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Article

Study on Comprehensive Evaluation Based on AHP-MADM Model for Patent Value of Balanced Vehicle

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Abstract: With the development of science and technology, people's travel modes have become more diversified, and self-balancing vehicles have become a popular travel tool for young people. However, in recent years, due to its quality instability, many regions have issued relevant bans, affecting the development of the balanced vehicle industry. In order to better understand balancing vehicle technology, this paper starts with the balancing vehicle patent, and carries out the following research: This paper first introduces the background and current situation of balanced vehicles and the patent. Then, the principle and model of multi-attribute decision-making based on the analytic hierarchy process (AHP-MADM) are described. According to the three-dimensional patent valuation system issued by the State Intellectual Property Office, a core patent valuation system is established. Then, the weights of patent evaluation attributes are calculated by the improved AHP. After, the patent value of the self-balancing vehicle is evaluated using the established AHP-MADM model. On this basis, the status of patent research and the development of self-balancing vehicles is studied to provide a reference for relevant industry personnel, especially R & D personnel, in future product technology updates and patent layout.

Keywords: AHP-MADM model; comprehensive evaluation; patent valuation; balanced vehicle

MSC: 97M40; 97N99

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1. Introduction

There are many studies on self-balancing vehicles, including technical improvements, laws and regulations, market analysis, etc. Published in 1985, the two-wheeled balance car model proposed by Kazuo Yamato in Japan is the earliest research on the balance car in the world [1]. In 1986, the world's first unicycle robot came out under the research of Schoolwinkel and others in the United States [2]. Since then, there have been related product and technological innovations abroad. Until the 2008 Beijing Olympics, my country applied the self-balancing vehicle "Segway" to security, and the self-balancing vehicle quickly became popular in China and attracted the attention of many scholars and enterprises. With the maturity of intelligent technology after 2014, electric self-balancing vehicles have tended to be intelligent and reached the hottest event in 2018. At present, China occupies an important position in the global self-balancing vehicle market and is the world's largest producer and exporter of self-balancing vehicles, and its demand and export volume are also growing continuously [3]. Although some regions have policy restrictions, they have not affected the popularity of self-balancing vehicles, and the reasons for these restrictions can provide us with directions for product improvement.

In order to understand the status quo of scientific research achievements in the self-balancing vehicle industry and improve the technology in a targeted manner, it is necessary to obtain a comprehensive and in-depth understanding of the technology of the industry. The patent is the best tool for measuring the technical content of an enterprise [4], which can intuitively and accurately reflect the production capacity of scientific and technological innovation [5]. At present, patented technologies related to self-balancing vehicles in the world are mainly concentrated in China, but Japan and the United States have made greater contributions in the origin stage. The Soopat patent search website was used to conduct a simple search until 31 December 2021. The results are shown in Figure 1 and Table 1.

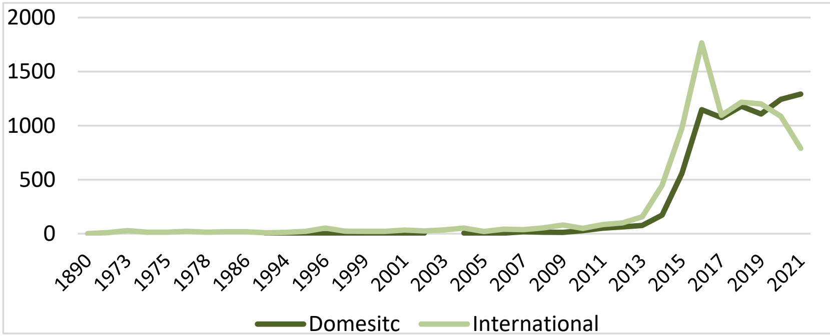

Figure 1. Trend of patent applications for self-balancing vehicles.

Table 1. Number of different patent types of self-balancing vehicles at home and abroad.

Type	Invention	Utility Model	Design
Domestic patent	2334	3248	2741
Foreign patent	1474	66	1
World patent	3808	3314	2742

From the trend of patent application for self-balancing vehicles in Figure 1, domestic patent research and development of self-balancing vehicles started late. In the early and mid term (1890–2008), foreign countries were the main force driving related patent applications and domestic-related applications were few. Since 2008, self-balancing vehicles have become popular in China, and the number of domestic-related patents has grown rapidly, accounting for a large proportion of the total international patents for self-balancing vehicles. From Table 1, the number of patents for self-balancing vehicles in China is obviously more than that of foreign countries. However, in these domestic applications, about 2/3 of the patents are utility models and appearance designs while almost all of the foreign applications focus on inventions. It can be seen that the average quality of foreign patented balance vehicles is higher.

In the current patent market, high-value patents only account for about 10% of the total number of patents, but their total value accounts for more than 80% of the total patent value [6]. Therefore, the mining of core patents for self-balancing vehicles is the key point. To identify the core patent, it is first necessary to evaluate the value of the patent. In the 1970s, the US intellectual property consulting company CHI and the US National Science Foundation (NSF) jointly developed the world's first patent attribute evaluation system, which included seven specific evaluation indicators such as the number of patents [7]. After, it was found that the single-dimensional patent value evaluation attribute system could not fully and accurately reflect its patent value, so a multi-dimensional evaluation attribute system was introduced based on this. For example, the two-dimensional system established by Park et al. [8] includes two dimensions: the inherent elements of technology and application elements. The three-dimensional system of law, technology, and market established by Lv Xiaorong [9], Wan Xiaoli et al. [10], and Xu Huabin et al. [11] only focuses on the selection of specific evaluation attributes; and Jin Xiaodong [12] proposed a three-dimensional attribute system of law, technology, and economy. Li Zhenya [13] and Li Zhipeng et al. [14] constructed a four-dimensional patent value evaluation attribute system based on factors such as law, technology, market, competition, and enterprise. Zhang Yanqiao [15], Yuan Zeming [16], and others proposed a five-dimensional system, which includes five dimensions of influencing factors, including technology, law, market, risk, enterprise degree, and management. The State Intellectual Property Office of my country officially released a three-dimensional evaluation system of law, technology, and economy, which contains 18 specific attributes of patent value evaluation.

AHP is a simple and convenient multi-attribute decision-making method proposed by Professor Satty [17]. When using AHP to solve complex decision-making problems, firstly, a hierarchical structure of decision-making problems from goals to alternatives is formed. Then, the decision-making elements at the same level are compared in pairs to obtain the solution to the problem. The method can be applied in different fields such as environmental science, industrial decision-making and healthcare systems. Sujan Piya et al. (2022) proposed a comprehensive fuzzy AHP-TOPSIS method to calculate the green score of the hotel industry based on 26 determined indicators in order to promote green practices in hotels and reduce the pressure of the hotel industry on the environment [18]. Billur Ecer, Ahmet Aktas, and Mehmet Kabak (2019) proposed an integrated AHP from the perspectives of economic, legal, location, and physical factors—the binary linear programming model—to simultaneously consider different criteria to determine the optimal investment plan for real estate [19]. Babak Daneshvar Rouyendegh (2016) proposed a decision model, combining the fuzzy analytic hierarchy process and data envelopment analysis to evaluate the various aspects of healthcare enterprises' performance to achieve effective responses and decisions based on actual conditions, and improve the enterprise performance [20]. Because there is no official website for patent value evaluation, we use the analytic hierarchy process (AHP) to evaluate the value of self-balancing vehicle patents and selected their core patents according to their multi-dimensional and multi-attribute characteristics. The judgment matrix is constructed by pairwise comparison, and the proportion of each attribute in the patent value is obtained. Finally, according to the specific attribute data of each patent, the high-value patents of the self-balancing vehicle are sorted to select their core patents.

In a word, self-balancing scooters are one of the most popular travel tools at the moment and the demand is increasing year by year, from 1.93 million units in 2015 to 6.07 million units in 2022. In 2020, the total shipments of electric self-balancing scooters in the world were 10.32 million units, of which 9.32 million units were from China, accounting for about 90% of the total shipments [3]. As the main force in the production and export of self-balancing vehicles, it is very important to continuously optimize and improve the quality of self-balancing vehicles and to innovate and create. The relevant attribute data of patents can directly reflect the technological innovation intention and the development of technological content in the technical field [4] and measure the technological improvement and R&D focus of enterprises. It is simple, efficient, and convincing to use patent data to reflect the R&D vitality and capability of an enterprise, and it is difficult for other evaluation attributes to achieve this effect [21]. At present, the quality of self-balancing vehicle products is uneven, the market is chaotic, and the relevant supporting systems for self-balancing vehicles on the road are not perfect. Many countries have issued relevant regulations for the control of self-balancing vehicles. The domestic research on self-balancing vehicles belongs to the latecomers, and the start is obviously later than that of foreign countries, but the later research and development, production, and sales are relatively heavy. Therefore, the technical improvement of my country's self-balancing vehicle and the mining of core patents are very worthy of attention, and the evasion of basic patents in foreign countries should be considered carefully. Additionally, the self-balancing vehicle industry is still in the stage of emerging development. On the basis of understanding the current situation and prospects of the entire industry, it is still necessary to invest a lot of manpower and capital to innovate and improve the technology of self-balancing vehicles. Furthermore, the identification of its core patents can better conduct patent layout and improve the competitiveness of enterprises.

Most studies have mainly focused on the production specifications, relevant restrictions or release policies, control principles, and product user experience of self-balancing scooter products, and there are few studies on their quality and patents. Therefore, in order to ensure improved development of the self-balancing vehicle industry, the research goal of this article is to evaluate the patent value of the self-balancing vehicle and select the core patents. This is not only conducive to self-balancing vehicle manufacturing enterprises to prescribe the right medicine, continuously improve core technologies, and develop high-value patents for self-balancing vehicles; it is also of great significance to the current research status and future development direction of the self-balancing vehicle industry.

