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Development Strategies of Autonomous Vehicles in Taiwan

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ABSTRACT— ***Autonomous vehicles can reduce traffic accidents, traffic congestion and parking demand and hence have great potential to become a major transportation mode in the near future. The potential market for autonomous vehicles is huge. Therefore, it is a necessity to develop strategies so as to outperform in this highly competitive world market. This research employs SWOT method to generate 14 criteria for the development of autonomous vehicles. Then, a decision-making method called "Decision Making and Trial Evaluation Laboratory-based Analytic Network Process" (DANP) is used to prioritize these criteria. Results show that two criteria that are strengths－Advanced Driver Assistance Systems (ADAS) and complete supply chain of Information and Communication Technology (ICT) – should be treated with priority and another criterion – lack of own auto-brand and first-tier supplier – is not the focus. The result is fully coincident with the real situation of industrial development in Taiwan and can be a good reference for Taiwan's government.***

Keywords—Autonomous vehicles, level of automation, Decision Making and Trial Evaluation Laboratory, Analytic Network Process.

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1. INTRODUCTION

Automobiles became a common transportation mode during the 20th century. Unfortunately, while people have enjoyed the fast and comfortable transportation services provided by vehicles, the traffic accidents, traffic congestion, and environmental pollution problems caused by vehicles have begun to attract more attention than ever.

The World Health Organization in 2015 [1] indicated that 1.25 billion people died due to traffic accidents, among which 90% were caused by aberrant driving behavior [2, 3]. Similarly, Taiwan's Department of Statistics (2015) [4] also showed that, among traffic accidents that cause fatalities within 24 hours, aberrant driving behavior (including drunk driving) accounts for 94.9% of total accidents. These accidents are accompanied with property loss and consumption of medical resources.

To reduce traffic accidents that occur due to aberrant driving behavior, the vehicular industry has moved towards the development of Advanced Driver Assistance Systems (ADAS) such as Adaptive Cruise Control (ACC), which provides an essential component for autonomous vehicles (AUVs), also known as automated, driverless, self-driving, or robotic cars. Anderson et al. (2016) [2] also suggested using autonomous vehicles in order to reduce the fatality of traffic accidents and improve traffic safety.

In addition to the consideration of traffic safety, the benefits of the use of autonomous vehicles can be extended to alleviating traffic congestion and saving parking spaces. Traffic congestion and the lack of parking spaces in Central Business Districts (CBDs) are common problems in cities. A public bus system is a possible solution but has often suffered from a shortage of drivers. To resolve these problems, AUVs, especially those endowed with a "sharing economy" function, have great potential.

Land transportation (mainly composed of vehicles driven by internal combustion engines) accounts for 22.1% of total emission of fine particulate matter known as $PM_{2.5}$ [5]. Should the vehicles powered by internal combustion engines be replaced by those powered by permanent magnet electric motors, the air pollution problem can be significantly improved. Since AUVs are electric cars, its use will be of great help in improving air quality and hence increasing sustainability in the community.

From the above data, it is clear that Taiwan should take part in this intense competition for the leading role of autonomous vehicles industry in the world.

The AUV's industry is essential for the prosperous development of Taiwan. However, in view of resources currently available, it is not possible for us to ambitiously develop the entire AUV industry. Only few strategies can be carried out in the near future. Therefore, the objective of this research is to generate strategies, and then prioritize them, for the development of autonomous vehicles in Taiwan.

2. PROBLEM STATEMENT

2.1 Level of Autonomous Vehicles

AUVs are vehicles in which at least some critical safety control functions (e.g., steering, throttle, or braking) occur without direct driver input. In general, the degree of driving automation includes six levels described by The SAE International [6] as shown in Table 1. The automated driving systems currently under testing (not currently available in the market) mostly fall within SAE levels 2 and 3. However, due to the advancement of dedicated short-range communication systems for AUVs, it is anticipated that highly- (SAE level 4) and fully-automated (SAE level 5) vehicles will be commercialized between 2025 and 2030, when autonomous driving systems that monitor the driving environment will become a norm.

Table 1: SAE level of autonomous vehicles

SAE Level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	the human driver does everything	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	an automated system on the vehicle can sometimes assist the human driver conduct some parts of the driving task	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	an automated system on the vehicle can actually conduct some parts of the driving task, while the human continues to monitor the driving environment and performs the rest of the driving task	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	an automated system can both actually conduct some parts of the driving task and monitor the driving environment in some instances, but the human driver must be ready to take back control when the automated system requests	System	System	Human driver	Some driving modes
4	High Automation	an automated system can conduct the driving task and monitor the driving environment, and the human need not take back control, but the automated system can operate only in certain environments and under certain conditions	System	System	System	Some driving modes
5	Full Automation	the automated system can perform all driving tasks, under all conditions that a human driver could perform them	System	System	System	All driving modes

Source: SAE International. 2016.

2.2 Development and Necessity of Autonomous Vehicles

AUV's development helps largely in enhancing traffic safety, alleviating traffic congestion and reducing parking space, especially in urban areas. Many countries strive very hard for the development of autonomous vehicles. For example, the Singapore government conducted a road test program using six autonomous taxis around a tech city and its vicinity in 2016. Japan also launched a driverless taxis program for the 2020 Tokyo Olympics game. Road testing and drawing of digital maps are currently undergoing work. In 2016, in the USA, seven states (Nevada, California, Florida, Michigan, Hawaii, Washington, and Tennessee), along with the District of Columbia, have allowed the testing of autonomous vehicles on roads and have enacted laws for autonomous vehicles. Other states have, since then, taken various legislative and executive actions relevant to AUVs.

