.e. scenarios) is still lacking. We propose a framework for scenario planning that leverages the insights from existing work on AV technology, and integrates the many perspective with the system-modeling technique of Fuzzy Cognitive Maps (FCM). We apply the framework in a case study. The work thus introduces a new approach to tackling the challenging problem of scenario planning for emerging technologies with many impacts. It also provides a review of the current status of AV technology.**

I. INTRODUCTION TO BACKGROUND

When making decisions about new technology applications or new product development, decision makers should systematically take into account how the technology or product may impact the world, including in new and surprising ways. By providing such a future vision, successful scenarios can challenge people's general perceptions and beliefs by defining the critical factors and trends that may impact the future [1]. Far-reaching changes as a result of technology development have happened historically and will likely also happen in the case of cutting-edge technologies. One such example is Autonomous Vehicle (AV) technology.

In the past few years, as the significant evolution of computing technology, data science, and smart devices has been changing people's lives, automotive and technology industries have made significant leaps towards bringing computerization to a human skillset – driving [2]. As one of the potential life-changers of the future, people have widely discussed AVs as experimental vehicles are hitting the road [3]. Technology companies are also stepping into the field, to get into the early market of autonomous vehicles. Furthermore, various relevant stakeholder groups, such as policymakers [2], technology decision makers, transportation planners, and regular car drivers (as potential technology users) also aim to understand more about AVs [4], to make decisions about future AV technology applications.

According to predictions made by technological experts, AV technology will bring significant changes to the on-ground transit system of modern cities. In the case of an intelligent transit system with AVs, all vehicles in operation will be in one system. People could ride with AVs on demand, rather than owning their private cars. AV could provide transportation service in urban areas for short-distance travel between their homes to other locations, or from one location to transportation centers for long-range transit service between towns and cities [5]. The transit system would be more sustainable, safe, efficient and smart than the current transit system. However, it will bring changes to people's lifestyles [4], residential preferences [8], career developments [9]. It will also impact social economics [6,7], regulations and policies [12], related industrial operation [12], environment [5, 20] and even transportation and urban planning [4,5]. As a result, many stakeholders may see fundamental impacts, not all of which are desirable. Impacts would likely be quite different, if AV adoption takes place in a different way and, for example, AVs are not owned and used by ridesharing services but by individual drivers. Today, it is not known how things will play out. However, any decision today, be it on urban or transportation planning, regulation, zoning, business development, etc. should take possible future developments into account in a systematic manner.

A systematic process must not only involve decision-makers but also stakeholders whose lives will be impacted. Scenarios must reflect the views of different subject matter experts and stakeholders on various aspects of interests (e.g. technology, urban planning) that relate to AV technology. More long-term, these different decision-making areas need to be combined into a holistic decision-making system [4], that is based on an integrated scenario of future AV technology applications that can provide insights into the various perspectives and needs of different stakeholder groups. However, to date, such integrated scenarios of AV technology are missing from the literature.

Participatory scenario development frameworks, such as [1, 10] provide a direct way to gather stakeholder groups' opinions in order to create holistic scenarios. Within these frameworks, Fuzzy Cognitive Maps (FCM) [11], are used as a tool for investigating stakeholders' and experts' cognitions and perceptions on specific research topics and model them in a semi-quantitative format. They thus serve the purpose of connecting experts and stakeholders with modelers and result, in a relatively short time, in simulation models that are used to explore multiple scenarios. Participatory, FCM-based scenarios can thus provide a methodology for the creation of integrated scenarios for AV technology. This paper explores these capabilities by developing and applying a participatory framework for the creation AV technology scenarios.

To this end, it will briefly review the current development stage of the AV technology, review existing studies on AV technology and its impacts. This results in a list of topic areas and concepts that need to be included in a scenario study on AV technology. It then proposes a framework for how to use participatory FCM modeling as a tool for building integrated scenarios for AV technology. The framework relies on subject matter experts and stakeholders to comment on the identified topics and concepts and discuss connections between them. This leads to a quantitative simulation model that is used to generate alternative future scenarios. The paper demonstrate this approach with data from an ongoing transportation planning project. The work makes two major contributions: it describes, further develops, and critically assesses the capability of FCM as a tool for participatory scenario planning. Moreover, it develops integrated scenarios for AV technology that can inform future research and decision-making processes.

The paper will have the following sections: Section 1 will be a brief review of AV technology. Section 2 will be a review of existing scenarios of AV technology from different perspectives. Section 3 will focus on a review and comparison of two existing FCM-based scenario planning frameworks and position them within the context of other system modeling approaches, such as system dynamics methods. Section 4 will be a proposed FCM-based scenario planning framework that is designed to address the specifics of AV technology, namely the complexity and potential breadth of social, technical, environmental, and economic impacts on diverse stakeholder groups. After a demonstration of the application of the proposed FCM-based scenario planning framework with a short case study, the paper will end with current findings and discussions.

II. A Brief Introduction to Autonomous Vehicle (AV) Technology

Autonomous vehicles are vehicles that can perform all driving functions with or without human drivers and are also called self-driving vehicles or, when no driver is present, driverless vehicles [12]. They are robotic cars with intelligent algorithms that not only operate the car but also adapt to real-time traffic status on the road. When future smart transit system of a smart city are envisioned, AV refers to so-called “fully autonomous vehicles” which cam perform all driving functions without human drivers and without a wheel and any manual control system [5].

According to A study report from Sandia National Laboratories the autonomous vehicle system is a combination of five functional technology areas [13]:

- **Mobility**, which describes the overall performance of the internal vehicle control system and the central platform for all kinds of vehicles.
- **Localization**, which is also called “position determination,” is usually be designed as an independent system that capturing the changing status of the vehicles. It is also always be conceived as an output function as one of the general systems for all kinds of vehicles.
- **Simple Navigation**, which is functioning as enhance the vehicle’s internal responses to the outside environmental information through gathering information from external sensors. It is usually supporting the actions of the vehicles for a single mission.
- **Mission and Task Planning**, which is representing the system behavior as a whole, without any direct links with either sensory input or controller output [13]. However, it commands on all the actions for the system.
- **Communication**, which provides the links between vehicles, the global systems, and other connected devices. It is playing an important part to make an autonomous vehicle actually “autonomous.”

The relationship among these five functional components of Autonomous Vehicles is shown in the following figure (Fig. 1) [13]:

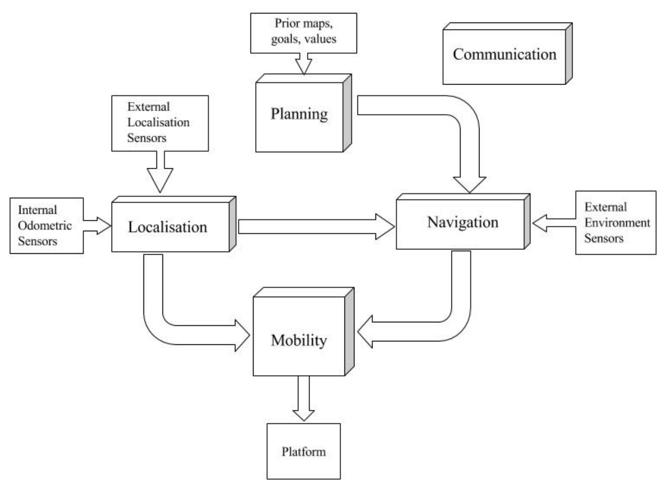

Fig. 1: Schematic of the relationship among the different functional components of an AV system [13]

Sensore enable the localization and navigation system, which both serve the purpose of improving the mobility of the vehicle. The central platform of the vehicle will still be necessary for the autonomous vehicles to build-in another intelligent system. Another critical functional component will be the communication system that makes the communication between vehicles and between technical systems within a single vehicle becoming possible.

Right now, the autonomous vehicles are still in the road-test stage, and more than 30 companies across the world are working on AV technology development, which including computing technology companies as Apple, Google and Baidu; automobile manufacturers as BMW, Ford, Tesla, Volvo and Daimler; and car sharing service companies as Uber, Car2go, and Didi from China [9]. Auto manufacturers are expected to launch autonomous vehicles into the market in a predicted timeframe of 2020 to 2025 [3]. In the U.S., several states are proceeding with AVlation, -enabling legislation, including California, Florida, Nevada, Michigan and Washinton, D.C. [2]. Autonomous vehicles are thus stepping closer to every-day car user on the road. With a mixture of expectations and doubts, people now have the general sense that AV technology will become a part of the future and this vision will lead the further technology development of AV technology.

