Systems Thinking in the Zero Emission Solution for Railway Diesel Locomotive

A Case Study for Battery Train with Partial Electrification from Norwegian Railway Sector

Hawar Said
University of South-Eastern Norway
Kongsberg, Norway
hawar19@gmail.com

Mo Mansouri
University of South-Eastern Norway
Kongsberg, Norway
mo.mansouri@usn.no

***Abstract*— This paper seeks to understand the Zero Emission solution that the Norwegian Railways Directorate adopted in its 2019 report. The report presented the battery with partial electrification as an ideal solution for achieving the government's goals of reaching Zero Emission. Using the battery as a replacement for diesel engines is a new technology in Norway. The newly proposed technology for use in the railway sector is a new challenge and raises many questions about its suitability to operate on the Norwegian railway. In this paper, we applied the concept of Systems Thinking methodology. We applied this methodology to get deeper understanding of the system and its boundaries. Understanding the issues could be of influence now or in the future, as well as identifying and defining the stakeholders and understanding their needs. The tools we used in this paper are: applying Cynefin framework to sort the set of issues that managers face in five contexts, applying Openness (context diagram) to manage the chaos and complexity by understanding the context of its environment, applying CATOWE analysis to understand the stakeholder perspective and the impact of the issues, applying WHY question to understand why the actors do what they do, applying Systemigram to understand and model the system of interest and also to visualize the representation of the system structure, & applying Leverage points to identify places in the system that a small force change can cause a large effect in system behavior.**

Keywords*— *Systems Thinking; Battery Train; CATOWE; Openness of system; Leverage points; Systemigram; Zero Emission; Systems Engineering.

I. INTRUDUCTION

A. Understanding the new technology

This paper discusses many factors that have impact on systems and their environment by applying System Thinking. This will help us to increase the understanding of the internal and external requirements of the new technology. The early understanding of the demands of the desired system are also mentioned in the system engineering handbook [4] and defined as a factor for developing and improving the systems.

Using the battery train as a new solution in the Norway Railway System will increase the uncertainty and make the boundary unambiguous. In this project, it would be difficult to predict the issues caused by interaction of the human – machine and the environment. We need to understand the system type to predict the possible issues that can face our system. This new technology requires more analyzing and studies to improve their performance and to ensure the operational safety in the Norwegian Railway Sector.

The Cynefin framework identified five contexts, as introduced by Snowden and Boone [2]. The framework offers the decision makers five contexts to demonstrate the differentiation among them by showing the nature of the relationship between cause and effect, as shown in Figure 1.

The Cynefin framework will help the management of an organization to select the right context and involve the right stakeholders to make a proper decision.

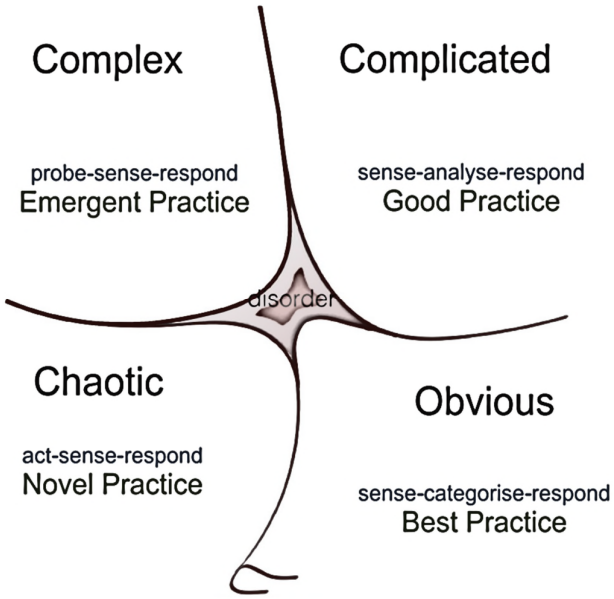

Figure 1. Domains of the Cynefin framework; the dark domain in the center is disorder.

