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Application of the Analytical Hierarchy Process for Autonomous Truck Strategies of Commercial Vehicles

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Abstract: This research reports on the development of a model to measure the value of a given traffic strategy for freight truck traffic through the perspective of multiple involved agencies. The model was designed as an Analytical Hierarchy Process (AHP) model, wherein each perspective was broken down into sub-criteria in subsequent tiers. These sub-criteria would then be compared to each other to determine the overall weights of each perspective in evaluating different traffic control strategies. The model was created to determine the value of four specific perspectives: the Economic, Safety, Environmental, and Mobility Perspectives of a given traffic control strategy. These perspectives were tested through the surveying of 24 experts within the state of Florida involved in the field of transportation, who were consulted to determine the weights of each perspective and its criteria using pairwise comparisons. Once completed, the model was then tested to evaluate the overall priority of three alternatives: one in which no strategy was employed, one in which a strategy was employed at a speed of 55 mph, and one in which it was employed at 75 mph. The results showed that safety was selected as the most important perspective among all the consulted experts. Since the strategy of implementation at 55 mph was deemed the safest, it was calculated as the most sustainable alternative, despite its lower speed and efficiency lowering the economic and mobility priorities. This supports the implementation of the AHP model in upper-level decision making, as it allows management to determine the best decision that will placate all lower-level parties, preventing conflict and increasing overall workplace efficiency.

Keywords: analytical hierarchy process (AHP); perspective; economic; safety; mobility; criterion

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1. Introduction

There exist various measurable outcomes when implementing a change in traffic control strategy such as the increase in average travel speed, reduction in total traffic delay, and lowering of greenhouse gas emissions. One must assess the efficacy of the change through the collection of quantitative and qualitative data. These results assist decision-makers in deciding whether implementing the strategy is a viable solution to a problem, or if the benefits of doing so are outweighed by the cost.

However, issues arise when decisions are so broad as to involve multiple bodies and agencies in approving them. These disparate parties may agree on a specific policy when there are no disadvantages but may conflict with each other when one party benefits at the expense of another. Citing some examples, many traffic agencies would prefer to extend the width of roads to increase the capacity and flow rate of traffic, but this process may be too expensive for the governmental agency in charge of funding it. It could also be too taxing on the environment with removed greenery and increased pollutants, which may cause agencies like the Environmental Protection Agency (EPA) to deny the project. The time and manpower necessary to make the extension could choke the present traffic flow to unacceptable levels, causing district traffic agencies to refuse to collaborate.

As such, it is important to test each suggested alternative through multiple perspectives and criteria. Although this may still lead to some involved parties suffering additional costs, it does allow those parties to compromise on a decision and mitigate the negative aspects for the slighted parties.

The original research reported here was performed as part of the doctoral thesis for co-author A Mohamed [1], who sought to improve the efficiency of freight truck movement. The thesis consisted of two main sections: the introduction, modeling, and testing of an autonomous traffic management strategy; and another section where it was assessed qualitatively by using a Multi-Criteria Decision Model (MCDM). The traffic strategy implemented featured truck platooning, wherein trucks were organized into convoys of indeterminate length, formed within an exclusive truck lane. Unfortunately, little research has been performed on this type of control, as it involves providing more freedom to truck movement when most strategies involve limiting them, whether in speed or transitionary movement.

While the strategy can be modeled, and quantitative data gathered, the efficacy of the strategy will face resistance as most departments in charge of transportation are predisposed to limiting freight truck movement. As such, results that simply state the strategy will increase productivity would face criticism from parties concerned over the effects on traffic safety and mobility. However, if the MCDM successfully accounts for all these potential perspectives and proves the strategy will be effective enough in each area to placate those concerns, the results of the model will be seen with higher authenticity.

For this paper, the authors will focus on the creation and implementation of the MCDM, as well as how the results can be used in future decisions. Starting with the literature research performed to determine the best model to use (Section 2), this report will then detail the methodology used in the creation of the model (Section 3), followed by the results of the implementation (Section 4), before considering potential weaknesses and criticisms (Section 5) and forming the ultimate conclusion on the efficacy of the MCDM (Section 6).

The MCDM chosen was the Analytical Hierarchy Process (AHP) model, wherein each perspective and its criteria will be set into a tiered structure so that each criterion can be weighted with respect to the others in terms of overall value and desirability. This model was introduced by Thomas Saaty [2] and has seen use in several experiments and research, such as Berrittella et al. [3], which used it in their paper "An Analytic Hierarchy Process for the Evaluation of Transport Policies to Reduce Climate Change Impacts" and Moslem et al. [4] in their paper "A Systematic Review of Analytic Hierarchy Applications to Solve Transportation Problems: From 2002 to 2022".

With this model, the ultimate policy selected should be the most acceptable compromise to all parties involved, otherwise denoted as "the most sustainable" alternative.

2. Literature Review

In preparation for the article, additional research was conducted into previous studies and projects that dealt with the application of MCDMs, both in the field of traffic analysis and in other multi-perspective decisions.