Some universities and private companies also conducted road testing. Michigan University has put effort and resources into autonomous vehicle testing starting from June 2017. Two autonomous buses have been operated in the north campus for a two-mile road segment between two designated buildings. Uber provided an autonomous vehicle dial-a-ride service (with two engineers sitting inside the car for monitoring) in Pittsburg in October 2016. Registered customers can use its APP to reserve a car. AUVs have yet to be effectively developed in Taiwan, but they have attracted attention from both the government and the transportation community. In October 2017, the International Council for Local Environmental Initiatives (ICLEI) held the EcoMobility World Festival in Kaohsiung, Taiwan. The Festival was co-organized by the EcoMobility Alliance and the Kaohsiung city government. During the meeting, the EasyMile Technology Company provided a test ride on an autonomous shuttle bus, EZ 10, for the conference participants and Kaohsiung citizens in order to display a low-carbon, energy-saving, eco-friendly transportation mode. So far EZ 10 has been tested in more than 20 countries in the world. EasyMile also launched a car-maker program for a 12-meter driverless bus in 2017.

Although it is a general perception that AUVs can help alleviate aberrant human driving behavior, it does not imply traffic accidents involving AUVs won't happen. After the first fatal accident by Tesla's Autopilot system in 2016, revisions for laws and standards for AUVs were discussed around the world. Additionally, the US NEC (National Economic Council) and the NHTSA (US National Highway Traffic Safety Administration) released federal standards in 2016 that regulate how automated vehicles react if their technology fails, how passenger privacy is to be protected, and how riders are to be guarded should an accident occur.

AUVs can also increase road capacity by shortening the vehicle gap in traffic flow and help reduce parking spaces needed in urban areas. In addition, the use of electric cars including AUVs has its appeal for its ability to reduce the air pollution due to traffic. An additional and important feature associated with AUVs is the "sharing economy," if "surplus" capacity of AUVs can be released and shared by other public users. The idea is analogous to Uber passenger services. The core of the "sharing economy" is the concept of sharing or renting vehicles instead of owning them. Car rental and carpooling services are types of the "sharing economy," and can largely reduce the number of vehicles and parking spaces demand. Further, renting AUVs (particularly those equipped with full automation devices) is significantly more advantageous when compared with renting manually-controlled, internal combustion engine-powered cars, because AUVs do not require drivers and can be rented without regular renting and returning procedures at car rental shops.

It is anticipated that 2.5 billion automobile vehicles will be made available in the market [7]. Hence, there can be no doubt that autonomous vehicles will become a trend in future transportation systems [8, 9] and no county wants to be left behind in this competitive market. However, given the limited resources, each country should focus only on appropriate niche strategies (by SWOT analysis) and prioritize these strategies (by DANP methods) which will be described in the following sections.

2.3 SWOT Analysis

The implementation of AUVs is becoming a worldwide trend. In Taiwan, however, its implementation faces many problems, including road testing, related laws on liability when a car accident occurs, car insurance, hardware and software development, and AUV security management. To cope with these problems, Taiwan government should come up with effective strategies and apply them according to their priority. In order to generate effective strategies, this study conducts SWOT analysis (i.e., strengths, weaknesses, opportunities and threats) concerning AUV development strategies in Taiwan. The results find that Taiwan's strength lies in an advanced and well-established Information and Communication Technology (ICT) manufacturing industry chain. The following describes the results in more detail.

According to a SWOT analysis concerning the development of autonomous vehicles in Taiwan, four dimensions (Strengths, weaknesses, opportunities, and threats) can be identified, which in turn can be extended into 14 criteria, i.e., S1~S2, W1~W5, O1~O5, and T1~T2, as shown in Table 2.

Table 2: Dimensions and criteria for the development of autonomous vehicles

Dimension	Criterion/Strategy	Description
Strengths(S)	S1: Core technology of ADAS	Key technology and (embryo) supply chain available for ADAS system: Technology such as image recognition, multi-sensor fusion, information transmission and security for ADAS is available in Taiwan.
	S2: Complete supply chain of ICT	Strong ICT technology: Taiwan Semiconductor Manufacturing Company, Limited (TSMC) has been an Original Equipment Manufacturer (OEM) for car chips ordered by NVIDIA AI. Foxconn Technology Group produces sensors needed for autonomous vehicles through their investment in TetraVue. MediaTek (MTK) Inc. has put an effort on the development of relevant electronic chips for autonomous vehicles. In short, Taiwan’ s current level of technology can support the development of AUV’s relevant industry.
Weaknesses(W)	W1: lack of own auto-brand and first-tier supplier.	Vehicle control technology: Electronics companies in Taiwan lack the capability to integrate accessories/parts into a complete system as an AUV requires. Taiwan is as a second-tier accessories-provider; its companies normally do not own well-known commercial brands. It is therefore difficult for Taiwan to acquire the opportunities to cooperate with international car manufacturers for AUV development.
	W2: existing technologies are not yet matured.	Industrial chain for whole vehicles: The complete industrial chain for whole vehicles is not yet established and the key components of technology for autonomous vehicles need to be enhanced.
	W3: insufficient professional talents.	AI technology: Development of autonomous vehicles needs advanced AI technology, which is a weak point in Taiwan.
	W4: regulations revision/amendment running behind.	Regulations: The current regulations have not kept up with the pace of autonomous vehicles development and is clearly behind the advanced countries.
	W5: development policy is unclear.	Development policies: The policies concerning the development of autonomous vehicles are yet to be clarified and need more time to come up with a complete national plan.
Opportunities(O)	O1: integrated with intelligent transportation systems.	Infrastructure and relevant services: autonomous vehicles can fulfill the last-mile gap in Taiwan’s current transportation systems. This functioning is especially useful for “transfer” purpose at rail stations, arrival/departure late at night, as well as infrequent transportation services in rural areas (that do not have enough public transportation services).
	O2: fostering bio-system of autonomous vehicles.	Complete supply chain for autonomous vehicles: A complete supply chain for autonomous vehicles includes vehicle manufacturers, transportation companies, system integrators, mobile Internet business and back-stage management. Once a complete supply chain is established, new hardware provider industry can evolve.
	O3: exploiting new market for the components of autonomous vehicles.	Component market of autonomous vehicles: Global companies of autonomous vehicles are looking for partners for cooperation. Taiwan has technologies on AUV’s components such as detectors (LIght Detection And Ranging, LIDAR), recognition (sensor fusion), analysis and decision-making (AI driving logic) as well as software/hardware such as displays, storage, wireless communication.
	O4: accelerating advanced research and promoting niche market.	Advanced technologies: Ambient sensors, precise positioning, and HD Mapping need to be researched more rapidly. It is observed that autonomous vehicles are highly demanded in harbors, warehouses, farmlands, and mineral areas which would be the niche market to penetrate.
	O5: market penetration for autonomous vehicles is increasing.	Aging society: Taiwan is moving toward an aging society which would produce a higher demand for autonomous vehicles. This trend will become more significant if sharing economy is in place.
Threats(T)	T1: global companies take part in the severe competition.	Potential competitors: As compared with internationally known big companies such as Google, Tesla, and the like, Taiwan falls behind in many aspects in the arena of autonomous vehicles. Moreover, many companies in Taiwan are short of capital as compared with those big companies. Nevertheless, if we can find a niche in the industry, we have a chance to play a role in the big market. Our major threats come from South Korea and China who are striking very hard for the innovation and technology enhancements. We could soon be phased out in this fiercely competitive game if we don’t have correct and systematic development strategies and execution ability.
	T2: relevant patents are in place.	Lack of Patents: Technologies and patents important to the development of autonomous vehicles are held by international big companies. This will make the development of AUVs more difficult than one would otherwise anticipate.