In this paper, the AHP-MADM (multiple attribute decision-making based on the analytic hierarchy process) model is applied to the patent value evaluation of self-balancing vehicles. Firstly, according to the constructed judgment matrix, each evaluation attribute at the same level is compared and scored, and the comprehensive weight of each evaluation attribute is calculated by the improved analytic hierarchy process (AHP). Secondly, specific data and non-quantitative attribute-related information of the twenty patent quantitative attributes with relatively high comprehensive evaluation are collected and normalized processing is performed. Then, the algorithm of the AHP-MADM model is used to compare and rank the value of the patents and analysis and evaluation is conducted.

As shown in Figure 2, this article mainly consists of five parts. The first part is the introduction, which describes the relevant background and significance of the evaluation of the patent value of the self-balancing vehicle. The second part is the research method, which describes the concept, implementation steps, and system of the AHP-MADM method in this article. The third part takes the patent value evaluation of the self-balancing vehicle as an example, conducts an empirical analysis on the AHP-MADM method, constructs the evaluation system, determines the weight of the attributes, and collects data. The 20 patents for self-balancing vehicles that were initially screened are compared and sorted, and their core patents are selected. The fourth part provides the analysis and recommendations based on the comprehensive measurement results. The final part provides the conclusions, summarizing and evaluating the relevant content of the whole article.

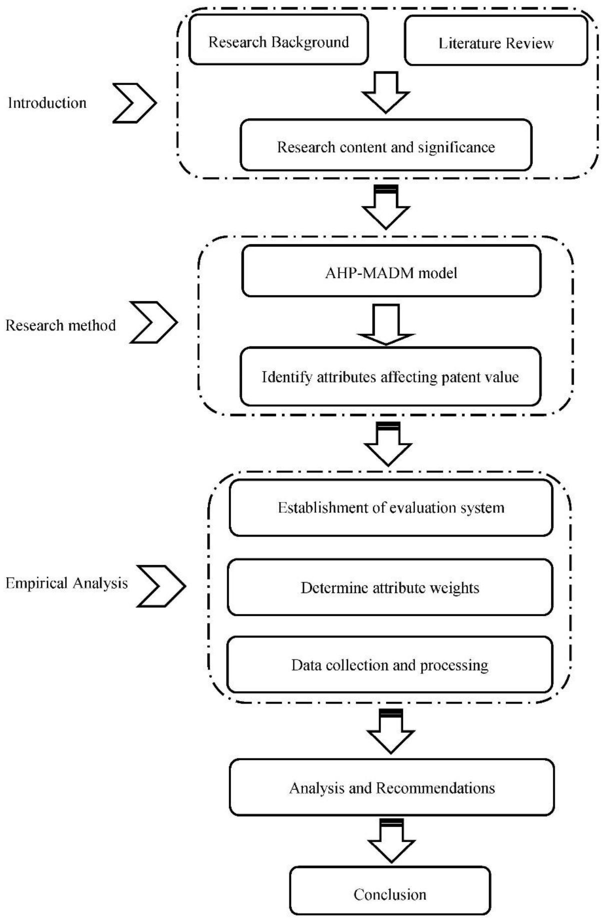

Figure 2. Structure of the article.

2. Research Methods

2.1. AHP-MADM Model

AHP solves a problem by decomposing a complex problem into multiple simple levels that affect the final result, thereby forming a multi-level structure. The attributes at each level are compared pairwise, a judgment matrix is constructed, the weight of each attribute is obtained through a series of operations, and finally, the total weight of each factor is obtained. It can directly divide problems with complex hierarchical structures and many influencing factors into simple comparisons and calculations at a single level. At present, this method has been applied to various fields, and it is one of the important methods of patent value evaluation.

The specific improved process of AHP [17] is as follows:

I. Attribute system establishment, judgment matrix construction, and aggregation.

The problem is clarified, the decision-making goal is determined, and the analytic hierarchy process model of the attribute system is established. According to the "1–9 scaling method" shown in Table 2, a certain element factor C at the upper level is used as the evaluation criterion, and m factors at this level are compared in pairs to determine the matrix elements.

Table 2. The 1–9 scale and its definition [17].

Scaling	Definition
1	Two activities contribute equally to the objective.
3	Experience and judgment slightly favor one activity over another.
5	Experience and judgment strongly favor one activity over another.
7	An activity is strongly favored, and its dominance is demonstrated in practice.
9	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between the two adjacent judgements.
Reciprocal	If an activity has one above number assigned to it when compared with a second activity, then the activity has the reciprocal when compared to the first.

Therefore, according to the judgment opinions of the k^{th} expert E_k, where the set of experts is expressed as $\{E_k \mid k = 1, 2, \ldots, K\}$, the judgment matrix B^k shown in Table 3 is constructed as follows:

Table 3. Judgment matrix B^k.

C	B_1^k	B_2^k	$\cdots$	B_j^k	$\cdots$	B_m^k
B_1^k	b_{11}^k	b_{12}^k	$\cdots$	b_{1j}^k	$\cdots$	b_{1m}^k
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
B_i^k	b_{i1}^k	b_{i2}^k	$\cdots$	b_{ij}^k	$\cdots$	b_{im}^k
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
B_m^k	b_{m1}^k	b_{m2}^k	$\cdots$	b_{mj}^k	$\cdots$	b_{mm}^k

Then, matrices obtained from the experts are aggregated using the geometric mean method (Equation (1)) as discussed in [22]. In Equation (1), K represents the total participating experts:

$$b_{ij} = \sqrt[K]{\prod_{k=1}^{K} b_{ij}^k},\ k = 1, 2, \ldots, K,\ i, j = 1, 2, \ldots, m. \quad (1)$$

Therefore, according to Equation (1), the unified aggregation judgment matrix B shown in Table 4 is constructed.

Table 4. Unified aggregation judgment matrix B.

C	B_1	B_2	$\cdots$	B_j	$\cdots$	B_m
B_1	b_{11}	b_{12}	$\cdots$	b_{1j}	$\cdots$	b_{1m}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
B_i	b_{i1}	b_{i2}	$\cdots$	b_{ij}	$\cdots$	b_{im}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
B_m	b_{m1}	b_{m2}	$\cdots$	b_{mj}	$\cdots$	b_{mm}

II. Calculation of single-level weights

After the unified aggregation judgment matrix is established, the weight of the relative importance order between the elements at this level relative to a certain element at the previous level and the elements related to it should be calculated according to the unified aggregation judgment matrix, that is, the hierarchical single sorting is carried out. This is the basis for ranking the importance of all elements of the hierarchy relative to the highest level. For the unified aggregation judgment matrix, the maximum eigenvalue root is obtained first, and then its corresponding eigenvector a is found, that is, $Ba = \lambda_{\max}a$, where $B = (b_{ij})_{m\times m}$, $a = (a_1, a_2, \ldots, a_m)^T$ and the component a_i of a corresponds to the relative importance of m elements, that is, the weight coefficient. For the calculation of single-level weight coefficients (relative importance), this paper uses an approximate calculation method of weight coefficients commonly used called the square root method that is different from Satty's original AHP method. The calculation step is divided into two steps:

i. The approximate eigenvectors are obtained by geometrically averaging the row vectors of the matrix, and the formula is as follows:

$$\bar{a}_i = \sqrt[m]{\prod_{j=1}^{m} b_{ij}},\ i,j = 1,2,\cdots,m \tag{2}$$

ii. The approximate eigenvectors are normalized to obtain the weight of each attribute, and the formula is as follows:

$$a_i = \bar{a}_i \Big/ \sum_{i=1}^{m} \bar{a}_i,\ i = 1,2,\cdots,m \tag{3}$$

III. Verify Consistency

The criterion for measuring the quality of the matrix is whether the judgment in the matrix has satisfactory consistency, and if the judgment matrix has a relationship $b_{ij} = b_{ik}/b_{jk}$, $(i, j, k = 1, 2, \ldots, m)$, it is said that the judgment matrix has complete consistency. However, due to the complexity of objective things and the diversity of people's subjective perceptions, and the one-sidedness that may arise, it is obviously impossible for every judgment to be consistent, especially for evaluation systems with many indicator factors and a large scale. In order to ensure that the results obtained by applying the improved AHP are basically reasonable, it is necessary to perform a consistency test on the unified aggregation judgment matrix. This test is usually performed simultaneously in conjunction with the above single-level weight coefficient (relative importance) calculation.

i. According to the characteristic equation $\boldsymbol{Ba} = \mathbf{diag}(\lambda_1, \lambda_2, \ldots, \lambda_m)\boldsymbol{a}$ and Formula (3), it is easy to calculate the maximum characteristic root $\lambda_{\max} = \max\{\lambda_1, \lambda_2, \cdots, \lambda_m\}$, where $\lambda_i = \sum_{j=1}^{m} b_{ij}a_j/a_i, (i = 1, 2, \cdots, m)$, and use $\lambda_{\max}$ to calculate the consistency index (*Consistent index*, *C.I.*) as follows:

$$C.I. = \frac{\lambda_{\max} - m}{m - 1}. \tag{4}$$

ii. The error of judgment increases as the matrix order m increases, so the influence of m should be taken into account when judging the consistency. The literature [17] gives the test value of the average stochastic consistency index calculated by the 500 sample judgment matrix. Therefore, the average random consistency index shown in Table 5 is compared to find the corresponding average random index (*Random index*, *R.I.*).

Table 5. Average random consistency index table [17].

Matrix Order	1	2	3	4	5	6	7	8	9	10	11	12
R.I.	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54

iii. Then, the average random consistency index is used to modify *C.I.*, that is, the consistency of the unified aggregation judgment matrix is reflected by the random consistency ratio (*Consistency ratio*, *C.R.*) as follows:

$$C.R. = \frac{C.I.}{R.I.}. \tag{5}$$

When *C.R.* < 0.1, the unified aggregation judgment matrix conforms to the consistency test; otherwise, the ratio needs to be readjusted until *C.R.* < 0.1.

