Integrated Business and Technical System Modeling of Rail Projects with Uncertainty Analysis

by

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ABSTRACT

Overseas technical cooperation and technology transfer projects has many hurdles. An example is the overseas expansion and operation of high-speed railways, which are highly integrated systems. This research uses the Northeast Corridor SCMAGLEV project, a Japanese high speed railway system overseas cooperation project with the United States planned and promoted as a model, to consider what type of hurdles exist and options & decision-making for dealing with them. We decided to proceed with building a model with the aim of proposing useful measures to deal with complex projects.

Aimed to be a useful management method and decision-making material for projects with such complex characteristics, we built a prototype model that integrates business and technical systems and enables uncertainty analysis.

Advantage of this model is that it allows us to consider combinations of multiple system decisions and multiple business decisions. Taking advantage, for example, the research led to the following analysis: By looking at the distribution of uncertainty, it became possible to visualize the state of risk sharing due to differences in schemes (e.g., PPP and Non-PPP). In addition, by focusing on items where the expected NPV changes significantly depending on the business decision, it became possible to identify in advance contract forms where it is difficult to set numbers. In addition, we were able to visualize that the impact of long-term borrowing and interest cannot be ignored depending on the business scheme. We found that the prototype model is useful for aiming for overall optimization while considering complex combinations.

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Disclaimer

The analysis and research given in this thesis is from the findings of the author's personal research, which does not represent an official policy or opinion of Central Japan Railway Company and/or the NEC SCMAGLEV project.

Table of Contents

Abstract…...……………………………………………………………………………………3
1 Introduction.. 11
- 1.1 Introduction to the SCMAGLEV system 11
- 1.2 SCMAGLV technology as a high-speed rail system 12
- 1.3 Introduction to the US NEC (Northeast Corridor) SCMAGLEV project 13
- 1.4 Problems/challenging points of the project.. 14
- 1.5 Structure of this paper 15

2 Literature review for related research and projects 16
- 2.1 Literature review for SCMAGLEV system and project’s uncertainty 16
- 2.2 Analytical Review of US Northeast Corridor Transportation 16
- 2.3 Literature review for railway characteristics of the Northeast Corridor of the United States 17
- 2.4 Background of the technology/infrastructure transfer 18

3 Questions and Motivations 20
- 3.1 Questions 20
- 3.2 Motivations 20

4 Research Approach 22
- 4.1 Introduction.. 22
  - 4.1.1 Concept of the method 22
  - 4.1.2 Introduction to methodology.. 22
- 4.2 Technological overview of Superconducting Maglev system (system study) 23
  - 4.2.1 The Principle of the Superconducting Maglev system.. 24
  - 4.2.2 Propulsion System 24
  - 4.2.3 Levitation / Guide System.. 25
  - 4.2.4 Technological/System decomposition of the SCMAGLEV system............................... 26
- 4.3 Current stakeholders and funding/financing 26
  - 4.3.1 Stakeholders proposing the project 26

    4.3.2 Stakeholders of Maglev Deployment Program (MDP) 27
    4.3.3 Funding/financing for the current project 28
    4.3.4 Assumed process decomposition of the current NEC SCMAGLEV project 28
  4.4 Theoretical scheme and partnership options of the NEC SCMAGLEV project 29
    4.4.1 Theoretical scheme options 29
    4.4.2 Evaluation for each discussion item whether to adopt 30
    4.4.3 Remained theoretical scheme options 32
  4.5 Theoretical business decomposition of the NEC SCMAGLEV project 33
  4.6 Differences in regulations and standards that cause system differences between high speed rail system in Japan and the United States 35
    4.6.1 Introduction 35
    4.6.2 Texas RPA 35
    4.6.3 Potential of SCMAGLEV RPA 37
    4.6.4 Regulations and standards to be considered 37
5 Modeling 40
  5.1 Modeling of technical system model 40
    5.1.1 The model building process of the technical system model 40
    5.1.2 Model output as API (Application Programming Interface) 42
  5.2 Modeling of business model 43
    5.2.1 Preparation of the business model 43
    5.2.2 Company/Group type, Alternative Business Options, and model input 45
    5.2.3 Integration with Technical System Model and generated output 47
  5.3 Uncertainty Analysis Model 48
    5.3.1 Overview and assumptions 48
    5.3.2 Major uncertainties incorporated 49
    5.3.3 Output of the model 50
6 Discussion 52
  6.1 Analysis example 1: results from focusing on one company 52

6.2 Analysis example 2: PPP results and focusing on different revenue distribution rate 53

7 Conclusion and future work 56

7.1 Conclusion 56

7.2 Proposal of future work 57

Appendix A: STPA on Japanese HSR's safety system 58

List of Figures

Figure 1: Principles of SCMAGLEV vehicle’s guidance and levitation 12

Figure 2: Chuo-Shinkansen project plan..... 13

Figure 3: Northeast Corridor Cities. 14

Figure 4: Prototype modeling concept..... 23

Figure 5: Cross sectional View of MagLev system. Source: How it works (Baltimore-Washington Rapid Rail) 24

Figure 6: Top-down View of MagLev System. Source: How it works (Baltimore-Washington Rapid Rail)..... 25

Figure 7: Propulsion Subsystem in MagLev. How it works (Baltimore-Washington Rapid Rail) 25

Figure 8: System decomposition of the SCMAGLEV system for operation purpose with system boundary 26

Figure 9: Assumed process decomposition of the current NEC SCMAGLEV project..... 28

Figure 10: Business decomposition in the system definition and adjustment phase..... 33

Figure 11: Business decomposition for purely private conducted project case after Preparation and System Design Phase..... 34

Figure 12: Business decomposition for PPP considered case after Preparation and System Design Phase 34

Figure 13: Business decomposition for purely private conducted project case with contract methods..... 44

Figure 14: Business decomposition for PPP considered case with contract methods..... 44

Figure 15: Result of example distributed NPV analysis with uncertainty (with 5 percent DR for 40 years) for Company A 51

Figure 16: Results from focusing on one company (Company A: Franchised railroad company) 53

Figure 17: PPP results on case A (18% Distribution)..... 54

Figure 18: PPP results on case B (15% Distribution) 54

Figure 19: PPP results on case C (cost + fee contract)..... 55

List of Tables

Table 1: Theoretical scheme options of the NEC SCMAGLEV project 30

Table 2: Update of Remaining Theoretical Options 32

Table 3: Compression load requirement and collision resistance requirement 36

Table 4: Interpretation of key regulations/standards 38

Table 5: Example of input and options for the System Design Decisions in the technical system model 41

Table 6: Company/Group type and roles with Alternative Business Options 45

Table 7: Example of Business Decisions Input........ 46

Table 8: Example of the model output integrated business model's input and system model's output 47

Table 9: Example of Uncertainty Analysis Model sheet 49

Table 10: Result of example case deterministic NPV analysis (with 5 percent DR for 40 years) for Company A 50

1 Introduction

There are many hurdles in overseas technical cooperation and technology transfer projects. An example is the overseas expansion and operation of high-speed railways, which are highly integrated systems. This research uses the Northeast Corridor SCMAGLEV project, a Japanese high speed railway system overseas cooperation project with the United States planned and promoted as a model, to consider what type of hurdles exist and options & decision-making for dealing with them.

1.1 Introduction to the SCMAGLEV system

The superconducting linear motor car called as SCMAGLEV is a magnetic levitation type railway that uses magnetic levitation and magnetic drive to significantly reduce friction and achieve high-speed and stable running. The aim is to use superconducting maglev technology to levitate trains and achieve extremely high-speed movement.

The technological overview of the SCMAGLEV system outlines its unique features and operational principles. Unlike traditional railway systems, this system utilizes superconducting magnets and ground coils to create a contact-less transport system.

As a principle of how it works, the system employs superconducting magnets on board the vehicles and ground coils on the guideway. Electromagnetic forces between these magnets and coils propel, levitate, and guide the train. Electric current passing through propulsion coils on the guideway generates a magnetic field, propelling the train forward by interacting with the onboard magnets. When the train passes over levitation coils, induced currents create electromagnetic forces that both levitate and guide the train without external power.

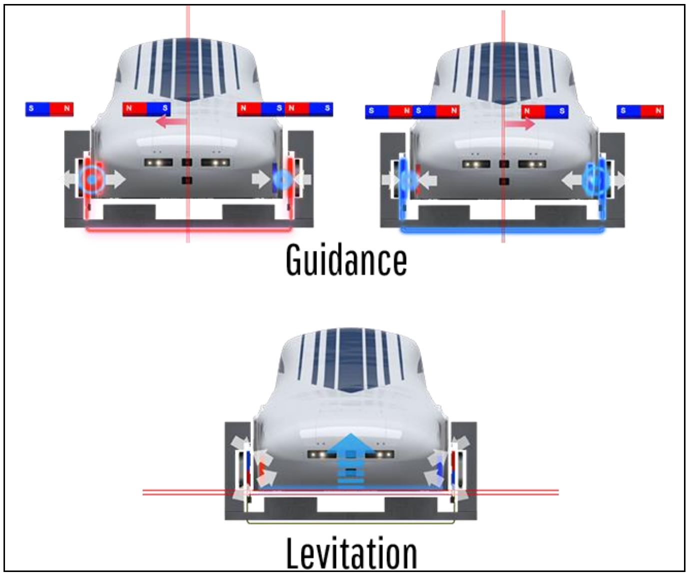


Figure 1: Principles of SCMAGLEV vehicle's guidance and levitation

(Source: Central Japan Railway Company [1])

In 2015, SCMAGLEV train set a world record speed of 603 kilometers per hour (375 miles per hour) during a manned test run in the Yamanashi Maglev Line where Central Japan Railway Company (JR-Central) continuously improving their maglev technology.

1.2 SCMAGLV technology as a high-speed rail system

The Chuo Shinkansen which utilizes the SCMAGLEV technology represents the cutting edge of Japan's railway technology and is expected to become the transportation infrastructure of the future. It was developed by Central Japan Railway Company (JR-Central) and is currently under construction in Japan between Tokyo and Nagoya (eventually it will be extended to Osaka). JR-Central is the operator of the Tokaido Shinkansen, which started operation in 1964 as the world's first high-speed railway between Tokyo Station and Shin-Osaka Station in addition to operating conventional lines in the central region of Japan. Regarding to the Tokaido Shinkansen, in the more than 50 years since its opening, the train has remained safe, with no train accidents resulting in the death of passengers on board. The Chuo Shinkansen will be developed as a technology that will enable even higher speed operation, while maintaining a culture of safety and technology that have enabled the high-speed operation of the Tokaido Shinkansen.

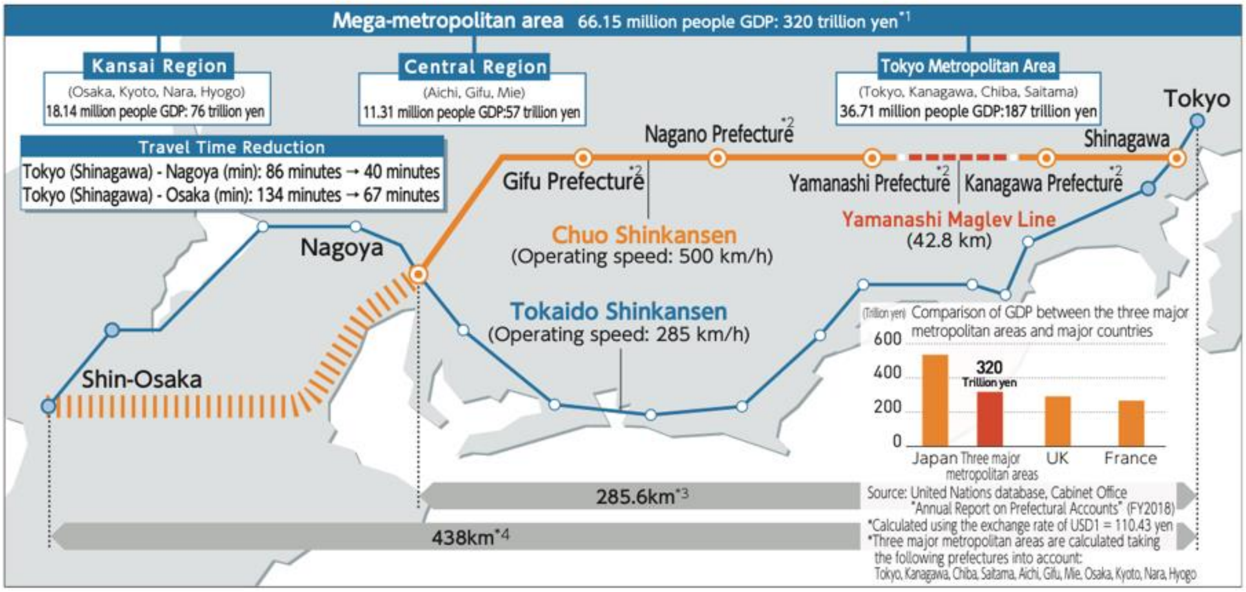


Figure 2: Chuo-Shinkansen project plan

(Source: Central Japan Railway Company [2])

1.3 Introduction to the US NEC (Northeast Corridor) SCMAGLEV project

On the other hand, the Northeast Maglev project is a high-speed rail project aiming to bring superconducting magnetic levitation (SCMAGLEV) train technology to the Northeast Corridor of the United States. The project is primarily focused on creating a SCMAGLEV system, which utilizes superconducting magnets to achieve high speeds and smooth rides.

SCMAGLEV trains boast the potential to reach operation speeds surpassing 311 miles per hour (500 kilometers per hour), far outstripping conventional high-speed rail systems. This velocity would dramatically slash travel durations between major cities in the Northeast Corridor, including Washington D.C., Baltimore, Philadelphia, and New York City. The massive infrastructure project, which aims to eventually connect Washington D.C. and New York City in one hour, will include six other intermediate stations, according to plans published by the promoting company of the NEC SCMAGLEV project [3]. The six intermediate stations are, from the south, BWI Airport, Baltimore, Wilmington, PHL Airport, Philadelphia, and EWR Airport. The initial phase of the SCMAGLEV project will connect Washington D.C. and Baltimore with a station at BWI Airport by 15 minutes [4]. For Phase I, environmental impact assessments are currently underway.

Figure 3: Northeast Corridor Cities.

(Source: The Northeast Maglev [5])

Advocates of the project contend that the SCMAGLEV system would mitigate congestion on highways and at airports, offering a more efficient and environmentally friendly transportation alternative. Moreover, they assert it would foster economic expansion throughout the Northeast Corridor.

The project has garnered participation from both public and private sectors. Central Japan Railway Company (JR Central), renowned for its maglev train development in Japan, plays a pivotal role by contributing technology and expertise. Furthermore, various U.S. government agencies and private investors have expressed interest in supporting the endeavor.

1.4 Problems/challenging points of the project

This project is a quite challenging project that involves international technology transfer of highly integrated high-speed rail system technology.

With international relocation, there are a wide variety of things to consider, such as different budget characteristics, changes in requirements due to different laws and technical standards, a wide range of stakeholders, and cultural differences. Furthermore, consideration should also be given to the perspective including the restructuring required to apply these to SCMAGLEV, a new generation of highly integrated high-speed rail system. Additionally, the process of sharing highly specialized SCMAGLEV knowledge among stakeholders in all phases of planning, approval, development, design, construction, and operation is expected to be challenging. All of these can create major uncertainties that affect the future of the project.

1.5 Structure of this paper

This model project is a complex project in which the scale of the business, the construction of the system from a technical perspective, the synthesis with the regulatory aspects, and many stakeholders are organically intertwined. We would like to explore approaches that can help resolve these issues.

Thus, in this paper as the following of this introduction (Chapter 1), we will conduct the literature review in Chapter 2 for related research and projects to gain the insight related to the project and technology. In Chapter 3, we will explain about the questions and motivations to be approached in this paper.

After the Chapter 4 shall be is the main points of this paper. In Chapter 4, we will prepare the making the business and system integrated modelling which will explained in Chapter 5. In the following chapters, after the modeling, we will make the discussion using the results (Chapter 6) and list the future works (Chapter 7).

2 Literature review for related research and projects

In deciding on the approach for this paper, we conducted a literature review to search for knowledge that could be gained from past projects and related research.

Started with the SCMAGLEV system, a technological instrument of the Northeast Corridor SCMAGLEV Project, which is intended to use as a model project in this study. Next, proceeded with a review of research on the regional and transportation especially railway's characteristics of the Northeast Corridor of the United States, which is the region where I plan to apply this method. Finally, we conduct a review exploring a wide range of industries as examples of transferring technology and infrastructure between different countries.

2.1 Literature review for SCMAGLEV system and project's uncertainty

Mr. Ishii [6] researched the risks associated with demand forecasting and research and development (R&D) performance faced by Japan's Chuo Shinkansen Maglev Project using the SCMAGLEV system and how to deal with them. One of the main challenges he noted was accurately estimating future demand for maglev trains, as the SCMAGLEV system would require a dedicated power conversion system (PCS) for each train, and by further research new uncertainties arise due to advances in PCS technology due to development. Therefore, he proposed a hybrid real options model and used this model to estimate the value of the project and perform sensitivity analysis to determine whether investment in research and development of PCS technology is advantageous to the project. It was suggested that. This is expected to provide insight into potential development strategies for the project and enhance the decision-making process for stakeholders.

This research which conducted before the construction of Chuo Shinkansen started shows a demand forecasting and R&D performance can be main factors of various uncertainties of the project. In current situation, even the fundamental R&D has already been done for the SCMAGLEV, demand forecasting is still important factor to be considered.

2.2 Analytical Review of US Northeast Corridor Transportation

The Northeast Corridor is already a big area and getting bigger from an economic point of view. Despite covering just 2 percent of the country's landmass, the Northeast region accommodates 17 percent of the nation's inhabitants and contributes to 20 percent of the nation's GDP, constituting a $2.6 trillion economy. [7] Conservative estimates suggest that intercity travel will increase by 45 percent, rising from 161 million annual trips to 230 million by 2040. [8]

NEC, which is the economic center of the United States and is expanding, analyzed three transportation modes: expressways, airways, and railways.

Regarding to the highways, according to a study performed by Texas A&M Transportation Institute in 2015, the expressways in the NEC area are is 12% of all US highway lane miles but account 52% of the worst highway bottlenecks in the US. Moreover the 22% increase in auto travel is expected by 2040. [9]

In regard with the airways, the air trips counted in the Northeast area is 30% of all US air trips, but the 50% of nationwide delays originate in New York City. Moreover the 102% increase in aviation boarding is expected by 2040. [10]

In relation to the railways, 75% of weekday rail commuters in the US utilize ones in Northeast Corridor area, yet its rail infrastructure is outdated, having been in service for over a century. Originally not intended for high-speed transportation, the Northeast Corridor faces limitations due to its shared infrastructure among 9 passenger and 4 freight railroads. Speed is restricted by the slowest trains on the network, meaning even high-speed trains like Acela operated by Amtrak can only reach an average of 85 miles per hour. Presently, merely 6% of the NEC's rail infrastructure is capable of accommodating speeds of 150mph. On the other hand, the 115% increase in intercity rail travel is estimated by 2040. [11]

In particular, the proportion of shared tracks on the current main lines of the Northeast Corridor railways is high. Amtrak only operates one block of track between Baltimore and Philadelphia and two blocks between New York and Boston as their designated line. A high percentage of other lines are shared with commuter rails. As will be discussed in detail in a later section of this paper, lines with shared tracks, also known as interoperability, create a situation where it becomes more difficult to ensure safety on high-speed railways. This can be said to be one of the factors limiting the introduction of high-speed railways in the NEC, which is such a busy area.