From the above discussion, it is clear that Taiwan should focus on the niche market, rather than the entire AUV market.

3. RESEARCH METHOD

This study employs "Decision Making and Trial Evaluation Laboratory-based Analytic Network Process" (DANP), a combined method of Decision Making and Trial Evaluation Laboratory (DEMATEL) method and analytic network process (ANP), to explore the possible strategies for development of autonomous vehicles. The DEMATEL method was intended as a tool to study the cause and effect relationships among evaluation criteria of a complex and intertwined problem whereas the ANP is essentially an extension of Analytic Hierarchical Process (AHP) [10] such that interdependence and feedback relationships among the criteria can be effectively taken into account. So far, there are three different versions of ANP that can be identified, i.e., [11. 12, 13]. These three methods have different theoretical backgrounds and respective applications. However, considering the computational effort required for tackling practical problems, Chiu et al.'s version [13] of ANP is best to use.

The DANP method that combines DEMETAL together with Chiu et al.'s [13] ANP will be described step by step in the following:

1. Calculate the direct-influence matrix by scores and normalize direct-influence matrix

The interdependence between each pair of criteria can be measured using a five-point scale ranging from 0 (absolutely no influence) to 5 (very high influence). The scores thus obtained from a questionnaire survey can be used to calculate the direct-influence matrix *G* in which each element g_{ij} denotes the degree of direct influence of factor *i* on factor *j*. Each diagonal element of the direct influence matrix represents the degree of the influence of one criterion on itself, which takes the value of zero.

$$G = \begin{bmatrix} g_c^{11} & \cdots & g_c^{1j} & \cdots & g_c^{1n} \\ \vdots & & \vdots & & \vdots \\ g_c^{i1} & \cdots & g_c^{ij} & \cdots & g_c^{in} \\ \vdots & & \vdots & & \vdots \\ g_c^{n1} & \cdots & g_c^{nj} & \cdots & g_c^{nn} \end{bmatrix} \quad (1)$$

The normalized direct-influence matrix *X* can be acquired by premultiplying the direct influence matrix *G* by a constant *v*, i.e.

$$X = vG \quad (2)$$

where constant *v* can be obtained by the following formula:

$$v = \min_{i,j} \left\{ \frac{1}{\max_i \sum_{j=1}^{n} g_c^{ij}}, \frac{1}{\max_j \sum_{i=1}^{n} g_c^{ij}} \right\}, i = 1,\cdots,n; j = 1,\cdots,n \quad (3)$$

Hence, the maximum sum of a row or column in *X* is 1.

2. Calculate the criterion-based total-influence matrix T_c and find criterion-based normalized total influence matrix T_c^{nor}

The criterion-based total-influence matrix T_c can be calculated by summing up X, X^2, …,X^S as follows:

$$T_c = \left[t_c^{ij} \right]_{n\times n} = \lim_{s\to\infty} \left(X + X^2 + X^3 + \cdots + + X^s \right) = X \left(I - X \right)^{-1} \quad (4)$$

where *S* approaches infinity and *I* denotes identity matrix. It is noted that the higher the value of *S*, the lower the interdependence between each pair of criterion.

