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DISCUSS THE EFFICIENCY EVALUATION OF WIRELESS CHARGING TECHNOLOGY WITH THE NEWLY DEVELOPED DEA MODEL: TAKING THE AUTONOMOUS MOBILE ROBOT (AMR) AS AN EXAMPLE

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Abstract

According to the information provided by Yano Research Institute (2021): "The global wireless power supply market is continuing to expand at an annual rate of more than 10%, and it is estimated that by 2031 it will grow compared to 2021 About 3.6 times." In other words, in the future vision of Smart City, the development of Wireless Charging Technology, that is, "how to optimize the supply and demand control of energy" is definitely a very important issue. In contrast, if the wireless charging technology can be applied to the unmanned transportation system to replace the annoying problems of manpower support and complex wiring engineering of traditional wired charging and so on, Then it will definitely be able to reduce labor costs and improve the safety and efficiency of work; at the same time, it can even achieve the goal of automated factory and implement 24-hour work as an unmanned chemical factory. In this article, the *t*EWM-AR model (the newly developed DEA model) is used for efficiency evaluation, which not only has the characteristics and benefits of convenient operation and direct contact with the Experts, but also will be another evaluation method that approximates the real state of the statistical population. Furthermore, when 'AMR's wireless charging technology can overcome the cost problem in the short term, and truly achieve a positive correlation with the global development trend', in this case, two helpful results will be obtained: (1) It can help related industry to carry out a comprehensive digital transformation and the goal of "smart factory, factory with lights off". (2) At the same time, it can also provide relevant decision-makers in the industry with another operation strategy of highly efficient 'unmanned economy' and 'reduced labor costs'.

Keywords: wireless charging ; Autonomous Mobile Robot (AMR) ; Data Envelopment Analysis (DEA) ; *t*EWM-AR (Three-Stage Weighted Proportional Interval Estimation) Model

Introduction

According to the article "2022 Edition Smart City Energy Management Status and Future Prospects " published by the Yano Institute of Economic Research in Japan on October 31, 2022: "In the Intelligent City, in order to be able to realize the 3Es of energy (Energy Security, Economic Efficiency and Environment), we will develop an energy supply business that utilizes locally produced energy and distributes it. It is important to optimize energy supply and demand control through comprehensive management of energy resources." (Yano Research Institute, 2022)

In the application market of unmanned vehicles, that is including: Autonomous Mobile Robot (AMR), Automated Guided Vehicle (AGV), etc., their main charging modes are divided into two types: including "contact charging plug" and "Replacement battery". Moreover, (1) they all require a lot of charging time and labor costs, and (2) after a long period of wear and deterioration, they also require regular replacement of charging equipment.

The Technology for Wireless Charging

The so-called "wireless charging" technology refers to the transfer of electric energy to the device object waiting to be charged through the transmission method in the air through magnetic field induction or magnetic field resonance, so that annoying connecting wires can be saved. The development of this technology has gradually made people's lives more convenient; especially, entering the era of the Internet of Everything and electric vehicles, the technology of wireless charging is even more important. At the same time, "wireless charging" can also overcome the problem of connector incompatibility between different brands, and "wireless charging" can also avoid the trouble that each charging product needs to be provided with an independent power supply device. (Lee, 2017)

The Importance of the Wireless-Charging

Wireless charging (or inductive charging, non-contact inductive charging) technology is through the technology of 'near-field induction, inductive coupling', and the power supply device (charger) transmits energy to the 'target device for power consumption' to provide the It is used for the kinetic energy of device operation. In other words, there is no need to use physical wires to connect the charger and the electric device; that is to say, the wireless charging technology is indeed more convenient and flexible than the wired charging technology.

At present, the Wireless Charging market is still in the continuous expansion of demand, and its application focus has surpassed the Wireless Charging demand market for smartphones, and then penetrated into (Edge) Computing Devices, Wearable Devices, Audio Wearable Devices, Small Home Appliances, Smart Home Devices, and wider fields of medical, industrial, robotics, automotive and 5G communications,...etc.; these new applications

have unique device appearance, design challenges and charging requirements, and There is a strong desire for interoperability.

The Advantages and Disadvantages of the Wireless Charging Technology

Driven by the mainstream trend of intelligence and high automation, the handling equipment used in the industry, the power they need, especially Wireless Charging will be the guarantee for the stable operation of these handling equipment. In other words, the Wireless Charging technology will fully support the mainstream trend of "intelligence and high automation".

In today's demand market, wireless charging technology can be divided into two methods: Low-power charging and High-power charging. Low-power charging such as mobile phones and other devices often use electromagnetic induction charging methods. The use of High-power charging, such as electric vehicles, uses resonance to transmit energy to the energy storage element of the power-consuming device through the power supply equipment, so as to provide the operation of the power-consuming device.