III. Existing Raw Scenarios of AV Technology from Different Perspectives

Scenarios are descriptions of potential future situation that can help organizations prepare for possible eventualities, and make them more flexible and more innovative [23]. Scenarios provide and outline of some, particularly interesting, aspects of alternative futures, similar to scenarios in the arts, where the term refers to an overview of the plot of a dramatic work [24]. By constructing scenarios, decision-makers gain such outlines and can move forward into the future by learning from the causes of future events and circumstances [25]. The alternative futures that are described in the scenarios are usually understood as the results of a combination of trends and policies [26]. Scenario planning techniques are used by decision-makers to articulate the mental models of the future, to support better decision-making [27]. From all of this evidence, constructing scenarios for the future of autonomous vehicle technology would be helpful for promoting the decision-making and research.

As the time for AV adoption is approaching, more and more research work on the topic appears. Various of research works are reflecting the different perspectives of the different research focuses or interests. They are coming up with different raw scenarios, which are the original scenarios that only based on their research perspectives. By looking into the current raw scenarios regarding the world with autonomous vehicles on the road, they are from different perspectives, which only reflects the perceptions that from separated angles. They are like pieces of the puzzles of a holistic vision of how the future world will be like with autonomous vehicles or intelligent traffic systems. The research works also showing the evidence of significant concerns or impacts that may lead to different technology application or development decisions for autonomous vehicles. The raw scenarios from the separate view of angles could support the decision-making of partial decision-making processes. Without a whole vision, the partial decision-making actions may impact a long-term or sustainable development of AV technology because of a short-vision or specification. Therefore, applying the ideas from the raw scenarios for constructing integrated scenarios of AV technology, will be a critical need for the decision-makers and policymakers, regarding the future applications and developments of AV technology.

From the scenario planning perspective, an integrated scenario is not a simple combination of the raw scenarios but will need to build up through a participatory research process with stakeholder groups [10]. The goal of reviewing the existing raw scenarios of AV technology from different perspectives is to get the general sense of the fundamental cognitions of AV technology from various points of views, and what the potential integrated scenario may be. The sources of the narratives of the raw scenarios are from research papers, technology blogs, and reports from consulting companies. There are several themes appears from these raw scenarios, which are – people's lifestyles, economics, policies and regulations, environmental impacts, and transportation and urban planning.

A. People's Lifestyles:

- Giving equal access to the public transportation systems, in particular for the individuals who have physical disabilities, the elders, the youths, and individuals who cannot drive with other possible reasons or difficulties [5, 16].
- Creating a "third space" which is neither home nor working places, as another potential social place for the AV users [5].
- The assumption that the ownership of private cars will drop significantly, and sometimes people may be willing to share a vehicle with strangers under conditions where several unrelated people travel in the same vehicle [14].
- The car passengers can performance greater productivities while traveling in autonomous vehicles [17].
- Cars can communicate with each other by themselves [19].
- Autonomous vehicles are expected to be safer than human-operated cars [3].
- Potential changes in residential preferences:
    - People could have the freedom to pick up the housing areas so that the city would be extended [5].
    - Younger householders (<40 years old) will be further away from the downtown area for cheaper housing units and better education locations; while more elderly householders (>40 years old) will move to the downtown area for avoiding long average waiting time for traveling on the road [8].
    - Workers will have more freedom regarding resident location choices, such as they can live closer to better education facilities and their consumer infrastructure, rather than being constrained by the site of their offices [8].
- Potential Career Impacts: People who have a job with driving for a living would potentially lose their work,

especially for delivery, heavy truck drivers, bus drivers, taxi drivers, and chauffeur drivers [9].

B. Economics

- Mileage-based tax on autonomous vehicles use [15], which is suggesting that the tax collected regarding AV usage would base on the miles they traveled during a period.
- The operating costs of Avs are assumed to be lower with electric propulsion and smaller vehicles [6].
- Shared Autonomous Vehicles (SAV):
    - Driverless cars can be called on demand through mobile devices and shared with other passengers [5].
    - Early adopters would choose to begin with fixed routes or transit lines [18], to fit the consideration on the operating costs and use a simple algorithm for limited contact points with a large size of share fleets.
    - Autonomous vehicles seem to be focused on shared fleets and will focus on freight and high occupancy transport.
- Related Industrial Operation:
    - Using drones to associate with autonomous vehicles for delivery [12].
    - Automated container stacking, trailer positioning, and container delivery system at significant ports [12].
    - Safe and efficient automated mining process [12].

C. Policies and Regulations

- The liability law for autonomous vehicle accidents will need to be clarified [3].
- Policymakers step into the free market of autonomous vehicles, working with insurers, manufacturers and consumer groups to develop standards and regulations [20].
- Making policies for protecting the data ownership and the privacy terms for AV users [2, 20].
- Developing federal guidelines for autonomous vehicle certification [2].

D. Environment Impact

- Reduce the carbon footprints from city transportation system [5].
- Reduce energy use and fuel emissions [20].

E. Transportation and Urban Planning

- Silenced driving roads, with a smart and connective transportation system [5].
- Reducing congestion of the traffic, and improving the efficiency of the transportation system [5].
- Autonomous vehicles will enhance land use and park more densely so that most of the parking spaces could be replanned for other purposes [5, 20].
- The shopping facilities and public entertainment places may need to be re-planned for the convenience of autonomous vehicles [5].
- Impact roadway design and the built environment to yield urban areas, make the urban area safer, more efficient and more attractive [21].
- The urban planning that associated with autonomous vehicles would be people-friendly and human-centered [21].
- Could also build individual tunnels for driverless vehicles [22].
- The trend of the urban transportation system is increasing the mobility, where all modes of transport are intimately connected, with large-scale collective mobility, and only the "last mile" journeys are conducted individually [4].
- The transportation system will develop into a more data-driven and demand-based mass transit system of high convenience and well connected with individual automated services [4]. The city and the whole transportation system should also be able to run "autonomously" [5].

To conclude from the above review points of existing scenarios from different perspectives, a vision of the close future with autonomous vehicles may give more people more freedom to choose where to live, and more accesses to public transportation services. Share fleet model will be widely applied for transportation services, where will be more demand-driven and data-driven. The liability laws and regulations for data privacy for users will be crucial. Retail stores, bars, and theaters may change the way they serve people than now. People may never need to worry about being late, or they can even work on the autonomous vehicles on the way. There will be a more quiet city road and city freeways. The car crashes and traffic jams will be reduced. Moreover, autonomous vehicles can help people with delivery, positioning, mining, and other industrial processes.

The above narrative is a general vision for the autonomous vehicle era, without details and integration process, which may not be capable enough as a future scenario that can support the decision-making process. This general vision could be further developed into integrated scenarios for autonomous vehicles through a participatory process with stakeholder groups. These raw scenarios or the concepts that abstract from the raw scenarios would trigger the knowledge exchanges and deliveries within or between different stakeholder groups. Through the process, they maybe can answer even more questions. Would people like to share a vehicle with some unknown strangers? Would people like a silence road without any sound of vehicles? Would people accept the disappearing of retail stores along the street? Would they want a broader walking way in front their houses? There is still much information needs to be filled with the scenarios. With the contributions of various perceptions, opinions, and knowledge from stakeholders, the separated raw scenarios from different aspects would be able to be integrated into a bigger picture. To achieve the process of construct integrated scenarios for AV technology, a tool for investigating the perceptions of stakeholders, and would be able to build the integrated scenario. The following part of the paper will introduce the function of Fuzzy Cognitive Maps (FCM) as a potential tool for building up the integrated scenario and will briefly demonstrate the process.

IV. Fuzzy Cognitive Maps (FCM) Based Scenario-Building Frameworks

As mentioned in the previous session, scenarios are describing the potential future events basis on the current stage of the technology, development trends, and policies. As shown above, various of raw scenarios have been defined. Regarding the scenario planning and constructing techniques, many classical approaches could come up with final scenarios. People with different expertise and backgrounds should collaboratively build scenarios. During the scenario building, the participants would be possible to provide different mental models and can challenge each others' worldviews beyond the limitation of group thinking [1]. Since scenario planning techniques are also being a way to articulate the mental models for decision-makers or stakeholders, cognitive maps would also be a tool for approaching the scenario planning techniques [28]. Kosko invented Fuzzy Cognitive Maps (FCM) which are extension and enhancement of a cognitive map with the additional capability to model complex chains of causal relationships through weighted causal links [11]. From the literature, Fuzzy Cognitive Maps (FCM) based scenario development approach had been proposed and used for scenario planning and constructing studies [10, 27]. This paper will mainly focus on FCM based scenario development process.