The first subject of focus was on the advantages of cost-benefit analysis (CBA) in general, a precursor MCDM that focuses exclusively on monetary cost and benefits in decision making. Myriad studies within the European Union were analyzed, including Jones et al. [5] in their paper "Transport Infrastructure Evaluation Using Cost-Benefit Analysis" and Beukers et al. [6] in their paper "Why Cost-Benefit Analysis is perceived as a problematic tool for assessment of transport plans: A process perspective". Both asserted that, although the model itself was useful as a tool, there were inherent flaws due to both the inability to define a clear parameter of value, as well as preconceptions and biases between decision-makers using the tool.

These studies were not the only ones critical of the CBA methodology. Vreeker et al. [7] were another such group, who set out to improve the scale of the CBA model to include other perspectives, such as sociological and environmental effects. They tested this new model on an airport expansion in the Netherlands in their paper "A multicriteria decision report methodology for evaluating airport expansion plans". Another researcher, Petter Naess [8], focused on questioning the assumptions made and their possibly erroneous conclusions in his paper, "Cost-Benefit Analysis of Transportation Investments: Neither critical nor realistic". Finally, a study held by two researchers, Peter Mackie and John Preston [9], "Twenty-one sources of error and bias in transport project appraisal", set out to identify the main contribution to these errors, eventually citing the failure to balance the quantitative and qualitative data as the main contributor.

With the CBA model seemingly ineffective, the research then focused on the next iteration, the life cycle assessment (LCA) and economic input–output (EIO) models, as well as their hybridized form, the EIO-LCA model. As the name implies, the LCA focuses on the societal impacts of a decision, dealing with the issues that arise during its lifetime of operation, while the EIO models focus on the economic and monetary costs of installation, only focusing on the future in terms of when a return on investment is expected. The EIO-LCA model, developed by Hendrickson et al. [10], was the next choice for the MCDM but was still incomplete.

The next, and final model reviewed, was the Triple-Bottom Line (TBL) model, as outlined in the report "Triple-Bottom-Line Accounting of Social, Economic and Environmental Indicators—A New Life-Cycle Software Tool for UK Businesses" by Thomas Weidmann and Manfred Lenzen of the University of Sydney [11]). As an LCA model, it incorporated three of the main concerns in a decision: the economic, societal, and environmental results. Since this was serviceable for the purposes of this research, this model was used as a baseline for the development of the AHP model.

Further research was performed as to the best way to develop the AHP model, and successful case studies were analyzed, such as the previously mentioned studies of Berrittella et al. [3], Poh et al. [12], Zhou et al. [13], and Labib et al. [14]. These studies, as well as various more on dynamic traffic modeling and sustainability assessment, were all consulted in order to develop the AHP model used in this report.

3. Methodology

In the broadest terms, the creation of an AHP model follows a process consisting of the following steps (Figure 1), detailed further within the section.

To begin, the model itself needs to be structured. Since it is a hierarchal structure, the model needs to be separated into layers, or "levels", in order of priority (Figure 2).

The top level of any AHP model should be the overall goal of "the most sustainable" alternative or solution. This would then be followed by Level 2, where all the involved parties and perspectives are identified, followed by the sub-criteria of each perspective in Level 3. Finally, the potential alternatives will be identified and listed in Level 4, where all criteria will contribute to their priority in different weights to be decided. Subsequent levels can be created for each criterion, depending on the complexity of the problem, but for the purposes of this paper, four levels will suffice.

Once completed, the data then need to be collected and compiled. With the data compiled, the next step is to determine the weights of each perspective and criteria by using pairwise comparisons. Pairwise comparisons are where each element of the respective levels is compared against each other element in pairs until each possible combination is ranked in terms of priority. In this paper, the ranking is performed with Saaty's Intensity Scale.

The third step of the AHP is to determine the weight from the pairwise comparisons between all the elements. This can be achieved by arranging elements into a square matrix Saaty, Berrittella et al., Moslem et al., [2–4]. Each element of the matrix's diagonal will be given a value of 1. In order to compute the importance of the elements, a square matrix is developed as follows:

$$A = \begin{bmatrix} \frac{a_1}{a_1} & \frac{a_1}{a_2} & \cdots & \frac{a_1}{a_n} \\ \frac{a_2}{a_1} & \frac{a_2}{a_2} & \cdots & \vdots \\ \vdots & \cdots & \ddots & \vdots \\ \frac{a_n}{a_1} & \cdots & \cdots & \frac{a_n}{a_n} \end{bmatrix}$$

where a1, a2..., and an are comparison weights obtained from step 2.