In this way, from the perspective of the current economic size, future economic growth, strong travel demand, and problems faced by current transportation modes, it can be said that the Northeast Corridor of the United States requires solutions using new transportation modes. It is considered appropriate that the NEC SCMAGLEV project has been proposed as one of the contributing projects there.

2.3 Literature review for railway characteristics of the Northeast Corridor of the United States

Mr. Doi's research [12] analyzes key elements in the infrastructure design and operation of high-speed rail (HSR), which is expanding around the world. He emphasized the design and monitoring of "ilities" that is essential for the sustainable operation of HSR. Focusing on safety, availability, and profitability as three essential “ilities”, he investigated the dynamic behavior of the Tokaido Shinkansen in Japan and NEC (Northeast Corridor) in the United States. On the Tokaido Shinkansen, three "ilities" form a positive feedback loop to ensure the successful operation of the high-speed railway. Although NEC has shown high profitability, it has not performed very well in terms of safety and availability due to several systemic factors.

This study provides the viewpoint that there is room for improvement in safety and availability from the perspective of analyzing the market for railway systems in NEC in the United States.

2.4 Background of the technology/infrastructure transfer

Although there are hurdles in transferring technology/infrastructure overseas, the purpose and background behind the implementation of such transfers to date is to obtain benefits through market expansion. For example, in the mode of transportation that this paper will discuss, it would be a great advantage to increase the number of modes of transportation that have common standards, thereby fostering and passing on the technology and culture of parts supply and maintenance. In this respect, it can be said that this is one of the sustainable development measures by expanding not only to the domestic market, which has limitations, but also to overseas markets, where there are fewer restrictions in terms of market size.

In Japan, many "new transportation systems" have been planned and operated so far. The term of new transportation system here refers to a new transportation system that has been developed through the development of new technologies and means of transportation that have functions and characteristics different from those of conventional transportation, or by reforming existing transportation means. In a broad sense, SCMAGLEV (Chuo Shinkansen), which is a high-speed railway serving as a mass transit system, is also included in this classification.

In a narrower sense, the "new transportation system" is a public transportation system that primarily targets small or medium volume transportation. For example, there are trains that exhibit unique operating standards, such as Skyrail [13], one of the world's rare dangle trains that operated in Hiroshima prefecture. Most of these are determined to be optimal according to local usage conditions and are introduced. However, if the product is not adopted in other regions and a state of so-called galapagosization occurs, parts that cannot be produced in common will be made to special order. In this situation, there is a risk that they may no longer be able to purchase them in the future depending on the business status of the partner they rely on. Transportation facilities, which need to go through a procurement process with many parties when it comes to daily maintenance and equipment renewal, are truly team-run operations, supported by groups from many corporate entities. Therefore, in order to prevent a one-of-a-kind system from causing problems in procuring parts when updating equipment, transportation facilities should create common systems and standards at other locations to make parts cheaper or discontinue them. Being in a "Galapagos state" is not necessarily a good thing. It is a reasonable strategy to avoid this. It is said that these factors were also behind the discontinuation of Skyrail service in May 2024.

Another example is the Peach Liner of the Tokadai New Transit in Aichi prefecture [14], abolished in 2006. They adopted the VONA (Vehicle of New Age) standard as rare among new transportation systems. The much amount of money required to upgrade the equipment after that was the trigger for its decommissioning. VONA was an original standard that was different from AGT (Automated Guideway Transit) standard [15], which was established by the Japan Transportation Planning Association in 1983.

SCMAGLEV (Chuo Shinkansen) is a high-speed railway that serves as a mass transit system, and although it can be said that the situation is different from the above-mentioned example of a public transportation system that targets small and medium volume transportation in the region, currently it can be said a unique technology application. Therefore, while the market is located in economically important areas in Japan, such as Tokyo and Osaka, when looking at the world market, as mentioned in the previous section, the northeastern area of the United States, which is an area with a similarly large economic scale, it seems logical to target the corridors and aim for common standards by expanding the market.

For transportation systems, which have their own unique characteristics and standards, expanding the market is one of the most important priorities. The model project in this paper involves overseas expansion, so it is necessary to coordinate the technologies between countries that generally adopt different standards. It will be necessary to carefully analyze which parts are unique (and not just in a good sense in this case) and how they will be handled in different countries.

3 Questions and Motivations

3.1 Questions

In the previous chapter, obtained suggestions on points to consider from related past research and projects. The following are the major questions in this paper.

- What considerations are there in a project to realize a highly integrated system? What options are possible?
- What considerations are unique to international technology transfer?
- What kind of business scheme is expected to be used to promote a large-scale infrastructure project?
- What uncertainties exist in realizing a long-term project? How can they be reflected in decision-making?
- The above items are not all independent and need to be considered in the context of overall optimization. Are there methods that can be used from this perspective?

In order to further consider the first two questions, it is assumed that a review of the laws that affect both the system and business aspects will be essential. In addition, from the perspective of high-speed railway technology originating in Japan, it is assumed that consideration of what kind of approach can be considered will also be necessary since it will be regulated in a foreign country.

The next questions are very important, related to business approaches and uncertainties in large-scale projects, so it is assumed that it will be necessary to organize them with reference to the current state of the project and consider theoretically possible approaches.

The last question leads to consideration of how to manage the system construction and project management as a series and as a whole, which is always a difficult point in technical projects. Although it is a general question, the hurdle of deriving a clear solution is considered to be a high challenge.

3.2 Motivations

As described so far, this model project is a complex project in which the scale of the business, the construction of the system from a technical perspective, the synthesis with the regulatory aspects, and many stakeholders are organically intertwined. The existence of these many elements means that there are detailed decisions on the system and business aspects, and while there should be a considerable number of combinations in theory, in reality it is difficult to consider various combinations and predict the result of the combinations.

For example, although it is a simplified example, even within a single company, the person (department) who builds the system and the person (department) who builds the business plan may be different, making it difficult for them to be organically and dynamically involved. There may also be cases where the organizations (companies) in charge of them are different, and therefore the stakeholders consider their interests in different directions. Therefore, in this complex project, it is useful to extract the essential elements that are necessary, and then to have a means of linking the two elements that are easily separated, especially business and systems. If a method that leads to the pursuit of overall optimization can be pursued on that basis, it may be useful as an approach that can be applied not only to the model project but also to similar projects.

Therefore, through this paper, we propose a methodology for approaching the above needs and the ultimate goal is that this paper will provide insights on how to deal with obstacles and uncertainties in projects and ultimately enhance the decision-making process of stakeholders involved in the project.

4 Research Approach

The main part of this study including analysis will consist of two parts:

1. Clarifying the points to be considered and possible uncertainties in high-speed rail projects including the viewpoint from the international technology transfers
2. Utilizing prototype modeling, presenting possible options for dealing with complex project, and exploring how they can help the decision-making

4.1 Introduction

4.1.1 Concept of the method

Based on the motivations discussed in Chapter 3 and considering approaches to bring more benefit and insight, we will proceed with the following concept:

<Concept of the method>
Analysis for technical options (engineering and operation etc.) and business options (scheme, procurement, role of responsibility etc.) satisfying requirements (e.g., regulatory/standard) with possible uncertainties.

As a concreate method of the concept above, we will produce the prototype modeling presenting possible options for dealing with complex project, which can be approached from both of technical system and business approach.

4.1.2 Introduction to methodology

In this section, since the NEC Maglev project started in the 2010s and is partially underway, we will summarize the current stakeholders, etc. On the other hand, since this project is a model for consideration in this paper, we will not eliminate business options from the reason that it has been already done. Theoretically possible options and business models should be on the table.

To this end, we will first perform a decomposition from the following two big aspects: technical system and business. This is because by breaking these down, we can see the uncertainties brought about by each sub-level and the requirements that need to be considered. This type of requirement is often brought from regulations and technical standard, which sometime give the constraints for the options in decisions. From a combination of these, we will identify and consider theoretical and realistic options and business models including ones for each process.

Furthermore, a modeling prototype with uncertainties to be considered will be presented and discussed to evaluate the project.

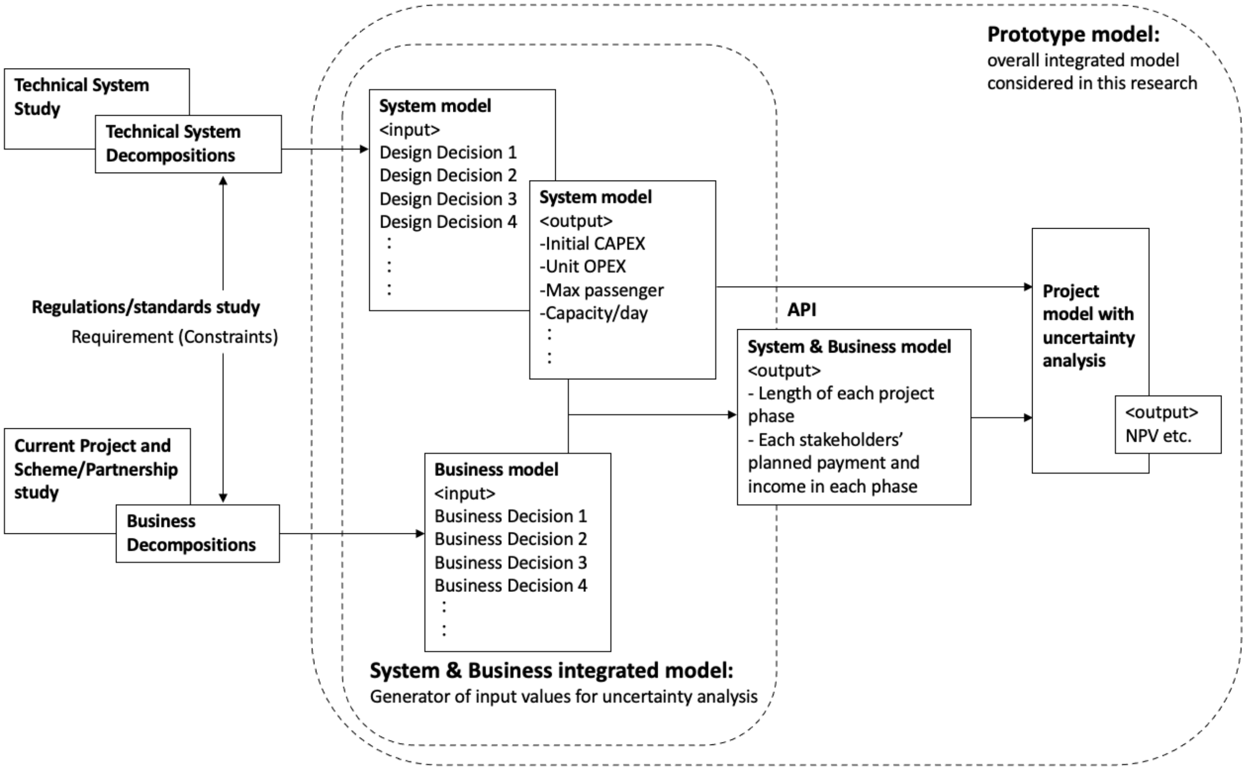


Figure 4: Prototype modeling concept

The above diagram shows the concept of the over-role integrated project model addressed in this research. In this Chapter 4, we will conduct studies regarding the technical system and current project including scheme/partnership that eventually connects to both models of system and business. The studies and system/business decompositions we will conduct in this Chapter 4 will form the basis for building the model in Chapter 5.

4.2 Technological overview of Superconducting Maglev system (system study)

The SCMAGLEV system stands as a state-of-the-art technology exclusive to Japan. Diverging from conventional railway methods, it employs a contactless transportation approach by harnessing magnetic force interactions between onboard superconducting magnets and ground coils.

Basic technological overview of the SCMAGLEV system is provided in this section.

4.2.1 The Principle of the Superconducting Maglev system

Within the SCMAGLEV system, each vehicle is equipped with superconducting magnets (SCM) on both of its sides. Complementing this, the guideway features two distinct types of ground coils: the Propulsion coil and the Levitation coil. Through the electromagnetic force generated between the on-board magnets and the ground coils, the vehicle experiences propulsion, levitation, and guidance functionalities.

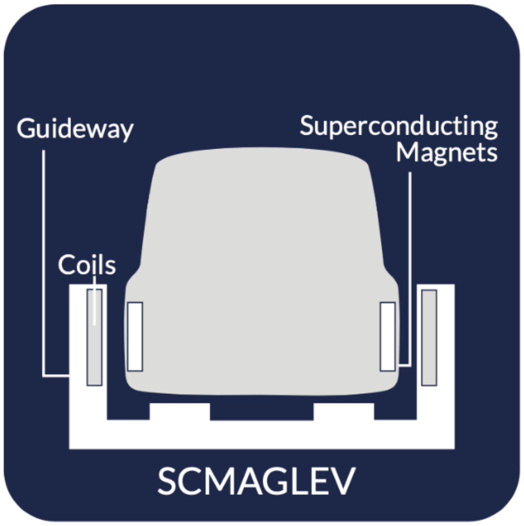


Figure 5: Cross sectional View of MagLev system.

(Source: Baltimore-Washington Rapid Rail [16])

4.2.2 Propulsion System

Propulsion in the SCMAGLEV system operates through the electromagnetic force exerted between the propulsion coils embedded in the guideway and the Superconducting Magnets (SCM) installed on the vehicle. When an electric current flows through the propulsion coils on the guideway, it generates a magnetic field with distinct north and south poles. Consequently, the vehicle is propelled forward as a result of the attractive force between opposite poles and the repulsive force between like poles, acting between the ground coils and the SCM on the vehicle.

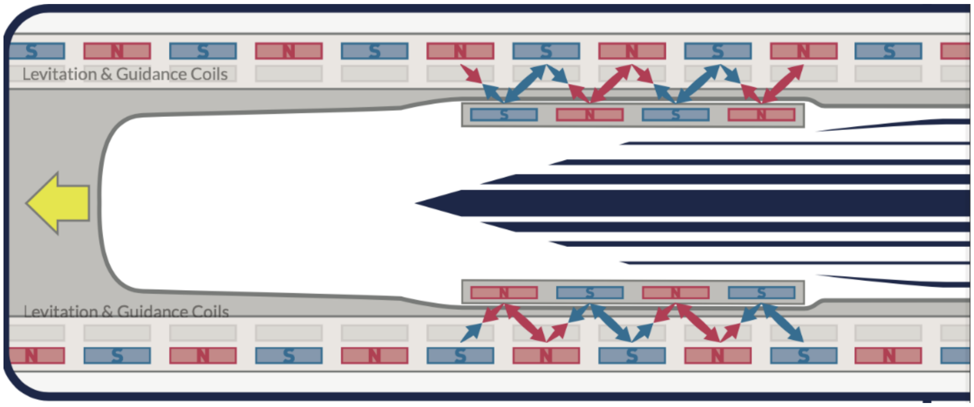


Figure 6: Top-down View of MagLev System.

(Source: Baltimore-Washington Rapid Rail [17])

4.2.3 Levitation / Guide System

In contrast to the propulsion system, the levitation or guide system operates autonomously, requiring no external power source. As the SCM speeds over the "8"-shaped levitation coil, a current is induced within it, traversing through the levitation and guidance coils on either side. This process generates an electromagnetic force that simultaneously exerts an upward push (repulsive force) and a pulling force (suction power) on the vehicle. Additionally, by interlinking the appropriate levitation coils on both sidewalls, these coils can function as a guide system. As the vehicle approaches one sidewall, a circulating current between these two coils is induced, generating a guiding force to maintain the vehicle's trajectory.

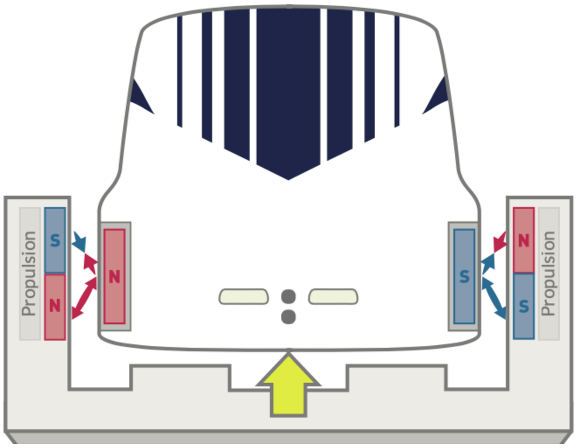


Figure 7: Propulsion Subsystem in MagLev.

(Source: Baltimore-Washington Rapid Rail [18])

4.2.4 Technological/System decomposition of the SCMAGLEV system

As a mass transit agency, SCMAGLEV's purpose is to operate trains and transport passengers to their destinations. For this purpose, we focused here on the operation and disassemble the system and display it as following.

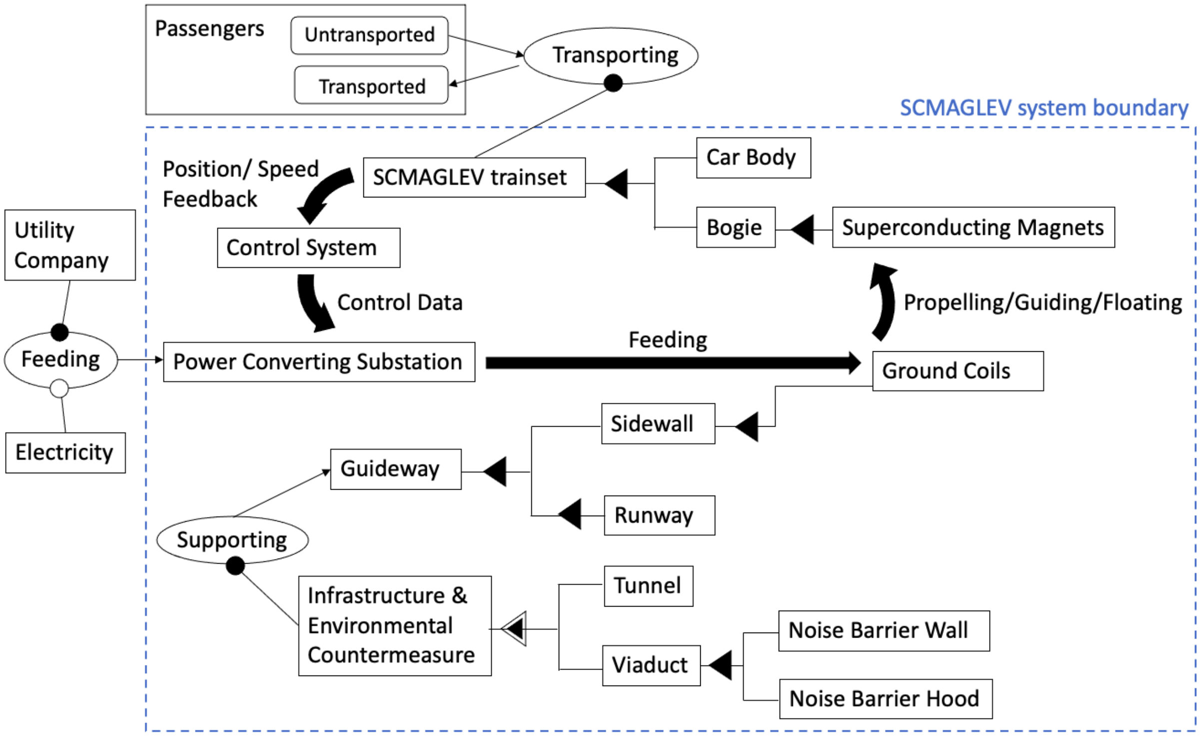


Figure 8: System decomposition of the SCMAGLEV system for operation purpose with system boundary

Note: This chart is a selection of primary elements and does not completely cover the entire system.