Furthermore, wireless charging technology can be used not only in public enterprises, but also in homes. Although, it has many benefits, it also has its other side. Therefore, before planning to switch to wireless charging technology, it is worth understanding its advantages and disadvantages. Among them, the advantages of wireless charging include the following:

(1) The handling equipment can operate stably without interruption because this is the way of 'wireless' transmission of 'power energy' across the air.
(2) Using wireless magnetic induction mode charging, the device can be invisible.
(3) Effectively avoid the risk of contact wear and sudden arc sparks and enhance durability.
(4) There is no need to configure additional electric actuators, and it can be used universally for "multi-device charging" between different devices; it can reduce equipment costs.
(5) The wireless charging solution is beneficial to the "unmanned economy" and reduces labor costs.

In contrast, wireless charging technology still has its disadvantages, including:
(1) The wireless charging speed is relatively slow.
(2) Wireless charging may be limited by mobile space.
(3) Consumption of battery (energy storage) elements may occur; (Pinkoi, 2021)

The above 3 shortcomings of wireless charging technology, in principle, belong to the issue of power and efficiency of the equipment, and urgently need to be broken through.

Wireless charging is the future trend. In addition to mobile phone chargers, many electric vehicles of internationally renowned brands have begun to be equipped with wireless charging technology. As for the wireless charging technology of handling equipment (AMR, AGV), in addition to performance indicators,

such as: (1) transmission efficiency, (2) transmission distance, (3) shielding effect of obstacles, (4) metal foreign objects Intrusion protection mechanism, (5) Feasibility of misplaced charging, etc. (Lee, 2017); There should be another challenging indicator, that is "transmittable interoperability between different handling devices."

Research Methods

Because the Data Envelopment Analysis (DEA) can deal with multiple inputs and outputs at the same time, it can be applied in a wide range and is more suitable for general performance evaluation problems; and the analysis results are more acceptable to various units. Even so, DEA is not a panacea, and it inevitably has limitations or disadvantages as described below.

(1) The input and output data should be very clear.
(2) "Homogeneity" is required among the evaluated units; it is not appropriate to compare units of different nature or scale.
(3) The result evaluated by DEA is the relative efficiency of each unit, not the absolute efficiency. (Bao, 2008)
(4) The traditional DEA model generally has the unreasonable problem that the variable weight is "0". (Bao *et al*., 2019)

In order to solve the unreasonable problem that the DEA model generally has variable weight is "0" and the weight range evaluation that can more closely match the real state; the research method of this paper will adopt the *t*EWM-AR model.

This model is a newly developed DEA model, which not only combines the theory of Experts Weighting Method (EWM) and the concept of Assurance Region (AR) model. At the same time, a set of holistic operation methods of "Expert Interview" is designed; this is similar to the Delphi Method (DM) with expert survey method, but also the operation method of Expert Group Decision -Making. The operational elements of "Expert Interview" include: "Consultation, questionnaire, and feedback opinions." In this way, a new DEA model is generated, which is called "Three-Stage Weighted Proportional Interval Estimation"- *t*EWM-AR Model.

Although the aforementioned Deffie method (DM) is completely different from the data envelopment analysis (DEA), it is the result of expert group decision-making. The research method of DM does not require a large number of samples, but the samples should be representative; because it is based on the intuitive subjective judgment of experts, it is possible to measure the opinions of most experts on the set issues during the research process. (Dalkey & Helmer, 1963; Hartman, 1981; Song Wenjuan, 2001)

The "Expert Interview" designed by the *t*EWM-AR Model is an expert survey partially similar to the Delphi Method (DM); the interviews need not be many, the only requirement is that, as far as the topic to be explored is concerned, they must all be the "Experts", and their opinions have the value of consultation and reference. The number of experts can be determined according to the size

of the forecast subject and the width of the area involved, generally no more than 20.

All in all, the efficiency evaluation method of the *t*EWM-AR model adopted in this paper is a complete set of operation methods including "Expert Consultation", "Expert Questionnaire" and "Feedback Expert Opinion". The predictable impact of this includes at least: (1) Following the EWM theory to highlight the connotation of the importance of the association between variables; (2) 95% Confidence Interval will be tightened; (3) The average value will not change too much.