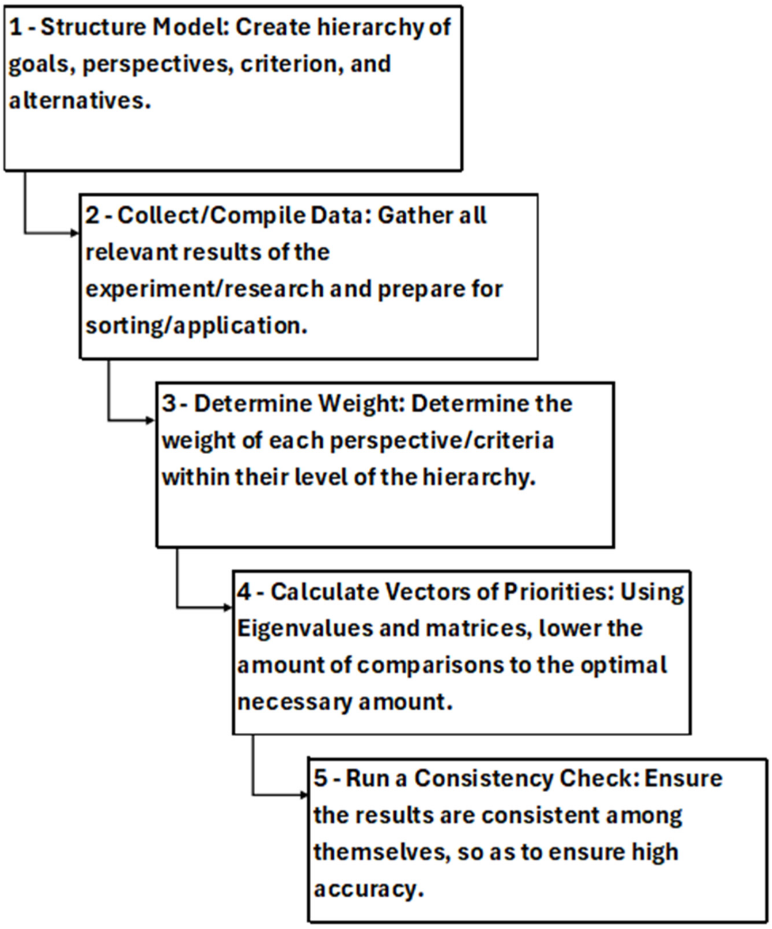

Figure 1. Flowchart of standard creation of AHP model [2].

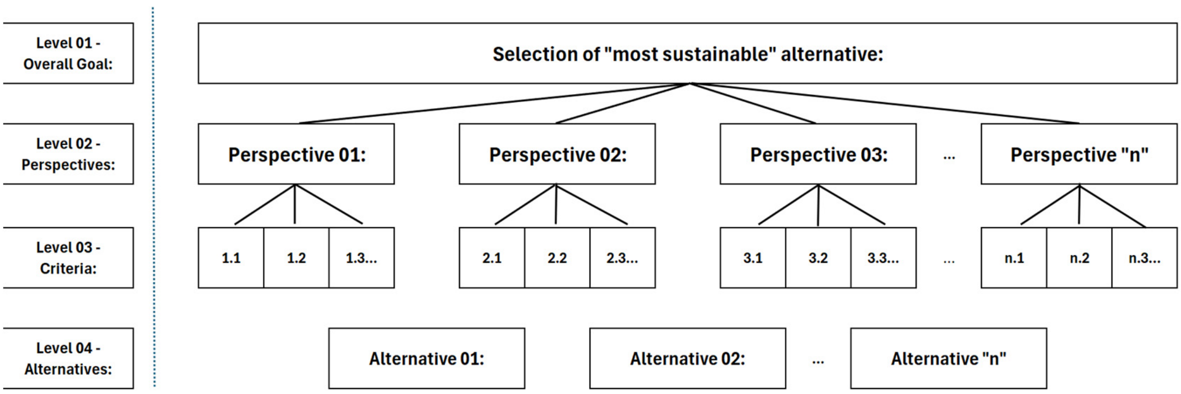

Figure 2. Graphical representation of simplest AHP hierarchy [2].

Followed by finding the vector of priorities, the priorities of elements are determined with the Eigenvalue method [15], with the goal of reducing the number of pairwise comparisons by solving for the principal Eigenvalue W of the matrix A, as follows:

$$AW = \lambda_{MAX}\, W \quad (1)$$

where λ_{MAX} is the largest Eigenvalue of A matrix, and W is a normalized vector obtained by use of a set of linear equations.

The final step is to measure the inconsistency of each judgment. The consistency ratio must be calculated to ensure the consistency of the decision-making process The consistency ratio is defined as

$$CR = CI/RI \quad (2)$$

where CI is the consistency index and RI is the random index. The CI for a matrix A is calculated as

$$CI = (\lambda_{MAX} - n)/(n - 1). \quad (3)$$

RI is a consistency index that depends on the number of pair comparisons. Ref. [2] provides a table of random consistency indices. If $CR < 0.1$, the level of consistency will be acceptable.

With the model now characterized, testing can now begin.

The overall goal of this research is to find "the most sustainable" alternative to a proposed traffic control strategy. The strategy selected, "Exclusive Truck Platoon Lanes (ETPLs)", involved creating an exclusive lane for freight trucks, where they will be organized into a convoy at a constant speed using Coordinated Adaptive Cruise Control (CACC) technology.

In theory, the ETPLs would be installed along all major highways, such as US interstates and state roads. These lanes would, as the name implies, only allow freight trucks to enter and leave the lane to limit interaction with passenger vehicles. This is due to the slower acceleration and braking of a freight truck compared to a standard passenger vehicle causing conflict, which could potentially lead to a collision or overall increased delay.

The CACC technology would be a standard installation on every truck involved in a company dealing with commerce. This would ensure that even trucks from different companies would be able to coordinate through the technology. This system would connect to the other trucks in a convoy as soon as the newest truck entered and would regulate the speed and distance of the truck to maintain a consistent and uniform convoy. Although the driver would still need to adjust the wheel to account for turns and other motions, the CACC technology would lower the accumulated fatigue and stress from having to maintain speed and vigilance. If the model were advanced enough, it could even provide advanced warnings of upcoming turns observed by the leading truck.