Cognitive mapping captures individuals' unique perceptions [29] and views of the world, either through interviews that would further be transcribed into causal maps [30] or through self-guided mapping approaches [31]. In scenario development and strategic planning knowledge of mental maps is used to identify key issues of the scenario domain and guide the exploration of alternative futures in a group setting [32-34]. The detailed process of scenario building with cognitive maps may differ from researcher to researcher, but a similar design is shared behind the approach, which is taking a group effort that starts with the capture of individual worldviews through cognitive maps [30, 34]. Under some circumstances, individually constructed cognitive maps are integrated into a composite cognitive map that could capture relevant knowledge of all scenario planners [35]. By looking into the group mental model, the scenario planners or decision-makers would be able to detect the group interests or shared opinions with the future alternatives. Furthermore, as the people who are participating in the scenario constructing stage are the group of individuals who are likely to provide their different views of worlds, their individual opinions, components or thinking paths, would also be captured and reflected on the integrated mental map. The weighted causal connections of their different components and the other elements in the FCMs would also be kept in the integrated mental model. In this way, a more completed future picture for the research objective, as adopting AV technology in this project, would become clearer and composited. Fuzzy Cognitive Maps (FCM) could improve decision makers' ability to understand the dynamic behavior of causal cognitive maps [11, 36]. With the function of testing dynamic changes of the cognitive maps by translate scenarios as input vectors into the cognitive maps, decision-makers would get the simulation results from the map, which could improve the supporting power for the decision-making process.

From the above discussion, and according to the literature, FCM has several properties that could particularly useful for scenario planning:

1) FCMs are based on causal cognitive mapping and thus share the advantage of the accepted intuitive method [1];

2) Cause maps and the resulting FCMs can be easily modified or extended by adding new concepts and relations or changing the weights assigned to causal links [36];

3) FCM calculation is relatively straightforward and only requires standard spreadsheet [1].

With all of these properties of FCM, the FCM-based scenarios could be able to combine the best of two worlds: the openness and prospective qualities of scenario methods, and the potential for rigid analysis found in formal, simulated-based scenario approach [1]. As a semi-quantitative modeling method [10], FCM can naturally present the qualitative data as stakeholders' opinions into quantitative calculatable adjacency matrix with the given causal weights between the concepts in the maps that directly from the stakeholders [11]. Moreover, from the participatory perspective, FCM has the advantages of providing an accessible understanding method to the stakeholders, easy to train the participants, a high level of integration, a short time performance and could offer a systematical description of the mental models [10].

There are five distinct steps for general scenario planning [34, 37] as the following chart (Fig. 2):

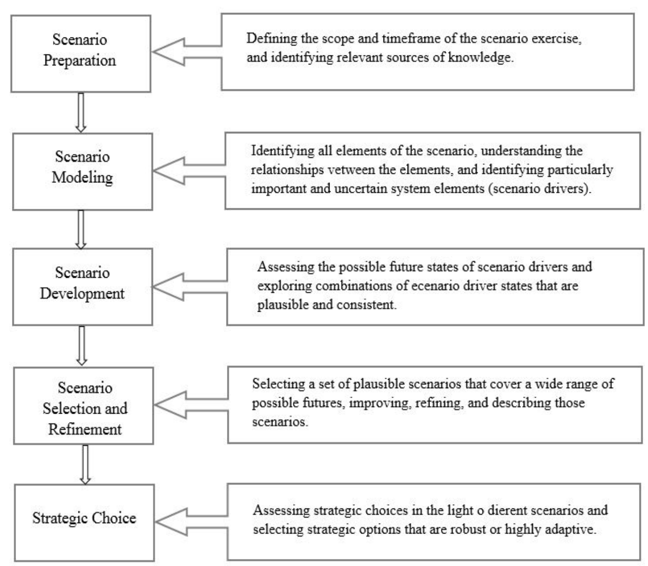

Fig. 2: The Five Distinct Steps of General Scenario Planning [34, 37]

Based on the five general steps of scenario planning, Jetter et al. [1] proposed the scenario development process by fit the six steps of FCM building in the scenario planning steps, with exploring the quantitative analytical feature of FCM. On the other hand, van Vliet et al. [10] proposed the scenario development process by adopting the characteristics and functions of FCM, with the technique of storylines and simulate (SAS) and qualitative modeling methods. Since both of these FCM-based scenario development processes were created independently, they have their process steps, functions, properties, and limitations. However, both of them proposed the potential of FCM for scenario building. Furthermore, both of the approaches showed that the participatory process, like workshops, is working well with FCM scenario construction.

Here in the following is a brief comparison of both van Vliet's scenario planning framework [10] and Jetter' framework [1], together with the general scenario constructing steps [34, 37] (Table 1):

TABLE I

General Scenario Construction Steps [34, 37]	**van Vliet's Framework [10]**	**Jetter's Framework [1]**
Scenario Preparation	**Define which factors are important** a: Write down post-its with issues (individual) b: cluster individual issues and discuss importance (group)	**Scenario Preparation** (Provides clarification of the objective, time frame, and boundaries of the scenario project.)
		Knowledge Capture (Capture the knowledge of individual experts – need to be combined with the maps of other specialists.)
Scenario Modeling	**Define which relations exist** (small groups)	**Scenario Modeling** (A modification of the "raw" cognitive maps provided by the experts.)
Scenario Development	**Define sign and strength of relationships** a: Define if relationships are positive or negative b: Define relative strength of relationships in four classes (++, +, -, --)	**Scenario Development** (Conceptual Design of FCM: Scenario planners calculate the FCM model for different input vectors that represent plausible combinations of concept states.
Scenario Selection & Refinement		**Scenario Selection & Refinement** (Detailed Design of FCM: Using a small number of different end vectors, all of which represent an inherently consistent raw scenario.)
Strategic Choice	**Presentation and discussion of FCMs**	**Strategic Decisions** (Test, interpretation, and validation of model results.)

Comparison of General Scenario Building Process [34, 37], van Vliet's FCM-based Scenario Building Approach [10], and Jetter's FCM-based Scenario Building Approach [1]

As another essential kind of collaborative modeling method, system dynamics approach also has the function to apply a systematic thinking and model complex systems and reflecting stakeholder groups' opinions [41]. It has proved to be good with supporting a strategic point of view, for matching the concerns of top-level decision-makers [41]. Moreover, also, system dynamics would show the dynamic behaviors of influential factors that interactively involved in the decision-making system [41]. The system dynamics framework can also be used for generating scenarios with their capability of reflecting physical and information flows, help with understanding the non-linear dynamics behavior of uncertain conditions [42]. Then why the choice for fulfilling the research goal is a proposed FCM-based scenario-building framework, but not a system dynamics approach? There could be a comparison table in the following (Table 2):

TABLE II

Comparison Categories	**System Dynamics Approach**	**FCM-based Scenario-building Framework**
Majority of users	Top-level decision makers [41]	Various of stakeholder groups including decision makers [10].
The scope of Decision-making Usage	Social, Economics, Environmental, Policy Making, Organization Management [41]	Objective Oriented [11]
The represent of systematic thinking	Yes [41]	Yes [11]
Visual presentation	Causal-loop Diagrams and Stock-flow Diagram [44, 45]	Fuzzy Cognitive Maps [11]
Presentation of the causal relations	Causal-loop Diagram for positive or negative cause-effect and stock-flow diagram for the degree of impact [44, 45]	Numerical causal weights directly assigned to the causal links between concepts in the maps [11].
Major Steps	1. Problem articulation; 2. Dynamic hypothesis; 3. Formulation; 4. Testing; 5. Policy formulation and evaluation [42]	1. Scenario preparation; 2. Scenario modeling; 3. Scenario development; 4. Scenario selection and refinement; 5. Strategic Choice [34, 37]
Dynamic Behaviors of the system structure	Close responding loops [41, 44, 45]	Open and flexible network structures [11]
Easy to understand the system and process	Somehow complicated [45]	Easy for stakeholders to understand [10]
Simulation Feature	Through stock-flow diagrams [42, 45]	Directly using input vectors and adjacency matrix for calculation [1, 10]
Knowledge capture feature	Yes. Could either from literature [41] or group [43].	Yes. Could gather from literature, group or individual [1, 11].
Knowledge exchange feature	Might create massive situations within a management group if individuals have different opinions [43].	Could easily bridge the modeler and stakeholders and provide the way of knowledge sharing and exchange [10].
Need of Hypothesis	Yes [42]	No [1, 10]
Link to Storyline and Scenario Narratives	Not clear	Yes [10]

Comparison of System Dynamics Approach and FCM-based Scenario Building Framework

From the table above of the comparison between system dynamics approach and the FCM-based scenario-building framework, the FCM-based framework is showing more advantage features for participatory modeling with the participating of various of stakeholders or stakeholder groups [11]. With the situations of stakeholder involvement, since the system dynamics would majorly use for creating the view of top-management teams [41], with the closing responding loops system structure [44, 45], the flexibility of the system would be limited. In this case, with an open and flexible system structure of FCM [11], it would be able to tolerant the different opinions and concepts that raised up from stakeholders and reflect all of the relevant components into the map directly. In this case, the massive situation of group modeling [43] could turn into a post-analysis process with the raw data that contributed to the maps. In this way, FCM also helps with the knowledge exchange within or between groups.