Figure 1 shows the five-decision making contexts, namely: obvious, complicated, complex, chaotic, and disorder (the actual context is not known), in order to aid or help the managers to make sense of a situation. Cause and effect on the new battery train system have no answers and cannot be deduced, unless in retrospect. "*Instructive patterns ... can emerge,*" write Snowden and Boone, "*if the leader conducts experiments that are safe to fail.*" Cynefin calls this process "*probe–sense–respond*" [2].

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B. Battery Train - with partial electrification

This new technology is still under study and testing process in Norway. The National Directorate for Norway, using this solution, aims to reduce the CO_2 (Carbon dioxide) emission to the community and provide clean energy for the environment. "*This concept is compatible with today's technology and can therefore be used on the entire existing rail network,*" says the Railway Directorate.

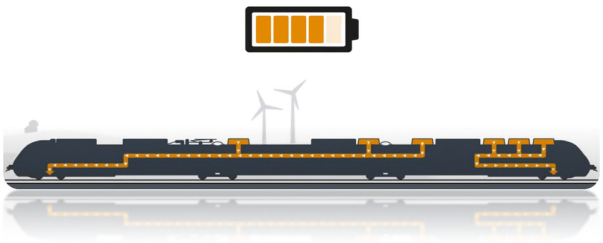

Figure 2. Bombardier train

The train will become more stable, less noisy, will have less vibration and zero emissions after replacing the diesel engines with a battery-powered engine. This solution optimizes the energy efficiency and provides maximum safety. The batteries will be installed on the roofs of the locomotives. The batteries will supply the motors and the mount with the power necessary to control all moving parts.

Figures 2 and 3 illustrate a bombardier train which can travel at a maximum of 160 km/h for more than 7 hours without the need for additional impetus, such as diesel engines or electric power.

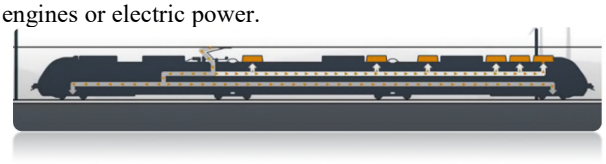

Figure 3. Recharging the battery for Bombardier train

The batteries can be recharged within 7-10 minutes and this is done by connecting the wattage to the batteries as they travel along the lines that have electrical power. Each battery has 5-8 years lifetime with daily operation.

II. Background

The Norwegian Government Transport Committee has requested the Railway Directorate to investigate the possibility of a test project with Zero Emissions Solutions for railway vehicles. The Norwegian National Railways Directorate Performed a study in 2019. The study was performed in partnership with Bane NOR SF (infrastructure manager) and Norske Tog AS (a train company) and Trains manufacturers [9]. The study was called The Null Emissions Solutions for Non-Electrified Railways (NULLFIB) [9].

The study suggested many alternatives to replace the fossil fuel with zero emission solutions for non-electrified stretches, considering best financial alternatives.
The options that have been selected were:

- Hydrogen
- Biogas
- Biodiesel
- Battery
- Battery operation with partial electrification

The study selected the battery with partial electrification as the most durable and robust alternative to replace the diesel engines because it would be expensive and require more international coordination to refill the other forms of fuel (hydrogen, biogas or biodiesel) in case of crossing borders. This solution will increase the socio-economic savings according to the National Railway Directorate "*A transition to zero-emission solutions will reduce the railway's carbon footprint, and will provide favorable socio-economic savings*".

III. Paper Method and Solution Challenge

The paper is based on outcomes from the National Directorate and Bane NOR infrastructure, and we applied qualitative research methods using reports and article outcomes observations and informal communication with suppliers. This paper applies the System Thinking methodology to provide the understanding of the solution.

The National Directorate collaborated with Norske Tog AS to provide battery-powered engines to their vehicles by using Bane NOR infrastructure to ensure the Zero Emission. All three actors (National Directorate, Norske AS & Bane NOR) have focused on the new technology, which is still unclear and unambiguous. The battery solution is new to the market and unknown for a lot of railway companies. The Norwegian government requires adopting the new solution with a high level of focus on Zero Emission to provide an operational and cost-effective rolling stock to the Norwegian community.