The goal of dedicated truck lanes is to enhance the sustainability of freight movement by reducing the crash rate, emissions, and travel time [16].

CACC technology can help improve safety by limiting the impact of human error with the use of autonomous technology. In addition, the fatigue level can be reduced as only the lead driver must be fully alert, while the subsequent drivers in the platoon can rest [17].

Furthermore, fuel efficiency can be improved as trucks travel at higher speeds with fewer number of stops [18]. Trucks in a platoon would drive close enough to each other for a resultant reduction in dragging force, and thus, lower fuel consumption would occur.

Exclusive truck lanes are suitable for areas with a high level of congestion and provide an acceptable level of service for the trucks to travel faster and safer than without these exclusive lanes. Truck platooning reduces the headway between trucks, resulting in an increase in road capacity.

These are all issues ETPL implementation would be used to solve or, at the very least, inhibit. However, the implementation can also potentially lead to negative results if applied without consideration for other perspectives. Three years after the study of this paper commenced, a research review study was performed by [19], "Platooning of connected automated vehicles on freeways: a bird's eye view". In it, the researchers hoped to measure the possible advantages of truck platooning strategies, similar to ETPL, as well as identify any areas of further necessary improvement or study.

The review was generally positive, with several of the advantages outlined in the previous few paragraphs repeated within. However, the study also made note of several unexplored aspects. One such aspect was the model structure itself, as the review noted that most models were deterministic and infinite, meaning the platoon itself would be an eternal structure that simply changed the lead vehicle with the subsequent vehicles joining and leaving at predetermined intervals. While this could serve as a model, this is not reflective of reality, and as such, could lead to incorrect assumptions in implementation.

Another aspect that was not often considered was the reaction of human drivers. While the ETPL somewhat alleviates this by forbidding entry entirely, this too has difficulties in enforcing it in reality. If the roadway stretch is sufficiently saturated enough that the ETPLs are seen as a desirable alternative, passenger vehicles will take them if available if no law enforcement is present. Even then, considering the scope of ETPL implementation across the highways, proper coverage by law enforcement may be infeasible.

Finally, it was noted that the communication method for the CACC was never clearly defined and standardized. This includes details like the refresh rate for the system's calculations, the integration without being affected by other communication devices, or possible defenses from cyber-attacks and other threats.

It is reviews such as this that demonstrate the importance of decision-making tools like the AHP model. All the research was conducted by traffic and travel experts, but this led to an unfortunately narrow view that did not consider small but critical complications that may be obvious to those in other fields. While the model can always be improved and refined, its necessity in ensuring a complete holistic view of the problem should always be considered.

With the purpose of testing the AHP model set, the research itself needs to be summarized. The research set out to study the effects of ETPL implementation through a simulation model, VISSIM. The VISSIM 10 software was advanced enough to calculate driver-to-driver interactions, thus creating a model that could account for changes on a micro level due to the manipulation of several parameters, such as traffic volume, truck percentage, and speed limit. The resulting data from this study are too large to include here, so only the highlights of this study will be listed. When ETPL strategies were implemented, the data showed the following:

- Average speed and acceleration of standard passenger vehicles were overall lowered, increasing average travel time by approximately 0.8%.
- Average speed of freight trucks was increased, while acceleration was set at zero due to the CACC systems maintaining a constant speed. This would lower average travel time by approximately 16%.
- Due to the exclusion of passenger vehicles from the ETPL, the lack of interaction between the two types would overall reduce the risk of crashes. In addition, the CACC technology will help reduce driver fatigue, further reducing the risk of crashes.
- Since the platooning would reduce the effect of drag force and wind resistance on the subsequent trucks in the convoy, overall fuel efficiency would be improved, therefore lowering total greenhouse gas emissions.

With these findings, alternatives to evaluate the efficacy of the ETPL were decided. The first alternative was the base scenario, wherein no ETPL implementation was present. The second alternative involved ETPL implementation at a speed limit of 55 mph, while the final alternative involved implementation at 75 mph.

With the overall goal and alternatives established, the individual perspectives and criteria must also be determined. The research decided on four perspectives, with eleven total criteria split among them. In order, the four perspectives were as follows:

1. Economic Perspective;
2. Safety Perspective;

3. Environmental Perspective;
4. Mobility Perspective.

These perspectives are detailed as follows:

(1) The Economic Perspective involves all decisions involving payment and funding. Those involved would be parties such as federal road agencies, taxpayers, and those in charge of the freight who gain revenue from the transportation. The criteria to be weighted are as follows:
   ○ Vehicle Operating Cost: The travel time has direct and indirect impacts on the economy due to the loss of personal time and the cost of delaying delivery of goods. Thus, governmental and economic analysts use travel time to compare investments in transportation planning and management. According to a mobility report (2015), the cost of delay associated with congestion is $101 per hour for trucks and approximately $17 per hour for other vehicles.
   ○ Initial and Maintenance Cost: This criterion considers the direct costs of building new lanes, as well as continuous costs for operation and maintenance.
   ○ Goods Cost and Productivity: Trucks are considered the main mode of share because all goods are moved by trucks at some point. Enhancing the performance of trucks on highway systems can increase productivity and reduce the cost of delivering goods.

