Study on Hybrid Autonomous Trucking System (HATS) Problem Complexity

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The goal of this study is to break down and analyze the complexities surrounding the implementation of an electric hybrid autonomously controlled trucking system (HATS) for the mass transportation of goods. HATS represents a new category of commercial vehicles that exhibit both electric hybrid powertrains, and artificial intelligence for self-driving capabilities. Problem complexities are broken down from a social, economic and environmental perspective using a transdisciplinary approach. Study motivation arises from the fact that tons of goods are moved thousands of miles across the world using semi-trucks and in order to do so, thousands of drivers spend days on end out on the open road. This results in high CO_2 emissions as well as loss of precious family time for drivers. As a potential solution, modern computing technology offers artificial intelligence (AI) to increase efficiency and replace these drivers all together. Considering this potential however, there are a significant number of issues surrounding the proposition that need to be solved before implementation can begin.

Keywords: electric hybrid, autonomous, transdisciplinary approach, artificial intelligence; trucks.

1 Introduction

Hybrid technology is a recent development that has increased the efficiency of automobiles, trains, and other vehicles used in the personal and commercial transportation industry. The definition of hybrid is mixing parts or processes to achieve the same goal [1]. In vehicles, the hybrid process refers to applying more than one method of energy transfer through the power train. The most common method utilizes conventional internal combustion engines coupled with electronically assisted systems, often being electric motors that engage at cruising speeds. This technology has been proven to increase fuel efficiency in personal automobiles and is just now being implemented into commercial transportation vehicles as well. A few companies such as Wrightspeed Powertrains and Thor Trucks are investigating the integration of all-electric powertrains into existing trucks, and the implementation of electronically assisted locomotion techniques as well.

Wrightspeed is "re-powering the world's largest urban fleets" by installing range-increasing electric and internal combustion hybrid powertrains. Such hybrids are shown to perform with 67% less fuel consumption and 63% less emissions [2]. HATS can take this concept to the next level by adding it to an autonomous, self-driving platform. Fuel savings combined with a driverless platform could save the transportation industry millions of dollars that would otherwise be spent on fuel or driver compensation.

Thor Trucks (Figure 1) are currently producing the ET-1, a fully electronic heavy-duty truck made for transporting goods and materials long distances. The ET-1, like Wrightspeed's drive trains and HATS future trucks, are heavily reliant on battery packs that have long tough duty cycles [3]. Lithium ion cells are of standard use in this application due to their qualities that provide rapid charging capabilities, large relative battery capacity and low maintenance. Introducing artificial intelligence (AI) into the hybrid equation creates a new set of complexities that, like hybrid powertrains, require heavy investigation prior to integration.

Figure 1: Thor Trucks ET-1 [3].

While AI is a relatively new technology, its potential has proven promising with regards to guidance and long distance commutes. Products such as Skydio's R1 drone take advantage of high-quality cameras in conjunction with advanced processors and AI that essentially allow it to follow a subject in any direction with high accuracy [4]. Combing this technology with hybrid semi-trucks would allow them to lock on and follow any manned vehicle in front of them with high accuracy and precision for miles or hours on end. On the surface, the idea entertains advantages such as the economic gain of eliminating the driver, accident reduction and even potentially reducing CO_2 emissions. However, given the publics exposure to such a system as HATS, there are several potential problems that may arise, and which need to be accounted for before such technology reaches ubiquity.

2 Complexities

Designing a hybrid semi-truck driven by AI may seem as if it were solely an engineering problem but the most important characteristics lie not in system design alone, rather in its implementation. The HATS system would be a product intended for use by the public and on public roadways throughout the country with the primary focus being that of commercial application. Inherently, the integration of computer software that would essentially drive a 40 ton vehicle cannot be done without consultation of legislation, overall public opinion, and safety. It is assumed that the general public would exhibit a negative reaction to the idea of driving next to a vehicle of such magnitude while knowing that it does not have a human driver in control. Because the concept is so new, many of the laws regarding AI controlled semi trucks have not been established as of yet. Seeing how no functional system is currently in place, establishing a set of laws or guidelines to control these self-driving vehicles will bring up a couple problems of their own. These new laws can be anything pertaining to safety, traffic considerations, and how much control an AI system is allowed to have while on the road.