IV. Calculation of the total-level combined weights

It is assumed that the importance of all attributes $B_1^{(n-1)}, B_2^{(n-1)} \cdots, B_m^{(n-1)}$ at the upper level n-1 on the overall target system is $(b_1^{(n-1)}, b_2^{(n-1)}, \cdots b_m^{(n-1)})$, respectively, and the relative importance of the attributes $B_1^{(n)}, B_2^{(n)} \cdots, B_n^{(n)}$ at this level n corresponding to $B_i^{(n-1)}$ is $(a_1^i, a_2^i, \cdots, a_n^i)^T$. Then, the combined importance of the attribute $B_j^{(n)}$ at level n is:

$$b_j^{(n)} = \sum_{i=1}^{m} b_i^{(n-1)} a_j^i,\ i = 1, 2, \cdots, m, j = 1, 2, \cdots, n. \tag{6}$$

Finally, the combined weighted vector $W = (w_1, w_2, \cdots, w_m)^T$, where $w_j = b_j^{(n)}$, of the attributes is obtained using Equation (5).

In this study, considering the multi-dimensional and multi-indicator characteristics of the patent value and the advantages of improved AHP, the AHP-MADM model is used to evaluate the value of self-balancing vehicle patents and select its core patents. As shown in Figure 3, on the basis of the patent value evaluation system, the total-level combined weight of each attribute is calculated by the AHP-MADM model, and the weighted comprehensive attribute value is calculated for sorting.

For the specific problem of certain multi-attribute decision-making [23], first, it is assumed that the set of final selection alternatives is $X = \{x_1, x_2, \cdots, x_n\}$, and the set of attribute is $U = \{u_1, u_2, \cdots, u_m\}$, and the measurement result of the alternative x_i on the attribute u_j is a_{ij}. Then, the steps of the method of the AHP-MADM model are as follows:

Step 1: According to the multi-attribute decision matrix and the alternatives to be evaluated, the original data matrix shown in Table 6 is constructed.

Table 6. Initial data matrix.

	u_1	u_2	$\cdots$	u_j	$\cdots$	u_m
x_1	a_{11}	a_{12}	$\cdots$	a_{1j}	$\cdots$	a_{1m}
$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$	$\cdots$	$\vdots$
x_i	a_{i1}	a_{i2}	$\cdots$	a_{ij}	$\cdots$	a_{im}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
x_n	a_{n1}	a_{n2}	$\cdots$	a_{mj}	$\cdots$	a_{nm}

Step 2: The improved AHP, that is, Formulas (1)–(6), is used to obtain the total-level combined weights $W = (w_1, w_2, \cdots, w_m)^T$ of the attribute.

Step 3: The established original data decision matrix $A = (a_{ij})_{n\times m}$ is normalized. Formula (7) is used for normalized calculation of the benefit-type attributes, and Formula (8) is used for normalized calculation of the cost-type attributes. Let I_1 be the set of benefit-type attributes, and I_2 be the cost attribute set, $N = \{1, 2, \cdots, n\}$, $M = \{1, 2, \cdots, m\}$. Then, the formulas are as follows:

$$r_{ij} = \frac{a_{ij} - \min\limits_{1\le i\le n}\{a_{ij}\}}{\max\limits_{1\le i\le n}\{a_{ij}\} - \min\limits_{1\le i\le n}\{a_{ij}\}},\ i \in N, j \in I_1 \tag{7}$$

$$r_{ij} = \frac{\max\limits_{1\le i\le n}\{a_{ij}\} - a_{ij}}{\max\limits_{1\le i\le n}\{a_{ij}\} - \min\limits_{1\le i\le n}\{a_{ij}\}},\ i \in N, j \in I_2 \tag{8}$$

Finally, the normalized data matrix $R = (r_{ij})_{n\times m}$ is obtained, as shown in Table 7.

Table 7. Normalized data matrix.

	u_1	u_2	$\cdots$	u_j	$\cdots$	u_m
x_1	r_{11}	r_{12}	$\cdots$	r_{1j}	$\cdots$	r_{1m}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\vdots$	$\cdots$	$\cdots$
x_i	r_{i1}	r_{i2}	$\cdots$	r_{ij}	$\cdots$	r_{im}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
x_n	r_{n1}	r_{n2}	$\cdots$	r_{mj}	$\cdots$	r_{nm}

Step 4: Comprehensive measurement results $z_i(W)$ $(i \in N)$ of different alternatives are obtained. The formula is as follows:

$$z_i(W) = \sum_{j=1}^{m} w_j r_{ij}, i \in N \tag{9}$$

Step 5: According to the comprehensive measurement results $z_i(W)$, the set of the alternatives $\{x_i | i = 1, 2, \cdots, n\}$ is sorted in descending order.

2.2. Evaluation Attributes Affecting Patent Value

The general patent value is divided into general, important, essential, and core levels from low to high. Among them, the core patents are high-tech innovation achievements that are difficult to avoid [24] and have the highest value. At present, the official website of the State Intellectual Property Office of my country released a patent value evaluation system in 2012. It includes the legal dimension (stability, avoidability, dependence, justiciability of infringement, period of validity, multinational applications, patent licensing status), the technical dimension (advancedness, industry development trend, scope of application, dependency of supporting technologies, substitutability, maturity), and the economic dimension (market application, competitors, market scale, policy adaptability, market share), totaling 18 specific subdivision indicators in 3 dimensions [25]. Because the core patent has the characteristics of high competitiveness, high value, high originality, and irreplaceability, its evaluation indicators can be adjusted accordingly, regardless of whether it has the avoidability, dependence, and dependency of supporting technologies. According to the data sources of the evaluation indicators, a three-dimensional evaluation system is established for economic value (market application, enterprise patent volume, sales ratio), technical value (number of inventors [26], number of citations [27], number of classification numbers, number of citations [28,29], number of claims [30]), and legal value (number of families [31], number of pages of the specification, survival period [32], and licensing status [33]).

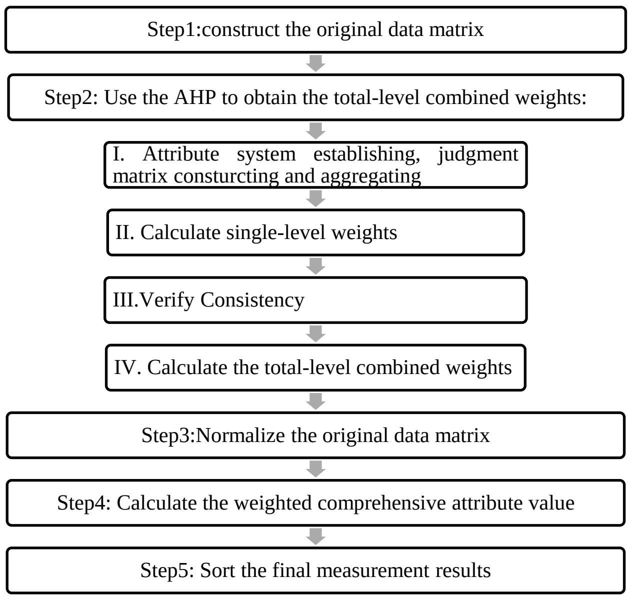

Figure 3. Methodological steps of the AHP-MADM model.

Among them, the economic value of patents is important but difficult to judge. At present, the methods of obtaining economic value from patents in the market mainly include product transformation, licensing, and rights protection. The value of product transformation depends on whether the patent can be applied to the market. Whether it is transformed into a product or not, if it is transformed into a product and put into the market, from the perspective of the enterprise itself, its market share and target customer group will affect the final income. In addition to itself, the competitor's status as the patent user who converts the product also directly affects the earnings of the patented product. If it is not converted into a product, and the patent is directly used to convert it into economic value, there are only several ways of licensing, transfer, and litigation, and the price will be affected according to the value of the patent and the market competitiveness of the patent holder. The cost is high and low. In terms of policy adaptation, policy support, policy prohibition, and policy incentives will directly affect the development and market capacity of the entire industry rather than specific companies and the patents they hold.

Patents include inventions, utility models, and designs [34]. Except for the lower requirements for designs, both inventions and utility models require technical innovations or improvements. The higher the degree of technological innovation, the better the improvement effect and the higher its technical value is. Specifically, the technology is advanced and mature, which is mainly reflected in the number of inventors, the number of citations and be cited. The larger the R&D team, the higher the industry status of the inventor, the stronger the overall R&D strength, and the easier appearance of high-tech patents. The more citations, the more content the inventor refers to, the stronger the technical background and the more secure the content. The more times it is cited, the more it can prove that its technology is widely recognized and has great innovative creativity and reference. When the scope of the application of a patent is wide, the more fields it can be applied to and the greater the value it exerts. Generally speaking, the greater the number of claims, the wider the scope of technical protection, and it is difficult for it to be declared invalid.

The status of legal protection is very important. As we all know, the patent application cycle is long, and the maintenance cost is high. Sometimes, it is necessary to hire a professional agent to manage this process. The purpose of this series of upfront investments is to obtain legal protection. In reality, there are many cases in which patents with good technological innovation and a high market application rate are worthless to others as wedding dresses due to weak legal protection. According to the protection object, protection period, and corresponding rights stipulated by the law, it can be seen that the legal value is high, and the protection scope of the patent should be as wide as possible, which requires a large number of claims and a large number of similar families. The patent protection period is as long as possible, the validity period is long, and the maintenance is renewed upon expiration. The protection effect is as high as possible, and it depends on the writers of the specification mastering certain skills, not only to ensure the scope of protection but also to do a good job of evasion and to ensure the determinability of infringement.