Criterion-based normalized total influence matrix T_c^{nor} can be obtained from Eq. (4) as follows.

$$T_C^{nor} = \begin{bmatrix} t_1^{11}/t_1^1 & \cdots & t_k^{1j}/t_k^1 & \cdots & t_m^{1n}/t_m^1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_1^{i1}/t_1^i & \cdots & t_k^{ij}/t_k^i & \cdots & t_m^{in}/t_m^i \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_1^{n1}/t_1^n & \cdots & t_k^{nj}/t_k^n & \cdots & t_m^{nn}/t_m^n \end{bmatrix} = \begin{bmatrix} t_{11}^* & \cdots & t_{1j}^* & \cdots & t_{1n}^* \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_{i1}^* & \cdots & t_{ij}^* & \cdots & t_{in}^* \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_{n1}^* & \cdots & t_{nj}^* & \cdots & t_{nn}^* \end{bmatrix} \tag{5}$$

Where

$$t_k^i = \sum_{j=1}^{n_k} t_k^{ij}, i = 1,\cdots,n, k = 1,\cdots,m \tag{6}$$

3. Analyze the total influence matrix

The row and column sums of total influence matrix components $\left[t_c^{ij}\right]$ can be expressed as follows:

$$r = \left[\sum_{j=1}^{n} t_c^{ij}\right] = \left[t_c^i\right]_{n\times 1} = \left(r_1, \cdots, r_i, \cdots r_n\right)' \tag{7}$$

$$s = \left[\sum_{i=1}^{n} t_c^{ij}\right] = \left[t_c^j\right]_{1\times n} = \left(s_1, \cdots, s_i, \cdots s_n\right)' \tag{8}$$

The sum of r_i and s_i, i.e., $r_i + s_i$, defines the importance of criterion *i*. Subtracting s_i from r_i, i.e., $r_i - s_i$, defines two different groups. If $r_i - s_i$ is positive, criterion *i* is in the causal group; otherwise, criterion *i* is in the affected group. The values of $r_i + s_i$ and $r_i - s_i$, respectively, represent the degree of importance and intensity of causality for criterion *i*.

4. Find cluster-based total influence matrix T_D and cluster-based normalized total influence matrix T_D^{nor}

Suppose *n* criteria can be grouped into *m* clusters, the cluster-based total influence matrix T_D can be obtained from criterion-based total influence matrix T_c

$$T_D = \begin{bmatrix} t_D^{11} & \cdots & t_D^{1j} & \cdots & t_D^{1m} \\ \vdots & & \vdots & & \vdots \\ t_D^{i1} & \cdots & t_D^{ij} & \cdots & t_D^{im} \\ \vdots & & \vdots & & \vdots \\ t_D^{m1} & \cdots & t_D^{mj} & \cdots & t_D^{mm} \end{bmatrix} \tag{9}$$

Cluster-based normalized total influence matrix T_D^{nor} can be obtained from Eq. (9) as follows.

$$T_D^{nor} = \begin{bmatrix} t_D^{11}/t_D^1 & \cdots & t_D^{1j}/t_D^1 & \cdots & t_D^{1m}/t_D^1 \\ \vdots & & \vdots & & \vdots \\ t_D^{i1}/t_D^i & \cdots & t_D^{ij}/t_D^i & \cdots & t_D^{im}/t_D^i \\ \vdots & & \vdots & & \vdots \\ t_D^{m1}/t_D^m & \cdots & t_D^{mj}/t_D^m & \cdots & t_D^{mm}/t_D^m \end{bmatrix} \tag{10}$$

where

$$t_D^i = \sum_{j=1}^{m} t_D^{ij}, i = 1,\cdots,m \tag{11}$$

5. **Find unweighted super-matrix W_c by transposing the criterion-based total influence matrix T_c^{nor}**

$$W_c = \left(T_C^{nor}\right)' = \begin{bmatrix} t_{11}^* & \cdots & t_{1j}^* & \cdots & t_{1n}^* \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_{i1}^* & \cdots & t_{ij}^* & \cdots & t_{in}^* \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_{n1}^* & \cdots & t_{nj}^* & \cdots & t_{nn}^* \end{bmatrix}' = \begin{bmatrix} W_c^{11} & \cdots & W_c^{i1} & \cdots & W_c^{m1} \\ \vdots & & \vdots & & \vdots \\ W_c^{1j} & \cdots & W_c^{ij} & \cdots & W_c^{mj} \\ \vdots & & \vdots & & \vdots \\ W_c^{1m} & \cdots & W_c^{im} & \cdots & W_c^{mm} \end{bmatrix} \tag{12}$$

where prime outside the parenthesis denotes the matrix transpose operator.

6. **Find weighted super matrix W_c^* by premultiplying unweighted super-matrix W_c by cluster-based normalized total influence matrix T_D^{nor}**

$$W_c^* = T_D^{nor} W_c = \begin{bmatrix} t_D^{nor_{11}} \times W_c^{11} & \cdots & t_D^{nor_{i1}} \times W_c^{i1} & \cdots & t_D^{nor_{m1}} \times W_c^{m1} \\ \vdots & & \vdots & & \vdots \\ t_D^{nor_{1j}} \times W_c^{1j} & \cdots & t_D^{nor_{ij}} \times W_c^{ij} & \cdots & t_D^{nor_{mj}} \times W_c^{mj} \\ \vdots & & \vdots & & \vdots \\ t_D^{nor_{1m}} \times W_c^{1m} & \cdots & t_D^{nor_{im}} \times W_c^{im} & \cdots & t_D^{nor_{mm}} \times W_c^{mm} \end{bmatrix} \tag{13}$$

7. **Find the weight associated with each criterion by computing the limit of weighted super-matrix**

$$w = \left(w_1, \cdots, w_j, \cdots, w_n\right) = \lim_{\phi \to \infty} \left(W_c^*\right)^{\phi} \tag{15}$$

4. RESULT ANALYSIS

Based on the SWOT analysis, we conducted a survey asking 11 respondents to rate the correlation between the fourteen criteria. The questionnaire survey is then used in the DANP. The Influential network relations map (INRM) can be depicted in Figure 1 (see also Table 5).