For the scenario planning needs, with the feature of the testing hypothesis [42], system dynamics would be better used for simulating limited assumptions of future scenarios that within the scope of management goals. It would work well for the social, economics, environment, and organization management fields that with a clear vision of the future and limited variables that would impact the decision outcomes. For new technology and product development, the future vision is in a relatively higher level of uncertainty. In the case of Autonomous Vehicle technology, there might be no assumptions ahead because the future of this particular technology and product is still fuzzy. The impact factors would also be in a significant number of the contributions of various stakeholders or stakeholder groups, which will make the whole system complex, yet dynamic and flexible. The goal of the new technology development scenario building will be creating a set of possible futures, with holistic thinking of all possible impacts and try to reflect the visions from all stakeholders. In this way, the creation of the scenarios will provide the decision makers a big picture of an integrated vision into the possible futures. With the flexibility of FCM, the goal would be fulfilled.

Another possible graphical modeling approach which can also support meaningful and complex causal modeling and inference in the probabilistic case, which is the influence diagram [48]. However, since the influence diagram is used explicitly in pure probabilistic situations and has limited quantitative calculation features [48], it would not be able to simulate the scenarios accurately.

Hence, FCM-based scenario planning framework would be the choice of this particular research.

V. A Proposed FCM-based Scenario-Building Process for AV Technology Application

From Table 1 above, both of the FCM-based scenario building frameworks fit the general scenario building steps but integrated with the features of FCM, with one of the same intended application domain – scenario workshop [1]. The different application domains are: For van Vliet's approach, stakeholders are actively participating in all steps and emphasis on policy scenarios. For Jetter's approach, stakeholder inputs are captured offline, before the workshop, and focus on technology/business scenarios [1]. Through the comparison of both FCM-based approaches, for building up an integrated scenario for AV technology, the framework would be a combination of both of the frameworks. Since there are already separated raw scenarios of AV technology are existed, both the storyline and the integration of the mental models of diverse stakeholders [1] will be significant. However, from the perspective of research design, from the separated raw scenarios to the integrated scenario, one of the most important step would be an integrated mental model from various of stakeholder groups, so the proposed of the FCM-based scenario building approach will majorly base on Jetter 's framework [1]. The following part of the paper will be the discussion of the proposed FCM-based scenario planning framework for AV technology with the key motivations, intended application domain, and steps of the draft framework.

The **key motivations** for this proposed FCM-based scenario planning framework are to improve the usefulness of cognitive mapping for integrated scenario building through:

- **Translate the separated raw scenarios into mental model components for AV technology**: Try to translate the scenario statement from the previous research works into possible mental model components as the beginning components of the cognitive mapping process, before the further data collections from experts and stakeholders.
- **Integration of the cognitive maps from diverse stakeholders [1]:** Try to integrate the individual maps within the same stakeholder group with all the concepts from the map building process and the connected structures, into an integrated map that could reflect the opinions of the whole stakeholder group.
- **Fuzzy Cognitive Maps scenario construction [1]:** Using the different input vectors with the combinations of different activated and inactivated components to the integrated map for the scenario testing. Therefore, different future scenarios could be constructed.

Then, **the steps of the proposed FCM-based Scenario Planning framework** would be like the followings:

- **Scenario Preparation:** Identify the separated scenarios with different perspectives of AV technology, and translate the statements of scenarios into the beginning components for stakeholders' FCMs with the scope of the study. As the statements of scenarios have been clustered, the beginning components could also be clustered. Furthermore, as the modeler, it is needed to set up for the data collection methods that would apply to the research design. The possible data collection methods could include (but not limited to) individual interviews, participatory workshops, and online surveys. A potential empty FCM with beginning components for the stakeholders' FCM construction could be shown in the following figure[1] (Fig. 3[2]):

[1] The online FCM tool comes from: www.mentalmodeler.org

[2] Color code of component clusters: Purple: Objective Component; White: People's Lifestyles; Orange: Economics Impacts; Blue: Policies and Regulations; Green: Environment Impacts; Yellow: Transit and Urban Planning.

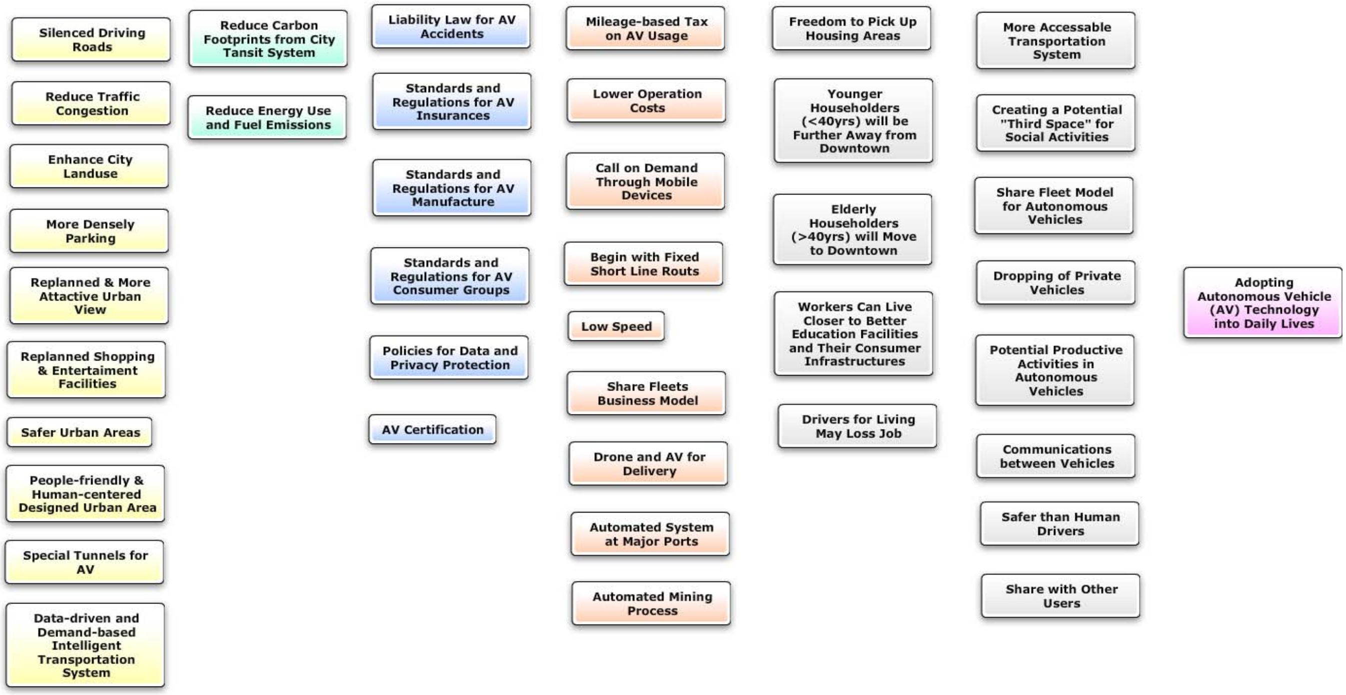

Fig. 3: A potential beginning FCM

- **Knowledge Capture:** Showing the beginning FCM to the experts and stakeholders. Based on the feature of FCM, capturing the individuals' or stakeholder group's knowledge with following questions: 1) Do all the components make sense to put in the FCMs? 2) Does there any other unshown components that they want to add into the FCMs? 3) What weighted causal connections will they make between the components as the structure of the FCMs? In this way, the individuals' or stakeholder groups' perceptions of the AV technologies would be able to collect.
- **Scenario Modeling:** Using the raw FCMs that got from the previous step, making the following processes: 1) Compare the "raw" cognitive maps from the previous step with the beginning components and other relevant components that the stakeholders may add into the FCMs. Figure out the FCMs with similar ingoing and outgoing arrows to the objective component ("Adopting Autonomous Vehicle (AV) Technology into Daily Lives"). 2) Integrate the individual FCMs with all the components from the individual maps and the average of the weighted connections between components.
- **Scenario Development**: Activating the different combinations of components in the integrated cognitive maps as input vectors to the adjacency matrix of the integrated map from the previous step. Document the stable systematic scenario testing outputs for the status of the objective component ("Adopting Autonomous Vehicles Technology into Daily Lives").
- **Scenario Selection and Refinement:** For each of the stabilized FCM scenario testing results, the combinations of the activated and inactivated components would be able to consider as the clues of the narratives of the potential scenarios. The scenario selection would need to based on the current situation and resources, to pick up the scenarios that could lead to possible future works. Usually, the number of the possible scenarios would be from 3 to 6, depending on the real decision-making needs.
- **Produce Narratives of the Possible Scenarios:** Since the nature of the possible scenarios is the supportive references for the future decision-making process, it would be essential to write the narratives of the scenarios. Using the selected combinations of the activated and inactivated cognitive maps components, with the comprehensive information to describe the scenario as stories of the vision of the AV technology adoptions to the daily lives.