3. Empirical Analysis for Patent Value Evaluation of Self-Balancing Vehicles

3.1. Construction of a Patent Value Evaluation System for Self-Balancing Vehicles

Although the number of patent applications for self-balancing vehicles in China far exceeds that of foreign countries, the application time is decades later than that of foreign countries and the appearance is also greater. The quality of patents is uneven. The evaluation of the patent value and the selection of core patents will play a very important role in the development, layout, and protection of self-balancing vehicle patents in the future.

In order to make the evaluation based on the AHP-MADM model more scientific, reasonable, and convincing, according to the official patent value evaluation system issued by the State Intellectual Property Office, a core patent value evaluation system is built as shown in Table 8, and the core patent value evaluation is set as the target layer A; the subordinate legal, economic, and technical values as the system layer B; and the specific patent value evaluation attributes as the indicator layer C.

Table 8. Core patent value evaluation system.

First-Level Indicator A	Second-Level Indicator B	Second-Level Code	Third-Level Indicator C	Three-Level Code
Patent Value	Economic Value	u_1	Market application	v_1
			Enterprise patents	v_2
			Sales ratio	v_3
	Technical Value	u_2	Number of inventors	v_4
			Number of citations	v_5
			Number of classification numbers	v_6
			Be cited	v_7
			Number of claims	v_8
	Legal Value	u_3	Number of siblings	v_9
			Manual pages	v_{10}
			Survival period	v_{11}
			License status	v_{12}

The first-level indicator (A): the target level, that is, evaluation of the patent value.

The second-level indicator (B): system layer, which has several aspects that affect the value of patents, including economic value u_1, technical value u_2, and legal value u_3 (three aspects).

The third-level indicator (C): the basic layer, which is a specific indicator that affects the value of the patent.

3.2. Determination of Attribute Weights Based on the AHP-MADM Model

To calculate the weight for the identified three second-level indicators and twelve third-level indicators as discussed in Table 8, the improved AHP method was implemented. Six experts were contacted to collect information pertaining to the pairwise comparison of the indicator and develop the pairwise comparison judgment matrix. The experts were provided with four comparison matrices and asked to fill these matrices, as shown in Tables A1–A4 of Appendix A, using the Satty scale as shown in Table A5 of Appendix A. Among the set $\{E_k \mid k = 1, 2, \ldots, 6\}$ of six experts, two were university teachers E_1 and E_2 and the rest included a college student E_3, patent examiner E_4, patent agency practitioner E_5, and enterprise product R & D personnel E_6.

Therefore, according to the expert scoring questionnaire for core patent value evaluation shown in Appendix A, a total of 24 pairwise comparison matrices were obtained from 6 experts as shown in Tables 9–12.

Table 9. Judgment of six experts' scoring for the importance of core patent value indicators.

B	u_1	u_2	u_3	Second-Level Weight of Indicator Criteria					
				E_1	E_2	E_3	E_4	E_5	E_6
u_1	1	1/4, 1/3, 1/5, 1/3, 1/4, 1/2	1/2, 1/3, 1/4, 1/2, 1/2, 1	0.1429	0.1634	0.0936	0.1634	0.1429	0.2402
u_2	4, 3, 5, 3, 4, 2	1	2, 2, 3, 2, 2, 3	0.5714	0.5396	0.6267	0.5396	0.5714	0.5499
u_3	2, 3, 4, 2, 2, 1	1/2, 1/2, 1/3, 1/2, 1/2, 1/3	1	0.2857	0.2970	0.2797	0.2970	0.2857	0.2098
Consistency ratio (C.R.)				0	0.01	0.08	0.01	0	0.02

Table 10. Judgment of six experts' scoring for the importance of economic value indicators.

C_1	v_1	v_2	v_3	Third-Level Weight of Indicator Criteria					
				E_1	E_2	E_3	E_4	E_5	E_6
v_1	1	1/2, 1/3, 1/2, 1/2, 1/2, 1/2	1/3, 1/4, 1/3, 1/2, 1/2, 1/4	0.1667	0.1220	0.1375	0.1958	0.1958	0.1429
v_2	2, 3, 2, 2, 2, 2	1	1, 1/2, 1/2, 1/2, 1/2, 1/2	0.3885	0.3196	0.3333	0.3108	0.3108	0.2857
v_3	3, 4, 3, 2, 2, 4	1, 2, 2, 2, 2, 2	1	0.4448	0.5584	0.5292	0.4934	0.4934	0.5714
Consistency ratio (C.R.)				0.0079	0.0176	0.0226	0.0516	0.0516	0

Table 11. Judgment of six experts' scoring for the importance of technical value indicators.

C_2	v_4	v_5	v_6	v_7	v_8	Third-Level Weight of Indicator Criteria					
						E_1	E_2	E_3	E_4	E_5	E_6
v_4	1	1/4, 1/4, 1/3, 1/3,1/5, 1/3	2, 2, 1, 1, 1/4, 2	1/2, 1/2, 1/2, 1, 1/4, 1/3	1/2, 1/3, 1/2, 1/2, 1/7, 1/2	0.1053	0.0926	0.1157	0.1240	0.0478	0.1038
v_5	4, 4, 3, 3, 5, 3	1	8, 8, 3, 3, 1, 6	2, 2, 1, 3, 1, 1	2, 3, 1, 2, 1, 2	0.4211	0.4358	0.2950	0.3940	0.2336	0.3297
v_6	1/2, 1/2, 1, 1, 4, 1/2	1/8, 1/8, 1/3, 1/3, 1, 1/6	1	1/4, 1/4, 3, 1, 1, 1/6	1/4, 1/6, 1, 1/2, 1/2, 1/4	0.0526	0.0463	0.1526	0.1240	0.1945	0.0519
v_7	2, 2, 2, 1, 4, 3	1/2, 1/2, 1, 1/3, 1, 1	4, 4, 1/3, 1, 1, 6	1	1, 1/2, 1, 1/2, 1/2, 2	0.2105	0.1749	0.2184	0.1240	0.1945	0.3297
v_8	2, 3, 2, 2, 7, 2	1/2, 1/3, 1, 1/2, 1, 1/2	4, 6, 1, 2, 2, 4	1, 2, 1, 2, 2, 1/2	1	0.2105	0.2503	0.2184	0.2341	0.3297	0.1850
Consistency ratio (*C.R.*)						0	0.0505	0.0590	0.0046	0.0220	0.0059

Table 12. Judgment of six experts' scoring for the importance of legal value indicators.

C_3	v_9	v_{10}	v_{11}	v_{12}	Third-Level Weight of Indicator Criteria					
					E_1	E_2	E_3	E_4	E_5	E_6
v_9	1	1/2, 1/3, 1/2, 1/2, 1/3, 1/2	1, 1, 1/2, 1, 1, 1	3, 2, 2, 3, 4, 3	0.2341	0.1935	0.1899	0.2428	0.2202	0.2341
v_{10}	2, 3, 2, 2, 3, 2	1	3, 3, 2, 2, 2, 3	4, 3, 3, 4, 5, 4	0.4681	0.4883	0.4203	0.4387	0.4795	0.4681
v_{11}	1, 1, 2, 1, 1, 1	1/3, 1/3, 1/2, 1/2, 1/2, 1/3	1	3, 3, 2, 2, 3, 3	0.2115	0.2142	0.2685	0.2194	0.2267	0.2115
v_{12}	1/3, 1/2, 1/2, 1/3, 1/4, 1/3	1/4, 1/3, 1/3, 1/4, 1/5, 1/4	1/3, 1/3, 1/2, 1/2, 1/3, 1/3	1	0.0863	0.1040	0.1213	0.0991	0.0736	0.0863
Consistency ratio (*C.R.*)					0.0349	0.0683	0.0376	0.0120	0.0350	0.0349

The pairwise comparison matrices shown in Tables 9–12 were then checked for consistency. Through calculation, it was found that these pairwise comparison matrices are consistent, since the values of the consistency ratio are all less than 0.1, that is, the values of $C.R. < 0.1$.

Next, the unification was carried out using a geometric mean method as discussed in Section 2.1. Then, the unified aggregated matrix of economic, technical, and legal based on the above pairwise comparison matrices obtained from all six experts shown in Table 9 was formed as follows:

$$B = \begin{bmatrix} 1 & 0.2976 & 0.4673 \\ 3.3604 & 1 & 2.2894 \\ 2.1400 & 0.4368 & 1 \end{bmatrix}, \ \lambda_{max} = 3.0158 \tag{10}$$

Formulas (2) and (3) were used with the help of EXCEL software to calculate the weight vector of the second-level indicator criteria and retain four decimal places. The results are as follows:

$$w = (0.1493\ ,\ 0.5689\ ,\ 0.2818)^T.$$

The unified aggregated matrix was then checked for consistency. The maximum eigenvalue of the above judgment matrix B is λ_{max}, calculated to be 3.0158, and it was substituted into Formulas (4) and (5) to calculate the value of consistency ratio, as follows:

$$C.I. = 0.0100, C.R. = 0.0200.$$

Since the value of $C.R. < 0.1$, the unified aggregated judgment matrix B has complete consistency. If the result obtained from the unified aggregated matrix as a value of $C.R. < 0.1$ does not hold, the constructed judgment matrix obtained from all six experts needs to be modified until the result satisfies the value of $C.R. < 0.1$.