4.3 Current stakeholders and funding/financing

Given that the NEC Maglev project commenced in the 2010s and is presently in progress, we'll outline the current stakeholders. However, as this project serves as a model under consideration in this paper, we won't disregard potential business options simply because they've been previously explored. Theoretically plausible options and business models should remain open for discussion.

4.3.1 Stakeholders proposing the project

The following are the organization who are proposing the current NEC SCMAGLEV project.

Baltimore-Washington Rapid Rail (BWRR)

- A 100% US-owned, Maryland Based Franchised Railroad company
- Dedicated to deploying the 311mph SCMAGLEV train in the Northeast Corridor
- The role will be called as the franchised railroad company in this paper

Northeast Maglev (TNEM)

- A 100%US-owned company promoting the deployment of SCMAGLEV in the Northeast Corridor
- The role will be called as the promoting company in this paper

Central Japan Railway Company

- Japanese rail company with over 50 years experience in high-speed rail on the most travelled rail corridor in the world
- Developer of the SCMAGLEV system currently being deployed in Japan
- The role will be called as the technical provider in this paper

With these three stakeholders who are proposing the project at the center, various stakeholders from the public and private sectors have gathered through activities such as the MDP, which will be described later.

4.3.2 Stakeholders of Maglev Deployment Program (MDP)

In 1998, the Maglev Deployment Program (MDP) was established as part of the US Transportation Equity Act for the 21st Century (TEA-21). Its primary objective was to demonstrate the feasibility and effectiveness of Maglev technology as a safe and efficient transportation solution within the United States. [19]

In March 2015, the Federal Railroad Administration (FRA) announced the availability of funding through the Maglev Deployment Program (MDP). Subsequently, in April 2015, the Maryland Department of Transportation (MDOT), representing Baltimore-Washington Rapid Rail (BWRR), applied to the FRA for funds. The aim was to conduct preliminary engineering (PE) and National Environmental Policy Act (NEPA) work for BWRR's SCMAGLEV proposal. In 2016, the FRA allocated $27.8 million to MDOT for the preparation of preliminary engineering and NEPA analysis for an SCMAGLEV system connecting Baltimore, MD, and Washington, DC. Baltimore-Washington Rapid Rail actively participates in providing preliminary engineering expertise, technical assistance, and additional financial support for the NEPA process, in conjunction with the FRA grant. [20]

Following are the stakeholders manly involved into the MDP program for the first phase of the NEC SCMAGLEV project.

Federal Railroad Administration (FRA): Lead Federal Agency:

Maryland Department of Transportation (MDOT): Lead State Agency

Baltimore-Washington Rapid Rail (BWRR): Engineering/ Technical Consultant

Furthermore, it is obvious that local residents are also important stakeholders, as seen in the process of building consensus with residents during environmental impact assessments (EIS), for example.

4.3.3 Funding/financing for the current project

To date, the cost of the study phase like the Environmental Impact Statement has been paid for by a Federal grant, the Maglev Deployment Program. Regarding the financing for the project to implementation and construction, that is expected to come from a mix of sources. According to the promoting company, they give examples of the finance from Japan, U.S. government loan and grant programs, and the private sector. [21]

As an essential aspect of the international technology/infrastructure transfer, if government loan and/or grant programs are applied, it may be necessary to consider the Build America, Buy America Act which generally applies to awards made with federal financial assistance. [22] However, the act might waive the application of the domestic content procurement preference in the case of one of three exceptions: Public interest, Non-availability, and Unreasonable cost. Thus, it is assumed that there will be a need to discuss the extent to which it is applied (or not) to the highly integrated system like SCMAGLEV.

4.3.4 Assumed process decomposition of the current NEC SCMAGLEV project

In the previous section, we summarized the aspects of the project at the preparatory stage. Here we walk through the major steps required to bring a real infrastructure project/high-speed rail project to fruition. The following chart shows the assumed major process for the current NEC SCMAGLEV project.

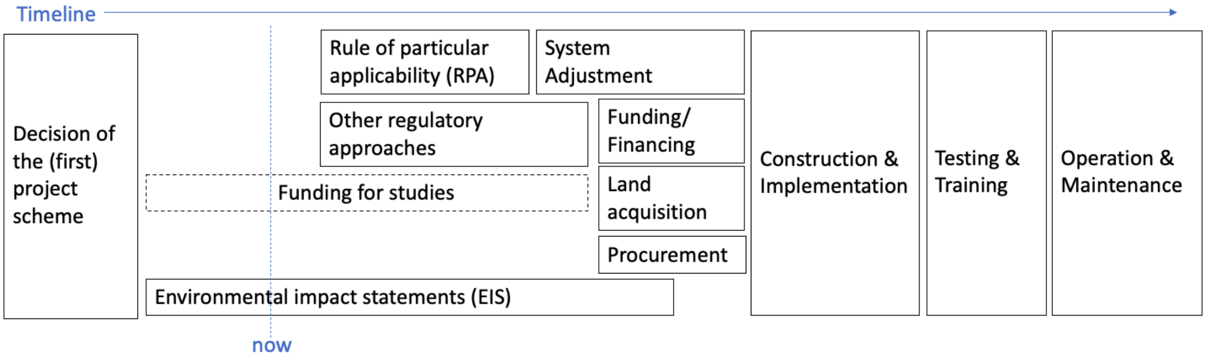


Figure 9: Assumed process decomposition of the current NEC SCMAGLEV project

Note: The applicability of RPA will be discussed later.

Note: This chart is a selection of primary elements and does not completely cover the entire project

According to the Promoting company, current status of the project study activity is after the DEIS.[23]. So, in the chart, there is indicator for the current status indicated as “now”.

System adjustment that reflects the results of EIS, regulatory approaches and compliance may be necessary. As mentioned in the literature review part (Chapter 2), although it can be said that the fundamental research and development of the SCMAGLEV system itself has been completed for the Chuo Shinkansen project in Japan, some system adjustment including system definitions may be necessary in the sense to comply with the requirements in the US.

Before the construction and system implementation, some main processes other than regulatory approaches and system adjustment are essential. Beyond research activities, the Funding/Finance process, which involves identifying and raising funds to physically realize a project, is essential. As is the fate of large-scale infrastructure projects, land acquisition will be necessary, depending on alignment identified through processes such as environmental impact assessments. This process is also inevitable before the actual construction work begins. It is also assumed that it is necessary to begin developing a procurement strategy at this point to ensure smooth construction and system implementation.

Additionally, “Testing & Training" is defined here as an important phase between the "Construction & Implementation" phase, which is the physical realization of the project, and "Operation & Maintenance", which is the ultimate goal of actually providing high-speed rail service. This phase is essential for safety and reliable service and railway operation.

4.4 Theoretical scheme and partnership options of the NEC SCMAGLEV project

In the previous section, we organized the process decomposition of the NEC SCMAGLEV project. For each of the elements decomposed there, there is a wide range of options regarding how to execute each main process. Regarding the discussion about the project scheme, here we will try to put many options on the table. It is mentioned here regardless of whether it is used in an actual project. In the following table, we identify and evaluate scheme options. First, organize what kind of items we can think of and what processes they will relate. Next, we will explain the evaluation taking into consideration system characteristics. Based on this, we will show what kinds of scheme options may remained out of theorical options.

4.4.1 Theoretical scheme options

First, we will identify the theorical options with related discussion items as following.

Table 1: Theoretical scheme options of the NEC SCMAGLEV project

Discussion items whether to adopt	**Related processes**	**Theoretical options**
• Separation of upper and lower railway operating system	• Operation & Maintenance	• Separation of upper and lower railway operating system • Integration of upper and lower railway operating system
• PPP (Public Private Partnership) approach	• Construction & Implementation • Operation & Maintenance	• PPP • Non-PPP (Purely private project)
• System adjustment	• System Adjustment	• With system adjustment • Same system as in Japan (As it is)
• US government loan and/or grant	• Funding/Financing	• include US government loan and/or grant in the fundraising • Not include US government loan and/or grant in the fundraising
• Procurement localization	• Procurement	• Complete procurement localization • Partial procurement localization • No procurement localization

4.4.2 Evaluation for each discussion item whether to adopt

Separation of upper and lower railway operating system

In railway operations in Europe and the United States, it is common to separate the entity that owns and manages the tracks and station buildings from the entity that manages the rolling stock and operation services. However, this way of thinking does not suit the operation of SCMAGLEV system. This is because control, including power supply, propulsion/braking mechanisms, and safety measures, is performed only when the infrastructure on the ground and the SCMAGLEV vehicle are operated with integration. Therefore, to put it simply, the Separation of upper and lower railway operating system is not adopted in SCMAGLEV, which uses the guideway system, which is dedicated ground equipment. Only the integration of upper and lower railway operating system will be adopted.

PPP (Public Private Partnership) approach

A public-private partnership (or PPP) approach is a cooperative arrangement between the public and private sectors that is commonly used to fund infrastructure projects. We will take Maryland's Purple Line as an example of the PPP project [24]. According to the Purple line, the basic structure of their PPP scheme is as following: MDOT MTA (Maryland Department of Transportation Maryland Transit Administration) retains ownership of the Purple Line. The Concessionaire is comprised of three main teams:

- Purple Line Transit Partners (PLTP) – responsible for the overall project, including financing and management of:
- Maryland Transit Solutions (MTS) – responsible for the design and construction of the Purple Line.
- Purple Line Transit Operators (PLTO) – will take over to operate and maintain the Purple Line for 30 years after completion.

We can read that the Maryland state pursued a PPP model to design, build, finance, operate and maintain the Purple Line in an effort to reduce costs and pass off some of the risk to private partners.

When considering the SCMAGLEV project, the first stage is a project that aims to be implemented between Washington and Baltimore, so the target public institutions (states) are limited. However, when considering the ultimate goal of extending the project to New York state in the future, it is necessary to construct a project scheme that spans multiple other states. Therefore, from the perspective of unifying the entities responsible for ownership and over-role projects, it is assumed that the hurdles for a public institution (state) to become a unified top entity are high. Looking at the actual project progress, the current policy of the promotion company is that the SCMAGLEV project between Washington DC and Baltimore will be owned and operated by the franchised railroad company in the private sector.

However, the larger the project, the greater the benefits of PPPs, which can divide up risks and responsibilities. It is also possible that having a public institution involved in the project's implementation could be advantageous in terms of fundraising (and interest). Therefore, not only the non-PPP but also PPP scheme will be considered here.

As seen in the Purple Line example above, there are many examples of role sharing, such as "Overall project management including financing responsibility", "Design and construction responsibility" and "Service operation and maintenance responsibility" can be options of the business decompositions.

System adjustment

Adopting the whole system of high speed rail as it is one of the most easiest approach in theory. Here, the total system is including civil engineering structures, signal equipment, rolling stock, operation management system, repair and maintenance proven and safety track record in Japan.

However, in realistic, because of the difference of the regulations, standards, cultures between the US and Japan, a certain level of adjustment is undeniable. And one change is not independent. As a system-wide approach, system adjustments must be made with an additional perspective of how other parts also need to respond to even the change. Therefore, we define system adjustment here as something that needs to be realistically incorporated into the process.

US government loan and/or grant

Possible future funding sources at this stage are not limited to a narrow range. According to the promoting company, they give examples of the finance from Japan, U.S. government loan and grant programs, and the private sector. [25]. So, we remain the both options from the following: "Include US government loan and/or grant in the fundraising" and "Not include US government loan and/or grant in the fundraising"

Procurement localization

As mentioned in the system adjustment section above, adopting the whole system of high speed rail as it is one of the easiest approach in theory. However, due to multiple factors such as regulations and requirements in the United States, the country where the system will be introduced, as well as indicators such as economic efficiency and economic effects, it is undeniable that some parts will be locally procured.

On the other hand, the core technology of the SCMAGLEV system, which is extremely unique, is expected to include many things that cannot be replaced, so it is unlikely that everything will be locally procured in the United States. Thus, the option of completely locally procurement is excluded from system characteristics.

4.4.3 Remained theoretical scheme options

Based on the discussion in the previous section, we will again define the remaining theorical options as following.

Table 2: Update of Remaining Theoretical Options

Discussion items whether to adopt	Related processes	Remained theoretical options
• Separation of upper and lower railway operating system	• Operation & Maintenance	• Integration of upper and lower railway operating system
• PPP (Public Private Partnership) approach	• Construction & Implementation • Operation & Maintenance	• PPP • Non-PPP (Purely private project)
• System adjustment	• System Adjustment	• With system adjustment • Same system as in Japan (As it is)
• US government loan and/or grant	• Funding/Financing	• Include US government loan and/or grant in the fundraising • Not include US government loan

		and/or grant in the fundraising
• Procurement localization	• Procurement	• Partial procurement localization • No procurement localization

4.5 Theoretical business decomposition of the NEC SCMAGLEV project

From the partnership/scheme analysis carried out in the previous section, a major turning point in the options when conducting business decomposition is whether to choose a scheme that considers PPP or a scheme that is purely led by the private sector. This is a particularly big turning point because it fundamentally relates to who will be the owner of the railway assets, i.e., who will be the client of the project including the construction work.

Also, as mentioned in the Stakeholder Study section, we have also learned about the current progress of the NEC SCMAGLEV project. If we were to divide the project into major elements, we could roughly divide it into the following four phases:

- System Definition and Adjustment Phase
- Preparation and System Design Phase
- Construction/System Implementation Phase
- Operation & Maintenance Phase

We will consider theoretical business decomposition. In theoretical business decomposition, we organize the necessary roles for each phase. The basic idea is that one company or multiple teams will fit into each role.

Here, only the System Definition and Adjustment Phase is written in a deterministic way because the model project is underway and the companies and entities that will take on these roles are clear. In contrast, from the subsequent Preparation and System Design Phase onwards, each role is expressed as one in which any company could fit, or there are multiple possible candidates.

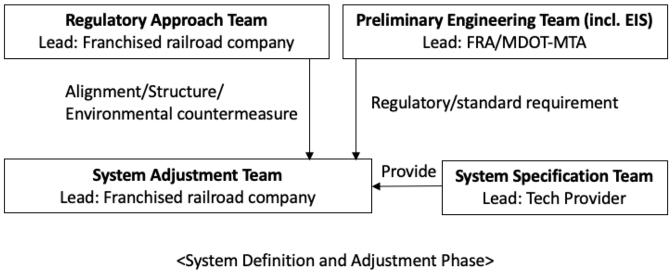


Figure 10: Business decomposition in the system definition and adjustment phase

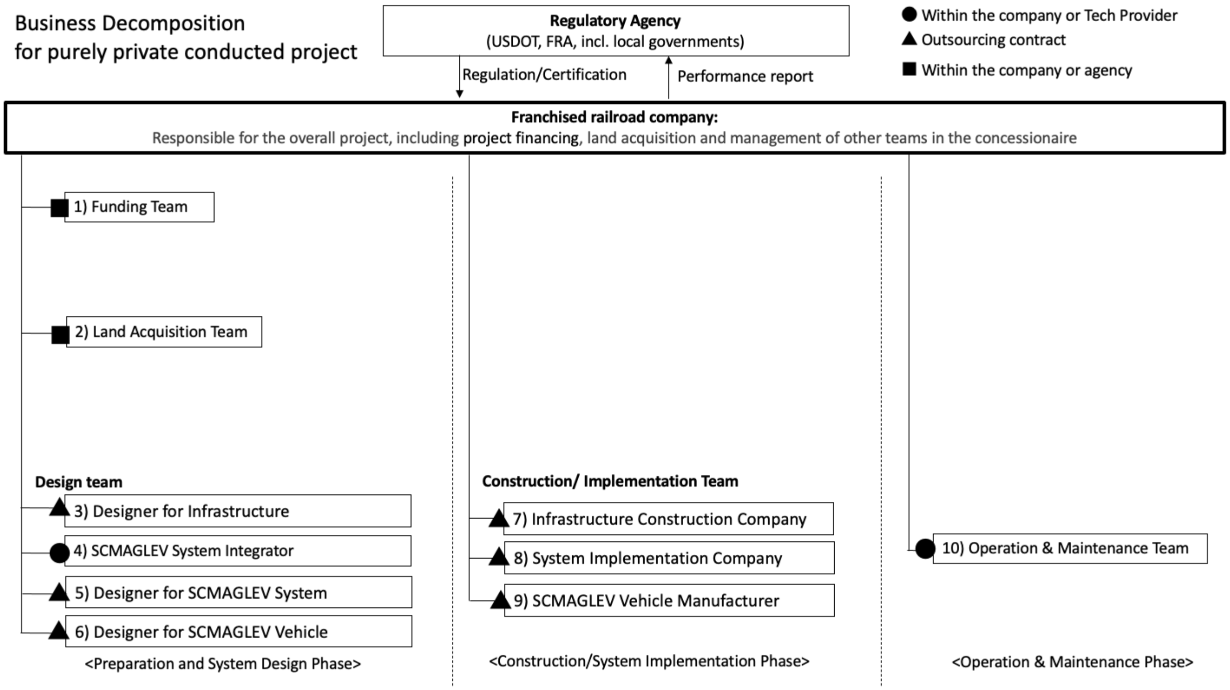


Figure 11: Business decomposition for purely private conducted project case after Preparation and System Design Phase

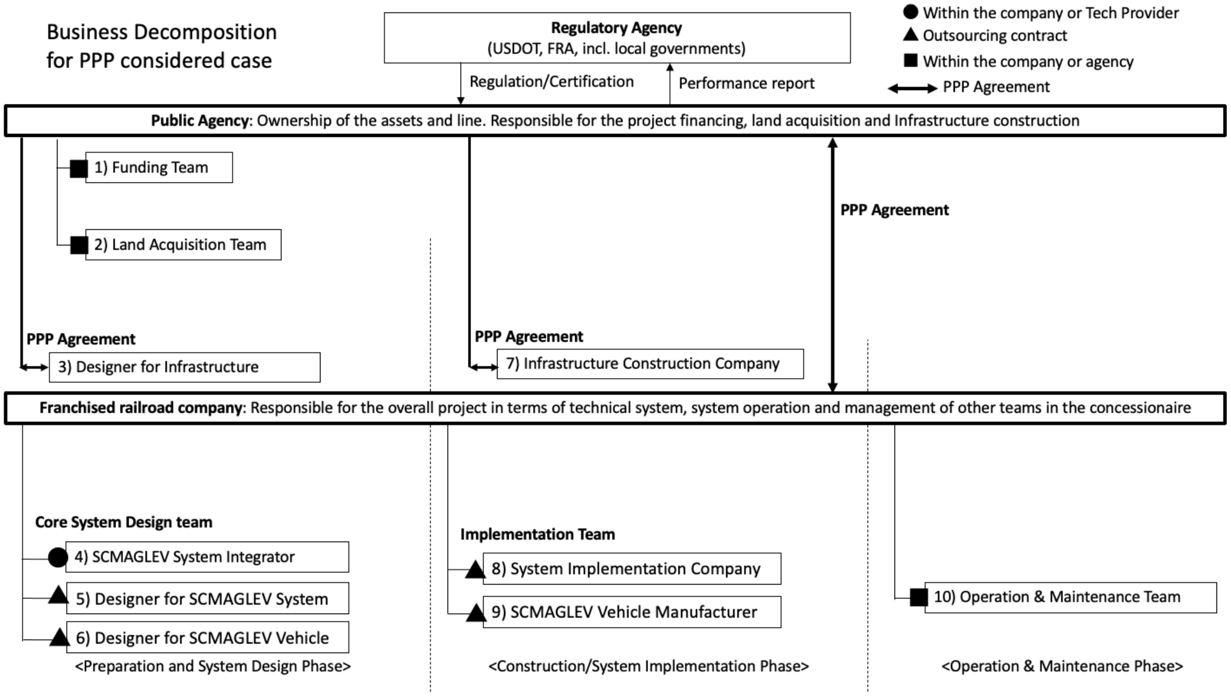


Figure 12: Business decomposition for PPP considered case after Preparation and System Design Phase

Note: This is a business decomposition assuming the Phase 1 Washington-Baltimore project

4.6 Differences in regulations and standards that cause system differences between high speed rail system in Japan and the United States

4.6.1 Introduction

Even when the same systems and services are targeted, the regulations and standards that apply to them often differ from country to country. Here, we will summarize the regulations and standards that can affect both the system and the project scheme, and consider how they can affect SCMAGLEV, a unique high-speed rail system.