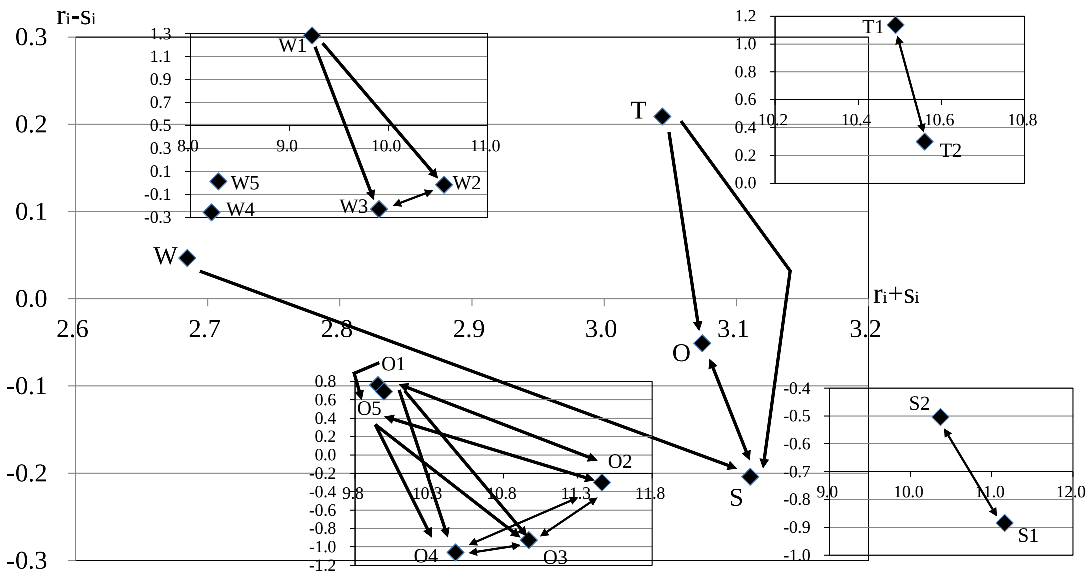

Figure 1: Influential network relations map (INRM)

The procedure of DANP has been described in Section 3. Based on the data collected, the result obtained in each step is shown in the following:

1. Calculate the direct-influence matrix (Table 3a) by scores and normalize direct-influence matrix(Table 3b)

We took the average of ratings from the eleven respondents, resulting in the direct influential matrix *G* (Table 3a).

Table 3a: Direct influential matrix *G*

Criterion	*S1*	*S2*	*W1*	*W2*	*W3*	*W4*	*W5*	*O1*	*O2*	*O3*	*O4*	*O5*	*T1*	*T2*
S1	0.0	2.5	2.0	2.2	2.3	1.5	1.3	1.7	2.9	2.7	2.5	2.2	2.0	2.5
S2	2.7	0.0	1.8	2.2	1.8	1.2	1.2	1.5	2.5	2.8	2.6	1.9	2.4	2.5
W1	2.7	2.3	0.0	2.5	2.2	1.7	1.6	1.5	2.8	2.9	2.6	1.8	2.1	2.4
W2	3.1	2.5	1.9	0.0	2.5	1.2	1.3	2.2	2.6	3.0	3.0	1.8	2.0	2.2
W3	2.8	2.5	1.8	2.7	0.0	1.1	1.3	1.6	2.4	2.4	2.5	1.6	1.7	2.2
W4	1.7	1.4	1.0	1.6	1.3	0.0	2.3	2.4	2.2	1.8	1.5	2.2	1.4	1.2
W5	1.7	1.7	1.2	1.6	1.7	2.5	0.0	2.4	2.2	1.7	1.9	1.5	1.4	1.5
O1	2.1	2.2	1.3	2.1	2.1	3.0	2.7	0.0	2.7	2.6	2.7	2.5	2.1	2.1
O2	2.9	2.7	1.7	2.6	2.6	2.3	2.4	2.5	0.0	2.8	2.5	2.3	1.8	2.2
O3	2.5	2.5	1.6	2.3	2.3	1.8	1.7	2.1	2.4	0.0	2.2	2.0	2.2	2.3
O4	2.0	2.0	1.3	2.2	2.6	1.6	1.6	2.0	2.6	2.3	0.0	1.7	1.5	2.5
O5	2.7	2.1	1.8	2.1	2.2	2.2	2.2	2.2	2.3	2.6	2.7	0.0	2.7	2.0
T1	3.2	2.8	2.2	2.7	2.5	2.1	2.1	1.8	2.8	2.5	2.6	2.3	0.0	2.8
T2	3.5	2.9	2.0	2.5	1.8	1.5	1.4	1.5	2.6	3.0	2.7	1.9	2.5	0.0

The direct influence matrix *G* can be normalized as G^{nor} by dividing each element by the maximum of maximum row sum and maximum column sum (Table 3b).