In the same way, based on the above pairwise comparison matrices obtained from all six experts shown in Tables 10–12, the unified aggregated judgment matrices C_1, C_2, and C_3 were constructed using the geometric mean method as discussed in Section 2.1. Then, Formulas (2) and (3) were used with the help of EXCEL software to calculate the weights of the third-level indicator criteria to find the maximum eigenvalue λ_{max} and it was substituted into Equations (4) and (5) to obtain the results of $C.I.$ and $C.R.$, and consistency verification was performed. The final result is as follows:

$$C_1 = \begin{bmatrix} 1 & 0.3919 & 0.3467 \\ 2.5516 & 1 & 0.4454 \\ 2.8845 & 2.2450 & 1 \end{bmatrix}, \lambda_{max} = 3.0525; \quad (11)$$

Calculated:

$$w_1 = (0.1503\ ,\ 0.3050\ ,\ 0.5448)^T\ ,\ C.I.\ =\ 0.0263,\ C.R.\ =\ 0.0505;$$

Since the value of $C.R. < 0.1$, the unified aggregated judgment matrix C_1 meets the consistency requirements.

$$C_2 = \begin{bmatrix} 1 & 0.2781 & 1.1225 & 0.4673 & 0.3793 \\ 3.5954 & 1 & 3.8880 & 1.5131 & 1.6984 \\ 0.8909 & 0.2572 & 1 & 0.5612 & 0.3709 \\ 2.1398 & 0.6609 & 1.7818 & 1 & 0.7937 \\ 2.6367 & 0.5888 & 2.6960 & 1.2599 & 1 \end{bmatrix}, \lambda_{max} = 5.0293 \quad (12)$$

Calculated:

$$w_2 = (0.0984, 0.3594, 0.0955, 0.2017, 0.2449)^T,\ C.I.\ =\ 0.0073,\ C.R.\ =\ 0.0065;$$

Since the value of $C.R. < 0.1$, the unified aggregated judgment matrix C_2 meets the requirements of the consistency test.

$$C_3 = \begin{bmatrix} 1 & 0.5503 & 0.8909 & 2.7500 \\ 2.2894 & 1 & 2.4498 & 3.7722 \\ 1.1225 & 0.4082 & 1 & 2.7500 \\ 0.3637 & 0.2651 & 0.3816 & 1 \end{bmatrix}, \lambda_{max} = 4.1308 \quad (13)$$

Calculated:

$$w_3 = (0.2283,\ 0.4544,\ 0.2245,\ 0.0928)^T,\ C.I.\ =\ 0.0436,\ C.R.\ =\ 0.0490;$$

Since the value of $C.R. < 0.1$, the unified aggregated judgment matrix C_3 meets the consistency requirements.

Finally, the total-level combined weight values of the third-level indicator attributes for the evaluation of the core patent value were obtained using Formula (6), as shown in Table 13. In the table, the local weight for the indicators is also enumerated. It should be noted that the same steps followed to identify the second-level weight were followed to identify the third-level weight of the indicators for the given criteria. Further, the total-level combined weight was calculated by multiplying the second-level weight of the indicator criteria with the third-level weight of the attributes.

As shown in Table 13, the weights of the core patent value evaluation attributes vary according to their importance. Among them, the four attributes with a weight value of more than 0.10 are the number of citations, be cited, number of claims, and manual pages, and the three attributes with a weight value of less than 5% are the market applications, enterprise patents, and licensing status, as shown in Figure 4.

Table 13. Total-level weight of the evaluation attributes for core patents.

Second-Level Indicators B	Second-Level Indicator Weight	Third-Level Indicator C	Third-Level Indicator Weight	Total-Level Weight
Economic Value	0.1493	Market application	0.1503	0.0224
		Enterprise patents	0.3050	0.0455
		Sales ratio	0.5448	0.0813
technical value	0.5689	Number of inventors	0.0984	0.0560
		Number of citations	0.3594	0.2045
		Number of classification numbers	0.0955	0.0544
		Be cited	0.2017	0.1148
		Number of claims	0.2449	0.1393
legal value	0.2818	Number of siblings	0.2283	0.0643
		Manual pages	0.4544	0.1280
		Survival period	0.2245	0.0633
		License status	0.0928	0.0261

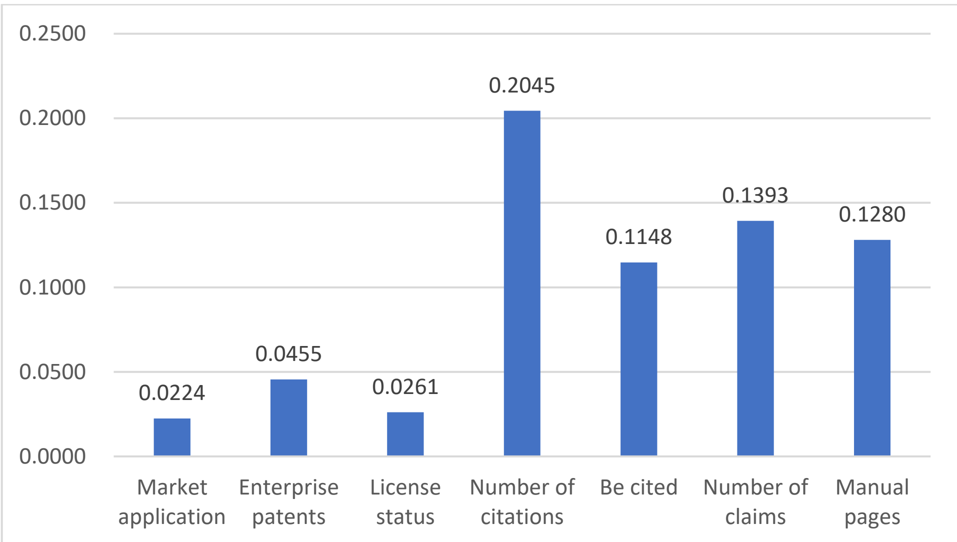

Figure 4. The top four and bottom three attributes and their weights in the weight vector.

3.3. Data Collection and Processing

3.3.1. Data Sources

The empirical case data in this paper was obtained from the following patent search websites:

Dawei (original data of balance car patents with a high overall value ranking (no market share): https://www.innojoy.com/searchresult/default.html) (accessed on 19 April 2022);

Baiteng ((supplementary data, supplementary individual data that is largely absent): http://www1.baiten.cn/Product/Searchand) (accessed on 20 April 2022);

Huajing Intelligence Network ((Balance Vehicle Enterprise Market Share): https://m.huaon.com/search?word=()) (accessed on 25 April 2022).

Table 14 below shows the top 20 patents and their related attribute data that ranked high in the comprehensive evaluation of domestic self-balancing vehicle patents in the patent search website.

Table 14. Original Attribute Data Matrix of Balance Vehicle Patents.

Patents	v1	v2	v3	v4	v5	v6	v7	v8	v9	v10	v11	v12
CN201510607441.2 Electric balance torsion car	transfer	56	1.80%	1	0	2	12	9	61	9	7	
CN201520864881.1 Electric balance car	transfer	56	1.80%	1	0	2	0	10	0	9	0	
CN201410262108.8 Electric balance torsion car		143	2.50%	2	36	1	81	10	61	6	8	
CN201510324294.8 An improved electric balance car	transfer	143	2.50%	1	9	1	16	10	74	17	7	transfer
CN201510328631.0 New electric balance car	transfer	143	2.50%	1	10	4	12	9	74	9	6	transfer
CN201810180450.1 Electric balance car and its supporting cover, starting method and turning method	transfer	143	2.50%	2	0	3	3	29	74	20	8	transfer
CN201510324381.3 Electric balance car		143	2.50%	1	3	3	12	10	61	15	7	
CN201510324580.4 Electric balance car		143	2.50%	1	2	1	9	9	73	16	6	
CN201611222975.4 A human-machine interactive somatosensory vehicle and its control method and device		143	2.50%	2	1	2	5	23	65	20	6	
CN201210421265.X A dual-wheel self-balancing vehicle control system and dual-wheel self-balancing vehicle	transfer	32	8.60%	3	2	2	16	10	1	19	10	transfer
CN200980151327.6 Apparatus and method for control of a dynamically self-balancing vehicle		6	8.60%	4	8	10	14	69	10	59	13	
CN201180011306.1 Apparatus and method for vehicle control		6	8.60%	4	5	4	6	46	21	40	12	
CN201810005593.9 Human-computer interaction somatosensory vehicle and its supporting frame		17	0.01%	1	0	1	0	10	0	8	7	
CN201710206692.9 A kind of balance car and its control method	transfer	2	0.03%	1	0	6	4	13	4	12	5	transfer
CN201510627152.9 Control method and device for balance car		27	8.60%	3	3	1	24	15	8	23	7	
CN201510363955.8 Control method and device for balance car		27	8.60%	3	3	1	12	27	8	35	5	
CN201510626948.2 Control method and device for two-wheeled balance car		27	8.60%	3	2	1	14	13	8	22	7	
CN201810180448.4-Electric balance car and its supporting cover, body and rotating mechanism	transfer	15	2.50%	2	0	3	0	25	73	19	8	transfer
CN201810005593.9 Human-computer interaction somatosensory vehicle and its supporting frame	transfer	15	2.50%	2	1	5	2	15	65	39	5	transfer
CN201810005593.9 Human-computer interaction somatosensory vehicle and its supporting frame	application	15	2.50%	2	1	5	2	15	65	39	5	transfer

3.3.2. Data Normalization

Because the evaluation criteria of different evaluation attributes are different, the results are also different, and it is difficult to compare them uniformly. Therefore, based on the scoring standards of the patent value evaluation system of the published papers, journals, textbooks, etc., the patent value scoring system (as shown in Table A6 of Appendix B) was built to facilitate subsequent unified dimensioning of the data.

Therefore, using Table A6 of Appendix B, we scored the attribute data, as shown in Table 14, to obtain the original score matrix of balance vehicle patents data shown in Table A7 of Appendix B. Next, by adopting Formula (7) to normalize the original score matrix data, the normalization matrix of patent data of self-balancing vehicles was obtained as shown in Table 15.

Table 15. (**1**) Normalization matrix of patent data of self-balancing vehicle. (**2**) Normalization matrix of patent data of self-balancing vehicle (continued).