The main focus system of this paper is the SCMAGLEV system. As explained in the introduction part (Chapter 1), the SCMAGLEV system being developed by JR-Central is based on the safety technology, culture, and operations that they have cultivated over more than 50 years of safe operation of Japan's Tokaido Shinkansen. Shinkansen and SCMAGLEV have many things in common. In particular, the concept of accident/collision avoidance, which forms the basis of safe operation, is quite important, and is a philosophy inherited from the Tokaido Shinkansen to SCMAGLEV.

4.6.2 Texas RPA

Here, we will explain the ongoing Texas High Speed Rail Project, which is another high-speed rail project in the United States that utilizes JR-Central's Tokaido Shinkansen technology. The project is being developed by Texas Central Railroad (TCRR) [26], an American private company, and is planned to connect Dallas and Houston over a distance of approximately 385 km in approximately 90 minutes at a maximum speed of 200 miles per hour. The plan is to introduce the technology and safety of the Tokaido Shinkansen to Texas, USA.

For this Texas high-speed rail project, 49 CFR Part 299 “Texas Central Railroad High-Speed Rail Safety Standards” [27], which took effect in December 2020, will apply. This applies to the Rule of Particular Applicability, which is a special FRA regulation that applies only to this Texas projects. This is the first time FRA has enacted RPA. From now on, it will be referred to as Texas RPA in this paper.

General railroad safety regulations in the United States include the FRA's regulations regarding system specifications, such as the following:

- 49 CFR Part 213 Track Safety Standard
- 49 CFR Part 236 Signal and Train Control System, Devices, and Appliances
- 49 CFR Part 238 Passenger Equipment Safety Standard

In the above-mentioned regular regulations, the classes from Tier I to Tier III for passenger rail vehicles are defined as follows. [28]

- *Tier I means operating at speeds not exceeding 125 mph.*
- *Tier II means operating at speeds exceeding 125 mph but not exceeding 160 mph.*
- *Tier III means operating in a shared right-of-way at speeds not exceeding 125 mph and in an exclusive right-of-way without grade crossings at speeds exceeding 125 mph but not exceeding 220 mph.*

Here, we will compare the compression load requirement and collision resistance requirement against collisions between trains in the vehicle structure as a representative example of Tier III and Texas RPA, which are classified into the same speed zone.

Table 3: Compression load requirement and collision resistance requirement

Trainset structure section	Tier III (§238. 703 & 705)	Texas RPA (§299.403)
Compression load requirement	1500kN [29]	980kN
Collision resistance against collisions between trains (Dynamic collision scenario)	With requirement	No requirement regarding train-to-train collisions in the trainset structure section. (*) Note: In other section, mainline mode of the ATC (Automatic Train Control) on-board equipment shall provide the following functions: (A) Prevent train-to-train collisions; and (B) Prevent overspeed derailments

(*) Note: dynamic collision scenario analysis using the 14,000-lbs steel coil scenario for potential hazards that might be present on the TCRR ROW (e.g., feral hogs, stray livestock, unauthorized disposal of refuse) is required in this section.

From the table above, it can be seen that the concept of required crashworthiness differs between Tier III vehicles and Texas RPA vehicles. This Texas RPA includes elements that ensure safety through accident/collision avoidance. In other words, Texas RPA includes multiple elements of the principle of accident avoidance, which is the basis of safety on the Tokaido Shinkansen. Examples include “System’s designated right-of-way (shall be permanently fenced)”, “No grade crossings”, “Distinction between service hours and maintenance hours”, “Training program”, and “Service proven Train Control System”. Considering that these comprehensive actions ensure safety throughout the system and avoid accidents and collisions, the requirement level required for the strength of the Trainset structure in Texas RPA has become easier.

A comprehensive approach is essential, and especially Tokaido Shinkansen's ATC system, a service-proven control system, is one of the most important as it directly prevents train-to-train collisions. When we applied STPA (Systems-Theoretic Process Analysis) to this essential system, ATC, and the operators that handle it (Appendix A), we obtained the following results. Most of the UCAs and recommendations mentioned in this STPA analysis are all covered by the current Tokaido Shinkansen system with well-trained operators, and we can definitely say that very strong safety is guaranteed. Through a total approach including highly reliable ATC, the level of accident/collision avoidance has been raised, and it can be said that it is also recognized in the rulemaking in the United States.

Additionally, the Japanese-style high-speed rail system, which ensures safety through a total approach, has the general advantage of lighter rolling stock, which in turn allows for the slimming down of infrastructure structures. This is supported by small numbers for compression load requirement and collision resistance against collisions between trains.

4.6.3 Potential of SCMAGLEV RPA

After the FRA issued the first RPA for Texas, now the new classification called Tier IV is proposed in the Notice of proposed rulemaking (NPRM) for the "Passenger Equipment Safety Standards; Standards for High-Speed Trainsets". The proposed definition is a below [30].

Tier IV system means any railroad that provides or is available to provide passenger service using non-interoperable technology that operates on an exclusive right-of-way without grade crossings, not comingled with freight equipment or Tier I, II, or III passenger equipment, and not physically connected to the general railroad system.

SCMAGLEV system is quite different from conventional rail. For example, trainsets are not interoperable with other trainset types, as they propel based on the relationship between the vehicle and ground equipment with such as power supply through a coil embedded in the guideway, Also, trainsets operate at 500 km/h (311mph) in excess of the current regulations (i.e., Tier I, Tier II, Tier III). Thus, this SMAGLEV system seems to be classified as future Tier IV and a total system approach is required to introduce the system in the US. This means that similar to Texas RPA, the NEC SCMAGLEV project also indicates that a future RPA petition is likely.

4.6.4 Regulations and standards to be considered

The technical standards for railways in Japan are based on the Ministerial Ordinance to Provide the Technical Standard on Railway [31]. Additionally, the Technical Regulatory Standards on Japanese Railways [32] provides more detailed guidelines.

This time, we will compare these Japanese technical standards with the FRA regulations in the United States explained in the previous section, and compare them with the results of the Texas RPA to organize standards that should be mainly considered in the NEC SCMAGLEV project in the future.

The following is the examples of the regulations and standard to consider for the NEC SCMAGLEV project.

FRA’s regulations: Regulations for the railroad system. Possibly covered by Petition of Rule of Particular Applicability (RPA)

Americans with Disabilities Act (ADA): Facilities for people with disabilities

National Fire Protection Association (NFPA) 130: Fire emergency response equipment (evacuation, fire prevention/fireproofing, etc.)

American Association of State Highway and Transportation Officials (AASHTO) standard: Earthquake response

Federal Communications Commission (FCC)’s standard: Regulations for communications by radio, television, wire, satellite, and cable across the United States

National Environmental Policy Act (NEPA): Environmental impact statement

Build America Buy America Act: Domestic content procurement preference for the case where government loan applies. Also, may need to consider the exception cases: Public interest, Non-availability, Unreasonable cost.

The interpretation of these regulations/standards when applied to the SCMAGLEV system and project is shown below.

Table 4: Interpretation of key regulations/standards

Regulations or standards	Issues and viewpoints when applied to the SCMAGLEV system and project
FRA’s regulations	・ General railroad safety regulations in the United States include the FRA's regulations regarding system specifications, such as the following: ➢ 49 CFR Part 213 Track Safety Standard ➢ 49 CFR Part 236 Signal and Train Control System, Devices, and Appliances ➢ 49 CFR Part 238 Passenger Equipment Safety Standard ・ Since SCMAGLEV is a proprietary and standalone system, areas that cannot be addressed by design changes are possibly covered by Petition of Rule of Particular Applicability (RPA).
Americans with Disabilities Act (ADA)	・ The Americans with Disabilities Act (ADA) prohibits discrimination against people with disabilities in several areas, including

	employment, transportation, public accommodations, communications, and access to state and local government' programs and services. ・ There are a wide variety of items to consider, but it is expected that this will be particularly referred to when considering wheelchair-friendly seating arrangements and in-car facilities, including toilets.
NFPA 130	・ Compliance with fire emergency response equipment regulations is defined. Specifically for evacuation in vehicles and on tracks, as well as fire prevention/fireproofing of equipment may be adopted appropriately.
AASHTO standard	・ AASHTO is the standard-setting organization for highway standards, and all highways in the United States are designed and constructed in accordance with standards set by this association. Furthermore, this association sets standards not only for expressways, but also for air, rail, maritime, and all other forms of public transportation. ・ In particular, it is expected that reference will be made to seismic design standards for infrastructure, and differences in earthquake standards between Japan and the United States will be taken into consideration.
FCC's standard	・ Possibility for compatible with different radio bands ・ Assumed that differences in standards and radio bands between Japan and the United States will be taken into consideration
National Environmental Policy Act (NEPA)	・ The project will have gone through the following main processes. 1)Preliminary Alternatives Screening Report, 2) Alternative Study, 3) Draft EIS, 4) Final EIS and 5) Record of Decision. ・ Through this EIS process, the important alignment and structure allocation for the project will be decided, as well as the extent to which environmental measures will be introduced.
Build America Buy America Act (BABA)	・ Domestic content procurement preference for the case where government loan applies. ・ On the other hand, also may need to consider the exception cases: Public interest, Non-availability, Unreasonable cost. ・ This may affect to the procurement strategy including the localizing

5 Modeling

5.1 Modeling of technical system model

We will create a technical system model for SCMAGLEV, an integrated technology, using the main system decompositions outlined in the previous chapter and the regulations that affect them as requirements.

The basic concept is to enter or select options in each system decision for the main elements as inputs, and then obtain costs, train capacity, etc. as outputs from the model.

5.1.1 The model building process of the technical system model

The actual model building process is as follows.

Step 1: Calculate the baseline cost for the system and project

We estimated a rough cost breakdown using the overall cost disclosed in the ongoing environmental impact assessment (DEIS [33]) of the NEC SCMAGLEV project and construction-related information for Japan's Chuo Shinkansen [34] to know the rough disassembly cost.

According to the promoting company, the total project cost is expected to be around 10 billion yen, depending on future decisions on the alignment, so we used this as a reference to get a sense of the scale and added the necessary elements.

Step 2: Make "System Design Decisions"

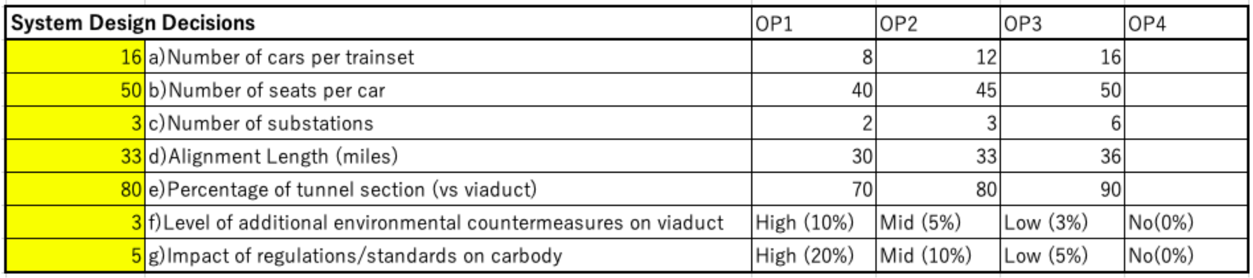
Design decisions in this model is made based on the following carefully selected elements.

- Number of cars per trainset
- Number of seats per car
- Number of substations
- Alignment Length (miles)
- Percentage of tunnel section (vs viaduct)
- Level of additional environmental countermeasures on viaduct
- Impact of regulations/standards on carbody

As inputs into the model, we select options within each system decision. As summarized in the previous section, due to the influence of different laws across countries, it was found that many regulations could affect the adjustment of the SCMAGLEV system. The system decisions which are likely to have a particularly large impact from the regulations were incorporated into the system decision of this model. The level will change depending on future discussions with regulatory authorities in the real world, but as inputs into the model and combination of those could be limited (like as constraints). In other words, we decided to extract and take into consideration the regulations/standards discussed in the previous section that have a particularly large impact on system definition.

By inputting numbers from each option, the output can be obtained. The table below shows an example of input and options.

Table 5: Example of input and options for the System Design Decisions in the technical system model



System Design Decisions		OP1	OP2	OP3	OP4
16	a)Number of cars per trainset	8	12	16	
50	b)Number of seats per car	40	45	50	
3	c)Number of substations	2	3	6	
33	d)Alignment Length (miles)	30	33	36	
80	e)Percentage of tunnel section (vs viaduct)	70	80	90	
3	f)Level of additional environmental countermeasures on viaduct	High (10%)	Mid (5%)	Low (3%)	No(0%)
5	g)Impact of regulations/standards on carbody	High (20%)	Mid (10%)	Low (5%)	No(0%)

Note: c) is assumed to be related to maximum and stable operation service frequency for the SCMAGLEV.

Step 3: Define the output and creating a formula

<Output group 1: Total CAPEX + breakdown cost>

This system model makes it possible to calculate the planned costs for a project. In addition to the cost of the vehicle and system, this also includes infrastructure costs, expected land costs, and design costs. These are defined as the total CAPEX. Also, by using the ratio of the decomposed base cost explained in the previous section to the overall estimated cost, it is possible to obtain not only the total CAPEX but also costs decomposed into a certain number of elements as output. In other words, the model expresses in mathematical form how the originally estimated base cost changes depending on the input options (system design decisions).

Total CAPEX

1) Infrastructure cost
    1-1) Tunnels and Viaducts
    1-2) Stations, Depots, and Buildings
2) System cost
    2-1) Power plant and Substation cost
    2-2) Others
3) Vehicle cost
4) System integration costs
5) Land acquisition cost

6) Design cost
    6-1) Infrastructure design cost
    6-2) System design cost
    6-3) Vehicle design cost

<Output group 2: Unit OPEX (per one trainset running)>

As another output, we defined unit OPEX, which is the cost of operation and maintenance converted into a unit per train run as a cost related to operations and maintenance.

Unit OPEX can be broken down into the following:

- OPEX Labor Costs per one trainset running
- OPEX Energy Costs per one trainset running
- OPEX Maintenance Costs per one trainset running

In terms of formulas, for example, the formula expresses how energy consumption changes depending on the number of cars per train.

<Output group 3: Max Capacity/day>

As the related to the operation plan which affect mainly the business plan, the number of passengers that can be transported per unit time (for example, the number of passengers that can be transported per day) is extremely important. Here, we defined operation hours/day as 18 hours (6AM-12PM) and modeled it to obtain the following output.

- Stable Operation Frequency/hour
- Total Operation Train Service/day
- Passenger Capacity Limit/trainsets
- Max Capacity/day

As an example of a mathematical relationship, Passenger Capacity Limit/trainsets can be calculated by multiplying the Number of cars per trainset and the Number of seats per car, which are in the inputs.

5.1.2 Model output as API (Application Programming Interface)

The outputs from the technical system model described in this chapter will be used as inputs for future business model integration models and uncertainty analysis models.

5.2 Modeling of business model

The main foundation of the business model is the business decomposition diagram created from the analysis results in the previous chapter. The business model will be constructed from the Preparation and System Design Phase onwards, which offers a range of options.

5.2.1 Preparation of the business model

<Regulation influence>
The biggest influence of regulations is the Build America Buy America Act (BABA). When government capital is received, the model defines local production as a necessity in procurement plans.

<Contract method before the operation starts>
Regarding the method of outsourcing contracts at the design and build stage (D/B), when calculating the "project cost" of such a large-scale project, it is common to include the cost of outsourcing (i.e., the contractor's profit) in the calculation. Therefore, in this model, we decided to adopt the "Cost including fee" method for the Contract Method (D/B). This is also applying to the system integrator role which the either of franchised railroad company or the tech provider company does.

Cost including fee method: Since design-build (implementation) is based on the premise of outsourcing from the beginning, we will assume that the cost was calculated based on a price that includes the contractor's profit and set this as the contract amount. In this case, we will calculate by setting the contractor's profit at 10% (contractor’s payment is 0.9 times of contractor’s income).

<Contract method after the operation starts>
In the model, we choose between the following two methods.

Cost plus fee method: Regarding operation, we assume that outsourcing is not planned from the start, and the contract amount with the contractor will be the planned operation and maintenance costs plus a 10% fee in this model.

Passenger revenue distribution method: The expenses for the contractor will be operation and maintenance costs, and the revenue for the contractor will be a "certain percentage of passenger revenue" determined in advance by the contract.

The above discussion is reflected in the business decomposition diagram from the previous chapter as shown below. How to think about contract methods and procurement plan were added to the figures.