IV. Applying the General System Thinking (GST)

One of the challenging aspects is knowing the boundary of the systems and their environment. The formalization of systems thinking goes to Ludwig Von Bertalanffys formulation of the General System Theory in 1940, which states *"... an important means of controlling and instigating the transfer of principles from one field to another, and it will no longer be necessary to duplicate or triplicate the discovery of the same principle in different fields isolated from each other*" [7]. In his book, the author mentions that the characteristics of the complex will manifest as new or emergent. Further, he explains the system complexity by interfaces. The elements are interacting and they are open to interact with their environments. We can introduce the environments as variables or circumstances surrounding the system of interest and the interaction between the two is done through interfaces. Therefore, the system context and interaction with their environments is the major principle to provide an understanding of the Openness of the system.

A. Openness of Battery Train

Stephen G. Haines stated "*All systems have boundaries which separate them from their environments. The concept of boundaries helps us understand the distinction between open and closed systems. The relatively closed system has rigid, impenetrable boundaries; whereas the open system has permeable boundaries between itself and the broader environment.*" [10]. The battery train as a system has elements that interact with each other and with their environments, therefore, we can consider the system as an Open System.

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J. Gharajeddaghi stated "*the controllable variables, the uncontrollable variables we can influence and the uncontrollable variables we cannot influence but will have to appreciate.*" [5]. The battery train has controllable variables that come to have influence within their environment and uncontrollable variables that have appreciating variables.

Figure 4 shows a context diagram of the battery-powered train and we can see the Openness of the battery-powered train. Figure 4 also shows the system boundary and the interaction between controllable and uncontrollable variables, on one side, and the system of interest, on the other side.

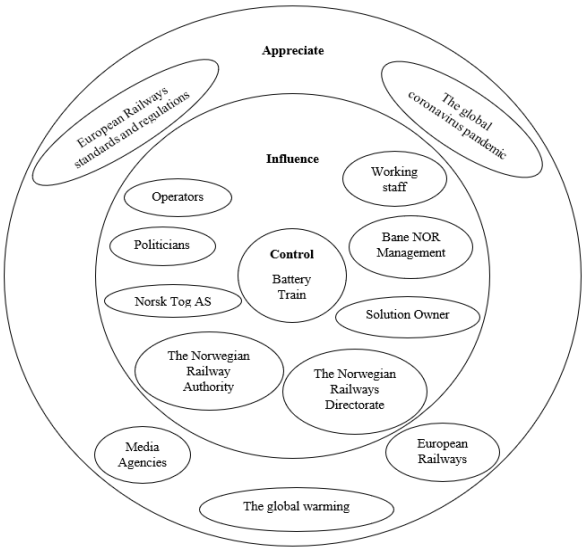

Figure 4. Openness Shows system boundary.

Openness consists of:

a) Control - refers to the system of interest

Battery-powered train

b) Influence - refers to the controllable variables that have influence within the system of interest environment

Operators can include railway companies such as VY or Cargo Net, The Norwegian Railway Authority, the Norwegian National Railways Directorate, staff working on the project, including managers and employees. The solution owner is the Government. Politicians that propose or create laws have power over the governmental strategies. Bane NOR SF Management wants to ensure good and safe solution for operators. Norske Tog AS wants to ensure good service to citizens.

c) Appreciate – Refers to the uncontrollable variables

The global coronavirus pandemic has a huge effect on CO_2 emissions. This abnormal situation caused CO_2 emissions cuts, maybe the largest fall we have seen. The global warming is another factor that is an uncontrollable variable. European railways companies can increase the emergence occurring. European railways standards and regulations have an effect on the Norwegian battery – powered train according to the operational conditions. Media Agencies will share the information of the new technology with the citizens to decrease the worry surrounding the new technology. They can provide feedback from the potential users to the working staff or to the competent authorities.