(1)						
Application Number and Name	**v1**	**v2**	**v3**	**v4**	**v5**	**v6**
CN201510607441.2 Electric balance torsion car	0.75	0.25	0.25	0.00	0.00	0.25
CN201520864881.1 Electric balance car	1.00	0.25	0.25	0.00	0.00	0.25
CN201410262108.8 Electric balance torsion car	0.00	0.50	0.25	0.25	1.00	0.00
CN201510324294.8 An improved electric balance car	0.50	0.50	0.25	0.00	0.25	0.00
CN201510328631.0 New electric balance car	0.50	0.50	0.25	0.00	0.25	0.75
CN201810180450.1 Electric balance car and its supporting cover, starting method and turning method	0.50	0.50	0.25	0.25	0.00	0.50
CN201510324381.3 Electric balance car	0.00	0.50	0.25	0.00	0.00	0.50
CN201510324580.4 Electric balance car	0.00	0.50	0.25	0.00	0.00	0.00
CN201611222975.4 A human-machine interactive somatosensory vehicle and its control method and device	0.00	0.50	0.25	0.25	0.00	0.25
CN201410515643.X Unicycle balance car	0.00	0.33	0.75	0.50	0.25	0.00
CN201210421265.X A dual-wheel self-balancing vehicle control system and dual-wheel self-balancing vehicle	0.67	0.33	0.75	0.50	0.00	0.25
CN200980151327.6 Apparatus and method for control of a dynamically self-balancing vehicle	0.00	0.00	0.75	0.75	0.25	0.75
CN201180011306.1 Apparatus and method for vehicle control	0.00	0.00	0.75	0.75	0.00	0.75
CN201710206692.9 A kind of balance car and its control method	0.50	0.00	0.00	0.00	0.00	1.00
CN201510627152.9 Control method and device for balance car	0.00	0.17	0.75	0.50	0.00	0.00
CN201510363955.8 Control method and device for balance car	0.00	0.13	0.75	0.50	0.00	0.00
CN201510626948.2 Control method and device for two-wheeled balance car	0.00	0.17	0.75	0.50	0.00	0.00
CN201510455016.6 Balance car parking method and device	0.00	0.17	0.75	0.50	0.00	0.00
CN201810180448.4 Electric balance car and its supporting cover, body, and rotating mechanism	0.50	0.00	0.25	0.25	0.00	0.50
CN201810005593.9 Human–computer interaction somatosensory vehicle and its supporting frame	0.50	0.00	0.25	0.25	0.00	1.00

Table 15. *Cont.*

(2)						
Application Number and Name	**v7**	**v8**	**v9**	**v10**	**v11**	**v12**
CN201510607441.2 Electric balance torsion car	0.25	0.00	1.00	0.25	0.25	0.25
CN201520864881.1 Electric balance car	0.00	0.00	0.00	0.25	0.00	0.25
CN201410262108.8 Electric balance torsion car	1.00	0.00	1.00	0.00	0.50	0.25
CN201510324294.8 An improved electric balance car	0.25	0.00	1.00	0.50	0.25	0.75
CN201510328631.0 New electric balance car	0.25	0.00	1.00	0.25	0.25	0.75
CN201810180450.1 Electric balance car and its supporting cover, starting method and turning method	0.00	0.50	1.00	0.50	0.50	0.75
CN201510324381.3 Electric balance car	0.25	0.00	1.00	0.50	0.25	0.25
CN201510324580.4 Electric balance car	0.00	0.00	1.00	0.50	0.25	0.25
CN201611222975.4 A human-machine interactive somatosensory vehicle and its control method and device	0.00	0.50	1.00	0.50	0.25	0.25
CN201410515643.X Unicycle balance car	0.00	0.00	0.50	0.25	0.50	0.75
CN201210421265.X A dual-wheel self-balancing vehicle control system and dual-wheel self-balancing vehicle	0.25	0.00	0.00	0.50	0.50	0.75
CN200980151327.6 Apparatus and method for control of a dynamically self-balancing vehicle	0.25	1.00	0.50	1.00	0.75	0.25
CN201180011306.1 Apparatus and method for vehicle control	0.00	1.00	1.00	1.00	0.75	0.25
CN201710206692.9 A kind of balance car and its control method	0.00	0.25	0.25	0.25	0.25	0.75
CN201510627152.9 Control method and device for balance car	0.50	0.25	0.25	0.75	0.25	0.25
CN201510363955.8 Control method and device for balance car	0.25	0.50	0.25	1.00	0.25	0.25
CN201510626948.2 Control method and device for two-wheeled balance car	0.25	0.25	0.25	0.75	0.25	0.25
CN201510455016.6 Balance car parking method and device	0.00	0.00	0.25	0.25	0.25	0.25
CN201810180448.4 Electric balance car and its supporting cover, body, and rotating mechanism	0.00	0.50	1.00	0.50	0.50	0.75
CN201810005593.9 Human–computer interaction somatosensory vehicle and its supporting frame	0.00	0.25	1.00	1.00	0.25	0.75

3.3.3. Measurement Results

Formula (9) was used to calculate the data in the data normalization matrix shown in Table 15(1),(2), and the measurement results of the 20 outstanding balance bike patents were obtained, as shown in Table 16.

Table 16. Ranking table of the patent value scores of self-balancing vehicles.

Sort	Patent	Measure Result	Gradient
1	CN200980151327.6 Device and method for dynamic self-balancing vehicle control	0.5771	1
2	CN201180011306.1 Device and method for vehicle control	0.5294	
3	CN201410262108.8 Electric balance torsion car	0.4788	

Table 16. *Cont.*

Sort	Patent	Measure Result	Gradient
4	CN201810005593.9 Human-machine interactive somatosensory vehicle and its supporting frame	0.3625	2
5	CN201510363955.8 Control method and device of balance car	0.3595	
6	CN201810180450.1 Electric balance car and its supporting cover, starting method and turning method	0.3447	
7	CN201510627152.9 Control method and device of balance car	0.3233	
8	CN201810180448.4 Electric balance car and its support cover, car body and rotating mechanism	0.3220	
9	CN201510328631.0 Novel electric balance car	0.3067	
10	CN201510324294.8 An improved electric balance car	0.2979	3
11	CN201510626948.2 Control method and device of two-wheeled balance car	0.2946	
12	CN201611222975.4 A human-machine interactive somatosensory vehicle and its control method and device	0.2911	
13	CN201210421265.X A dual-wheel self-balancing vehicle control system and dual-wheel self-balancing vehicle	0.2767	
14	CN201410515643.X Wheel balance car	0.2707	
15	CN201510324381.3 Electric balance car	0.2497	
16	CN201510607441.2 Electric balance torsion car	0.2095	
17	CN201510324580.4 Electric balance car	0.1938	4
18	CN201710206692.9 A kind of balance car and its control method	0.1839	
19	CN201510455016.6 Balance car parking method and device	0.1670	
20	CN201520864881.1 Electric balance car	0.1063	

4. Analysis and Recommendations

It can be seen from Table 16 that the patents of the first gradient include CN200980151327.6, CN201180011306.1, and CN201410262108.8 and the measurement results are 05771, 0.5294, and 0.4788, respectively. This is significantly higher than the patent measurement results of the second gradient, with a significant advantage.

From the line chart of the top three patent scores in Figure 5, it can be seen that the patent value measurement of the balance vehicles is generally higher, the technical value score is highest, the legal value is second, and the economic value score is lower. Although the ultimate purpose is to obtain profits, in terms of economic value, whether the patent itself can be transformed into a product, the market size of the entire industry where the patent is located and the market share held by the holder will affect its economic value. Many patents are for an advanced layout or to apply for relevant subsidies and name evaluations. Additionally, the use of patents to pledge financing is relatively small, the balance vehicle industry has good development momentum, the number of industries is large, and the market share is not high. Therefore, in order for the self-balancing vehicle industry to develop for a long time, it is necessary to achieve core competitiveness, take the lead in the innovation and improvement of the technical characteristics and effects of patents, and compete on the basis of product cost performance.

From Figures 4 and 6, it can be seen that the comprehensive weighted attributes value of the patent evaluation attributes ranks first, and the attributes with higher scores are the number of citations, the number of claims, manual pages, and sales ratio, all of which mainly reflect the technical value of the patent and the status of legal protection. From this, it is evident that the legal value attribute provides a protective environment to fully maintain its intellectual achievements. The technological innovation and improvement of patents are the most important attributes that affect the value of patents. In the future, we still need to work hard on product research and development and introduce talents and technical equipment, technologically ensure innovation as much as possible, and find professionals to write relevant documents. While ensuring the technical value, legal protection is also required to create good basic conditions for the economic transformation of later patents.

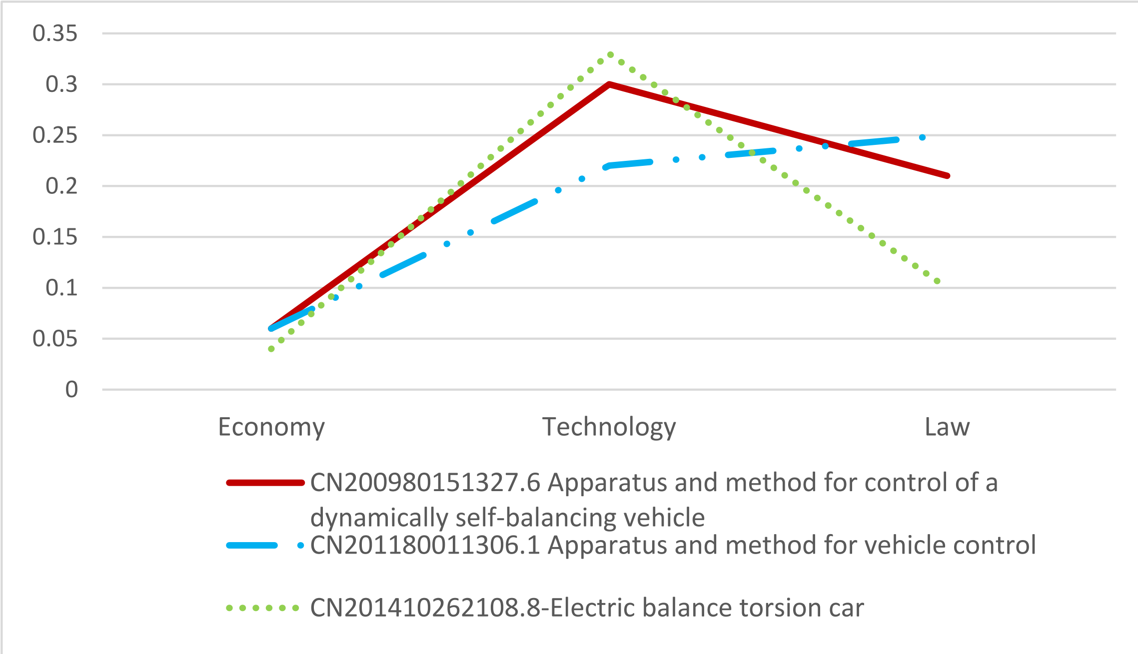

Figure 5. The patent measurement line chart of the top three measurement results.