Table 3b: Normalized direct influential matrix G^{nor}

Criterion	*S1*	*S2*	*W1*	*W2*	*W3*	*W4*	*W5*	*O1*	*O2*	*O3*	*O4*	*O5*	*T1*	*T2*
S1	0.000	0.075	0.059	0.065	0.067	0.043	0.038	0.051	0.086	0.081	0.075	0.065	0.059	0.075
S2	0.081	0.000	0.054	0.065	0.054	0.035	0.035	0.043	0.073	0.084	0.078	0.057	0.070	0.075
W1	0.081	0.067	0.000	0.073	0.065	0.051	0.049	0.046	0.084	0.086	0.078	0.054	0.062	0.070
W2	0.092	0.073	0.057	0.000	0.073	0.035	0.038	0.065	0.078	0.089	0.089	0.054	0.059	0.065
W3	0.084	0.073	0.054	0.081	0.000	0.032	0.038	0.049	0.070	0.070	0.075	0.049	0.051	0.065
W4	0.051	0.040	0.030	0.049	0.038	0.000	0.067	0.070	0.065	0.054	0.046	0.065	0.040	0.035
W5	0.051	0.051	0.035	0.049	0.051	0.073	0.000	0.070	0.065	0.051	0.057	0.046	0.040	0.043
O1	0.062	0.065	0.038	0.062	0.062	0.089	0.081	0.000	0.081	0.078	0.081	0.073	0.062	0.062
O2	0.086	0.081	0.051	0.078	0.078	0.067	0.070	0.075	0.000	0.084	0.073	0.067	0.054	0.065
O3	0.073	0.075	0.049	0.067	0.067	0.054	0.051	0.062	0.070	0.000	0.065	0.059	0.065	0.067
O4	0.059	0.059	0.038	0.065	0.078	0.049	0.049	0.059	0.078	0.067	0.000	0.051	0.046	0.073
O5	0.081	0.062	0.054	0.062	0.065	0.065	0.065	0.065	0.067	0.078	0.081	0.000	0.081	0.059
T1	0.094	0.084	0.065	0.081	0.075	0.062	0.062	0.054	0.084	0.075	0.078	0.067	0.000	0.084
T2	0.105	0.086	0.059	0.075	0.054	0.046	0.040	0.046	0.078	0.089	0.081	0.057	0.075	0.000

2. Calculate the criterion-based total-influence matrix T_c (Table 4a) and find criterion-based normalized total influence matrix T_c^{nor} (Table 4b)

Summing up G^{nor}'s with power to 1 until to B where B denotes a big number approaching infinity yields the criterion-based total influence matrix T_c (Table 4a).

Table 4a: Criterion-based total influence matrix T_c

Criterion	*S1*	*S2*	*W1*	*W2*	*W3*	*W4*	*W5*	*O1*	*O2*	*O3*	*O4*	*O5*	*T1*	*T2*
S1	0.371	0.405	0.300	0.386	0.375	0.300	0.289	0.330	0.440	0.441	0.425	0.346	0.343	0.386
S2	0.431	0.322	0.286	0.373	0.351	0.282	0.277	0.312	0.415	0.429	0.413	0.328	0.342	0.374
W1	0.454	0.405	0.250	0.400	0.380	0.313	0.305	0.332	0.446	0.454	0.435	0.343	0.352	0.388
W2	0.464	0.411	0.304	0.334	0.388	0.300	0.296	0.349	0.443	0.457	0.446	0.344	0.351	0.385
W3	0.426	0.383	0.282	0.381	0.294	0.275	0.274	0.311	0.406	0.410	0.404	0.315	0.319	0.359
W4	0.333	0.297	0.217	0.297	0.277	0.203	0.261	0.285	0.339	0.333	0.317	0.282	0.261	0.277
W5	0.346	0.317	0.230	0.308	0.299	0.279	0.206	0.294	0.351	0.343	0.338	0.275	0.270	0.295
O1	0.442	0.407	0.290	0.396	0.382	0.354	0.340	0.295	0.450	0.452	0.443	0.365	0.356	0.385
O2	0.480	0.437	0.313	0.425	0.410	0.345	0.340	0.376	0.391	0.473	0.452	0.373	0.363	0.403
O3	0.429	0.397	0.285	0.380	0.367	0.304	0.296	0.333	0.418	0.357	0.407	0.335	0.341	0.371
O4	0.395	0.362	0.260	0.358	0.358	0.284	0.278	0.314	0.403	0.398	0.324	0.310	0.307	0.356
O5	0.458	0.405	0.304	0.396	0.384	0.331	0.324	0.354	0.438	0.451	0.443	0.297	0.373	0.384
T1	0.505	0.455	0.337	0.442	0.422	0.351	0.344	0.370	0.485	0.484	0.473	0.386	0.325	0.434
T2	0.487	0.433	0.315	0.414	0.381	0.317	0.305	0.341	0.454	0.469	0.449	0.355	0.374	0.334

The criterion-based total influence matrix ***Tc*** can be normalized as T_c^{nor} (Table 4b) by dividing each element by the sum in that cluster (Table 3b).

Table 4b: Normalized total influence matrix T_c^{nor}

Criterion	*S1*	*S2*	*W1*	*W2*	*W3*	*W4*	*W5*	*O1*	*O2*	*O3*	*O4*	*O5*	*T1*	*T2*
S1	0.478	0.522	0.182	0.234	0.227	0.182	0.175	0.167	0.222	0.222	0.214	0.175	0.471	0.529
S2	0.573	0.427	0.182	0.238	0.224	0.180	0.176	0.164	0.219	0.226	0.218	0.173	0.477	0.523
W1	0.528	0.472	0.152	0.243	0.230	0.190	0.185	0.165	0.222	0.226	0.216	0.171	0.475	0.525
W2	0.530	0.470	0.188	0.206	0.239	0.185	0.182	0.171	0.217	0.224	0.219	0.169	0.476	0.524
W3	0.527	0.473	0.187	0.253	0.195	0.183	0.182	0.169	0.220	0.222	0.219	0.171	0.471	0.529
W4	0.529	0.471	0.173	0.236	0.221	0.162	0.208	0.183	0.218	0.214	0.204	0.181	0.485	0.515
W5	0.522	0.478	0.174	0.233	0.226	0.211	0.156	0.184	0.220	0.214	0.211	0.172	0.478	0.522
O1	0.520	0.480	0.164	0.225	0.217	0.201	0.193	0.147	0.225	0.225	0.221	0.182	0.481	0.519
O2	0.524	0.476	0.171	0.232	0.224	0.188	0.186	0.182	0.189	0.229	0.219	0.180	0.474	0.526
O3	0.520	0.480	0.174	0.233	0.225	0.186	0.181	0.180	0.226	0.193	0.220	0.181	0.479	0.521
O4	0.522	0.478	0.169	0.233	0.233	0.184	0.181	0.180	0.230	0.227	0.185	0.177	0.463	0.537
O5	0.531	0.469	0.175	0.227	0.221	0.190	0.186	0.178	0.221	0.228	0.223	0.150	0.493	0.507
T1	0.526	0.474	0.178	0.233	0.223	0.185	0.181	0.168	0.221	0.220	0.215	0.176	0.428	0.572
T2	0.529	0.471	0.182	0.239	0.220	0.183	0.176	0.165	0.220	0.227	0.217	0.172	0.528	0.472