(2) The Safety Perspective involves all decisions pertaining to the management of roads to prevent damage and loss of life. Those involved would be parties such as policymakers and law enforcement. The criteria to be weighted are as follows:
   ○ Traffic Conflict Points: The potential of a collision occurring rises with higher traffic volume, as that presents more opportunities for a mistake to occur.
   ○ Truck Driver Fatigue: As the time spent on the road increases, drivers will eventually suffer fatigue from lack of rest. This could lead to decreased focus, which also increases the chance of a collision occurring.
   ○ Crash Severity: Depending on the amount of vehicles involved, as well as other factors such as the sizes of the involved vehicles and average speed, the magnitude and damage of a potential collision could be much greater.

(3) The Environmental Perspective involves all decisions pertaining to the preservation of the environment. Those involved would be parties such as the EPA and local conservation groups. The criteria to be weighted are as follows:
   ○ Air Pollution: The transportation sector is the second largest source of US greenhouse gas (GHG) emissions. The US transportation sector produces about 498 million metric tons of carbon. Light-duty vehicles account for 61% of GHG emissions while medium to heavy-duty trucks are responsible for 23% of emissions.
   ○ Energy Consumption: This indicator is used to analyze the impacts of emissions on human health as well as contributions to global warming.

(4) The Mobility Perspective involves all decisions pertaining to the health of traffic flow, such as the flow rate and delay. Those involved would be parties such as the district traffic management and the roadway users. The criteria to be weighted are as follows:
   ○ Level of Service (LOS): A measurement of the general health of a roadway, characterized by geometric factors like size and length, as well as average flow rate and traffic count.
   ○ Passenger Vehicle Delay: The average delay faced by passenger vehicles due to low flow rate and increased traffic volume.
   ○ Freight Truck Delay: The average delay faced by freight trucks due to low flow rates and increased traffic volume.

With these parameters, the model has been completed and appears as follows (Figure 3).

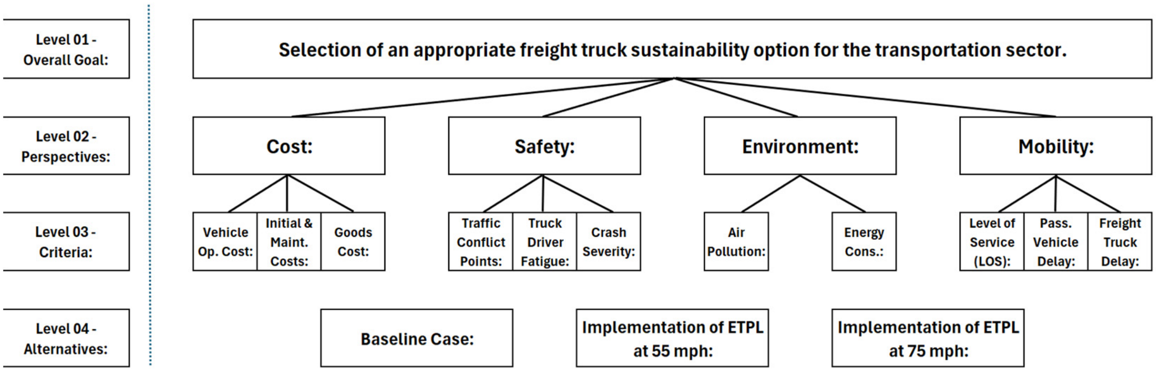

Figure 3. AHP for the appropriate freight sustainability option [1].

With the model now completed, the researchers then began testing the viability of using it to test the alternatives. In order to do so, pairwise comparisons between each perspective and criteria needed to be performed. These comparisons were conducted by 24 experts contacted by the researchers, all sourced from various agencies of academia, industry, and the Florida Department of Transportation (FDOT).

Once the experts consented to the experiment, they were given a survey to complete through the online survey site SurveyMonkey. The 24 total participants were split into three equal panels of eight participants, each tasked with their own unique surveys to complete.

The first panel was provided a survey to determine the weight of each perspective in Level 2 of the AHP model (Figure 4). This was conducted through a six-question survey that listed all possible pairwise combinations, wherein they would choose which perspective they valued more and at what intensity (Table 1). If one criterion was ranked higher than another in these comparisons, its weight was raised within the tier, while the less-desired perspective had its weight lowered. These weights were then transferred to the matrix introduced in step 3 of the Methodology, wherein they would be solved in order to calculate the local weight within their tier, which could be transformed into the global weight by multiplying it by the local weight of the tier above.

The second panel, meanwhile, was tasked with determining the weights of the sub-criteria for the Economic and Mobility Perspectives, with a total of 24 questions. While the first six questions were pairwise comparisons in the same vein as those in Panel 1, asking for both the preferred option between each possible pair of criteria and its intensity, the remaining 18 questions were slightly different. They instead made pairwise comparisons between each alternative in relation to each criterion while neglecting the intensity.

The final panel was tasked with the same survey structure as Panel 2, only now focused on the Safety and Environmental Perspectives. Again, the criteria of Level 2 were ranked alongside the intensity for the first four questions, while the remaining questions only ranked which alternative was most desirable pertaining to each criterion.

Table 1. The fundamental scale of pairwise comparison [2].