The tEWM-AR Model: Three-Stage Weighted Proportional Interval Estimation

In other words, if the collected data encounters certain influencing factors and deviates, it will lead to a certain degree of error results in the efficiency evaluation. Therefore, this paper adopts the *t*EWM-AR model as the research method of the case verification in Chapter 4; the following is the introduction of the *t*EWM-AR model, which is divided into four stages in sequence:

Stage 1 - "Experts' Consultation":

The key work at this stage is to produce two results through multiple and repeated experts' consultations, including: (1) the name of the research topic required for the case verification in Chapter 4 ;(2) In the process of designing the Expert Questionnaire, the names and appropriate quantities of the important reference factors (variables) that are required.

Stage 2 - "Expert Interview":

There are two key points: In addition to setting the conditions of the interviewees, the experts in the setting must be invited to provide their majors and fill out the "Expert Questionnaire".

Stage 3 - the Collection, Statistics and Analysis of the "Expert Questionnaire".

Among them, "Actual score", "Relative importance score", "Appraisal score", and "'Weight summation' of each relative importance" will be generated in sequence. An overview of the process for its generation is as follows:

Step 1: The algorithm of the "appraisal score" matrix is expressed as follows:
"appraisal score" matrix = "actual score" matrix * "relative importance score" matrix.

Step 2: The calculation algorithm of the "summation of relative importance" matrix of each variable is as follows:
For the "appraisal score" matrix, apply the theory of Expert Weight Method (EWM), emphasizing the connotation of the relative importance of each variable, in order to obtain the "weight summation' of each relative importance" matrix.

Stage 4 - the Collection, Statistics and Analysis of "Feedback Expert Opinion".

At this stage, the experts will

produce relevant information on the proportion of "reasonable or not" for "the ranking results of the "summation of relative importance weights" of the 6 variables".

As for such a complete set of evaluation methods used in this paper, it can be understood from the following two steps that the *t*EWM-AR model is indeed another evaluation method that approximates the true state of the parent population. (Bao *et al*., 2020)

Step 1: Execute *MS-Excel's* Data / 'Descriptive Statistics to obtain the "mean ($\bar{x}_i$, $\bar{y}_r$) and standard deviation *S*" of each variable.

Step 2: Apply the "mean and standard deviation" to generate a set of weight-limiting inequalities of "Interval Estimation of Pairwise Weight Ratio".

Suppose, DMU_j (j =1, …, n) uses input variable x_{ij} (i =1, …, s) to generate output variable y_{rj} (r =1, ..., t), then "Interval Estimation of Pairwise Weight Ratio" can be expressed as follows:

$$\left(\frac{\bar{x}_h}{\bar{x}_i+3S_{\bar{x}_i}}\right) v_i - v_h \le 0 \ , \left(\frac{\bar{x}_h+3S_{\bar{x}_h}}{\bar{x}_i}\right) v_i - v_h \ge 0 \ ;$$

$$\left(\frac{\bar{y}_k}{\bar{y}_r+3S_{\bar{y}_r}}\right) u_r - u_k \le 0 \ , \left(\frac{\bar{y}_k+3S_{\bar{y}_k}}{\bar{y}_r}\right) u_r - u_k \ge 0 \ ;$$

(3-1)

Among them, $i = 1, 2, \ldots, s$, $h = i+1$, and when $h > s$, then $h = 1$; $r = 1, 2, ..., t$, $k = j+1$, and when $k > t$, then $k = 1$.

Looking at the above, according to (3-1), we can know that "the weight-limiting inequalities of *t*EWM-AR model" does have the characteristics of a non-negative lower limit (Bao *et al*., 2020). Therefore, using the *t*EWM-AR model for efficiency evaluation not only has the characteristics and benefits of convenient operation and direct contact with experts, but also will be another evaluation method that approximates the true state of the statistical matrix.

The Results and Discussion of Example Verification

From various efficiency evaluation methods, we can know that the traditional data envelopment analysis (DEA) generally has the unreasonable phenomenon of the variable weight is "0", and even leads to the inequality of Interval Estimation of Pairwise Weight Ratio to get Negative value lower bound. Therefore, this article adopts a newly developed research method, that is, the *t*EWM-AR model that integrates the whole set of operation methods of " Expert Consultation ", " Expert Interview ", " Expert Questionnaire " and " Feedback Expert Opinion " into the efficiency evaluation .

All in all, the *t*EWM-AR mode combines the advantages of various methods such as "Expert Weight Method (EWM)", "Assurance Region (AR) Model", and 'Overall Operation Method of "Expert Interview"', so that The research method not only has the characteristics and benefits of "convenient operation and direct contact with experts"; at the same time, it will also be another evaluation method that approximates the true state of the statistical matrix.