3. Analyze the total influence matrix

The row sum and column sum for criterion *i* in the criterion-based total influence matrix *T* can be denoted, respectively, as r_i and s_i . Note that $\left(r_i + s_i\right)$ represents importance of criterion *i* and $\left(r_i - s_i\right)$ denotes causality (Table 5 and Figure 1). When the value of $\left(r_i - s_i\right)$ is positive, criterion *i* is a causal factor, otherwise, an affected factor.

Table 5: Importance and Causality of Each Criterion

Criterion	r_i	s_i	Importance $(r_i + s_i)$	Causality $(r_i - s_i)$	Quadrant
S1	5.138	6.022	11.160	-0.885	IV
S2	4.933	5.437	10.371	-0.504	IV
W1	5.257	3.974	9.231	1.283	II
W2	5.273	5.290	10.563	-0.017	IV
W3	4.840	5.067	9.907	-0.228	III
W4	3.980	4.237	8.217	-0.257	III
W5	4.149	4.136	8.285	0.014	II
O1	5.358	4.598	9.955	0.760	II
O2	5.582	5.881	11.463	-0.299	IV
O3	5.021	5.949	10.970	-0.928	IV
O4	4.708	5.770	10.477	-1.062	IV
O5	5.343	4.654	9.996	0.689	II
T1	5.813	4.677	10.490	1.137	I
T2	5.429	5.131	10.560	0.297	I
Total	70.824	70.823	141.674	0.001	
Average	5.059	5.059	10.118	0	

The criteria falling in the first quadrant (i.e., $r_i + s_i > 10.118$ and $r_i - s_i > 0$) are both important and dominate, whereas the criteria falling in the third quadrant are relatively less important and also being dominated. The second and fourth quadrants can be interpreted in a similar manner. It is clear that the criteria in the first quadrant should be treated with priority, while one should not pay too much attention to those in the third quadrant. Criteria falling in the third and fourth quadrants should be paid attention when the resources available are sufficient.

4. Find cluster-based total influence matrix T_D (Table 6a) and normalized total influence matrix T_D^{nor} (Table 6b)

Table 6a: Cluster-based total influence matrix T_D

Dimension	S	W	O	T
S	0.382	0.322	0.388	0.361
W	0.384	0.294	0.362	0.326
O	0.421	0.340	0.386	0.364
T	0.470	0.363	0.427	0.367

Table 6b: Cluster-based normalized total influence matrix T_D^{nor}

Dimension	S	W	O	T
S	0.263	0.222	0.267	0.249
W	0.281	0.215	0.265	0.238
O	0.279	0.225	0.255	0.241
T	0.289	0.223	0.262	0.225

5. **Find unweighted super-matrix W_c (Table 7) by transposing the criterion-based total influence matrix T_c^{nor} (Table 4b)**

Table 7: Unweighted super-matrix W_c

Criterion	*S1*	*S2*	*W1*	*W2*	*W3*	*W4*	*W5*	*O1*	*O2*	*O3*	*O4*	*O5*	*T1*	*T2*
S1	0.478	0.573	0.528	0.530	0.527	0.529	0.522	0.520	0.524	0.520	0.522	0.531	0.526	0.529
S2	0.522	0.427	0.472	0.470	0.473	0.471	0.478	0.480	0.476	0.480	0.478	0.469	0.474	0.471
W1	0.182	0.182	0.152	0.188	0.187	0.173	0.174	0.164	0.171	0.174	0.169	0.175	0.178	0.182
W2	0.234	0.238	0.243	0.206	0.253	0.236	0.233	0.225	0.232	0.233	0.233	0.227	0.233	0.239
W3	0.227	0.224	0.230	0.239	0.195	0.221	0.226	0.217	0.224	0.225	0.233	0.221	0.223	0.220
W4	0.182	0.180	0.190	0.185	0.183	0.162	0.211	0.201	0.188	0.186	0.184	0.190	0.185	0.183
W5	0.175	0.176	0.185	0.182	0.182	0.208	0.156	0.193	0.186	0.181	0.181	0.186	0.181	0.176
O1	0.167	0.164	0.165	0.171	0.169	0.183	0.184	0.147	0.182	0.180	0.180	0.178	0.168	0.165
O2	0.222	0.219	0.222	0.217	0.220	0.218	0.220	0.225	0.189	0.226	0.230	0.221	0.221	0.220
O3	0.222	0.226	0.226	0.224	0.222	0.214	0.214	0.225	0.229	0.193	0.227	0.228	0.220	0.227
O4	0.214	0.218	0.216	0.219	0.219	0.204	0.211	0.221	0.219	0.220	0.185	0.223	0.215	0.217
O5	0.175	0.173	0.171	0.169	0.171	0.181	0.172	0.182	0.180	0.181	0.177	0.150	0.176	0.172
T1	0.471	0.477	0.475	0.476	0.471	0.485	0.478	0.481	0.474	0.479	0.463	0.493	0.428	0.528
T2	0.529	0.523	0.525	0.524	0.529	0.515	0.522	0.519	0.526	0.521	0.537	0.507	0.572	0.472