Scale	Definition of Scale	Explanation
1	Equal importance	Two elements contribute equally
3	Moderate importance	One element is more important than the other
5	Strong importance	One element is preferred more strongly than the other
7	Very strong importance	An element is strongly dominant
9	Extreme importance	An element is preferred at the highest level of confidence
2,4,6,8	Intermediate values	It can be used to express intermediate values

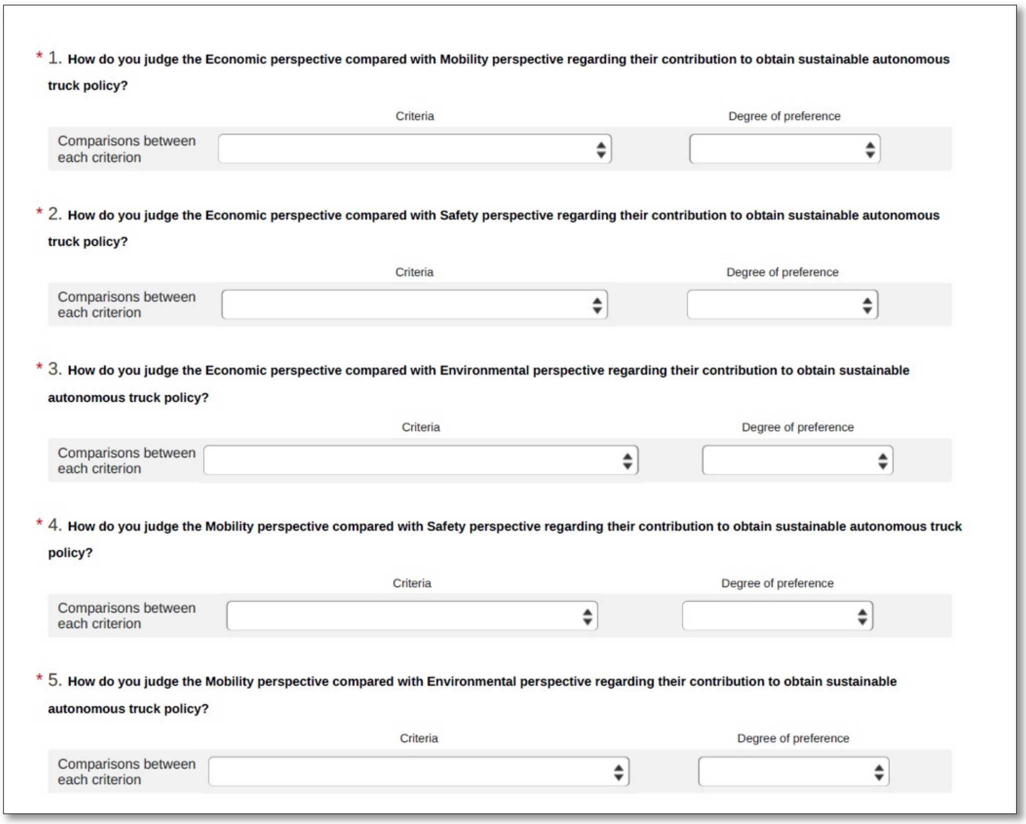

Figure 4. Survey provided to experts in Panel 1.

Once all the surveys were completed and returned, the researchers then ran a consistency check on each participant's answers using the consistency ratio outlined earlier (Table 2). If the ratio was calculated as 0.1 or lower, the results were considered valid and accepted. If not, the participant was asked to re-evaluate their submission and re-take the survey. Once all surveys were accepted, the results were compiled.

Table 2. Random consistency index values (RI) [2].

Size of Matrix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

Since the panel participants had no interaction with each other, the distributions of the weights should have been modeled as stochastic, or otherwise random and disconnected, as detailed in "Group decision making using the analytic hierarchy process" Basak & Saaty, 1993 [20]. However, the weights were modeled as deterministic, wherein it was assumed there was a general consistency between the participants' answers and reciprocity was maintained (i.e., if one perspective/criteria had a higher priority than another, the other perspective had the inverse. If criteria 1 was twice as valued as criteria 2, criteria 2 was half as desired as criteria 1).

The deterministic approach was justified as applicable due to the smaller size of the sample decreasing the odds of random error. This deterministic modeling also allowed the priorities of each alternative to be calculated as a geometric mean of the global weight of each perspective multiplied by the local weight of each criterion. As long as the consistency check was within acceptable parameters, the results were held as deterministic and therefore applicable to be modeled through the geometric mean.

4. Results

For the perspectives ranked in Panel 1, safety was consistently rated as the most important at 57% (Figure 5). This was followed by the Economic and Mobility Perspective, both at 15%, with the Environmental Perspective ranked the lowest at 13%.