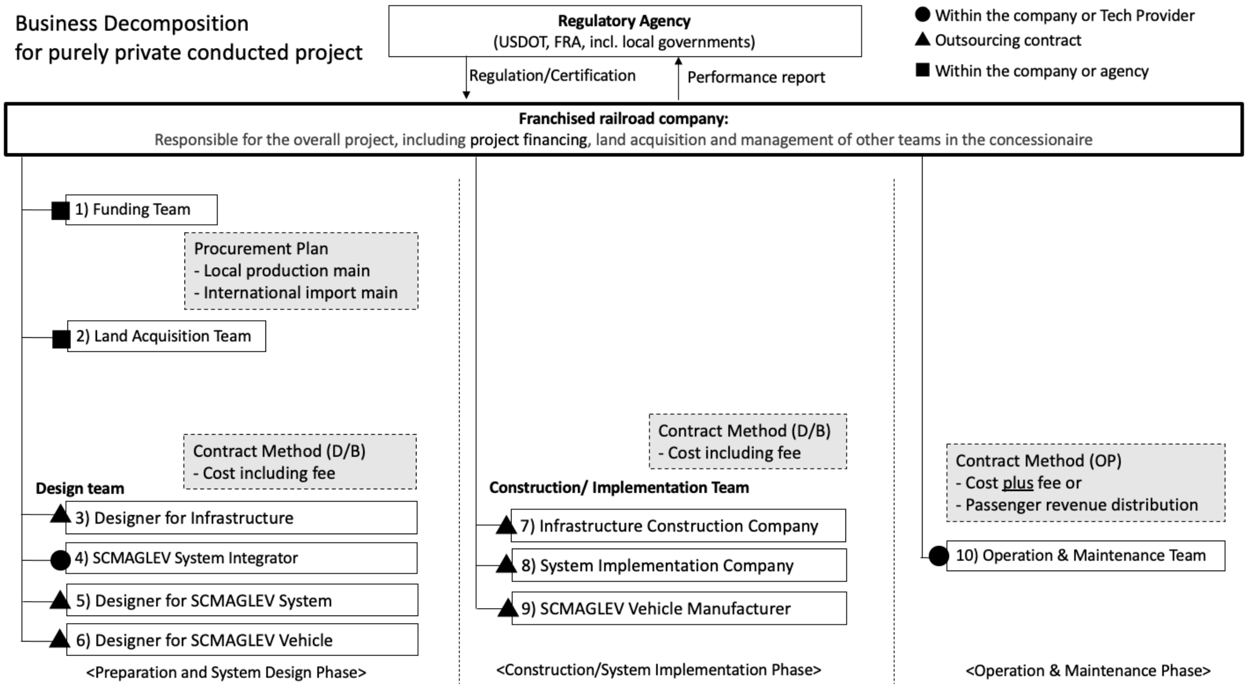


Figure 13: Business decomposition for purely private conducted project case with contract methods

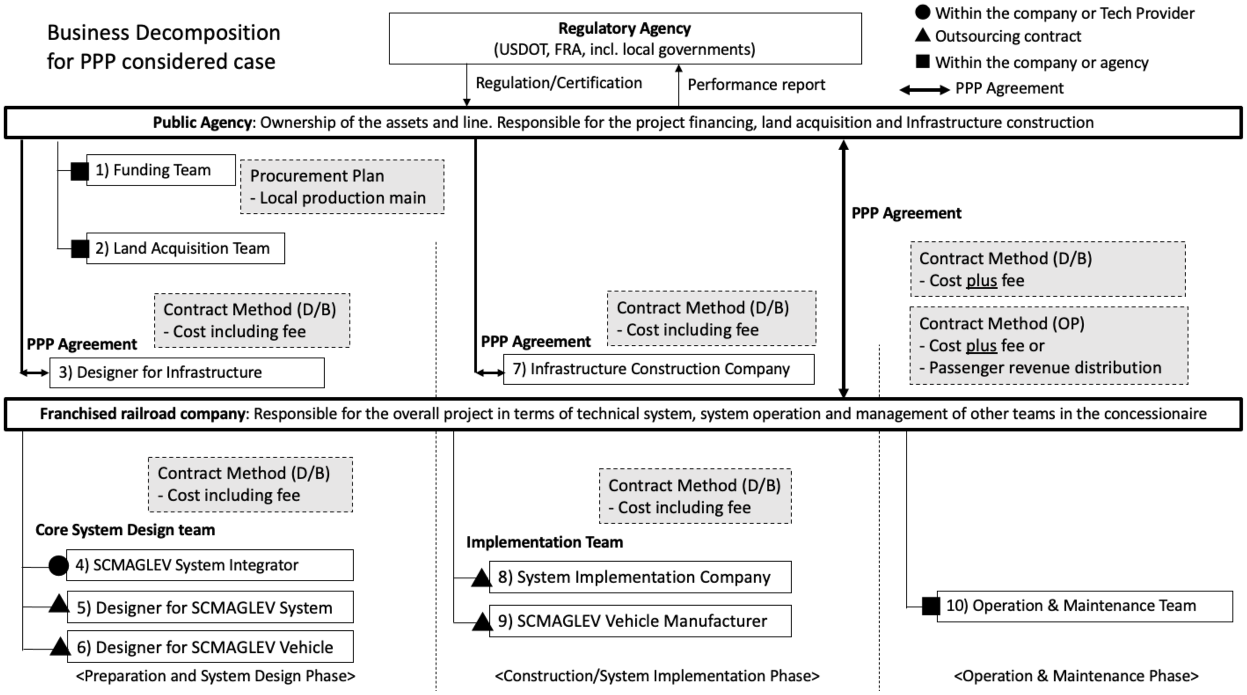
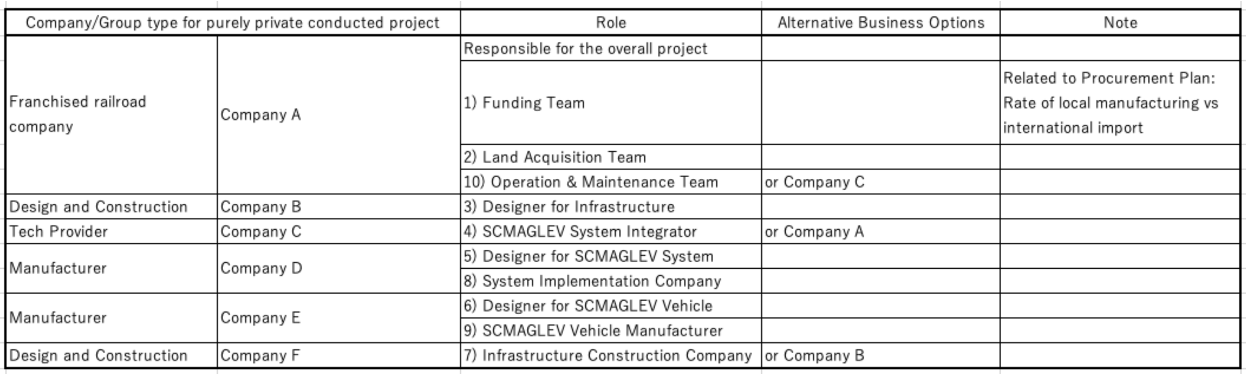


Figure 14: Business decomposition for PPP considered case with contract methods

5.2.2 Company/Group type, Alternative Business Options, and model input

The following table shows what type of companies (groups) can take on each role based on the business decomposition diagram with contract method in the previous section. If other companies can take on the role as an alternative business plan, it is also shown.

Table 6: Company/Group type and roles with Alternative Business Options



Company/Group type for purely private conducted project		Role	Alternative Business Options	Note
Franchised railroad company	Company A	Responsible for the overall project		
		1) Funding Team		Related to Procurement Plan: Rate of local manufacturing vs international import
		2) Land Acquisition Team		
		10) Operation & Maintenance Team	or Company C	
Design and Construction	Company B	3) Designer for Infrastructure		
Tech Provider	Company C	4) SCMAGLEV System Integrator	or Company A	
Manufacturer	Company D	5) Designer for SCMAGLEV System		
		8) System Implementation Company		
Manufacturer	Company E	6) Designer for SCMAGLEV Vehicle		
		9) SCMAGLEV Vehicle Manufacturer		
Design and Construction	Company F	7) Infrastructure Construction Company	or Company B	

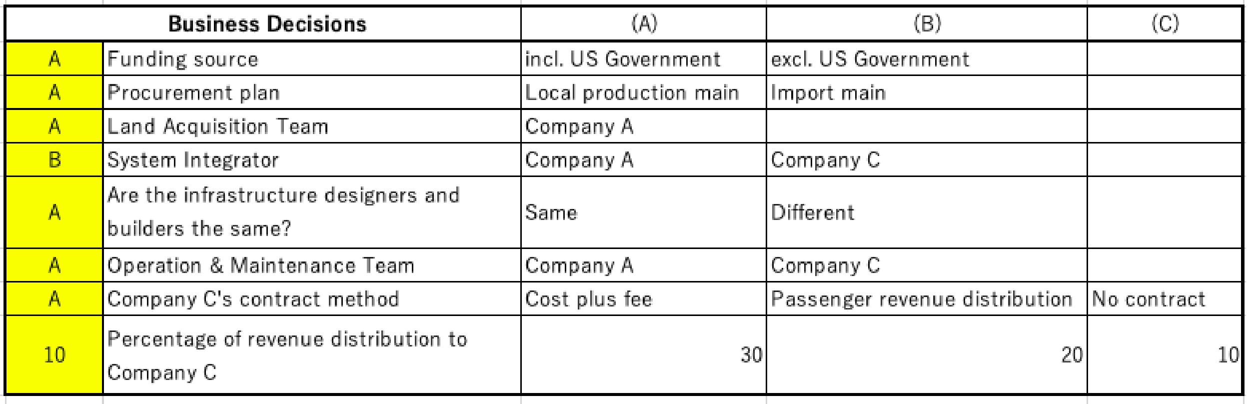
This will also be done in the case where PPP is taken into consideration.

Furthermore, from now on, the roles will be assigned to the following companies as follows:

- Franchised railroad company: Company A
- Design and Construction: Company B
- Tech Provider: Company C
- Manufacturer: Company D
- Manufacturer: Company E
- Design and Construction: Company F

The following table converts the above discussion into business decision options and inputs. By adding alphabets to the options, you can connect them to the outputs, which will be explained later.

Table 7: Example of Business Decisions Input



Business Decisions		(A)	(B)	(C)
A	Funding source	incl. US Government	excl. US Government	
A	Procurement plan	Local production main	Import main	
A	Land Acquisition Team	Company A		
B	System Integrator	Company A	Company C	
A	Are the infrastructure designers and builders the same?	Same	Different	
A	Operation & Maintenance Team	Company A	Company C	
A	Company C's contract method	Cost plus fee	Passenger revenue distribution	No contract
10	Percentage of revenue distribution to Company C	30	20	10

Each business decision input has associated guidance, such as the following, which determines the factors that will affect adjustments to the base price and phase duration. These examples show for the output generator for the purely public conducted business model.

<Funding source>

- If A, the procurement plan must be local main.
- If A, the interest is lower than B.

<Procurement plan>

- If A, +0.5 year for the Preparation and System Design Phase
- If B, CAPEX of vehicle cost and CAPEX of system cost will be increased by 10 percent.

<Land Acquisition Team>

- If A, +0.5 year for the Preparation and System Design Phase

<System Integrator>

- If A, +0.5 year for the Preparation and System Design Phase

<Are the infrastructure designers and builders the same?>

- If B, the cost paid for the company B will be increased by 50 percent.

Other factors that the model takes into account include the relatively longer time required for project implementation when PPP options are considered. Due to the difficulty in management due to an increase in participating organizations. For instance, the infrastructure design & construction, and the system design & implementation needs to be adjusted.

5.2.3 Integration with Technical System Model and generated output

As explained in the previous section, the key to calculating the output is to mathematically reflect the modifications associated with each business decision and the contracts and methods.

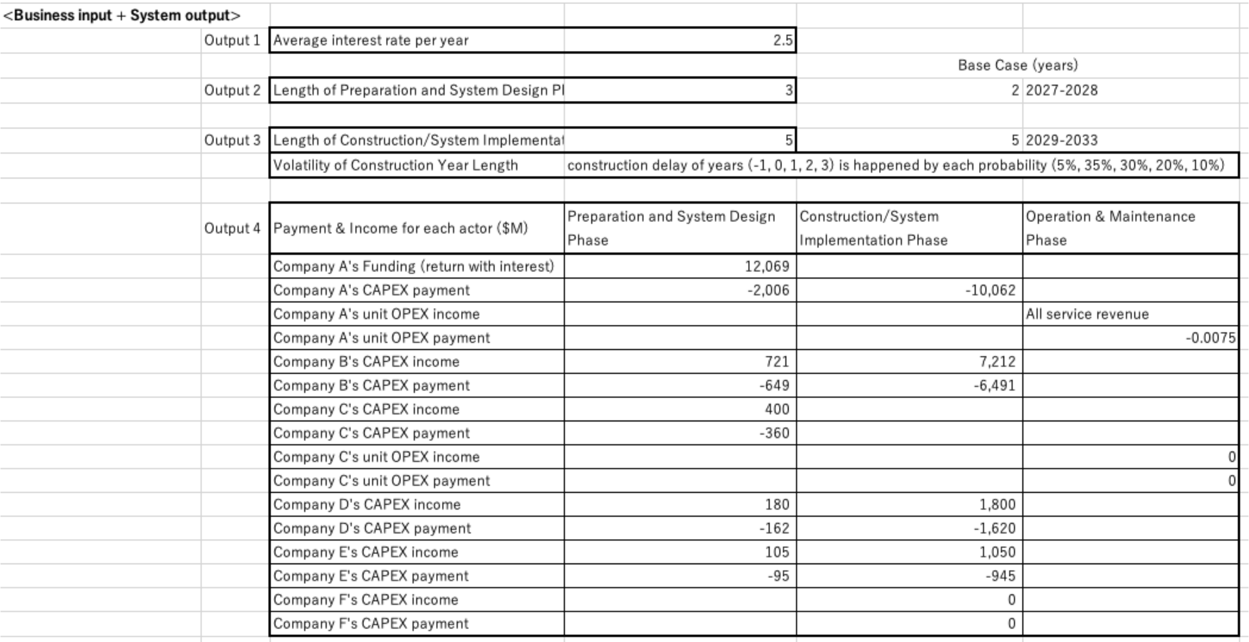
The costs (CAPEX and OPEX) corresponding to the system choice are obtained from output group 1 and output group 2 of the technical system model. Therefore, here, the input (selection) of the business model and the output of the technical system model are integrated and calculated.

Through this, the following set of figures for the countless combinations of options are obtained as the output of the integration of the business model and the system model.

- Length of each project phase
- Each stakeholders' planned payment and income in each phase

Following table shows an example of the model output, which eventually model input for the next uncertainty analysis

Table 8: Example of the model output integrated business model's input and system model's output



<Business input + System output>					
	Output 1	Average interest rate per year	2.5		
				Base Case (years)	
	Output 2	Length of Preparation and System Design Pl	3	2	2027-2028
	Output 3	Length of Construction/System Implementat	5	5	2029-2033
		Volatility of Construction Year Length	construction delay of years (-1, 0, 1, 2, 3) is happened by each probability (5%, 35%, 30%, 20%, 10%)		
	Output 4	Payment & Income for each actor ($M)	Preparation and System Design Phase	Construction/System Implementation Phase	Operation & Maintenance Phase
		Company A's Funding (return with interest)	12,069		
		Company A's CAPEX payment	-2,006	-10,062	
		Company A's unit OPEX income			All service revenue
		Company A's unit OPEX payment			-0.0075
		Company B's CAPEX income	721	7,212	
		Company B's CAPEX payment	-649	-6,491	
		Company C's CAPEX income	400		
		Company C's CAPEX payment	-360		
		Company C's unit OPEX income			0
		Company C's unit OPEX payment			0
		Company D's CAPEX income	180	1,800	
		Company D's CAPEX payment	-162	-1,620	
		Company E's CAPEX income	105	1,050	
		Company E's CAPEX payment	-95	-945	
		Company F's CAPEX income		0	
		Company F's CAPEX payment		0	

5.3 Uncertainty Analysis Model

5.3.1 Overview and assumptions

For the NEC SCMAGLEV project between Baltimore and Washington, we will conduct a timeline-based financial analysis of the scenarios (many combinations of options) generated using the business system integration model we have built so far.

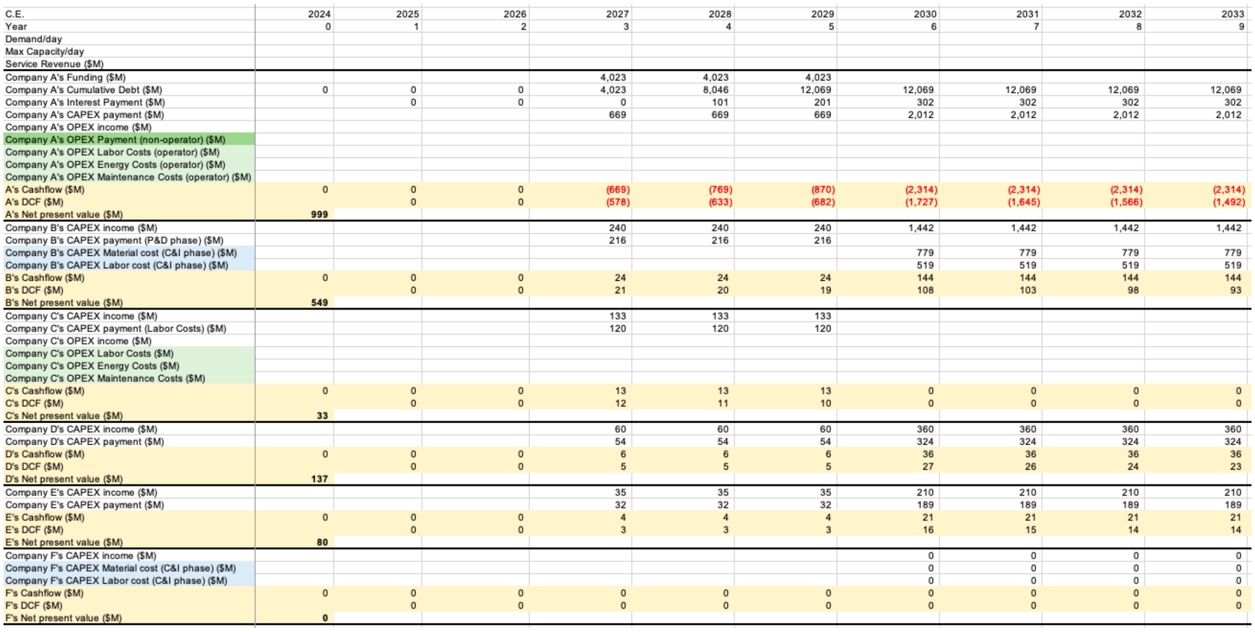
An excel-based model is created using a ground-up approach to approximate the Net Present Value (NPV) of the entire site using a Discount Cash Flow (DCF) methodology. It is expected that the amount of money (payment and income) for each stakeholder will be reflected from the Preparation and System Design Phase onwards, which is the next phase where actual project funds are required.

Representative assumptions are as follows:

- Evaluation period: Next 40 years (2024 is year 0)
- Discount rate in the model is 5 percent.
- Assumed average ticket price: $60/per passenger
- Demand: 53,000 passengers/day in 2035 [35]
- Demand increases after 2036: 3%

Other inputs are derived from the outputs of the business system integration model for each combination of scenarios. Another notable feature is that an NPV analysis was conducted for each stakeholder.