6. **Find weighted super matrix W_c^* (Table 8) by premultiplying unweighted super-matrix W_c (Table 7) by cluster-based normalized total influence matrix T_D^{nor} (Table 6b)**

Table 8: Weighted super matrix W_c^*

Criterion	*S1*	*S2*	*W1*	*W2*	*W3*	*W4*	*W5*	*O1*	*O2*	*O3*	*O4*	*O5*	*T1*	*T2*
S1	0.126	0.151	0.148	0.149	0.148	0.149	0.147	0.145	0.146	0.145	0.145	0.148	0.152	0.153
S2	0.137	0.112	0.133	0.132	0.133	0.132	0.134	0.134	0.133	0.134	0.133	0.131	0.137	0.136
W1	0.040	0.040	0.033	0.040	0.040	0.037	0.037	0.037	0.038	0.039	0.038	0.039	0.040	0.041
W2	0.052	0.053	0.052	0.044	0.055	0.051	0.050	0.051	0.052	0.052	0.052	0.051	0.052	0.053
W3	0.050	0.050	0.050	0.052	0.042	0.048	0.049	0.049	0.050	0.051	0.052	0.050	0.050	0.049
W4	0.040	0.040	0.041	0.040	0.039	0.035	0.045	0.045	0.042	0.042	0.042	0.043	0.041	0.041
W5	0.039	0.039	0.040	0.039	0.039	0.045	0.034	0.043	0.042	0.041	0.041	0.042	0.040	0.039
O1	0.044	0.044	0.044	0.045	0.045	0.049	0.049	0.038	0.047	0.046	0.046	0.046	0.044	0.043
O2	0.059	0.058	0.059	0.058	0.058	0.058	0.058	0.057	0.048	0.058	0.059	0.056	0.058	0.058
O3	0.059	0.060	0.060	0.059	0.059	0.057	0.057	0.058	0.059	0.049	0.058	0.058	0.058	0.059
O4	0.057	0.058	0.057	0.058	0.058	0.054	0.056	0.056	0.056	0.056	0.047	0.057	0.056	0.057
O5	0.047	0.046	0.045	0.045	0.045	0.048	0.045	0.047	0.046	0.046	0.045	0.038	0.046	0.045
T1	0.117	0.119	0.113	0.114	0.112	0.116	0.114	0.116	0.114	0.115	0.111	0.119	0.096	0.119
T2	0.132	0.130	0.125	0.125	0.126	0.123	0.124	0.125	0.127	0.125	0.129	0.122	0.129	0.106

7. **Find the weight associated with each criterion by computing the limit of weighted super-matrix, i.e.,** $\lim_{\phi\to\infty}\left(W_c^*\right)^{\phi}$ (Table 9a).

Table 9a: Limit weighted supermatrix $\lim_{\phi\to\infty}\left(W_c^*\right)^{\phi}$

Criterion	*S1*	*S2*	*W1*	*W2*	*W3*	*W4*	*W5*	*O1*	*O2*	*O3*	*O4*	*O5*	*T1*	*T2*
S1	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146
S2	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132
W1	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
W2	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
W3	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
W4	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
W5	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
O1	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
O2	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058
O3	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058
O4	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
O5	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
T1	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114
T2	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125

The limit weighted supermatrix can be reorganized in Table 9b.

Table 9b: The final result of DANP

Dimension	Dimension weight	Dimension Ranking	Criterion	Criterion Weight	Criterion ranking
Strengths (S)	0.277	1	S1	0.146	1
			S2	0.132	2
Weaknesses (W)	0.221	4	W1	0.039	14
			W2	0.052	8
			W3	0.049	9
			W4	0.041	12
			W5	0.040	13
Opportunities (O)	0.262	2	O1	0.045	11
			O2	0.058	5
			O3	0.058	5
			O4	0.056	7
			O5	0.046	10
Threats (T)	0.239	3	T1	0.114	4
			T2	0.125	3

With respect to dimension, strengths (S=0.277) rank first, opportunities (O=0.262) second, threats (T=0.239) third and weaknesses (W=0.221) fourth. In terms of criteria, the importance ranking is ordered as: S1 (=0.146), S2(=0.132), T2(=0.125), T1(=0.114), O2(=0.058), O3(=0.058), O4(=0.056), W2(=0.052), W3(=0.049), O5(=0.046), O1(=0.045), W4(0.041), W5(=0.04), and W1(=0.039).

5. CONCLUSION AND SUGGESTIONS

This study employs DANP method to prioritize the order of four dimensions as well as the fourteen criteria. The priority settings thus obtained can be a reference for the responsible agencies/institutions in Taiwan in formulating the national development plan for autonomous vehicles. It is clear that strengths dimension, which is regarded as an internal factor, should be focused upon for the purpose of developing the industry of autonomous vehicles; specifically, the core technology of ADAS as well as the complete supply chain of ICT should keep ahead in the world. On the other hand, the weaknesses dimension should not be focused upon because the relevant criteria such as W1 (lack of own auto-brand and first-tier supplier), W5 (development policy is unclear), and W4 (regulations revision/amendment running behind) need time to work on and have little influence on the international competition for the development of autonomous vehicles.

The limitation of this research is mainly due to the rather small number of respondents (11 experts in this area) in the questionnaire survey. To be more representative, the number of respondents should be increased and their background should cover a wide range of relevant areas in the industry of autonomous vehicles. In addition, to investigate the interrelationships between the accelerating the development of autonomous vehicles and its influential factors, there are some other methods that can be used instead of the DANP. Notable methods include structural equation modeling (SEM) and partial least squared structural equation modeling (PLS-SEM), which should be explored in the near future

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