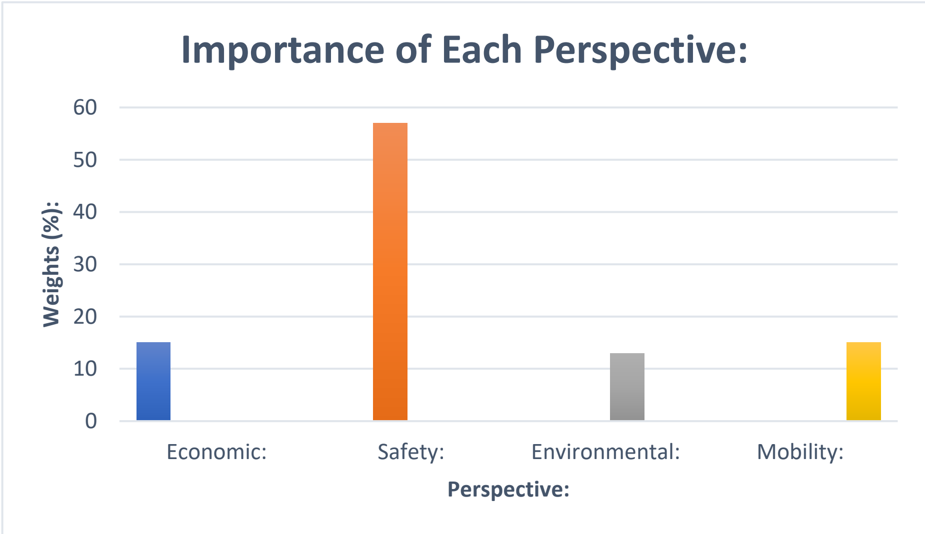

Figure 5. Relative importance of autonomous truck policy perspectives.

The results of Panels 2 and 3 are as follows (Tables 3 and 4 and Figure 6):

Table 3. Weight values for all criteria of Level 3 [1].

Economic:		Safety:		Environmental:		Mobility:	
Operating Cost:	28%	Conflict Points:	48%	Air Pollution:	70%	LOS:	40%
Initial/Maintenance Cost:	40%	Driver Fatigue:	18%	Energy Consumption:	30%	Passenger Delay:	22%
Goods Cost:	32%	Crash Severity:	34%	-	-	Truck Delay:	38%

With all the weights gathered, they were transformed from a local weight to a global weight. This was conducted by multiplying each local criterion weight by the weight of the preceding perspective.

The last stage is to find the relative priority of alternatives with respect to the four perspectives and finally to find the global alternatives with respect to the overall goal of the AHP model. The ranking of each policy was calculated by summing all global weights for each alternative as shown (Table 5). The ETPL implementation at 55 mph, with a global priority of 0.479, is the alternative that contributes the most to the goal of selecting the most sustainable autonomous truck policy. The ETPL implementation at 75 mph, with a global priority of 0.373, is the second most favorable alternative. The base scenario has considerably less global priority with a value of 0.149.

Table 4. Global and local weight of criteria and sub-criteria [1]. The colors are used to distinguish between tier numbers and their sub-tiers.

Tier:	Criterion:	Weight:	
		Local:	Global:
1.	Economic Perspective:	15%	15%
1.1.	**Initial and Maintenance Cost:**	40%	6%
1.2.	**Goods Cost and Productivity:**	32%	5%
1.3.	**Vehicle Operating Cost:**	28%	4%
2.	Safety Perspective:	57%	57%
2.1.	**Traffic Conflict Points:**	48%	27%
2.2.	**Truck Driver Fatigue Reduction:**	18%	10%
2.3	**Crash Severity:**	34%	20%
3.	Environmental Perspective:	12%	12%
3.1.	**Air Pollution:**	70%	9%
3.2.	**Energy Consumption:**	30%	4%
4.	Mobility Perspective:	15%	15%
4.1.	**Service Flow Rate:**	40%	6%
4.2	**Passenger Vehicles Delay:**	22%	3%
4.3.	**Truck Delay:**	38%	6%

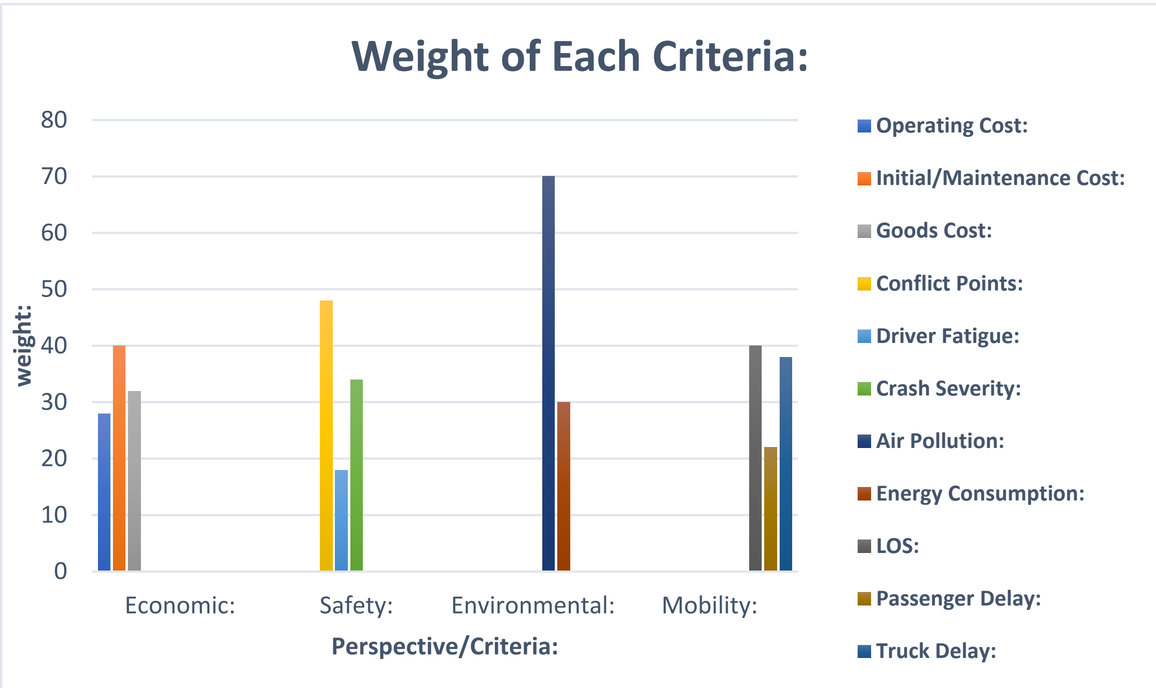

Figure 6. Weight of each criterion in terms of their perspective.