Table 9: Example of Uncertainty Analysis Model sheet



C.E.	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Year	0	1	2	3	4	5	6	7	8	9
Demand/day										
Max Capacity/day										
Service Revenue ($M)										
Company A's Funding ($M)				4,023	4,023	4,023				
Company A's Cumulative Debt ($M)	0	0	0	4,023	8,046	12,069	12,069	12,069	12,069	12,069
Company A's Interest Payment ($M)		0	0	0	101	201	302	302	302	302
Company A's CAPEX payment ($M)				669	669	669	2,012	2,012	2,012	2,012
Company A's OPEX income ($M)										
Company A's OPEX Payment (non-operator) ($M)										
Company A's OPEX Labor Costs (operator) ($M)										
Company A's OPEX Energy Costs (operator) ($M)										
Company A's OPEX Maintenance Costs (operator) ($M)										
A's Cashflow ($M)	0	0	0	(669)	(769)	(870)	(2,314)	(2,314)	(2,314)	(2,314)
A's DCF ($M)		0	0	(578)	(633)	(682)	(1,727)	(1,645)	(1,566)	(1,492)
A's Net present value ($M)	**999**									
Company B's CAPEX income ($M)				240	240	240	1,442	1,442	1,442	1,442
Company B's CAPEX payment (P&D phase) ($M)				216	216	216				
Company B's CAPEX Material cost (C&I phase) ($M)							779	779	779	779
Company B's CAPEX Labor cost (C&I phase) ($M)							519	519	519	519
B's Cashflow ($M)	0	0	0	24	24	24	144	144	144	144
B's DCF ($M)		0	0	21	20	19	108	103	98	93
B's Net present value ($M)	**549**									
Company C's CAPEX income ($M)				133	133	133				
Company C's CAPEX payment (Labor Costs) ($M)				120	120	120				
Company C's OPEX income ($M)										
Company C's OPEX Labor Costs ($M)										
Company C's OPEX Energy Costs ($M)										
Company C's OPEX Maintenance Costs ($M)										
C's Cashflow ($M)	0	0	0	13	13	13	0	0	0	0
C's DCF ($M)		0	0	12	11	10	0	0	0	0
C's Net present value ($M)	**33**									
Company D's CAPEX income ($M)				60	60	60	360	360	360	360
Company D's CAPEX payment ($M)				54	54	54	324	324	324	324
D's Cashflow ($M)	0	0	0	6	6	6	36	36	36	36
D's DCF ($M)		0	0	5	5	5	27	26	24	23
D's Net present value ($M)	**137**									
Company E's CAPEX income ($M)				35	35	35	210	210	210	210
Company E's CAPEX payment ($M)				32	32	32	189	189	189	189
E's Cashflow ($M)	0	0	0	4	4	4	21	21	21	21
E's DCF ($M)		0	0	3	3	3	16	15	14	14
E's Net present value ($M)	**80**									
Company F's CAPEX income ($M)							0	0	0	0
Company F's CAPEX Material cost (C&I phase) ($M)							0	0	0	0
Company F's CAPEX Labor cost (C&I phase) ($M)							0	0	0	0
F's Cashflow ($M)	0	0	0	0	0	0	0	0	0	0
F's DCF ($M)		0	0	0	0	0	0	0	0	0
F's Net present value ($M)	**0**									

5.3.2 Major uncertainties incorporated

We have identified 5 major uncertainties that likely to impact the success, the performance of your project. Each item and explanation are as following. Those will eventually give the range of the NPV with uncertainty scenarios. The uncertainty parameters can be freely changed as inputs. In this example, they were set as shown below.

1.“Uncertainty regarding the length of the construction schedule”

Uncertainty arising mainly from delays in local consultations. This will affect when revenue starts coming in. In normal cases, the sooner construction is completed, and revenue services can begin, the better the accounting balance will be. On the other hand, if construction takes a long time, income will come in late, which will worsen cash flow.

- Parameters: Construction delay of years (-1, 0, 1, 2, 3) is happened by each probability (5%, 35%, 30%, 20%, 10%) with Non-PPP plan. In the PPP considered plan, this was changed to the delay of years (-1, 0, 1, 2, 3) is happened by each probability (5%, 20%, 35%, 25%, 15%)

  Note: It is compared to the planned years generated by the system business model

2. “Uncertainty regarding Energy Costs”

We assume an increase in Energy Costs mainly due to soaring fuel prices. In this case, OPEX increases.

- Parameters: Standard distribution with σ = 15%

3. "Uncertainty regarding Material Costs"

We are assuming a price increase that will have a direct impact primarily on material and parts procurement. In this case, CAPEX will increase.

- Parameters: <u>Standard distribution with σ = 10%</u>

4. "Uncertainty regarding Labor Costs"

The main assumption is that labor costs will rise, driven by the rise in prices in recent years. In this case, both CAPEX and OPEX will increase.

- Parameters: <u>Standard distribution with σ = 5%</u>

5. "Uncertainty regarding Demand"

We are concerned about the possibility that actual demand will decrease compared to the predicted demand that is expected to arise mainly from the new lifestyle after the COVID, which affects revenue.

- Parameters: <u>Standard distribution with σ = 10%</u>

5.3.3 Output of the model

For the uncertainty analysis in the model, we used a Monte Carlo simulation method with 2000 iterations of random number generation. Below is an example of the deterministic NPV for one scenario and the results after introducing uncertainty for same scenario. In this way, the results can be displayed in a range.

Table 10: Result of example case deterministic NPV analysis (with 5 percent DR for 40 years) for Company A

Value Parameter	Base case analysis
NPV (USD-Million)	999

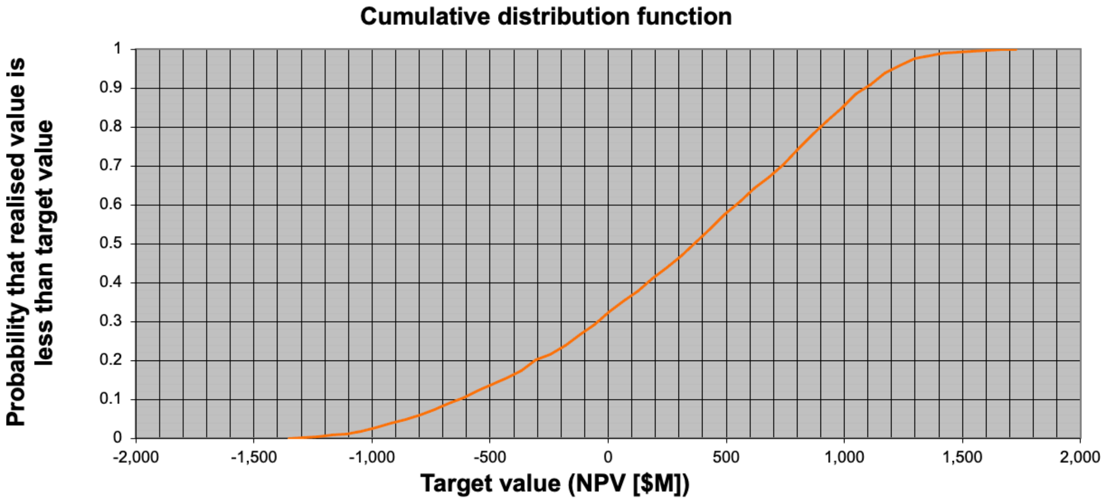


Figure 15: Result of example distributed NPV analysis with uncertainty (with 5 percent DR for 40 years) for Company A

Comparing the two above, we can see that the deterministic NPV, which happened to display one result, was a high number, in the top 80% of the distribution represented by the uncertainty analysis. This also highlights the importance of repeating the analysis multiple times.

This model construction makes it possible to analyze multiple combinations of systems and multiple combinations of business scenarios, including all stakeholder scenarios, which is expected to lead to the search for the overall optimal solution for the project.

6 Discussion

We will present the following group expression method once again, and then select representative scenarios to compare and discuss.

- Franchised railroad company: Company A
- Design and Construction: Company B
- Tech Provider: Company C
- Manufacturer: Company D
- Manufacturer: Company E
- Design and Construction: Company F

6.1 Analysis example 1: results from focusing on one company

By using the completed model, we tested multiple scenario combinations. First, we tested several different scenarios for Company A, which is expected to be most involved in the project.

<Scenarios for Company A>

(1) Private, G fund, Non-OP: Although it is a private project (Non-PPP), it is assumed that low-interest US government funds can be used to some extent. In this case, Company A will not be the railroad operator.

(2) Private, Non-G fund, Non-OP: The difference with (1) is that the funds used will mainly come from private investors and other sources, and are expected to have high interest rates.

(3) Private, G fund, OP: The difference from (1) is that Company A will also be responsible for rail operation and maintenance.

(4) Private, G fund, Non-OP, Max SS: The difference with (1) is that although the business case is the same, system investment (addition of substations) has been increased and operation frequency has been boldly increased.

(5) PPP, G fund, OP, Cost+fee: The difference from (1) is that Company A is taking into consideration the PPP scheme and participating in the partnership. Company A is also responsible for railway operation and maintenance.

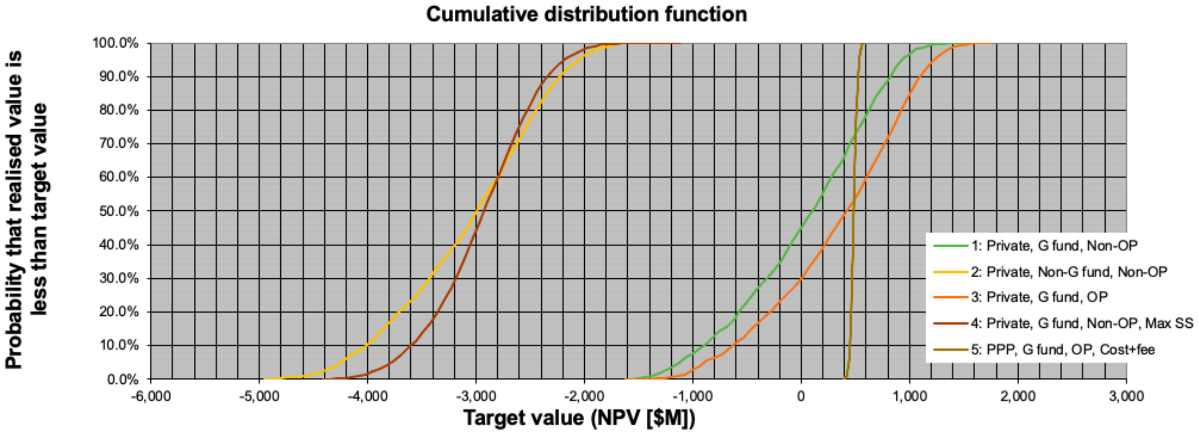


Figure 16: Results from focusing on one company (Company A: Franchised railroad company)

<Insight from this analysis>

- The difference between (1) and (2) shows that the difference in interest rates is large for Company A, which is making large capital investments. We can see that using government resources with low interest rates significantly improves the balance of payments.
- The difference between (1) and (3) shows that participating as an operator is likely to improve the balance of payments.
- The difference between (1) and (4) shows that excessive capital investment beyond demand will significantly worsen the balance of payments.
- The difference between (5) and the others shows that participating as part of a PPP scheme narrows the distribution range of the expected NPV. We can determine that risk is shared.

6.2 Analysis example 2: PPP results and focusing on different revenue distribution rate

Here, we use the results of a common system model to compare PPP cases. In all cases, the Public Agency will outsource railway operations to Company A. The method of outsourcing in the business model is varied.

Case A has an 18% revenue sharing, Case B has a 15% revenue sharing, and Case C has a cost + fee contract.

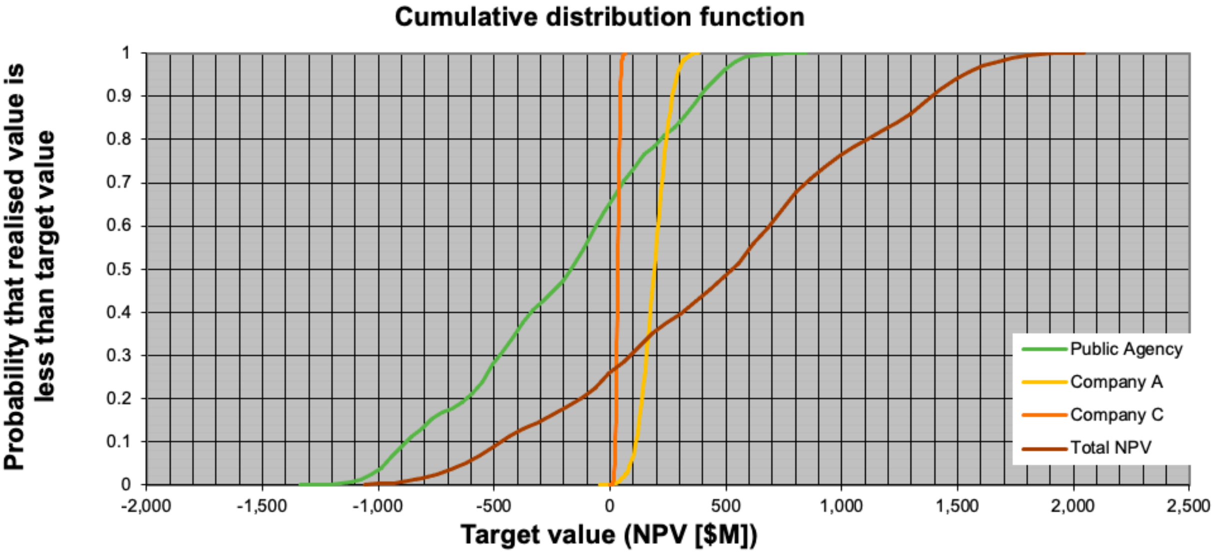


Figure 17: PPP results on case A (18% Distribution)

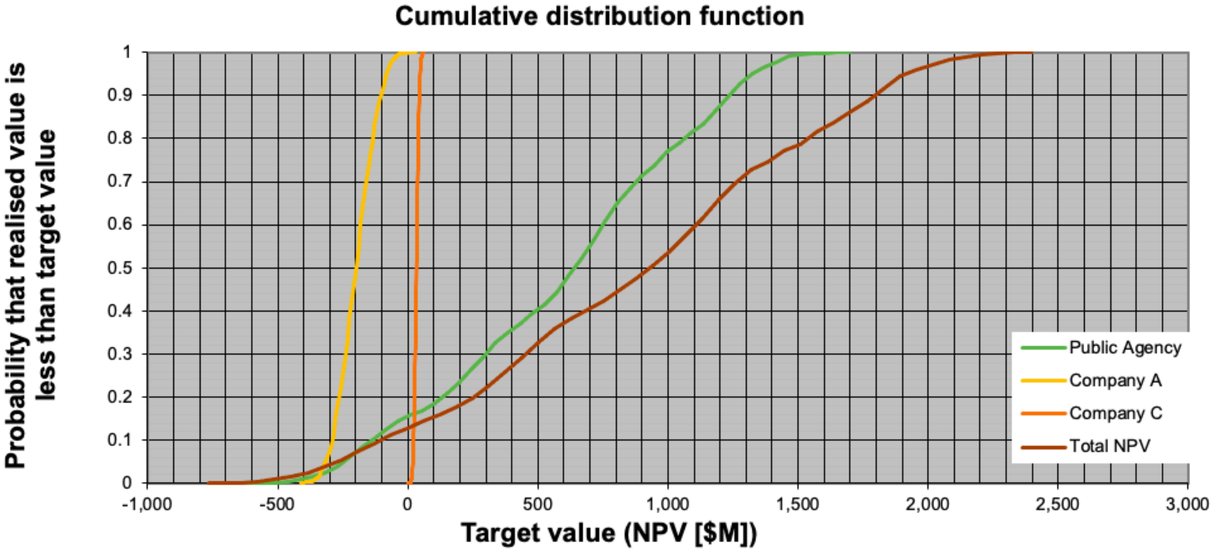


Figure 18: PPP results on case B (15% Distribution)

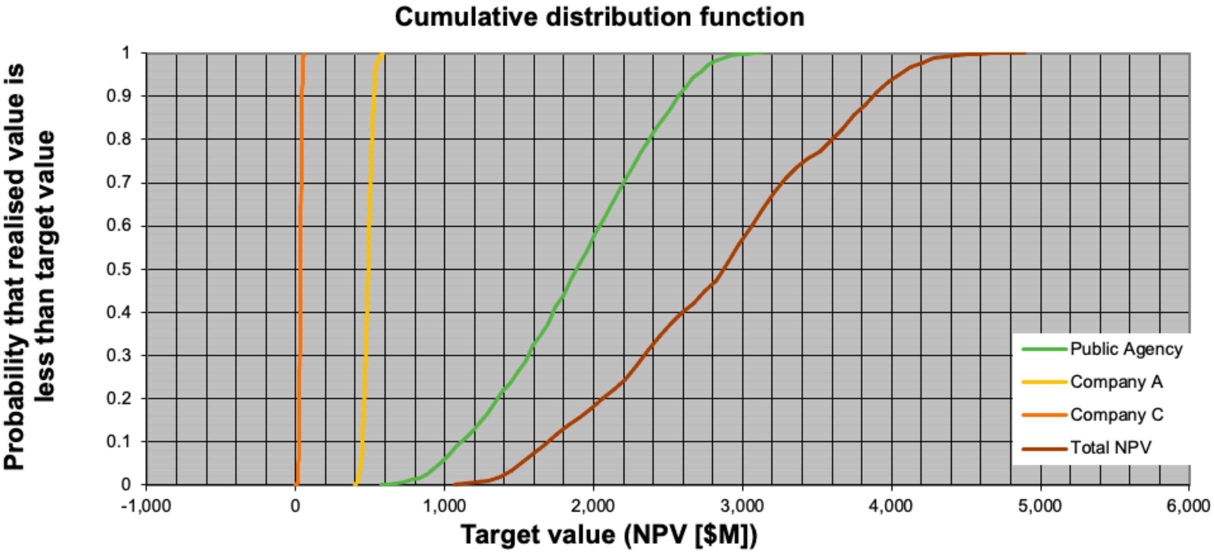


Figure 19: PPP results on case C (cost + fee contract)

<Insight from this analysis>

- In Case A, the expected NPV of Public Agency becomes negative, and in Case B, the expected NPV of Company A becomes negative. In other words, it is necessary to find an appropriate distribution rate between 15% and 18%, but with numbers this sensitive, it may be difficult to enter into an appropriate contract.
- In that respect, the cost + fee in Case C has better results for both parties and when looking at the overall NPV, and it can be seen that it is a contract and form that makes it easy to distribute risk.
- In this way, by looking side by side at the overall NPV and the NPV of each individual stakeholder, it is possible for project promoters to make overall optimal decisions.

7 Conclusion and future work

7.1 Conclusion

In this study, we modeled a project that has the following characteristics: 1) it is a complex integrated system; 2) it is a large-scale, long-term development project; and 3) it is necessary to consider differences in systems associated with international technology transfer. As a useful management method and decision-making material for projects with such complex characteristics, we built a prototype model that integrates business and technical systems and enables uncertainty analysis.

By looking at the distribution of uncertainty, it became possible to visualize the state of risk sharing due to differences in schemes (e.g., PPP and Non-PPP). In addition, by focusing on items where the expected NPV changes significantly depending on the business decision, it became possible to identify in advance contract forms where it is difficult to set numbers. In addition, we were able to visualize that the impact of long-term borrowing and interest cannot be ignored depending on the business scheme.

It is difficult to complete a large-scale project by focusing only on specific stakeholders (especially one's own organization). As part of this was shown in the discussion chapter, we found that the prototype model is useful for aiming for overall optimization while considering complex combinations.

These are some of the insights gained by actually exploring the model, but a further advantage of this model is that it allows us to consider combinations of all system decisions and all business decisions. It is expected that by taking the time to explore and incorporating automation tools, we will be able to find unexpected and new combinations and propose options that are more resistant to uncertainty. We will describe future development work, including these, in the next section, "Proposal of future works."