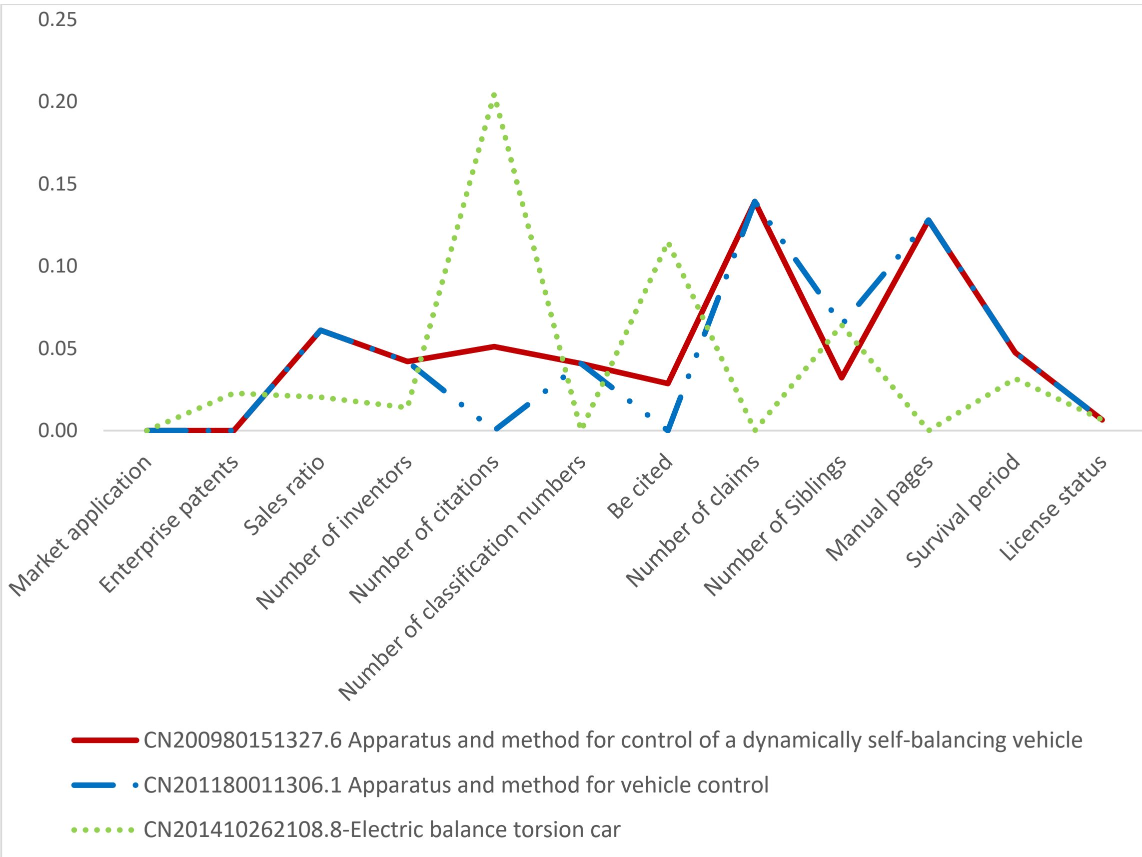

Figure 6. Line chart of the top three patent attribute scores.

The most popular companies in the current market for self-balancing scooters are No. 9, New Century, Lexing Tianxia, Airway, and Chike. Among the 20 high-value balance bike patents, the main brands are Segway, Hangzhou Chike, Xiaomi, and No. 9. Among them, No. 9 received investment from Xiaomi in 2014 and acquired Segway in April 2015. It ranked highest in the global electric balance vehicle market in 2020, accounting for 8.6%, and is a leading company in the global balance vehicle industry. At present, Segway's products and patents belong to No. 9 while Xiaomi's self-balancing scooter products are mainly manufactured by No. 9, so the three patent holders can be regarded as one. The main price of the No. 9 balance car on the e-commerce platform is 1400–4000, and the price of individual products is high. The most expensive is the Segway two-wheel off-road balance car, which is priced at 88,000. Among them, the most popular is the No. 9 balance car L6, which is priced at 1400–2000. According to the data from the Baiteng patent data retrieval website, there are 32 invention patents for self-balancing vehicles on No. 9, 180 for utility models, and 75 for appearance. Segway has 6 patents for self-balancing vehicles in China, and 64 patents for Xiaomi self-balancing vehicles. Hangzhou Chike is a high-tech enterprise jointly built by professional institutions. Its main products include Twisted Cars and Royal Tigers. The price on the e-commerce platform is 800–4000, among which the highest-selling Chike (CHIC) PI03 is priced at around 1600. In terms of patents, there are 157 patents for self-balancing vehicles, including 57 inventions, 54 utility models, and 46 appearances.

As shown in Figure 7, the highest comprehensive patent evaluation is Segway's CN200980151327.6, a patent for equipment and methods for the control of dynamic self-balancing vehicles. Because of the number of pages in the description, the number of weights, the number of families, and the relatively high number of arguments, this indicates that its technical content is advanced, its value is high, and its legal protection scope is good. However, the number of families and pages of the description of the high-value patents acquired by him are obviously inferior to those of Segway's patents. Addition, Hangzhou Chike is in the same family, especially the CN201410262108.8 patent, whose number of citations is higher than other patents, showing that its technical content is advanced and mature.

In summary, in order to better carry out the research, development, and protection of self-balancing vehicle patents, the following suggestions are put forward:

Suggestion 1: Pay attention to the utilization of patents, not only to apply for patents but also to apply them to the market, transform them into products, or license them, so that the patent market can be activated and bring benefits to the patent holders.

Suggestion 2: Pay attention to the quality of the patent. If the innovation degree of the patent is not high, it will inevitably affect the later use. At present, among the domestic balance vehicle patents, the appearance design accounts for a large proportion, and the number of patents is falsely high; however, in fact, the number of patents for inventions is low. For example, the number of Chinese patents of Segway is very small, but its value is higher than that of companies with a large number of patents. After all, enterprise development depends on the quality and layout of patents, not the number of patents.

Suggestion 3: Ensure a high-quality patent layout in advance. Now that the balance car has entered the era of intelligence, its technical requirements are higher. Its upstream technologies include chip manufacturing, sensor manufacturing, motor manufacturing, battery manufacturing, and other technical directions. According to the data of the patent search website, the current patent research and development focuses on steering control, terminal control devices operated by the rider, saddles, and accessories. Ensuring high-quality patent layout in advance, carrying out research and development in the upstream industry in advance, applying for patents, and finding basic patents to avoid or apply for licenses will help to prevent being blocked by patents in later stages and difficulties in product development and production.

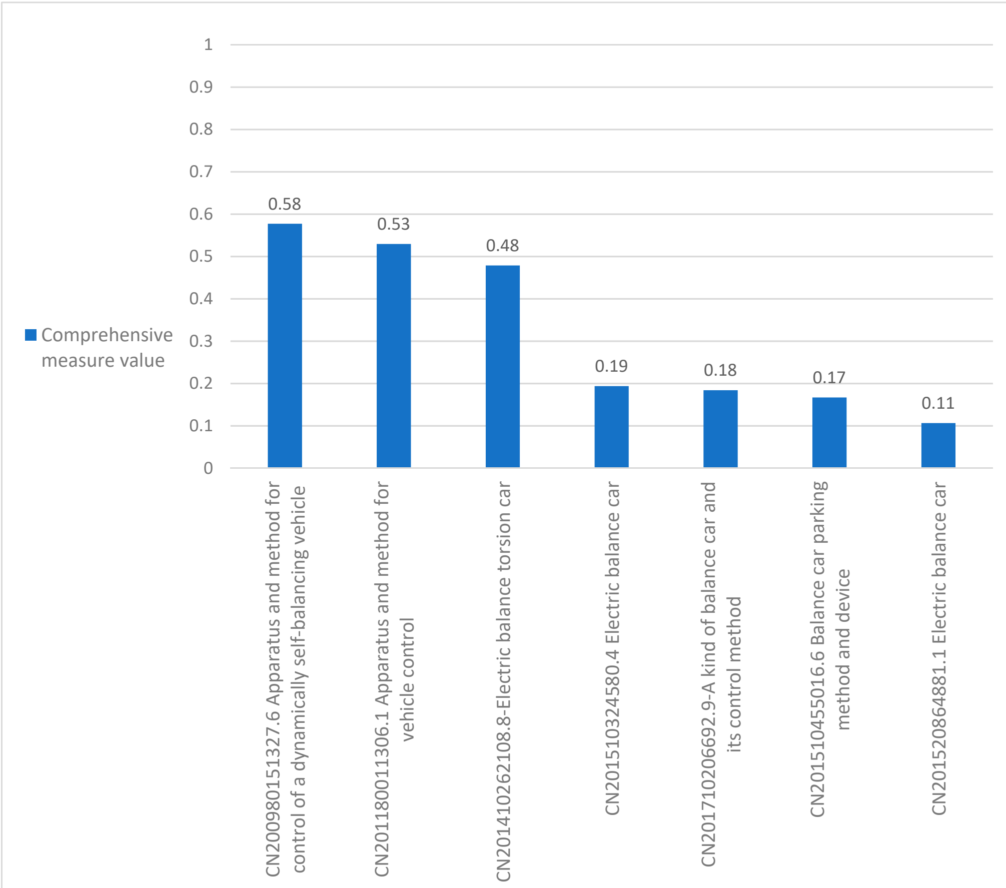

Figure 7. Histogram of the measurement results of the top three and bottom four.