With this proposed framework of the FCM-based scenario planning process, the stakeholders' opinions and cognitions regarding the topic of AV technology application would be able to be captured and reflected. For each stakeholder group, they would possibly provide similar insights based on the knowledge level of AV technology. In this way, the integrated map would be able to reflect the original thinkings from the whole stakeholder group. This would be a comprehensive vision of the alternative futures of AV technology applications from this stakeholder group. Then from the study, the integrated maps from different stakeholder groups, a holistic vision that based on all the relevant stakeholder groups would be able to be shown on the maps. Thus, integrated scenarios of the AV technology application in the future is showing.

For a final step, the whole process of the framework and the scenarios would need to be validated to see if it could serve the research goals.

V. A CASE STUDY OF SW CORRIDOR PLAN WITH AV TECHNOLOGY

This case study is a prior study as a demonstration of the proposed FCM-based scenario building framework, to see if the framework will meet the study purpose. This prior study is about the possible future scenarios for applying AV technology to a current on-going transit system improvement project that takes in place in the City of Portland, which is known as the Southwest Corridor Plan [46]. The general mission of the SW Corridor Plan is to improve the accessibility, functionality, and capability of the current and future transit system to connect the SW Portland to the other south cities [46], to enable a fully connected network that could activate all significant cities in the State of Oregon. There are possibilities that AV technology could be a part of the project. According to the "Portland Southwest Corridor Light Rail Transit Project Coordination Plan" [47], one of the specific possible ways of apply AV technology, is to use fully autonomous light rail trains along the SW Barbur Blvd. The operating company of the light rail trains is the local transit service provider TriMet, and SW Barbur Blvd. is one of the major routes of SW Corridor.

As a demonstration case study, there were four college students from Portland State University as the participants to the individual interviews as representatives from one of the stakeholder groups whose lives will be impacted with AV technology in the future. If the process would work for this sample participants, then it would be valid for broader use of other stakeholder groups.

Step 1: Scenario Preparation – Identifying scenario scope and setup for the one-on-one stakeholder interviews. In this step, the scenario scope will be within applying fully autonomous light rail trains along the SW Corridor. Some background introductions of the SW Corridor Plan and the method of Fuzzy Cognitive Maps are prepared as handouts to the participants before the interview. A background information survey was also given to each of the interviewees, as an evaluation of the degree of understanding of AV technology.

Step 2: Knowledge Capture of the Scenario Planning. This is the part when the interviewees are participating into the modeling process by making casual relations between the beginning concepts, give their causal weights to the map, and come up with their concepts from their understandings. In this stage, as the modeler, the primary task will follow the leads from the interviewees, recording their thinking and concepts, and reflect their opinions on the individual maps. To fit the prior study, another simplified empty map with beginning concepts are looking like the following figure (Fig. 4).

As one of the actions for the modeler to preparing for following scenario construction by activating or not activating concepts in the map, the concepts that provided by the interviewees' raw maps were also be categorized into different types. The types included "certainly impact factors" and "less/possible impact factors." One of the individual raw maps is like the Fig. 5 on the following page. The interviewees were able to understand and participate in the modeling process quickly.

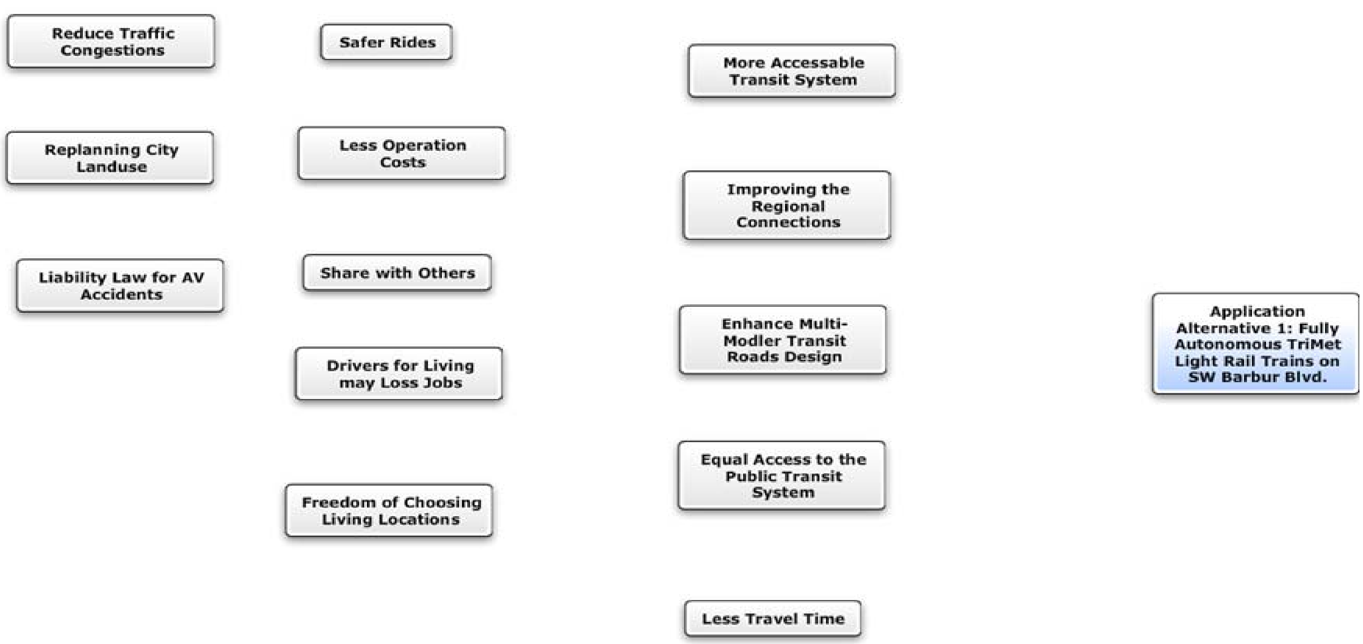

Fig. 4: A beginning FCM for the Application Scenario of Applying Fully Autonomous Light Rail Trains on SW Barbur Blvd.