In addition, this time we used the project for SCMAGLEV, a new high-speed railway technology, as an example of a complex project. However, the perspectives we learned up to the construction of the model, the system decomposition and business decomposition after reflecting constraints such as laws and regulations, etc., were useful steps in the preparation process for building a model for any project. We believe that one of the results was that we were able to organize the points of view and methods for building the model, including the actual model creation process that followed.

7.2 Proposal of future work

Based on the construction of this prototype model, we have listed below candidates for future improvement work, focusing on areas where further improvement is desired and areas that have yet to be considered.

・Considering the economies of scale in Japanese business due to market expansion to the world
・Analysis of economic impact of the project
・The number of teams in the consortium and the number of personnel in each company cannot be specifically evaluated, which is an item that affects schedule progress and flexible risk handling. (limits of Excel model)
・Proposal to deal with high risk for stakeholders who participate in only one phase, such as "construction only" in the extreme uncertain case
・Building flexible options to deal with uncertainty
・Improvements to increase quantitative accuracy of uncertainty distribution, rather than assumptions
・Implementation of training and test phases

Appendix A: STPA on Japanese HSR’s safety system

This appendix focuses on the STPA (Systems-Theoretic Process Analysis) on Japanese high speed rail’s ATC (Automatic Train Control) system and safety operation. While the system to target here is Tokaido Shinkansen high speed rail which operation has not had an accident resulting in cause casualties in onboard passengers since commencing operations in 1964, this philosophy and technology have been steadily inherited by SCMAGLEV's control system. We hope this analysis provides supplemental understanding for the reliability of the Japanese HSR’s safety system which had been one of the important factors to contribute to the FRA’s first Rule of Particular Applicability.

What is STPA? STPA (System Theoretic Process Analysis) is one of the frameworks to identify the cause of accidents even during the developing phase, so that hazards can be eliminated or controlled possible to leads to loss or accident, by defining the purpose of the analysis, modeling the control structure, identifying the unsafe control actions, and identifying the loss scenarios. STPA Handbook [36] provides a detailed explanation.

Step 1. Description of the system, goals

System’s name:

- Tokaido Shinkansen High-Speed Rail System

System’s overview:

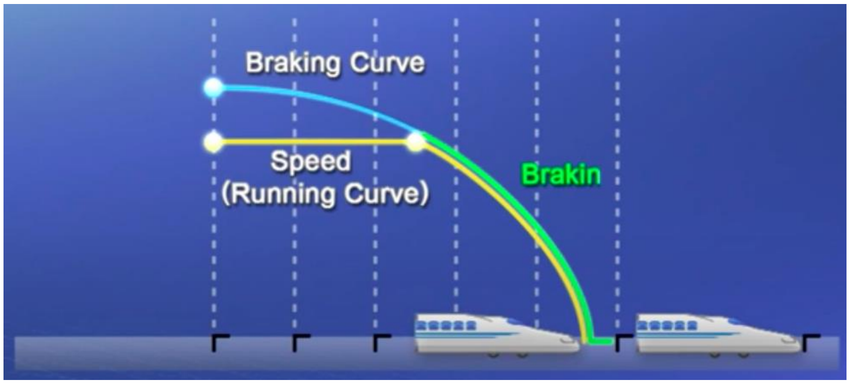
- The first high-speed railway line in Japan
- Maximum speed 285 km/h
- Having 59 year history from 1964
- Carrying over 6 billion passengers
- No accidents resulting in fatalities of passengers on board since operations commenced

System’s features:

- The big feature of the shinkansen system can be described from following two concepts: A) Crash Avoidance Principle and B) Total System Approach.

  [Crash Avoidance Principle]

  - ✓ Crash Avoidance principle is the basic philosophy dictating that any possibility of a crash be completely eliminated. Following two systems 1) the dedicated track for high-speed rail free of level crossings and 2) the ATC system (Automatic Train Control System) that prevents any crashes by controlling train speed mainly contributes to the principle. Moreover, Shinkansen is a standalone system based upon the Crash Avoidance Principle.



Automatic Train Control (ATC) system: Automatically controls the speed limit of high speed trains and prevents collisions from happening. Also serves as signal and control of the speed limit along the alignment conditions (Source: Retrieved from IHRA website)

[Total System Approach]

✓ Shinkansen is a system integrating rolling stock (vehicles), electric power, signals (ATC), communication systems, tracks, civil engineering structures and other tangible elements with intangible elements such as operations, maintenance, organization, and development.

<u>System's goals:</u>

- To carry the passengers from their origin to their destination by safety and speedy rail service using reliable high-speed rail system.

Step 2. Define the accidents (losses) and hazards of importance to the stakeholders.

<u>Losses:</u>

- L-1: loss of life or injury to people
- L-2: Vehicle loss or damage
- L-3: Loss or damage to objects outside the vehicle
- L-4: Loss of transport mission
- L-5: Loss of customer satisfaction

<u>Hazards:</u>

- H-1: Integrity of high-speed rail vehicle frame is lost [L-1, L-2, L-4, L-5]

- H-2: High-speed rail vehicle intrudes on a different route than a designated route [L-1, L-2, L-3, L-4, L-5]
- H-3: High-speed rail vehicle exceeds safe operating limits [L-1, L-2, L-3, L-4, L-5]
- H-4: High-speed rail vehicle derails [L-1, L-2, L-3, L-4, L-5]
- H-5: High-speed rail fails to reach destination [L-4, L-5]
- H-6: Massive delays on high-speed rail [L-5]

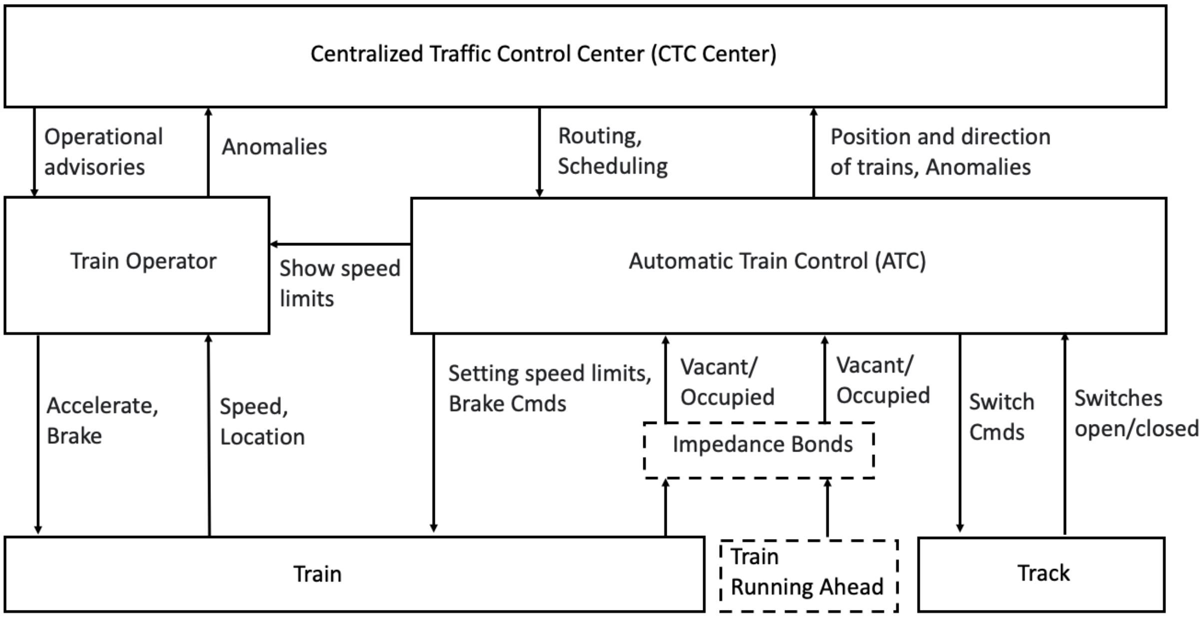
Related system constraints:

- SC-1: High-speed rail vehicle frame integrity must be maintained under worst-case conditions. [H-1]
- SC-2: If high-speed rail vehicle makes violate intrusion, then the violation must be detected and measures taken to prevent collision. [H-2]
- SC-3: If high-speed rail vehicle exceeds safe operating limits, then the violation must be detected and measures taken to prevent collision and/or derailment. [H-3]
- SC-4: If high-speed rail vehicle is derailed, then the measures must be taken to prevent overturning. [H-4]
- SC-5: If high-speed rail cannot be reach to the destination, then the operate company must provide passengers with alternative ways according to the contract. [H-5]
- SC-6: If high-speed rail service has massive delay, then the operate company must provide passengers with alternative ways according to the contract. [H-6]

One important hazard selected to analyze:

- H-3 (SC-3) would be the most important one to analyze.

Step 3. Hierarchical safety control structure that either exists



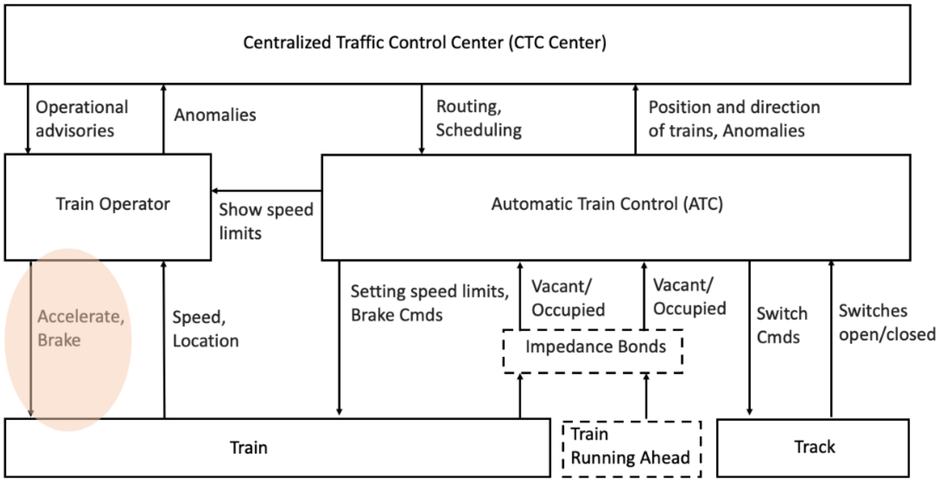
<The safety control structure that exists>

Note: From here and after, this control structure is a selection of primary elements and does not completely cover the entire system.

Step 4. Potential Unsafe Control Actions (UCAs) for human (operator) and automated (software) part

Note: From here and after, our analysis will be concentrated to the issues related to the hazard related to safety operation. In concrete words used in Q2, [H-2: High-speed rail vehicle intrudes on a different route than a designated route], [H-3: High-speed rail vehicle exceeds safe operating limits], and [H-4: High-speed rail vehicle derails] are included.

Human (Train Operator)

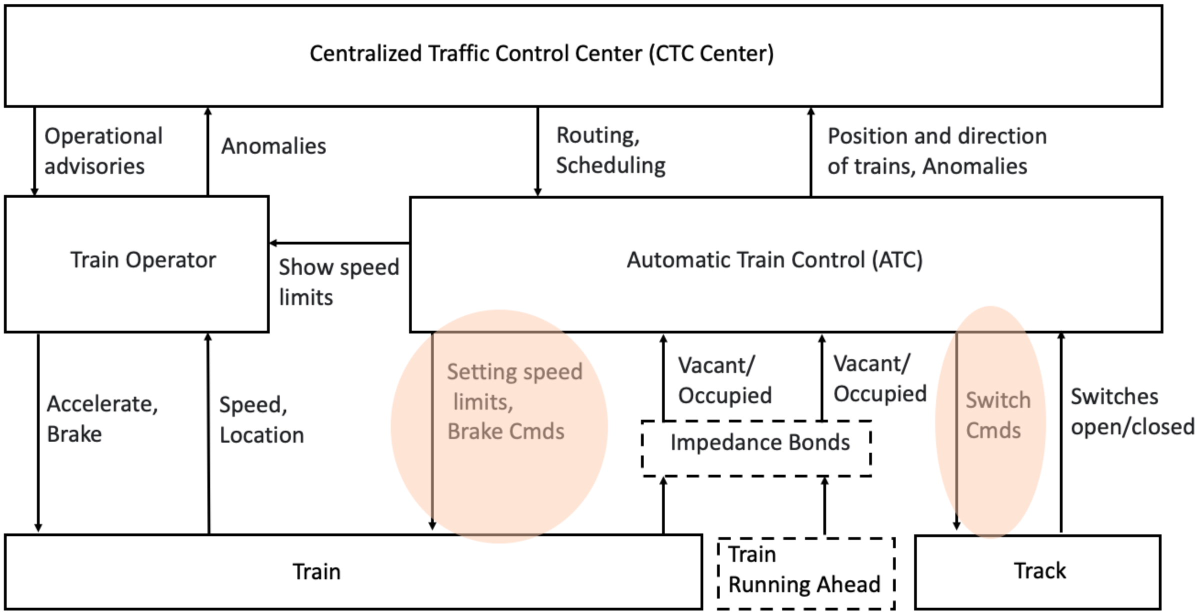


Control Action	**Not providing causes hazard**	**Providing causes hazard**	**Too early, too late, Order**	**Stopped Too Soon / Applied too long**
Accelerate Command	N/A	UCA-1: Train Operator provides Accelerate Command while stop signal is shown [H-2, H-3, H-4] UCA-2: Train Operator provides Accelerate Command when brake is applied [H-3, H-4]	UCA-3: Train Operator provides Accelerate Command before all passenger doors close at stations [H-3]	N/A

Control Action	Not providing causes hazard	Providing causes hazard	Too early, too late, Order	Stopped Too Soon / Applied too long
Brake Command	UCA-4: Train Operator does not provide Brake Command when the train is over speeding [H-3, H-4]	N/A	UCA-5: Train Operator provides Brake Command too late after the train becomes over speeding [H-3, H-4]	UCA-6: Train Operator stops providing Brake Command too early before train speed become lower than speed limits [H-3, H-4]

Unsafe Control Actions (UCA)	Controller Safety Requirements/Constraints
UCA-1: Train Operator provides Accelerate Command while stop signal is shown [H-2, H-3, H-4]	C-1: Train Operator must not provide Accelerate Command while stop signal is shown [UCA-1]
UCA-2: Train Operator provides Accelerate Command when brake is applied [H-3, H-4]	C-2: Train Operator must not provide Accelerate Command when brake is applied [UCA-2]
UCA-3: Train Operator provides Accelerate Command before all passenger doors close at stations [H-3]	C-3: Train Operator must not provide Accelerate Command before all passenger doors close at stations [UCA-3]
UCA-4: Train Operator does not provide Brake Command when the train is over speeding [H-3, H-4]	C-4: Train Operator must provide Brake Command when the train is over speeding [UCA-4]
UCA-5: Train Operator provides Brake Command too late after the train becomes over speeding [H-3, H-4]	C-5: Train Operator must not provide Brake Command too late after the train becomes over speeding [UCA-5]
UCA-6: Train Operator stops providing Brake Command too early before train speed become lower than speed limits [H-3, H-4]	C-6: Train Operator must not stop providing Brake Command too early before train speed become lower than speed limits [UCA-6]

Automated (ATC software)



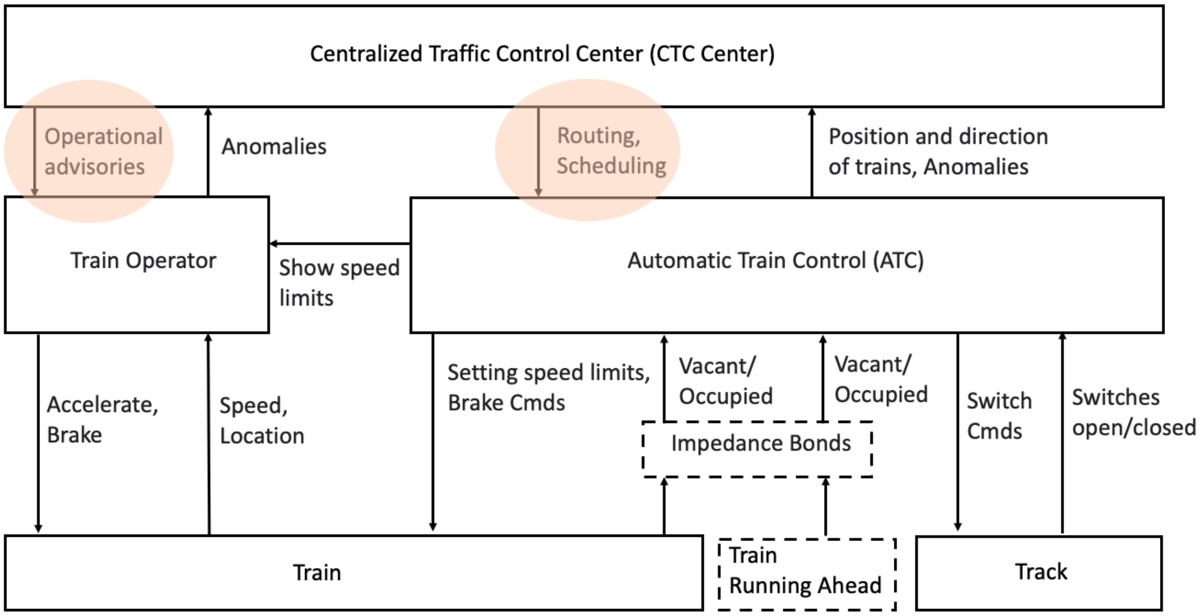
Control Action	**Not providing causes hazard**	**Providing causes hazard**	**Too early, too late, Order**	**Stopped Too Soon / Applied too long**
Setting speed limits	UCA-7: ATC does not set speed limit when the train is on the operational line [H-3, H-4]	UCA-8: ATC sets speed limit with excessive speed limit when the train is on the operational line [H-3, H-4]	N/A	N/A
Brake Command	UCA-9: ATC does not provide Brake Command when the train is over speeding [H-3, H-4]	UCA-10: ATC provides Brake Command with an insufficient level of braking when the train is over speeding [H-3, H-4]	UCA-11: ATC provides Brake Command too late after the train becomes over speeding [H-3, H-4]	UCA-12: ATC stops providing Brake Command too early before train speed become lower than speed limits [H-3, H-4]

Control Action	**Not providing causes hazard**	**Providing causes hazard**	**Too early, too late, Order**	**Stopped Too Soon / Applied too long**
Switch Command	UCA-13: ATC does not provide Switch Command when the train needs to proceed into the other routes [H-2, H-4]	UCA-14: ATC provides Switch Command when the train does not need to proceed into the other routes [H-2, H-4]	UCA-15: ATC provides Switch Command too late when the train needs to proceed into the other routes [H-2, H-4]	UCA-16: ATC stops providing Switch Command too early before the switch turns out completely [H-4]

Unsafe Control Actions (UCA)	**Controller Safety Requirements/Constraints**
UCA-7: ATC does not set speed limit when the train is on the operational line [H-3, H-4]	C-7: ATC must set speed limit when the train is on the operational line [UCA-7]
UCA-8: ATC sets speed limit with excessive speed limit when the train is on the operational line [H-3, H-4]	C-8: ATC must not set speed limit with excessive speed limit when the train is on the operational line [UCA-8]
UCA-9: ATC does not provide Brake Command when the train is over speeding [H-3, H-4]	C-9: ATC must provide Brake Command when the train is over speeding [UCA-9]
UCA-10: ATC provides Brake Command with an insufficient level of braking when the train is over speeding [H-3, H-4]	C-10: ATC must not provide Brake Command with an insufficient level of braking when the train is over speeding [UCA-10]
UCA-11: ATC provides Brake Command too late after the train becomes over speeding [H-3, H-4]	C-11: ATC must not provide Brake Command too late after the train becomes over speeding [UCA-11]
UCA-12: ATC stops providing Brake Command too early before train speed become lower than speed limits [H-3, H-4]	C-12: ATC must not stop providing Brake Command too early before train speed become lower than speed limits [UCA-12]