Table 5. Global priority calculations [1].

Perspective:	Global Weight:	Criterion:	Criterion Weight:		Base Scenario:		Implementation at 55 mph:		Implementation at 75 mph:	
			Local	Global	Local	Global	Local	Global	Local	Global
Economic:	0.15	I/M Cost:	40%	6%	0.30	0.018	0.36	0.022	0.32	0.019
		Goods Cost:	32%	5%	0.21	0.01	0.46	0.03	0.31	0.016
		Operating Cost:	28%	4%	0.24	0.01	0.29	0.012	0.47	0.019
Safety:	0.12	Conflict Points:	48%	27%	0.10	0.027	0.54	0.145	0.36	0.097
		Driver Fatigue:	18%	10%	0.12	0.012	0.48	0.048	0.40	0.04
		Crash Severity:	34%	20%	0.16	0.032	0.48	0.096	0.36	0.072
Environmental:	0.15	Air Pollution:	70%	9%	0.11	0.01	0.45	0.041	0.43	0.039
		Energy Cons.:	30%	4%	0.11	0.004	0.47	0.019	0.41	0.016
Mobility:	0.57	(LOS):	40%	6%	0.22	0.013	0.41	0.025	0.38	0.022
		Passenger Delay:	22%	3%	0.22	0.006	0.41	0.012	0.37	0.011
		Truck Delay:	38%	6%	0.13	0.008	0.49	0.029	0.37	0.022
Summation of Global Priorities:					-	0.149	-	0.479	-	0.372

5. Discussion

While the experimental model seemed to be a success in deciding the most sustainable option, there are also notable aspects to improve upon. One would be the sample size of the polled experts. While 24 may suit the needs of this experiment, it is still a relatively small number of samples to make a definitive judgment. This is further exacerbated by the lack of experts outside of the direct field of transportation, such as those in potential environmental and political fields only tangentially involved in traffic. In the future, the model sample size needs to be expanded to not only ensure higher authenticity but also to incorporate an even broader and more diverse number of relevant perspectives.

As for the experiment itself, there are also various points that should be considered for future refinement. The most notable would be how the experiment separates the perspectives into distinct groups when they share specific criteria. For instance, although the Safety Perspective focuses on the moral consequences, such as the loss of life, it is undeniable that there are also other consequences for cost and mobility. Accidents cause damage that must be repaired and interrupt the roadway flow, increasing delay for all other drivers. Although the experiment places safety as the most important perspective, that could be a misleading result due to a subconscious identification of those other perspectives. The end result may be acceptable to all parties but may not be accurate in its conclusion.

Finally, it is important to note that the experiment had a bias in that the ETPL only benefitted all four perspectives, excluding one criterion in passenger car delay, so pitting it against the baseline scenario is not a useful implementation of the AHP model. While this was alleviated by splitting the implementation into two speed limits, showing a clear distinction in safety and mobility, it is not a true test of the use of the AHP model.

Additionally, since the original research took place in 2018, there have been various studies between then and now that also tested the efficacy of the AHP model in decision-making. One such study was performed by Tavana et al [21], titled "Analytical Hierarchy Process: Revolution and Evolution". Seeking to improve the accuracy of the model, Tavana et al [21] developed five modified AHP models that either reduced the number of pairwise comparisons needed or introduced more complex decisions among participants than simple binary questions. Their results indicated that higher interaction between the participants and the questions improved the overall acceptability of the results involved after the fact, though increasing the number of pairwise comparisons decreased motivation and attentiveness in the participants.

6. Conclusions

Overall, the AHP model demonstrated a clear example of the inherent value of using a hierarchy of multiple perspectives to decide the most sustainable alternative. Although the base scenario was expectedly the least desirable option, as it offered no benefits compared to the ETPL implementation, it was an interesting result that the lower speed proved more desirable. A lower speed means longer travel times, higher delays, and as such, higher costs of vehicle operation and goods transportation. However, it is also significantly safer than a faster speed limit, so due to the high weight afforded to the Safety Perspective, it accrued a much higher priority despite losing weight from the Cost and Mobility Perspective.

It is in cases such as these where the AHP model supports compromise among the involved parties, wherein some may take disadvantageous circumstances for the total good of the group. While it is important to continue experimentation for ways in which it can be improved, the AHP model should always be considered when making decisions that must account for multiple involved perspectives. The value of using the AHP model even lies outside the discipline of traffic operations, as any managerial position can utilize it in making upper-level decisions with input from lower-level workers. Law and policymakers can use this system as an alternative to direct voting, as traditional voting still organizes the participants into discrete options that may not accurately reflect their interests. Altogether, the model can continue to see usage in the future, and with it, improvement and refinement.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14219702/s1.

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