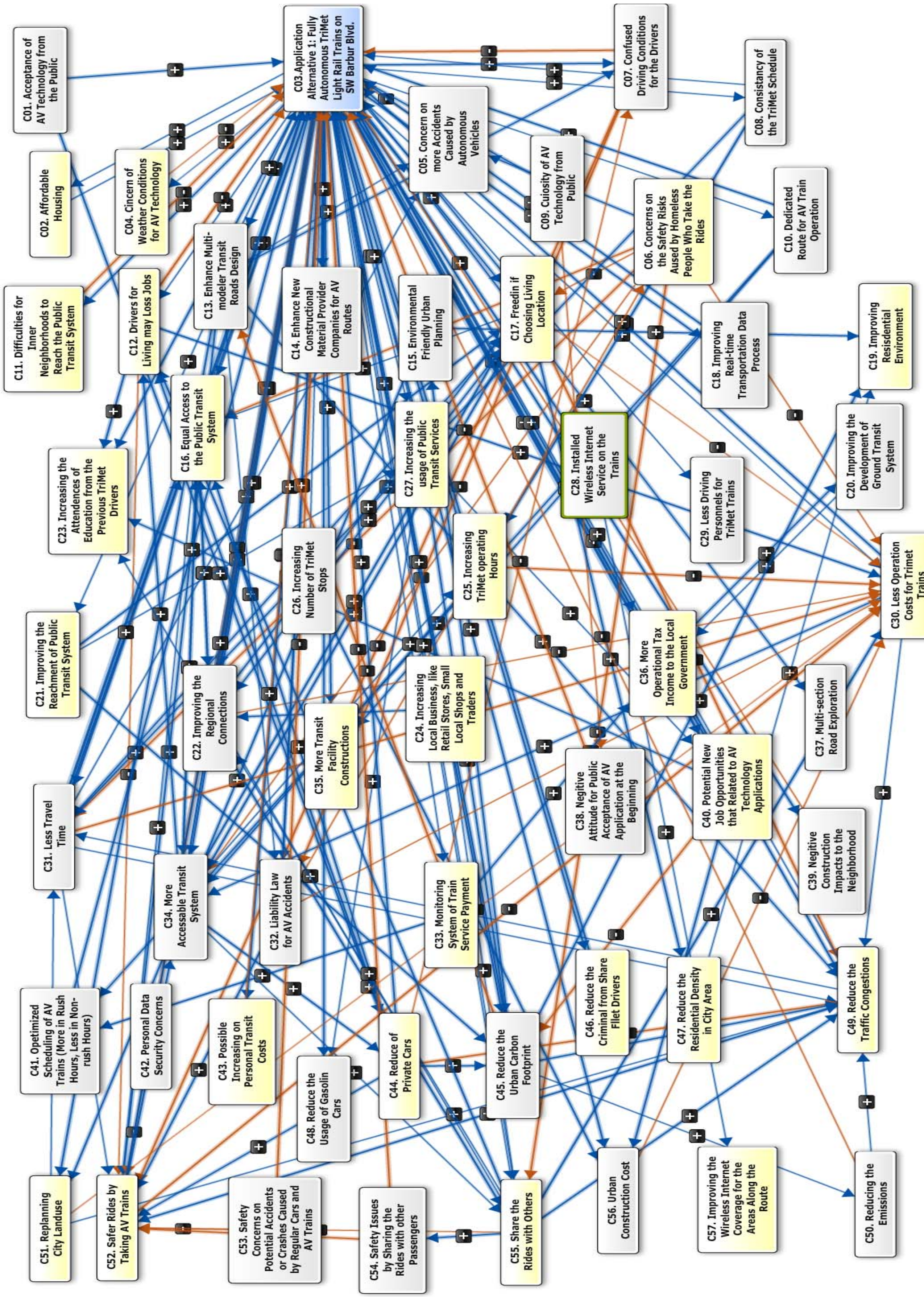

Fig. 5 The Integ

Fig. 5 Integrated Map of all the individual interviewees. The yellow color components are "Less/possible impact components", white color components are "certainly impact components", and the blue component is the objective component for the scenario building.

Name of the Impact Components	Scenario 3: Activate Several Certainly Impact Factors with the Combination of the value of -1 and +1
C01. Acceptance of AV Technology from the Public	-1
C02. Affordable Housing	Inactivate
C03. Application Alternative: Fully Autonomous TriMet Light Rail Trains on SW Barbur Blvd.	*N/A*
C04. The concern of Weather Conditions for AV Technology	Inactivate
C05. Concern for more Accidents Caused by Autonomous Vehicles	Inactivate
C06. Concerns about the Safety Risks Caused by Homeless People Who Take the Rides	Inactivate
C07. Confused Driving Conditions for the Drivers	-1
C08. The consistency of the TriMet Schedule	-1
C09. The curiosity of AV Technology from Public	-1
C10. Dedicated Route for AV Train Operation	1
C11. Difficulties for Inner Neighborhoods to Reach the Public Transit System	Inactivate
C12. Drivers for Living may Loss Jobs	Inactivate
C13. Enhance Multi-modeler Transit Roads Design	1
C14. Enhance New Constructional Material Provider Companies for AV Routes	Inactivate
C15. Environmental Friendly Urban Planning	Inactivate
C16. Equal Access to the Public Transit System	-1
C17. Freedom of Choosing Living Locations	Inactivate
C18. Improving Real-time Transportation Data Process	**1**
C19. Improving Residential Environment	Inactivate
C20. Improving the Development of Ground Transit System	**1**
C21. Improving the Reach of Public Transit System	Inactivate
C22. Improving the Regional Connections	**1**
C23. Increasing the Attendances of	Inactivate
C24. Increasing Local Business, like Retail Stores, Small Local Shops, and Traders	Inactivate
C25. Increasing TriMet Operating Hours	Inactivate
C26. Increasing Number of TriMet Stops	**1**
C27. Increasing the Usage of Public Transit Services	Inactivate
C28. Installed Wireless Internet Service on the Trains	Inactivate
C29. Less Driving Personnel from TriMet Trains	Inactivate
C30. Fewer Operation Costs for TriMet Trains	Inactivate
C31. Less Travel Time	Inactivate
C32. Liability Law for AV Accidents	Inactivate
C33. Monitoring System of Train Service Payment	Inactivate
C34. More Accessible Transit System	Inactivate
C35. More Transit Facility Constructions	Inactivate
C36. More Operational Tax Income to the Local Government	Inactivate
C37. Multi-section Road Exploration Planning	Inactivate
C38. Negative Attitude for Public Acceptance of AV Application at the Beginning	Inactivate
C39. Negative Construction Impacts to the Neighborhood	Inactivate
C40. Potential New Job Opportunities that related to AV Technology Applications	Inactivate
C41. Optimized Scheduling of AV Trains (More in Rush Hours, Less in Non-rush Hours)	Inactivate
C42. Personal Data Security Concerns	Inactivate
C43. Possible Increasing on Personal Transit Costs	Inactivate
C44. Reduce of Private Cars	Inactivate
C45. Reduce the Urban Carbon Footprint	Inactivate
C46. Reduce the Criminal from Share Fleet Drivers	Inactivate
C47. Reduce the Residential Density in City Area	Inactivate
C48. Reduce the Usage of Gasoline Cars	Inactivate
C49. Reduce the Traffic Congestion	Inactivate
C50. Reducing the Emissions	Inactivate
C51. Re-planning City Land Use	Inactivate
C52. Safer Rides by Taking AV Trains	Inactivate
C53. Safety Concerns on Potential Accidents or Crashes by Regular Cars and AV Trains	Inactivate
C55. Share the Rides with Others	Inactivate
C56. Urban Construction Cost	Inactivate
C57. Improving the Wireless Internet Coverage for the Areas Along the Route	Inactivate

Table 3 The Input Vector Construction of the Sample Scenario Alternative. Similar as in Fig. 5, the yellow components are the "less/possible impact components', the white components are the "certainly impact components," and the blue component is objective component of the scenario building.

Step 3: Scenario Modeling – Map Integration. Since the interviewees are from the same stakeholder group as the lay public and the potential future users of the full autonomous light rail trains, their raw maps could be integrated to reflect a holistic picture of the whole group. The fundamental process of map integration would be open coding all of the concepts that mentioned from the interviewees as the standardized concept list. Then change all of the languages in the map into the standardized concepts. Then using the proposed way from Kosko [11] to get the average casual weights when combining the four individual maps. The integrated map will be shown in Fig. 6. For this particular study, there were 57 concepts, and 179 causal connections appear in the integrated map.

Step 4: Scenario Development through FCM Scenario Testing. From the previous interview step, 28 concepts were marked as "less/possible impact factors.", with another 28 concepts were marked as "certainly impact factors." Similar to the Morphology Approach [27], the principal of doing FCM scenario testing is constructing input vectors by different combinations of activity and inactivity the concepts and multiplied by the adjacency matrix of the integrated map. The components from the integrated map can be activated with the value within the range of [-1, 1] as the input vector to the FCM scenario testing.

As a demonstration here in the following table (Table 3) is showing a test running by activating all the concepts in the integrated map with one of the combinations with the value of -1 and +1, then the input vector will be shown as the table 3.

This input vector is only lead to one of the possible scenarios regarding the situation of "Fully Autonomous Light Rail Trains on SW Barbur Blvd." Moreover, the value of +1 and -1 are showing the extreme cases when activating the impact factors with different conditions. After the calculation with the adjacency matrix of the integrated map, the simulation result of responding status value for the objective component was changing from 0 to a positive value, as shown in the figure (Fig. 6):

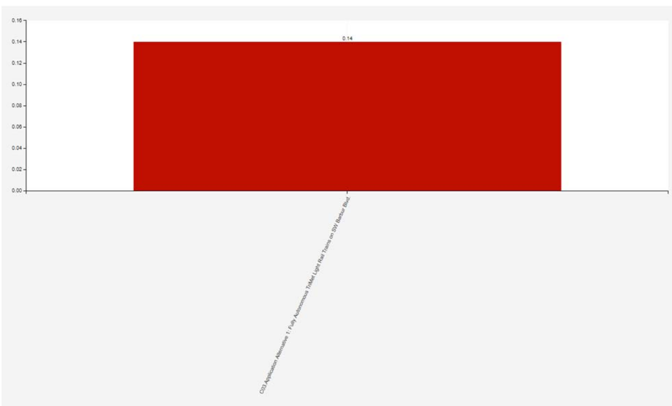

Fig. 6 Scenario Simulation Result of Responding Status Value of Alternative Scenario Factor of the example scenario

The changing of the responding status value is showing that under this scenario, the application of autonomous light rail trains along SW Barbur Blvd. will be supported. The narrative content of all the active components will provide this particular possible future to the decision-makers.

Step 5: Scenario Selection and Refinement. The previous step is showing how to develop one of the possible scenarios. With the similar process, a massive number of scenarios could be produced through the simulation responding tests with the different input vectors to the integrated map. The feature of producing not only one scenario outcome would fit the flexibility of scenario planning overall. However, too many scenarios would make the decision-makers confused about which alternative future should he follow or consider when making decisions. From the existing research works, three to five scenarios would be possible and feasible for the practical decision-making situation [1]. With the key factors or uncertainties which are leading to the most significant needs and concerns of the stakeholders, the decision-makers could select the scenarios that would most serve the stakeholders' needs and the current situation.