Following a similar thought process brings up the issue of programmed ethics and the level of autonomy each truck shall have. This topic can be realized with consideration of variable roadway situations. For example: as roadway conditions change, the natural human response is to drive according to the pre-set road safety laws and suggestions. An even more complicated but arguably more important example could be inner city conditions; where a driver is responsible for yielding to any pedestrian whenever and however they may present themselves. The same issue again applies to stop-and-go traffic as well. With that, a decision must be made as to what form of ethics an AI driving system should rely on as well as the quantifiable amount for which the system is intended to be used. In other words, the system must be pre-programmed to choose the “best” or most desirable outcome. However, these predetermined rules will need to set their own “practical” limit on how often they are called within the autonomous system. While these crucial factors may sound negative in context, proper consideration could result in overall accident reduction which would be a major HATS advantage.

Accordingly, the development of a system capable of reducing roadway accidents would ultimately reduce the need for a human driver. A reduction in semi-truck drivers presents an even larger complexity as well. This is because the semi-truck driver job market represents up to 3.5 million jobs in the U.S., where the average salary is around 41k/year [5]. Replacing just half of those jobs with HATS would result in a 71.8 billion dollar economic gain. Such a benefit could potentially offset the development cost by an exponential factor. However doing so would likely cause significant driver job loss and a shift in the overall shipping price of goods, both of which largely contribute to the semitruck market.

Another, and perhaps more beneficial economic complexity, lies in the potential emission reduction aspect as a result of AI integration. The idea here is that the optimization capabilities of AI would open the possibilities for drag reduction methods. By utilizing the accuracy and precision with respect to target tracking within HATS, several trucks could closely follow one another in a line, over long distances, without running the same risk human drivers face. Doing so would permit only the first truck in said line to experience the most aerodynamic drag. Accordingly, the following trucks would experience far less aerodynamic forces hence improving fuel economy within the other trucks. Lower fuel consumption means lower cost and in turn creates greater economic gains for all using the HATS system.

3 Structural Self Interaction Matrix (SSIM)

In order to break down the complex interaction surrounding the prescribed factors affecting HATS implementation, a structural self-interaction matrix (SSIM) shown in Figure 2 was formed. In the SSIM, ‘A’ indicates factor relation from the i (horizontal axis) element to the j (vertical axis) element. ‘V’ represents relation from j to i, ‘X’ indicates relation both ways and ‘O’ is used to indicate no relation. The SSIM is an invaluable tool used to break down problem complexity in the Transdisciplinary Approach.

i \ J		Public view and Laws	Accident reduction	Reduced emissions	Loss of jobs	Cost of development	Economic gains	Level of autonomy	Programmed ethics
Public view and Laws	1		A	A	A	X	A	V	V
Accident reduction	2			O	O	O	V	A	O
Reduced emissions	3				O	V	V	A	O
Loss of jobs	4					O	V	A	O
Cost of development	5						V	A	O
Economic gains	6							A	O
Level of autonomy	7								X
Programmed ethics	8								

Figure 2: Structural Self Interaction Matrix.

From the SSIM, two instances of equal interaction were necessitated. ‘Public View and Laws’ was found to affect the ‘Cost of Development’ and ‘Cost of Development’ equally affected ‘Public View and Laws.’ It was found that if the cost to effectively develop HATS was increased, the public’s perception of the economic benefit to HATS was reduced. Conversely, reduced public interest in HATS necessitates further investment in marketing to convince the public of the benefits HATS can afford, which thereby increases the overall cost of development to compound the issue. Furthermore, a negative public perception of HATS might result in the public feeling ‘uncomfortable’ with autonomous vehicles, this would likely result in increased laws pertaining to HATS to ease the public conscience. Added laws would force HATS developers to focus additional resources to maintain compliance, which ultimately serves to increase the cost of development.

Additionally, the 'Level of Autonomy' shared a mutual interaction with 'Programmed Ethics.' As the degree of autonomy in HATS is increased, there is an increased need for programmers to consider the ethical dilemma surrounding the autonomous control. However, as ethics are considered in the decision-making process, it may well dictate that the ethical decision sets the limit on the degree of autonomy. In the end these two sets of interacting factors will need to be carefully considered in the design process.