Unsafe Control Actions (UCA)	**Controller Safety Requirements/Constraints**
UCA-13: ATC does not provide Switch Command when the train needs to proceed into the other routes [H-2, H-4]	C-13: ATC must provide Switch Command when the train needs to proceed into the other routes [UCA-13]
UCA-14: ATC provides Switch Command when the train does not need to proceed into the other routes [H-2, H-4]	C-14: ATC must not provide Switch Command when the train does not need to proceed into the other routes [UCA-14]
UCA-15: ATC provides Switch Command too late when the train needs to proceed into the other routes [H-2, H-4]	C-15: ATC must not provide Switch Command too late when the train needs to proceed into the other routes [UCA-15]
UCA-16: ATC stops providing Switch Command too early before the switch turns out completely [H-4]	C-16: ATC must not stop providing Switch Command too early before the switch turns out completely [UCA-16]

Human (CTC Center)



Control Action	**Not providing causes hazard**	**Providing causes hazard**	**Too early, too late, Order**	**Stopped Too Soon / Applied too long**
Providing Operational Advisories (to the Train Operator)	UCA-17: CTC Center does not provide Operational Advisories in the emergency situation when the ATC system must be stopped using for all trains [H-3, H-4]	N/A	UCA-18: CTC Center provides Operational Advisories too late in the emergency situation when the ATC system must be stopped using for all trains [H-3, H-4]	N/A
Providing Information of Routing and Schedule of trains (to the ATC system)	UCA-19: CTC Center does not provide Information of routing and schedule before	UCA-20: CTC Center provides incorrect information of routing and schedule before	N/A	N/A

Control Action	Not providing causes hazard	Providing causes hazard	Too early, too late, Order	Stopped Too Soon / Applied too long
	the daily operation starts [H2, H-3, H-4]	the daily operation starts [H2, H-3, H-4]		

Unsafe Control Actions (UCA)	Controller Safety Requirements/Constraints
UCA-17: CTC Center does not provide Operational Advisories in the emergency situation when the ATC system must be stopped using for all trains [H-3, H-4]	C-17: CTC Center must provide Operational Advisories in the emergency situation when the ATC system must be stopped using for all trains. [UCA-17]
UCA-18: CTC Center provides Operational Advisories too late in the emergency situation when the ATC system must be stopped using for all trains [H-3, H-4]	C-18: CTC Center must not provide Operational Advisories too late in the emergency situation when the ATC system must be stopped using for all trains. [UCA-18]
UCA-19: CTC Center does not provide Information of routing and schedule before the daily operation starts [H2, H-3, H-4]	C-19: CTC Center must provide Information of routing and schedule before the daily operation starts [UCA-19]
UCA-20: CTC Center provides incorrect information of routing and schedule before the daily operation starts [H2, H-3, H-4]	C-20: CTC Center must not provide incorrect information of routing and schedule before the daily operation starts [UCA-20]

Step 5. Scenarios for each of the UCAs identified in Step 4

UCA	Scenarios	Recommendations
UCA-1: Train Operator provides Accelerate Command while stop signal is shown [H-2, H-3, H-4]	Train operator provides the accelerate command because he/she receives incorrect signal information shown in the speedometer on the train and believes that the train can be started to accelerate.	In this case, strong ATC brake would be applied because the train speed exceeds the speed signal (0 kph).
	Train operator provides the accelerate command while stop signal is shown because he/she is confused the brake lever and the accelerate lever.	In this case, strong ATC brake would be applied because the train speed exceeds the speed signal (0 kph).
UCA-2: Train Operator provides Accelerate Command when brake is applied [H-3, H-4]	Train operator continues to provide the accelerate command because he/she receives incorrect information shown in the speedometer on the train and believes that train speed does not exceed to the speed limit.	Always the brake command would be prioritized more than the accelerate command
	Train operator provides the accelerate command when the ATC brake is applied because he/she is confused the brake lever and the accelerate lever.	Always the brake command would be prioritized more than the accelerate command

UCA	**Scenarios**	**Recommendations**
UCA-3: Train Operator provides Accelerate Command before all passenger doors close at stations [H-3]	Train Operator sends accelerate command before all passenger doors close at stations because the train has time-behind at this time and he/she forgets to confirm the sign of the all passenger doors close.	In this case, there would be the circuit system which allows the train operator to accelerate only when all passengers doors close physically and completely.
	Train Operator sends accelerate command before all passenger doors close at stations, because there is malfunction of all passenger doors close sign and that is shown incorrectly.	In this case, there would be the circuit system which allows the train operator to accelerate only when all passengers doors close physically and completely.
UCA-4: Train Operator does not provide Brake Command when the train is over speeding [H-3, H-4]	Train operator does not provide the manual brake command because he/she receives incorrect information shown in the speedometer on the train and believes that train speed does not exceed to the speed limit.	In this case, ATC brake applies. By introducing ATC, to combine manual brake and automatic brake To upgrade accuracy of the speedometer To understand there might be tiny error regarding the speed meters
	Train operator sends the manual brake command to the train; however the brake is not applied because of the physical malfunction of the brake system.	In this case, ATC brake which uses different type of physical brakes applies. To multiplex of the physical brake system

UCA	Scenarios	Recommendations
UCA-5: Train Operator provides Brake Command too late after the train becomes over speeding [H-3, H-4]	Train operator delays to provide the manual brake command because he/she receives incorrect information shown in the speedometer on the train and believes that train speed does not exceeded to the speed limit.	In this case, ATC brake applies. By introducing ATC, to combine manual brake and automatic brake To upgrade accuracy of the speedometer To understand there might be tiny error regarding the speed meters
	Train operator delays to provide the manual brake command because he/she looks at incorrect information about the speed limit shown in the speedometer on the train and believes that train speed does not exceeded to the speed limit.	In this case, ATC brake applies. By introducing ATC, to combine manual brake and automatic brake To upgrade accuracy of the speedometer To understand there might be tiny error regarding the speed meters

UCA	Scenarios	Recommendations
UCA-6: Train Operator stops providing Brake Command too early before train speed become lower than speed limits [H-3, H-4]	Train operator sends the manual brake command to the train; however the brake is stopped to apply before train speed become lower than speed limits because of the physical malfunction of the brake system.	In this case, ATC brake which uses different type of physical brakes applies. To multiplex of the physical brake system
	Train operator stops sending the manual brake command before the train speed become lower than speed limits because he/she receives incorrect information shown in the speedometer on the train and believes that train speed has been already lowered to the speed limit.	In this case, ATC brake applies. By introducing ATC, to combine manual brake and automatic brake To upgrade accuracy of the speedometer To understand there might be tiny error regarding the speed meters
UCA-7: ATC does not set speed limit when the train is on the operational line [H-3, H-4]	ATC does not set speed limit when the train is on the operational line because the ATC system cannot get feedback about train positions throw impedance bonds by signal malefactions.	In this case, emergency brake applies. To introduce emergency brake designed as fail-safe
	ATC does not set speed limit when the train is on the operational line because the ATC system cannot get feedback about train positions because of circuit cutoff due to an iron object which is placed on the rail by maliciously.	In this case, emergency brake applies. To introduce emergency brake designed as fail-safe To make security countermeasure for track intrusion

UCA	Scenarios	Recommendations
UCA-8: ATC sets speed limit with excessive speed limit when the train is on the operational line [H-3, H-4]	ATC sends speed limit with excessive speed limit when the train is on the operational line because an adversary injected a command that put the ATC signal system into alternate operational mode.	In this case, emergency brake applies immediately after the ATC works differently from the scheduled and routed work in advance. To introduce emergency brake designed as fail-safe
	ATC sends speed limit with excessive speed limit when the train is on the operational line because of the physical malfunction of the ATC signal system.	In this case, emergency brake applies immediately after the ATC works differently from the scheduled and routed work in advance. To introduce emergency brake designed as fail-safe
UCA-9: ATC does not provide Brake Command when the train is over speeding [H-3, H-4]	ATC sends the automatic regular brake command to the train, but the brakes are not applied because an adversary injected a command that put the ATC braking system into alternate braking mode.	In this case, emergency brake applies. To introduce emergency brake designed as fail-safe
	ATC sends the automatic regular brake command to the train; however the brake is not applied because of the physical malfunction of the brake system.	In this case, emergency brake which uses different type of physical brakes applies. To multiplex of the physical brake system

UCA	**Scenarios**	**Recommendations**
UCA-10: ATC provides Brake Command with an insufficient level of braking when the train is over speeding [H-3, H-4]	ATC sends the automatic regular brake command to the train, but the brakes are not applied because an adversary injected a command that put the ATC braking system into alternate braking mode. As a result, insufficient deceleration may be provided.	In this case, emergency brake applies. To introduce emergency brake designed as fail-safe
	ATC sends the automatic regular brake command to the train; however the brake level is insufficient because of the physical malfunction of the brake system.	In this case, emergency brake which uses different type of physical brakes applies. To multiplex of the physical brake system
UCA-11: ATC provides Brake Command too late after the train becomes over speeding [H-3, H-4]	Flying objects covering the rail cuts-off the rail circuit and ATC delays to get the information feedback from impedance bonds. Thus, ATC delays to provide the automatic regular brake command.	In this case, immediately after the timing when the rail circuit is cut-off, the backup brake applies, and train stops safely. To introduce backup brake designed as fail-safe
	Because of occurrence of heavy power failure, ATC delays to provide the automatic regular brake command.	In this case, immediately after the timing when train lost the power, the backup brake applies, and train stops safely. To introduce backup brake designed as fail-safe

UCA	Scenarios	Recommendations
UCA-12: ATC stops providing Brake Command too early before train speed become lower than speed limits [H-3, H-4]	ATC sends the automatic regular brake command to the train, but the brakes are stopped to apply because an adversary injected a command that put the ATC braking system into alternate braking mode.	In this case, emergency brake applies. To introduce emergency brake designed as fail-safe
	ATC sends the automatic regular brake command to the train; however the brake is stopped to apply before train speed become lower than speed limits because of the physical malfunction of the brake system.	In this case, emergency brake which uses different type of physical brakes applies. To multiplex of the physical brake system
UCA-13: ATC does not provide Switch Command when the train needs to proceed into the other routes [H-2, H-4]	ATC does not provide Switch Command when the train needs to proceed into the other routes because an adversary injected a command.	In this case, emergency brake applies immediately after the ATC works differently from the scheduled and routed work in advance. To introduce emergency brake designed as fail-safe
	ATC does not provide Switch Command when the train needs to proceed into the other routes because of the physical malfunction of the ATC signal system.	In this case, emergency brake applies immediately after the ATC works differently from the scheduled and routed work in advance. To introduce emergency brake designed as fail-safe

UCA	**Scenarios**	**Recommendations**
UCA-14: ATC provides Switch Command when the train does not need to proceed into the other routes [H-2, H-4]	ATC provides Switch Command when the train does not need to proceed into the other routes because an adversary injected a command.	In this case, emergency brake applies immediately after the ATC works differently from the scheduled and routed work in advance. To introduce emergency brake designed as fail-safe
	ATC provides Switch Command when the train does not need to proceed into the other routes because of the physical malfunction of the ATC signal system.	In this case, emergency brake applies immediately after the ATC works differently from the scheduled and routed work in advance. To introduce emergency brake designed as fail-safe
UCA-15: ATC provides Switch Command too late when the train needs to proceed into the other routes [H-2, H-4]	ATC provides Switch Command too late when the train needs to proceed into the other routes because an adversary injected a command.	In this case, emergency brake applies immediately after the ATC works differently from the scheduled and routed work in advance. To introduce emergency brake designed as fail-safe
	ATC provides Switch Command too late when the train needs to proceed into the other routes because of the physical malfunction of the ATC signal system.	In this case, emergency brake applies immediately after the ATC works differently from the scheduled and routed work in advance. To introduce emergency brake designed as fail-safe

UCA	**Scenarios**	**Recommendations**
UCA-16: ATC stops providing Switch Command too early before the switch turns out completely [H-4]	ATC stops providing Switch Command too early before the switch turns out completely because an adversary injected a command.	In this case, emergency brake applies immediately after the ATC works differently from the scheduled and routed work in advance. To introduce emergency brake designed as fail-safe
	ATC stops providing Switch Command too early before the switch turns out completely because of the physical malfunction of the ATC signal system.	In this case, emergency brake applies immediately after the ATC works differently from the scheduled and routed work in advance. Moreover, physical circuit off due to incomplete pass way configuration leads to the emergency brake as well. To introduce emergency brake designed as fail-safe

UCA	**Scenarios**	**Recommendations**
UCA-17: CTC Center does not provide Operational Advisories in the emergency situation when the ATC system must be stopped using for all trains [H-3, H-4]	CTC Center does not provide Operational Advisories in the emergency situation when the ATC system must be stopped using for all trains because he/she is overwhelmed by the emergency situation.	In this case, emergency manual mode is also started by CTC, thus the train operator cannot make accelerate command as long as setting with ATC system mode on train.
	CTC Center does not provide Operational Advisories in the emergency situation when the ATC system must be stopped using for all trains because of malfunctions for the communication tool.	In this case, emergency manual mode is also started by CTC, thus the train operator cannot make accelerate command as long as setting with ATC system mode on train. To make back up communication tools
UCA-18: CTC Center provides Operational Advisories too late in the emergency situation when the ATC system must be stopped using for all trains [H-3, H-4]	CTC Center provides Operational Advisories too late in the emergency situation when the ATC system must be stopped using for all trains because he/she is overwhelmed by the emergency situation.	In this case, emergency manual mode is also started by CTC, thus the train operator cannot make accelerate command as long as setting with ATC system mode on train.
	CTC Center provides Operational Advisories too late in the emergency situation when the ATC system must be stopped using for all trains because of malfunctions for the communication tool.	In this case, emergency manual mode is also started by CTC, thus the train operator cannot make accelerate command as long as setting with ATC system mode on train. To make back up communication tools

UCA	**Scenarios**	**Recommendations**
UCA-19: CTC Center does not provide Information of routing and schedule before the daily operation starts [H2, H-3, H-4]	CTC Center provides incorrect information of routing and schedule before the daily operation starts because he/she is overwhelmed by the emergency situation.	In this case, ATC cannot make any pattern of signals (speed limits) and operation cannot be started. Thus, there is no safety critical scenario in this case.
	CTC Center provides incorrect information of routing and schedule before the daily operation starts because of network malfunctions between CTC and ATC.	In this case, ATC cannot make any pattern of signals (speed limits) and operation cannot be started. Thus, there is no safety critical scenario in this case.
UCA-20: CTC Center provides incorrect information of routing and schedule before the daily operation starts [H2, H-3, H-4]	CTC Center provides incorrect information of routing and schedule before the daily operation starts because he/she is overwhelmed by the emergency situation.	After all of scheduled information is provided, ATC system (automatic) and CTC operators (manual) would check if there is any conflict or suspicious so that they can find incorrect input.
	CTC Center provides incorrect information of routing and schedule before the daily operation starts because of network malfunctions between CTC and ATC.	After all of scheduled information is provided, ATC system (automatic) and CTC operators (manual) would check if there is any conflict or suspicious so that they can find incorrect input.

Step 6. Information should be passed to operations and a plan for operators to use that information

- From the STPA analysis, Identified Hazard, UCAs, Scenarios and Recommendations are we think required to provide to operations.
- Especially, in our STPA analysis, there is total 20 UCAs and 40 scenarios. I can say that all of them are potentially safety critical in the high speed railway operations. However, if I dare to specify the important information from them, we choose braking command issues which are most related to the safety operation and H-3 (SC-3) identified in Q2.
- Because of the ultimate fail safe design in the railway is to make strong brake when something happened. This is the one of strong points of the trains deferent from the airplanes which flies air and have enormous potential energy.

<Examples of Contents of Operations Management Plan>

General Classification	**Viewpoints**	**Example of the contents**
General Considerations	Scope and objectives	[scope] Tokaido Shinkansen's Safety operation plan with ATC system [objectives] To carry the passengers from their origin to their destination by safety and speedy rail service using reliable high-speed rail system.
Safety Organization (safety control structure)	Personnel qualifications and duties	Persons who understand the safety first culture in a railway company
	Department and manpower	Train Operator Department, CTC Center Department, Car Body Department, Signal Department, Track Department, ATC Development
	Subcontractor responsibilities	Appropriate suppliers and manufacturers

General Classification	**Viewpoints**	**Example of the contents**
Schedule	Critical checkpoints and milestones	The audit department conducts intensive audits and analyzes of cyber security in the real world, once every six months.
	Review procedures and participants	At the same time with the audit above, reviewing procedures and participants is conducted.
Operations hazard analysis	Identified hazards	・ H-2: High-speed rail vehicle intrudes on a different route than a designated route [L-1, L-2, L-3, L-4, L-5] ・ H-3: High-speed rail vehicle exceeds safe operating limits [L-1, L-2, L-3, L-4, L-5] ・ H-4: High-speed rail vehicle derails [L-1, L-2, L-3, L-4, L-5]
	Mitigations for hazards	・ By introducing ATC, to combine manual brake and automatic brake ・ To upgrade accuracy of the speedometer ・ To understand there might be tiny error regarding the speed meters ・ To multiplex of the physical brake system ・ To introducing fail safe emergency brake ・ To introducing fail safe back up brake etc.

Step 7. Summary

- We conducted the STPA analysis focusing on the "operational" and "safety" aspects of the Tokaido Shinkansen. As one important hazard selected to analyze, we choose the scenario that high-speed rail vehicle exceeds safe operating limits. In our STPA analysis, total 20 UCAs and 40 scenarios were identified. After pointing all UCAs and scenarios, recommendations for each UCA/scenario were made.
- Most of the recommendations especially related to the ATC system and operators have been covered in the real operational situation of the Tokaido Shinkansen. This whole philosophy will be incorporated into the SCMAGLEV system's automated control system.
- Our recommendation for the hardware division is to reinforce the audit department that conducts regular audits, including the perspective of strengthening cyber security measures, which seems to have been particularly characteristic in this STPA analysis. This viewpoint is always necessary in modern society, no matter what country.
- Another characteristic of railway companies is that they create a large number of teaching materials based on past accident events, and all employees learn about the accumulation of safety culture and the history of the technology they have cultivated. By analyzing the lessons learned from the past, they conducted contentious role-playing questions such as "How would you act as a crew member?" and "What perspectives are necessary to develop equipment and systems that protect safety?" For example, the most typical lesson from the past accident which we can point is "Never have trains stopped in the tunnel in the fire situation". That is because passengers cannot escape in the tunnel with smoke. In the real operation, this type of department specializing in safety is educating the related employees carefully.
- As a result of such type of analysis and lessons, most of the UCAs and recommendations mentioned in this STPA analysis are all covered by the current Tokaido Shinkansen system with well-trained operators, and we can definitely say that very strong safety is guaranteed.

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