B. CATWOE and Variable behavior

We identified two groups of controlled and uncontrolled variables that affect the system. The uncontrolled variables are predictable and the system should be prepared for such an environment. The controlled variables are influenced by the system and have a significant effect on decision making. We will analyze the controlled variables behavior because the organizations can change the controlled variables, but cannot change the uncontrolled variables.

Figure 5 shows the CATWOE analysis from Bane NOR SF' viewpoint to ensure a better understanding of the system of interest.

C.A.T.W.O.E ANALYSIS	
C	Bane NOR SF
A	Operators, The Norwegian Railway Authority, The Norwegian National Railways Directorate, Working Staff, Solution Owner, Politicians, Bane NOR SF Management, Norske Tog AS, The global coronavirus pandemic staff, The global warming staff, European railways companies, European railways standards and regulations staff and Media Agencies
T	The need for the purpose of the new system is met by presenting, evaluating, and deciding upon the results from the National Railways Directorate study.
W	Increase the work safety and reduce the cost and CO_2 emission
O	Government
E	Must operate within the European and Norwegian Railways lows and regulations

Figure 5. CATWOE analysis.

C. Influencing the actors

The actors have a significant effect on the system and we need to understand why they do what they do. This effect can have an effective role in system transactional environment. Understanding the actors needs and their influence on the process makes the system more understandable and gives the decisions maker more confidence over their decisions. Those actors have influence on the systems output.

J. Gharajeddaghi stated "*Thereafter, to be an effective player, one has to move yet higher, to the level of understanding, and learn why they do what they do. The why question is the matter of purpose, that of choice*" [5]. We can gain knowledge by asking the why question. Figure 6 shows the actors and why they do what they do.

In the past years, the Norwegian railway sector and politicians with government support showed increased interest in environmental purity and reducing the sources of energy that are harmful to the environment. This supports

the global organization trends such as the global warming and European Railway Management. The reduction of CO_2 will support global organization orientation and this project could have funding as an advantage.

The operators of the battery train are motivated by politicians and railway managers to replace the current trains with diesel engines by battery trains to ensure reducing the CO_2 and to participate in the railway activities to provide Zero Emission. Bane NOR SF is an agency that manages the railway infrastructure and has the responsibility for the safety of worker and the passengers. Norske Tog AS collaborated with Bane NOR SF while working on the first battery with partial electrification train as a pilot project within the Norwegian Railway infrastructure sector. The National Railway Directorate leads and supervises the project to ensure the performed work is within Norwegian laws and regulations. They will ensure a good communication with the regulation authority. The Norwegian Railway Authority will also provide guidance to ensure that the project is within Norwegian and international laws and to ensure sustainable and safe operation.

Actors	Why they do what they do
Operators	Provide feedback, test the new system, ensure it meets the purpose of CO_2 free
Politicians	Support the national and international community towards null emission
Working staff	Gain a better salary and experience. Collect and share information.
Owner	Lead, enable and accelerate the commercialization of the battery train.
Bane NOR SF	Ensure that the trains used on its railway lines are modern and safe.
Norske Tog	Owner of the train. Ensures the train is equipped with the new system as a pilot project. Provides the new technology to all operators.
Railway Directorate	Has the responsibility to develop new regulations and standards for the new system.
Railway Authority	Carries out supervision to ensure that companies in the rail industry operate in accordance with legal requirements regarding safety and security.

Figure 6. The actors and Why question.

The project manager will gain knowledge on the new system and how to deal with different situations the working staff could face. They ensure the staff has the necessary tools and the necessary documents to perform their work. The working staff also would gain work experience and probably better salary.

The Directorate study reports will probably take the uncontrolled variables into consideration and try to make them more predictable in order to position the battery train as a new solution to the market with high level of CO_2 reduction until getting the Zero Emission.

D. Systemigram

Sytemigram is derived from "Systemic Diagram" and provides a tool to help managers, working staff and project stakeholder to have a better understanding of the system concepts, processes, and events. This tool, through the diagram, allows the system to tell a story and catch shallow leverage points (Material & Processes) & deeper leverage points (Design & Intent).