As an added note, the SSIM reveals some other interesting trends. For starters, the Level of Autonomy' seems to have a great effect on the other factors across the board. 'Level of Autonomy' directly effects 'Accident Reduction,' 'Reduced Emissions,' 'Loss of Jobs,' 'Cost of Development,' and 'Economic Gains.' As a result, careful attention will need to be paid to 'Level of Autonomy' given its widespread affects. On the contrary, 'Economic Gains' is dependent on a number of other factors. That is, there are many factors that can diminish or increase 'Economic Gains.' Since economics is a driving reason for the implementation of HATS, factors that increase 'Economic Gains' should be optimized, and those that decrease 'Economic Gains' should be evaluated to minimize their effects.

4 Further Transdisciplinary Tools

As part of the Transdisciplinary Process, the developed SSIM was inputted to a computer program to assist in complexity breakdown. A further description of program operation is provided by A. Ertas [6].

$$A = \begin{array}{r} \\ \text{Public view and Laws } 1 \\ \text{Accident reduction } 2 \\ \text{Reduced emissions } 3 \\ \text{Loss of jobs } 4 \\ \text{Cost of development } 5 \\ \text{Economic gains } 6 \\ \text{Level of autonomy } 7 \\ \text{Programmed ethics } 8 \end{array} \begin{array}{c} \begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \end{matrix} \\ \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix} \end{array}$$

Figure 3: Initial Reachability Matrix.

The Initial Reachability Matrix shown in Figure 3 is directly derived from the SSIM shown previously. This matrix instead represents factor interaction with binary digits, either a '1' or a '0' instead of the 'A', 'V', 'X', or 'O.' After the Initial Reachability Matrix is formed, transitivity is accounted for in the following Transitivity Included Initial Reachability Matrix shown in Figure 4. Here additional factor interaction is considered using the transitivity property which can be briefly expressed as the mathematical logical. That logic follows as the conditions exist such that 'A' = 'B' and 'B' = 'C', therefore 'A' = 'C'. However, this method is instead applied to the HATS factors rather than algebraic manipulation. Figure 4 is later used for MICMAC analysis which will be explained in detail later.

$$R_f = \begin{array}{r} \\ \text{Public view and Laws } 1 \\ \text{Accident reduction } 2 \\ \text{Reduced emissions } 3 \\ \text{Loss of jobs } 4 \\ \text{Cost of development } 5 \\ \text{Economic gains } 6 \\ \text{Level of autonomy } 7 \\ \text{Programmed ethics } 8 \\ \text{Dependence} \end{array} \begin{array}{c} \begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \end{matrix} \\ \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \\ \begin{matrix} 7 & 4 & 4 & 4 & 8 & 8 & 8 & 8 \end{matrix} \end{array} \begin{array}{c} \text{Driving power} \\ 8 \\ 6 \\ 6 \\ 6 \\ 5 \\ 5 \\ 8 \\ 7 \\ \Sigma = 51 \end{array}$$

Figure 4: Final Reachability Matrix with transitivity.

Following the ISM process, factor 'level' partitions were established (Figure 5) to allow engineering design considerations to be made. Afterwards level partitions were combined with interaction associations to form the Digraph (section 5).

5 Digraph

The digraph is a more visual representation of the interactions between the factors identified in the SSIM analysis and the level partitions established in the preceding matrices. The digraph is shown in Figure 6. What we can gain from this is a quick and easy interpretation of the relationship between each factor and the hierarchy that is established. Each arrow is either one way or two way, indicating that the influence of the factor is either one directional or two directional, respectively. This type of diagram is helpful because it allows for the identification the relationships that have the most influence and therefore require more consideration as design decisions are made. From the MICMAC analysis and the

Factor #	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7	1,2,3,4,5,6,7	
2	1,2,5,6,7,8	1,2,7,8	1,2,7,8	
3	1,3,5,6,7,8	1,3,7,8	1,3,7,8	
4	1,4,5,6,7,8	1,4,7,8	1,4,7,8	
5	1,5,6,7,8	1,2,3,4,5,6,7,8	1,5,6,7,8	1
6	1,5,6,7,8	1,2,3,4,5,6,7,8	1,5,6,7,8	1
7	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	1
8	2,3,4,5,6,7,8	1,2,3,4,5,6,7,8	2,3,4,5,6,7,8	1
1	1,2,3,4	1,2,3,4	1,2,3,4	2
2	1,2	1,2	1,2	2
3	1,3	1,3	1,3	2
4	1,4	1,4	1,4	2

Figure 5: Level partitions.