Step 6: Produce Narratives of the Possible Scenarios. The most popular way of documenting the scenario outcomes that suggested by researchers is to write out a narrative story of the scenario alternative [49]. This could be an essential skill for any of the scenario planning researchers. And the scenario narrative writing could be applied to all the selected possible future scenarios. Just as shown in Table 3, the example alternative scenario of applying autonomous light rail trains along SW Barbur Blvd. may look like the following narrative:

"Even though the public may not accept the coming of the autonomous vehicle (AV) technology at all, the new fully autonomous TriMet Light Rail Train is now running on SW Barbur Blvd. There are no confused driving conditions caused by the train to drivers, and the TriMet operation schedule is becoming less consistent but flexible. The public is now willing to accept the AV technology, so they don't have curiosities of the new train. They even didn't notice that the new train is a fully autonomous one. There is a dedicated route for the AV train to operate on its trail. It is just be designed as one of the lanes on SW Barbur Blvd. Since the new train would on the road, SW Barbur Blvd. is also be reconstructed as a multi-modeler road, just as any of the other roads in downtown Portland. Just as the normal situation of the riding rights on any other TriMet Trains, there would still not equal access to the public transit system, to elders, or the homeless, or people with disabilities. But to operate the autonomous train well, the real-time transportation data process had been improved a lot. By adopting the fully autonomous train on the road, the development of ground transit system is enhanced to another level of diversity. Because of the new autonomous train running on the SW Barbur Blvd., people can easily travel from South Portland to Tigard than before, without waiting hours on I-5. The regional connections between Portland and Tigard are becoming better and better. People are falling in love with taking rides on the new autonomous train along SW Barbur Blvd., even may without knowing it is running autonomously. SW Barbur Blvd. is becoming a crowded road, more TriMet stops are built along the way – yes, why not to take the ride on the new autonomous light rail train for a short trip out of Portland?"

From the above case study, when walking through the steps that proposed as an FCM-based scenario planning framework, the alternative scenarios could be produced. They are directly and efficiently reflected the opinions of the stakeholders and stakeholder groups, and also well linked to the narratives of the alternative scenarios. There are several findings regarding the FCM-based scenario planning framework:

- With the advantages of the visualization and the flexible structure of Fuzzy Cognitive Maps, the interviewees are feeling relaxed when first know about this research method.
- The directory of FCM on concepts, causal relations, logic and visual displays are making the method to be understood easily by stakeholders.
- Fuzzy Cognitive Maps is a communication platform for knowledge exchange and learning.
- Fuzzy Cognitive Maps is a communication instrument that encourages exact demands and opinions, and could potentially make the voices to be heard by decision-makers.
- The framework is feasible to use in solving real-world problems.

For evaluating the scenario outcomes, there are some criteria from the previous studies [50-54] as the followings:

1. **The scenario outcomes should connect with the present [53].** Scenarios are talking about the possible futures, but not the real futures. One way to make them satisfied with the outcomes of the scenario building process is to make the scenarios connecting with the present. The "future thinking" is about looking into possible futures from the present.

2. **Not only one answer [51**]. One of the significant differences between scenario study and forecasting is that scenarios are looking for multiple possible answers; while the forecasting is only looking for one correct answer. Scenarios would provide a more flexible vision into the possible futures as references of the decision-making process. The flexibility is a characteristic of scenario building process.

3. **Scenarios should describe generically different futures rather than variations on one theme [50].** The feasible scenarios should cover a wide range of possibilities and highlight competing for perspectives while focusing on interlinkages and the internal logic within each future [50].

4. **The transparency of the scenario building process [53].** The transparency of the process would be the reason why the participants could accept the alternative future scenarios since they have the opportunity to know what is happening with the process.

5. **Scenarios should be able to guide the realistic actions [51].** The best way of making the scenarios be acceptable or feasible, is to see if the scenarios could give real guidance to the real actions in the current situation and provide support to the decision-making process. If there is some work can be done at present, the scenarios may more likely to become the real future.

6. **The scenario should have an internal consistency [50], [52], [55].** Only if the scenarios have their internal consistency, the audiences of the scenarios consider the production of the scenario planning is a good future story, which could be viewed as a long-term future vision [56].

7. **Novelty/Challenge [57**]. The scenario planning would like to see the differences, to encourage the different knowledge and opinions that might challenge the existing cognitions or knowledge.

Through the process of the prior study, the proposed FCM-based scenario building framework is valid to use for the new technology development scenarios, such as autonomous vehicle (AV) technologies. But for FCM-based scenario building framework, the following improvements could be pursued for the future steps:

1. A standardized map analyzing process from raw map building, raw map cleaning, concept coding, map comparison, to map integration. Kosko's process [11] is only one approach out of several different approaches from various researchers, which may limit the usability of FCM to different research topics.

2. A way to turn the FCM research process into a practical management tool that available for people. Right now the process of map building and map analysis is still complicated to people who don't have knowledge of FCM. FCM is doing well on the user's end, making the visual presentation straightforward to the research participants. For the back end of the modelers, the mechanism of FCM could still be simplified.

3. A way to efficiently simulate the scenario test results and pick up the different available scenario outcomes to the decision-makers and stakeholders.

VI. Conclusion

In this paper, through the literature review of autonomous vehicles, a gap of an integrated scenario for AV technology applications and impacts in the future has been defined. The research goal of the framework design towards the scenario construction. On the other hand, through a review of the existing FCM-based scenario planning methods, and other casual modeling tools like system dynamics and influence diagram, a framework for FCM-based integrated scenario building was proposed. The framework is proved to validate through a case study of applying AV technology on a current city planning project of Portland. The evaluation criteria for the scenario outcomes and some improve points of FCM-based scenario building process is also provided. The possible following steps would be explore the pirior study with an efficient way to gathering a bigger data from various stakeholder groups, and also explore the research objective of AV technology application from the usage only for the SW Corridor Plan in the city of Portland, but a broader scope of application domains, to further test if the framework would serve the research purpose and porduce feasible possible future alternatives for applying AV technology to the daily lives.

References

[1] A. Jetter and W. Schweinfurt, "Building scenarios with Fuzzy Cognitive Maps: An exploratory study of solar energy," Futures, vol. 43, no. 1, pp. 52-66, 2011.

[2] D. Fagnant and K. Kockelman, "Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations," Transportation Research Part A: Policy and Practice, vol. 77, pp. 167-181, 2015.

[3] M. Schellekens, "Self-driving cars and the chilling effect of liability law," Computer Law & Security Review, vol. 31, no. 4, pp. 506-517, 2015.

[4] CARE-North Plus, "Autonomous Vehicles -- impacts on the mobility of the future," archive.northsearegion. Eu, 2015. [Online]. Available: http://archive.northsearegion.eu/files/repository/20160113160412_CN+FactSheet_AutonomousTransport.pdf. [Accessed: 21- May- 2017].

[5] H. LIPSON, DRIVERLESS, 1st ed. [S.l.]: MIT Press, 2017.

[6] J. Cortright, "How much will autonomous vehicles cost?", CityCommentary, 2016.

[7] "Self-Driving Cars Will Be For Sharing," CityLab, 2017. [Online]. Available:https://www.citylab.com/life/2017/01/the-future-of-autonomous-vehicles-is-shared/512417/. [Accessed: 21- May- 2017].

[8] W. Zhang and S. Guhathakurta, "Residential Location Choice for Workers in the Era of Shared Autonomous Vehicles," ACSP Conference, Nov. 3-6, Portland, OR, 2016

[9] "Stick Shift: Autonomous Vehicles, Driving Jobs and the Future of Work," Center for Global Policy Solutions, 2017. [Online]. Available: http://globalpolicysolutions.org/report/stick-shift-autonomous-vehicles-driving-jobs-and-the-future-of-work/. [Accessed: 21- May- 2017]

[10] M. van Vliet, K. Kok, and T. Veldkamp, "Linking stakeholders and modelers in scenario studies: The use of Fuzzy Cognitive Maps as a communication and learning tool," Futures, vol. 42, no. 1, pp. 1-14, 2010.

[11] B. Kosko, "Fuzzy cognitive maps," International Journal of Man-Machine Studies, vol. 24, no. 1, pp. 65-75, 1986.

[12] B. Arseneau, S. Roy, J. Salazar and J. Yang, "Autonomous and Connected Vehicles: Preparing for the Future of Surface Transportation," www.hdrinc.com, 2015. [Online]. Available: http://www.hdrinc.com/sites/all/files/content/white-papers/white-paper-images/7334-autonomous-and-connected-vehicles-preparing-for-the-future-of-surface-transportation.pdf. [Accessed: 21- May- 2017].