The systemigram shows the interfaces, improves the communication and makes the stakeholders part of the decision-making. The systemigram was developed by John Boardman as a part of his approach to develop and provide the systems thinker with a conceptual modelling tool aligned with the soft systems method [8].

"*Integration is the word we use to introduce the subject matter of this chapter, which is systemic diagrams (referred to as systemigrams): what they are, how they are created, who would want to use them and why, and where they are headed as a decision-support tool, in our opinion*" [6]. Integration is the word that can be used to describe the Systemigram. Through the systemic diagram, we can define the system and how it interacts with the environment, define the different stakeholders and why they have interest, and express how they could be used to enable the system to achieve its goal effectively.

The systemigram in Figure 7 shows, from the top-left, the system of interest (battery train) and runs towards the purpose of the system, which is located down-right (Zero Emission). The battery train should be resilient in order to achieve its purpose by performing the system adaptability.

The elements of the system are classified into 5 groups with different colors. The selected groups are: Agencies (orange color), Physical Train (black color), Emission (green color), Infrastructure (gray color), and Financial influence (yellow color).

E. Leverage Points

The leverage point for any system has a significant effect over the entire system, where any small changes or modification can cause a large effect, as seen in Figure 7.

The Norwegian Railway Directorate has selected the battery train with partial electrification as a proper solution to the Norwegian Railway Sector. This will help the global effort to support zero emission. That means, the Government should provide the funding to the project. Adapting this solution means we should adapt laws, regulations, legislation, and commercial structure.

Applying the new battery on trains will make the transportation more cost effective and the load of the work for railway sector could be increased and cause new challenges to our system. D. H. Meadows stated "*Missing information flows is one of the most common causes of system malfunction. Adding or restoring information can be a powerful intervention, usually much easier and cheaper than rebuilding physical infrastructure*" [3].

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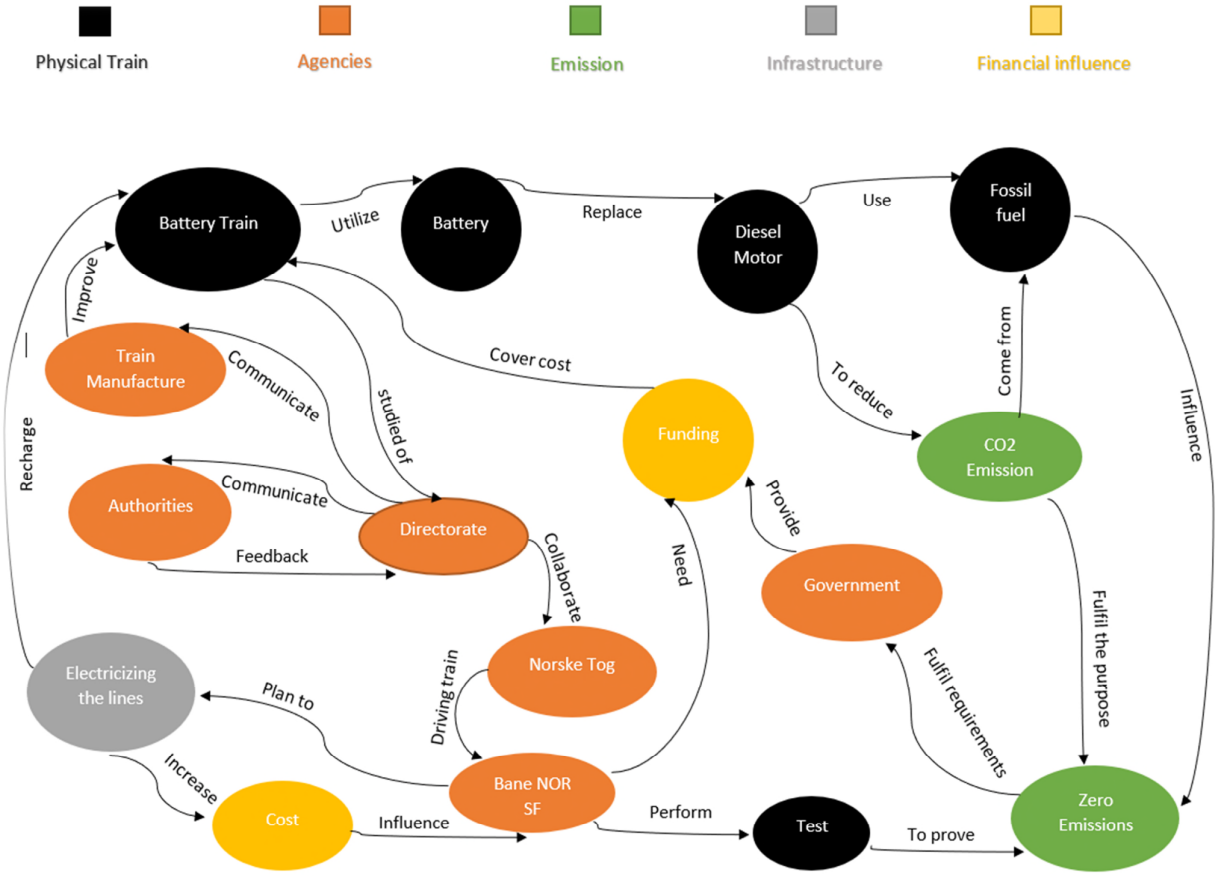