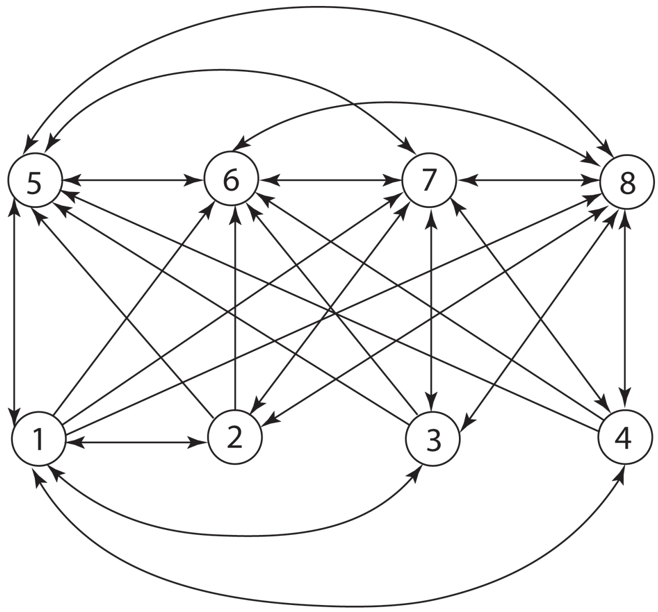

Figure 6: Digraph.

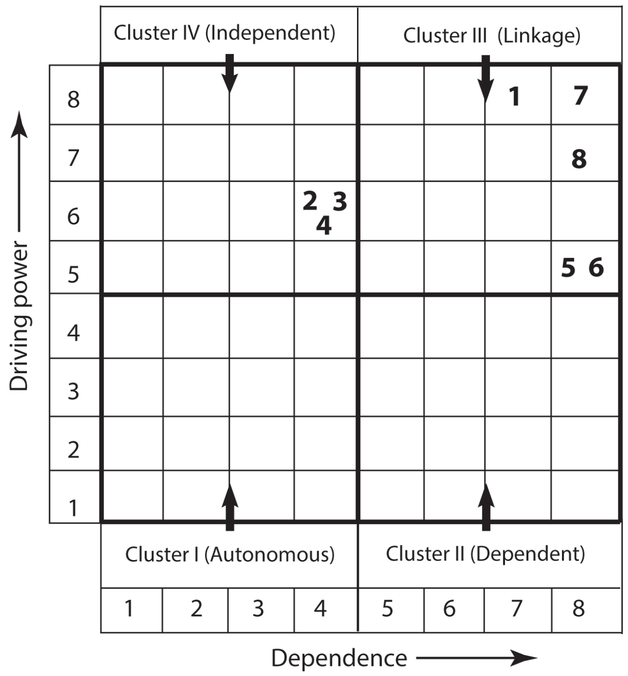

Figure 7: MICMAC diagram.

digraph, we can draw the conclusion that most of the factors detailed have high driving power and high dependence. While there are a few that have high driving power and low dependence, the factors of this system have a high overall dependence on each other. As mentioned before, the digraph also illustrates the level partitions of this analysis. These levels are a hierarchical representation of the factors involved and are calculated based on the separation of the antecedent set and the reachability set. As it pertains to the HATS, factors 5, 6, 7, and 8 are level I and as such are the most critical during the design consideration process. In the digraph, there is no source factor, or factor containing only outgoing arrows. This shows that the system being designed is cyclic and highly dependent. There are also no isolated factors in the system, as evidenced by the fact that all factors have an arrow coming in or going out. This again indicates a high level of dependence between the factors.

6 MICMAC Analysis

The MICMAC Analysis is a tool used to analyze complex problems (Figure 7). To analyze complex problem such as Hybrid Autonomous Trucks (HATs), we used the MICMAC Analysis to classify the factors influencing the HATs as Autonomous, Dependent, Linkage, or Independent. Further, MICMAC Analysis was utilized to indicate the dependence and the driving power of factors; and to provide interdependencies and an insight into the relative importance between eight factors.

6.1 First Quadrant (Quadrant I)

The first quadrant is an autonomous quadrant. The factors in this quadrant don't have much influence on the system. This indicates that autonomous factors have less driving power and are less dependent. In the present analysis, the lack of factors in autonomous region indicates that all the factors we considered are important. Therefore, all eight factors we assigned have significate influence on the Hybrid Autonomous Trucks problem analysis.

6.2 Second Quadrant (Quadrant II)

This quadrant is known as dependent. Basically, factors located in this region have low driving power and high dependency. In the present analysis there is the absence of the factors in this region which indicates that in our study of the Hybrid Autonomous Trucks we don't have any factors with low driving power and high dependency.