[13] H. Durrant-Whyte, "A Critical Review of the State-of-the-Art in Autonomous Land Vehicle Systems and Technology," Sandia National Laboratories, Albuquerque, tech. Rep, 2001.

[14] G. Correia and B. van Arem, "Solving the User Optimum Privately Owned Automated Vehicles Assignment Problem (UO-POAVAP): A model to explore the impacts of self-driving vehicles on urban mobility," Transportation Research Part B: Methodological, vol. 87, pp. 64-88, 2016.

[15] "Proposed state law would require emissions-free autonomous vehicles, and tax them by the mile - The Boston Globe," BostonGlobe.com, 2017. [Online]. Available: https://www.bostonglobe.com/business/2017/01/19/proposed-state-law-would-require-emissions-free-autonomous-vehicles-and-tax-them-mile/0Bdd6LRNzgMGpHGIzzT5DO/story.html. [Accessed: 21- May-2017].

[16] H. Grabar, "Will Everyone Own an Autonomous Car, or Will We Share Them?", Slate Magazine, 2017. [Online]. Available: http://www.slate.com/articles/technology/future_tense/2016/10/self_driving_cars_effects_on_cities_depend_on_who_owns_them.html. [Accessed: 21- May- 2017].

[17] S. Le Vine, A. Zolfaghari, and J. Polak, "Autonomous cars: The tension between occupant experience and intersection capacity," Transportation Research Part C: Emerging Technologies, vol. 52, pp. 1-14, 2015.

[18] "Self-Driving Cars Will Be For Sharing," CityLab, 2017. [Online]. Available:http://www.citylab.com/tech/2017/01/the-future-of-autonomous-vehicles-is-shared/512417/. [Accessed: 23- Mar- 2017].

[19] D. Norman, The design of future things, 1st ed. New York: Basic Books/Perseus Book Group, 2009.

[20] "Autonomous Vehicle Technology: How to Best Realize Its Social Benefits," www.rand.org, 2017. [Online]. Available: http://www.rand.org/content/dam/rand/pubs/research_briefs/RB9700/RB9755/RAND_RB9755.pdf. [Accessed: 21- May- 2017].

[21] "Envisioning Future Cities with Automated Vehicles Webinar | Urbanism NextUrbanism Next," Urbanismnext.uoregon.edu, 2017. [Online]. Available: https://urbanismnext.uoregon.edu/2017/01/17/envisioning-future-cities-with-automated-vehicles-webinar-2/. [Accessed: 23- Mar- 2017].

[22] L. Poon, "Imagining a Traffic-Free Future By Sending Driverless Cars Underground," CityLab, 2017. [Online]. Available: http://www.citylab.com/tech/2016/12/cartube-london-autonomous-vehicle-platoon-tunnels-traffic-congestion/509882/. [Accessed: 21-May- 2017].

[23] E. Hiltunen, "Scenarios: Process and Outcome," Journal of Futures Studies, vol. 13, no. 3, pp. 151-152, 2009.

[24] C. F. Joseph, Scenario Planning, Technological Forecasting and Social Changes, 65(2000) 115-123

[25] M. Godet, "How to be rigorous with scenario planning," Foresight, vol. 2, no. 1, pp. 5-9, 2000.

[26] E. Fontela and A. Hingel, "Scenarios on economic and social cohesion in Europe," Futures, vol. 25, no. 2, pp. 139-154, 1993.

[27] M. Amer, T. Daim, and A. Jetter, "A review of scenario planning," Futures, vol. 46, pp. 23-40, 2013.

[28] C. Goodier, S. Austin, R. Soetanto, and A. Dainty, "Causal mapping and scenario building with multiple organizations," Futures, vol. 42, no. 3, pp. 219-229, 2010.

[29] P. Zhang, and A. Jetter, "Understanding Risk Perception using Fuzzy Cognitive Maps," PICMET 2016, Hawaii, U.S.A., 2016.

[30] K. Warren, "Exploring competitive futures using cognitive mapping," Long Range Planning, vol. 28, no. 5, pp. 10-21, 1995.

[31] M.G. Bougon, Uncovering cognitive maps: the ‘‘Self-Q’’ technique, in G. Morgan (Ed.), Beyond Method: Strategies for Social Research, Sage, Beverly Hills, London, New Delhi, 1983, pp. 173–188.

[32] G. Probst, P. Gomez, Thinking in networks to avoid pitfalls of managerial thinking, Human Systems Management 8,1989.

[33] C. Eden and F. Ackermann, "A Mapping Framework for Strategy Making," 2017.

[34] U. Reibnitz, Scenario techniques, 1st ed. Hamburgo: McGraw-Hill, 1988.

[35] F. Ackermann, C. Eden and I. Brown, The Practice of linkMaking Strategies, A Step-by Step Guide, SAGE Publications, London, UK (2005) ISBN 0-7619-4494-X p. vi+265, #21.99.

[36] B. Kosko, Hidden patterns in combined and adaptive knowledge networks, International Journal of Approximate Reasoning, vol. 2, no. 4, pp. 377-393, 1988.

[37] H. De Jouvenel, "A Brief Methodological Guide to Scenario Building," Technological Forecasting and Social Change, vol. 65, no. 1, pp. 37-48, 2000.

[38] J. Greene, V. Caracelli, and W. Graham, "Toward a Conceptual Framework for Mixed-Method Evaluation Designs," Educational Evaluation and Policy Analysis, vol. 11, no. 3, p. 255, 1989.

[39] M. Alise and C. Teddlie, "A Continuation of the Paradigm Wars? Prevalence Rates of Methodological Approaches Across the Social/Behavioral Sciences", Journal of Mixed Methods Research, vol. 4, no. 2, pp. 103-126, 2010.

[40] "Scenario Evaluation - CMAP", Cmap.illinois.gov, 2018. [Online]. Available:http://www.cmap.illinois.gov/about/2040/supporting-materials/process-archive/scenario-evaluation.

[41] Coyle, R. (2008). *System dynamics modeling*. London [u.a.]: Chapman & Hall.

[42] Suryani, E., Chou, S., Hartono, R. and Chen, C. (2010). Demand scenario analysis and planned capacity expansion: A system dynamics framework. *Simulation Modelling Practice and Theory*, 18(6), pp.732-751.

[43] J. Vennix, "Group model-building: tackling messy problems," *System Dynamics Review*, vol. 15, no. 4, pp. 379-401, 1999.

[44] T. Binder, A. Vox, S. Belyazid, and H. Haraldsson, “Develop System Dynamics Models from Causal Loop Diagrams.”

[45] H. Min, W. Beyeler, T. Brown, Y. Son and A. Jones, "Toward modeling and simulation of critical national infrastructure interdependencies," *IIE Transactions*, vol. 39, no. 1, pp. 57-71, 2007.

[46] Portland Metro, “Southwest Corridor Plan,” 2017. [Online]. Available: www.oregonmetro.gov/public-projects/southwest-corridor-plan.

[47] “Portland Southwest Corridor Light Rail Transit Project Agency Coordination Plan Table B-2 : Draft EIS Section Review Requested,” p. 2017, 2017.

[48] A. Dawid, "Influence Diagrams for Causal Modelling and Inference," International Statistical Review / Revue Internationale de Statistique, vol. 70, no. 2, p. 161, 2002.

[49] K. der Heijden, Scenarios: the art of strategic conversation. John Wiley & Sons, 2011.

[50] “SCENARIO PLANNING: A TOOL FOR STRATEGIC THINKING Schoemaker, Paul J H Sloan Management Review; Winter 1995; 36, 2; Periodicals Archive Online pg. 25,” 1995.

[51] M. Godet and F. Roubelat, “Creating the Future: The Use and Misuse of Scenarios,” Long Range Plann., vol. 29, no. 2, pp. 164–171, 1996.

[52] M. Amer, T. U. Daim, and A. Jetter, “A review of scenario planning,” Futures, vol. 46, pp. 23–40, 2013.

[53] G. Ringland and P. Schwartz, Scenario Planning: managing for the future. 1998.

[54] M. Godet, “The Art of Scenarios and Strategic Planning,” Technol. Forecast. Soc. Change, vol. 65, no. 1, pp. 3–22, 2000.

[55] L. Börjeson, M. Höjer, K. H. Dreborg, T. Ekvall, and G. Finnveden, “Scenario types and techniques: Towards a user’s guide,” Futures, vol. 38, no. 7, pp. 723–739, 2006.

[56] S. P. Schnaars, “How to develop and use scenarios,” Long Range Plann., vol. 20, no. 1, pp. 105–114, 1987.

[57] I. Wilson, “Mental maps of the future: an intuitive logics approach to scenarios,” Learn. from Futur. Compet. foresight Scenar., pp. 81–108, 1998.