5. Conclusions

Although the development of self-balancing vehicles in recent years has encountered problems involving quality, patents, systems, etc., which have indeed affected the scale of the industry, the current scale of China's self-balancing vehicle market still exceeds 10 billion, and there are many related manufacturers, accounting for the global self-balancing vehicle market. The export share is large. In addition, the research enthusiasm for self-balancing vehicles from all walks of life has not subsided. On the contrary, since 2010, the number of studies on self-balancing vehicles has been numerous and wide-ranging and its popularity has continued to grow. Under the research of relevant personnel, a lot of related systems on self-balancing vehicles have been introduced one after another at home and abroad to make up for the problem of incomplete systems. However, most scholars research and supplement their product production specifications, related restrictions or release policies, control principles, and product user experience, and rarely carry out research on the quality and patents of self-balancing vehicles. Therefore, studying the core patents of self-balancing vehicles is of great significance to the current research status and future development direction of the industry. Continuous improvement of technology, research and development of high-value patents for self-balancing vehicles, and prescription of the right medicine will help to better ensure the development of the self-balancing vehicle industry.

Based on the AHP-MADM model and combined with the patent value evaluation system, this paper analyzed the core patents of domestic self-balancing vehicles. Based on the characteristics of core patents, 12 detailed evaluation attributes in 3 aspects of economy, technology, and law were considered and extracted, and a patent value evaluation system of core patents was constructed. The improved AHP-MADM model was used to determine the weight of different evaluation attributes, the value of 20 outstanding patents was evaluated and ranked, and high-value patents were selected to provide a reference for the development direction and patent layout of self-balancing vehicle enterprises in later stages. Through the research on decision-making based on the improved AHP method and its patent value evaluation in balance vehicles, it was found that the AHP-MADM model is scientific and efficient, simple in operation, and strong in practicability in the above-mentioned empirical analysis. Additionally, it has been widely used in a series of multi-criteria options such as tourism, shopping, and quality evaluation. It can be used in more fields in the future.

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Data Availability Statement: The empirical case data, the top 20 patents and their related attribute data that rank high in the comprehensive evaluation of domestic self-balancing vehicle patents showed in Table 14 in this paper comes from patent search websites Dawei, Baiteng and Huajing Intelligence Network.

Conflicts of Interest: The authors declare that there are no conflict of interest regarding the publication of this paper.

Appendix A

Expert Scoring Questionnairefor Core Patent Value Evaluation

1. Your current status in the patent field belongs to which of the following:
    - □ University teacher
    - □ College Students
    - □ Patent examiners
    - □ Patent agency practitioners
    - □ Enterprise product R&D personnel
    - □ other
2. The name of the institution you belong to is:
3. Please fill in the following table according to the scoring instructions:

Table A1. Judgment of the importance of core patent value indicators.

B	**Economic Value (u_1)**	**Technical Value (u_2)**	**Legal Value (u_3)**
Economic Value (u_1)	1		
Technical Value (u_2)		1	
Legal Value (u_3)			1

Table A2. Judgment of the importance of economic value indicators.

C_1	**Market Application (v_1)**	**Enterprise Patents (v_2)**	**Sales Ratio (v_3)**
Market application (v_1)	1		
Enterprise patents (v_2)		1	
Sales ratio (v_3)			1

Table A3. Judgment of the importance of technical value indicators.

C_2	Number of Inventors (v_4)	Number of Citations (v_5)	Number of Classification Numbers (v_6)	Be Cited (v_7)	Number of Claims (v_8)
Number of inventors (v_4)	1				
Number of Citations (v_5)		1			
Number of classification numbers (v_6)			1		
Be cited (v_7)				1	
Number of claims (v_8)					1

Table A4. Judgment of the importance of legal value indicators.

C_3	Number of Siblings (v_9)	Manual Pages (v_{10})	Survival Period (v_{11})	License Status (v_{12})
Number of siblings (v_9)	1			
Manual pages (v_{10})		1		
Survival period (v_{11})			1	
License status (v_{12})				1

Table A5. Scoring Instructions.

Score	Definition
1	Two activities contribute equally to the objective.
3	Experience and judgment slightly favor one activity over another.
5	Experience and judgment strongly favor one activity over another.
7	An activity is strongly favored and its dominance is demonstrated in practice.
9	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between the two adjacent judgements
Reciprocal	If an activity has one above number assigned to it when compared with a second activity, then the activity has the reciprocal when compare to the first.

Appendix B

Table A6. Patent value scoring table.

Attribute	2 Points	4 Points	6 Points	8 Points	10 Points
Market application	Not applied, difficult to apply		Not applied, easy to apply		Applied
Enterprise patents	Rare	Less	General	Many	More
Sales ratio	Very small	Small	General	Large	Very Large
Number of inventors	1	2	3	4	5 people and above
Number of classification numbers	1	2	3	4	Category 5 and above
Number of Citations	0–5	6–10	11–20	20–30	30 and above
Be cited	0–10	11–20	21–30	31–40	40 and above
Number of claims	1–10	11–20	21–30	31–40	40 and above
Number of siblings	Domestic only		2–10		10 or more
Manual pages	1–7	8–14	15–21	22–28	28 pages or more
Survival period	within 3 years	4–7 years	8–11 years	12–15 years	16+ years
License status		No license		Licensed	

Table A7. (**1**) Original Score Table of Balance Vehicle Patents Data. (**2**) Original Score Table of Balance Vehicle Patent Data (Continued).

(1)

Application number and name	v1	v2	v3	v4	v5	v6
CN201510607441.2 Electric balance torsion car	10	4	4	2	2	4
CN201520864881.1 Electric balance car	10	4	4	2	10	4
CN201410262108.8 Electric balance torsion car	2	6	4	4	4	2
CN201510324294.8 An improved electric balance car	6	6	4	2	4	2
CN201510328631.0 Novel electric balance car	6	6	4	2	2	8
CN201810180450.1 Electric balance car and its supporting cover, starting method and turning method	6	6	4	4	2	6
CN201510324381.3 Electric balance car	2	6	4	2	2	6
CN201510324580.4 Electric balance car	2	6	4	2	2	2
CN201611222975.4 A human-machine interactive somatosensory vehicle and its control method and device	2	6	4	4	4	4
CN201410515643.X Wheel balance car	2	4	8	6	2	2
CN201210421265.X A dual-wheel self-balancing vehicle control system and dual-wheel self-balancing vehicle	6	4	8	6	4	4
CN200980151327.6 Device and method for dynamic self-balancing vehicle control	2	2	8	8	2	8
CN201180011306.1 Device and method for vehicle control	2	2	8	8	2	8
CN201710206692.9 A kind of balance car and its control method	6	2	2	2	2	10
CN201510627152.9 Control method and device of balance car	2	3	8	6	2	2
CN201510363955.8 Control method and device of balance car	2	3	8	6	2	2
CN201510626948.2 Control method and device of two-wheeled balance car	2	3	8	6	2	2
CN201510455016.6 Balance car parking method and device	2	3	8	6	2	2
CN201810180448.4 Electric balance car and its support cover, car body and rotating mechanism	6	2	4	4	2	6
CN201810005593.9 Human-machine interactive somatosensory vehicle and its supporting frame	6	2	4	2	2	10

(2)

Application number and name	v_7	v_8	v_9	v_{10}	v_{11}	v_{12}
CN201510607441.2 Electric balance torsion car	4	2	10	4	4	4
CN201520864881.1 Electric balance car	2	2	2	4	2	4
CN201410262108.8 Electric balance torsion car	10	2	10	2	6	4
CN201510324294.8 An improved electric balance car	4	2	10	6	4	8
CN201510328631.0 Novel electric balance car	4	2	10	4	4	8
CN201810180450.1 Electric balance car and its supporting cover, starting method and turning method	2	6	10	6	6	8
CN201510324381.3 Electric balance car	4	2	10	6	4	4
CN201510324580.4 Electric balance car	2	2	10	6	4	4
CN201611222975.4 A human-machine interactive somatosensory vehicle and its control method and device	2	6	10	6	4	4
CN201410515643.X Wheel balance car	2	2	6	4	6	8
CN201210421265.X A dual-wheel self-balancing vehicle control system and dual-wheel self-balancing vehicle	4	2	2	6	6	8
CN200980151327.6 Device and method for dynamic self-balancing vehicle control	4	10	6	10	8	4
CN201180011306.1 Device and method for vehicle control	2	10	10	10	8	4
CN201710206692.9 A kind of balance car and its control method	2	4	4	4	4	8
CN201510627152.9 Control method and device of balance car	6	4	4	8	4	4
CN201510363955.8 Control method and device of balance car	4	6	4	10	4	4
CN201510626948.2 Control method and device of two-wheeled balance car	4	4	4	8	4	4
CN201510455016.6 Balance car parking method and device	2	2	4	4	4	4
CN201810180448.4 Electric balance car and its support cover, car body and rotating mechanism	2	6	10	6	6	8
CN201810005593.9 Human-machine interactive somatosensory vehicle and its supporting frame	2	4	10	10	4	8

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