6.3 Third Quadrant (Quadrant III)

This third quadrant is called linkage. Factors with high driving power and high dependence fall in this quadrant. In our analysis, five following factors fall in linkage region: (5) Cost of Development, (6) Economic Gains, (8) Programmed Ethics, (1) Public View and Laws, and (7) Level of Autonomy. We will give extreme importance to these factors because any action on them will affect the entire HATs system. Therefore, designing the HATs is a challenging as we have five factors in the linkage region. We should perform a detailed analysis on these factors to properly integrate them in the system.

6.4 Fourth Quadrant (Quadrant IV)

This is an independent quadrant. It contains factors with weak dependence but strong driving power. According to our analysis, three following factors appear in the independent quadrant. Accident Reduction (2), Reduced Emissions (3), and Loss of Jobs (4) are all key factors and important elements to consider when analyzing the application of Hybrid Autonomous Trucks. Accident Reduction (2) is an important element for the performance and the application of Hybrid Autonomous Trucks. Nowadays, the rate of the accident caused trucks is high. Most accidents are caused by drivers. Utilizing Hybrid Autonomous Trucks will reduce systematically accident rate in our society. Therefore, the application of such system will be beneficial for our society.

Reduced Emissions (3) is an independent and it's an important factor to consider for the application of HATs. Nowadays, pollution is a major concern for the environment and Trucks contribute to the environmental pollution because they use fossil fuels. Using Hybrid Autonomous Trucks will significantly reduce the amount of the CO_2 injected everyday by trucks operating with fossil fuels.

Loss of Jobs (4) is also an important factor to control as it falls in independent and high driving power. We need to pay a maximum attention to this factor as it has an impact on other factors and can influence the application of HATs negatively. Therefore, it is important to find a way to compensate the job loss created by the utilization of the Hybrid Autonomous Trucks.

7 Discussion

After incorporating the previous transdisciplinary tools, it was realized that further factor discussion was necessitated. With the HATS there are three main points that need further discussion; pros and cons need to be weighed as well with respect to specific factors. We will be looking specifically at the social, environmental, and economic factors brought about by the introduction of automated commercial trucks.

7.1 Social Impact

The social domain focuses mainly on the development of human relationships, success in the adaptation of individual value and achieving overall implementation goals. The integration of HATS means new comfort zones will have to be established to ensure the public mutually accepts with the idea of actively driving alongside large autonomous vehicles. To best outline the in-depth social interaction, it is imperative to begin by considering the factors that inhibit HATS the most.

From an engineering prospective, the benefits of allowing a sophisticated computing system to replace a human driver arguably outweigh risk. However, the extensive adaption of an innovation depends not on technological barriers but on public opinion. A survey from MIT revealed that nearly half of the American public is un-comfortable with the loss of control that comes with automated vehicle even though it is statistically safer [7]. From this study it is shown that people tend to associate a level risk with control. Meaning, they are likely to feel safer with someone (a human) in control of their vehicle. The notion of a computer system in control of a vehicle rather than a human would make people uncomfortable. A similar problem can be seen in modern “Autopilot” features in Teslas even though they have been proven to be remarkably safe. The irrational fear of self-driving cars will delay the adoption of this technology. The hesitation to adapt will ultimately contribute to the delay in changing some laws with the US Automation Policy which seeks to design a legal framework to balance safety and innovation.

One of the greatest advantages that HATS creates to counteract the negative context of allowing AI to control a vehicle is accident reduction. Allowing the advanced guidance systems required to successfully operate HATS, such as those of Skydio’s R1, it can be assumed that a reduction in human driver error can be expected. Fatal traffic accidents like drunk driving and sleeping behind the wheel will be reduced significantly if not eliminated. According to the Federal Motor Carrier Safety Administration, there were 119,000 serious injury accidents involving large vehicles in 2016 [8], all of which are a result of human reaction and impulsive error. The goal of HATS is to greatly decrease this number over time by eliminating human error with advanced AI.

7.2 Environmental Impact

The environmental domain emphasizes the protection of the integrity and resilience of ecological systems [6]. Self-driving vehicles are a relatively new technology, so there is only a limited amount of information that associates hybrid autonomous vehicles with their environmental impact. However generally speaking, it is known that autonomous vehicles whether they be electric or electric hybrid in nature, will require batteries in order to function. Thus the further implementation of self-driving vehicles would require an increase in the battery supply, so battery production can be evaluated to measure the environmental impact of autonomous vehicles.