Figure 7. Systemigram for battery train

In Figure 7, we can see from the Systemigram how important the communications and feedback among Directorate Authorities and the train manufacturers is, in case modifications to satisfy the European and Norwegian railways are required. Therefore, the system should have a new method of communication and feedback for better response, such as putting the information on a website and giving access to the users, depending on their positions in the organization.

Additionally, Bane NOR SF must change the stretches to build new electrified stretches to enable recharging the new battery train. This will make the railway sector ready to receive more battery-operated trains that cover the entire Norway stretches. However, this will also cause an increase in the cost to Bane NOR, due to the need to build a new stretch.

One of the new impacts that could affect the new project is the Coronavirus global pandemic. The world has become increasingly isolated and the advice from experts goes against being in groups, which could further spread infection. Among the measures taken is to reduce the use of public vehicles, including locomotives. This approach may have a negative impact in terms of financing the project and in terms of continuing to implement it.

Another leverage point is how the new battery train influences human factors. The new technology will require a new type of working staff with a high education level. In addition, it requires a new type of data and IT systems to deal with it.

V. Conclusion and Recommendations

We need to rethink the design of the Norwegian Railway infrastructure and understand the impacts of the new technology on the cities. Rebuilding or building new lines to fit the new system will require resource, money, and time to perform the works.

The battery train is considered a railway solution for Zero Emission, but not as the only one. This solution will increase the awareness in the community and have a positive impact on the global environment in terms of global warming, noise, and clean air. However, at the same time, increasing fears of lack of clarity of the new technology system and the need to improve the quality of train service exist.

This paper has presented the new battery train technology of with partial electrification by using the Systems Thinking Methodology Framework. The purpose was to understand the complexity of the system, locate the system boundaries, identify and define the uncontrollable and controllable variables within the system environment, allocate the stakeholders and their roles, and visualizing the system through applying the Systemigram.

The paper used Openness to categories the system variables. Some of the variables can be controlled by actors

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categorized under Influence such as operators. Another group no one has control over are variables which are unpredictable, categorized under Appreciated, such as the global Coronavirus pandemic.

The paper used the WHY question technique to find out why different actors do what they do. This method helps the project managers to understand the expectation of stakeholders for this new system. In addition, CATOWE analysis is performed from the stakeholder viewpoint.

Using the Systemigram allowed us to see the system from a different and bigger point of view. This tool demonstrates the complex systems in a simple way and helps visualize the elements and their influence in the system. This tool makes the communication among different stakeholder easier and effective.

Further, we want to recommend Systems Thinking methodology to be used. It can be used in any field of Engineering research or analysis and many different areas of specialization. This methodology makes the system better understood by identifying its strengths and weaknesses and how the system elements are connected internally and externally. Also, it facilitates the process for developing and improving the system's outputs.

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