It is a common assumption that hybrid and electric cars are better for the environment since they don’t emit pollutants to their immediate surroundings, or at least emit less. However, there are many aspects neglected in this assumption. To measure the environmental impact of these vehicles, it is important to consider the product during the manufacturing process, the life of the product, and the means to dispose of the product at the end of its useful life. After taking everything into consideration, it is debatable to say electric (or hybrid) cars are better than the regular gasoline car. According to a study by the Union of Concerned Scientist on the topic “Cleaner Cars from cradle to Grave”, comparing the manufacturing process of the petrol versus the batteries of the electric cars, including all the resources, it was determined that during manufacturing process the electric car was responsible for 1 tone more of Carbon emission than their petrol counterpart [9]. The majority of these emissions stem from battery production.

Lithium ion batteries are a common battery type used for electric vehicles and production of such batteries involves a great deal of pollutants. For starters, the manufacturing of lithium batteries involves extracting of lithium compounds from the soil, and the process to do so is not very environmentally friendly as it is associated with the release of tons of carbon emissions. During the electric vehicle life, most of the electricity used to power it comes from the burning of carbon containing fuels such as coal and natural gas. Thus carbon emission are still produced over electric vehicle life. Lastly, the end of an electric vehicle’s useful life requires the disposal of potentially hazardous environmental pollutants such as the lithium from used batteries.

While these inherent electric vehicle issues have no current solution, HATS implementation can be designed to reduce the overall impact. By using a ‘Hybrid’ vehicle design rather than a strictly electric variant, battery consumption would be reduced relative to a completely electric fleet. However as renewable resources continue to reach ubiquity, potential exists in the future to entirely eliminate carbon emissions emitted during the electric vehicle life. HATS would still be able to benefit from such electric production in the future as battery charge could be supplemented with electricity produced from environmentally friendly sources. None-the-less HATS serve as a stop gap measure in the meantime.

From this discussion we can see that a lot of the negative impacts that could be brought about by such an automated trucking system, is mainly form the older technology and outdated infrastructure currently in place.

7.3 Economical Impact

Economically, the goal of any new technology is to improve human welfare. HATS can do so primarily by reducing transport costs to ultimately reduce the cost of goods and services. Another aspect that would permit HATS to improve welfare is by eliminating the tedious need for drivers to operate transport trucks. The Texas transportation Institute estimates that 75 large cities in the US experience 3.6 billion hours of delay (wasted time stuck in traffic), 21.6 billion liters of wasted fuel while they are stuck in traffic, and this all amounts to 67.5 billion USD in lost productivity [10]. The projection predicts this problem to get worse and cost the United States trillions of dollars between 2013 and 2030. Many nations face a similar problem.

The integration of HATS concept could reduce such losses. To begin with, human drivers are generally inefficient and contribute to many deaths and thousands of dollars in destruction every year. Additionally, poor driving skill adds to the congestion of transportation networks, a significant problem for especially urban areas. HATS offers potential to eliminate the issue of human error in the transportation system to reduce losses and deaths. On the downside, however, is the sheer job loss that would result from HATS implementation. In the United States about 3.8 million jobs are occupied by the truck drivers, school bus drivers and Taxi drivers, with autonomous vehicles these jobs will be lost [11].

HATS potentially poses a great threat, or a great benefit to the economy, and in the long run that benefit would hopefully be for the greater good of humanity. Ultimately careful consideration is necessitated to evaluate the economic impact of HATS. Following these three sections it becomes apparent that economics is one of the key benefits from HATS, but it is very important that all three topics discussed are addressed properly for a truly successful design.

8 Conclusion

This study gives a more in-depth look to the adaptation of a fully automated trucking system. To help improve the efficiency within the trucking industry. The authors of this paper took a transdisciplinary approach to help consider exactly how the HATS system will affect the world.

The SSIM (Digraph, and MICMAC) analysis performed to see how the different factors of the overall system relate to each other and how they relate amongst one another. Also, we have discussed how this new approach will both positively and negatively affect society, the environment and the economy. Combining these three independent sustainability subjects, one can get a good base design for the automated trucking system proposed. We can also see, in depth, how HATS will affect not only the industry but society by improving efficiency and optimizing the trucking industry around the world.

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