The Stage 1 of the tEWM-AR Model - Consultation to Experts

As mentioned in an earlier section of this article, the current demand market for "wireless charging" technology has penetrated into (edge) computing devices, wearable devices, hearing devices, small appliances, smart home devices, and medical, industrial, robotics , automotive and 5G communications, ... and other broader fields; this development trend has indeed inspired a new generation of "wireless charging" technology solutions, including low-frequency induction and resonance, high-frequency resonance, emerging high-frequency NFC charging, and ultra-high frequency “long-distance” wireless charging based on radio frequency (RF), infrared (IR) or ultrasound (US) technology.

The various technical applications mentioned above do provide many feasible solutions for the "Wireless Charging" technology of handling equipment (AMR, AGV), but there are still factors that may affect the overall performance of different technologies, including: (1) wireless charging The charging time of the transmission, (2) the transmission distance (wireless charging sensing range), (3) the shielding effect of obstacles, (4) the protection mechanism of metal foreign objects intrusion, (5) the feasibility of misplaced charging, (6) different Transportable interoperability between handling equipment.

In view of the above, in conjunction with the "research topic" required for case verification" and "relevant reference important factors (variables) required for the design of the " Expert Questionnaire "", this article is aimed at "the above- mentioned various "Wireless Charging" technologies", Various considerations that may affect the overall performance are "collected, screened and extracted"; finally, the results are provided to " Expert Consultation ". The following is a summary description of How to implement 'Expert Consultation'. The object of "Expert Interview" can be the same as the object of "Expert Consultation"

The main task during this step is to 'determine and produce the name of the "research topic" required for example verification in this paper', and 'the name and Appropriate Quantity'. As for the way of generating the "research topic" of this article, it has experienced many times and repeated "Expert Consultation". The following are summaries of the contents of the last three 'Expert Consultation' processes:

- For the "research topic" proposed in this article, provide the name and appropriate number of variables that have been collected, screened and extracted out for the design of the "Expert Questionnaire".
- Correct the name and quantity of "variables" successively.
- Adjusted the name of "research topic", and revised the names of all "Variables" again.

In the end, the experts unanimously approved the names of the "research topics" and the "variables" of the evaluation in this paper:

- Research Topic: " Efficiency Evaluation of Wireless Charging

Model for Autonomous Mobile Robots (AMR)".

- Names of 6 reference important factors (variables) for evaluation, including:

1. The charging time for wireless transmission.
2. Transmission distance (the wireless charging sensing range).
3. Shielding effects of obstacles.
4. The protection mechanism of metal foreign body intrusion.
5. Feasibility of dislocation charging.
6. Transmittable interoperability between different unmanned handling equipment.

The Stage 2 of the tEWM-AR Model - Interview With Experts

Furthermore, while completing the "Expert Consultation" and determining the "research topic", this article successively invited 20 experts related to this research topic" and asked them to provide professional knowledge and "actual score". The following is a description of the implementation method of the second stage, which is also divided into two steps in sequence:

Step 1: Setting up the object of "Expert Interview"

In line with the research topic: "Efficiency Evaluation of Wireless Charging Model for Autonomous Mobile Robots (AMR)", the object of "Expert Interview" in this article is set as: "Those who have worked in the production department of the technology manufacturing industry for more than 3 years Department Director or Manager" (see Table 4-1).

Step 2: Design and manufacture of the "Expert Questionnaire", and then invite relevant experts

After many consultations with experts, this paper has obtained two results at this stage, including:
(1) The name of the research topic is determined as "Efficiency Evaluation of Wireless Charging Model for Autonomous Mobile Robots (AMR)";
(2) The names of the six reference important factors (variables) for the appraisal have also been determined.

Therefore, the main work during this step is to design an "expert questionnaire" that conforms to the efficiency evaluation method of the *t*EWM-AR model according to the "research topic name" and "variable name" (see Appendix A).

The Stage 3 of the tEWM-AR Model - Recycling, Statistics and Analysis of Experts' Questionnaire

At this stage, the statistical results of the "Expert Questionnaire" will generate the following four tables in sequence:
(1) Actual score matrix (Table 4-2);
(2) Relative importance score matrix (Table 4-3);
(3) Appraisal score matrix (Table 4-4);
(4) Weight summation' of each relative importance matrix (Table 4-5);

The following 4 steps can illustrate the generation process of these 4 tables:
Step 1: For the charging time of wireless transmission (the first important reference factor (variable)), invite experts to provide "expert score" to establish an "Actual score" matrix.

Table 4-1 Relevant materials of the experts interviewed for this article

	Expert	Current Company Position	Interview Time
1	Expert A	Manager	August 16, 2022
2	Expert B	Manager	August 16, 2022
3	Expert C	General manager	August 18, 2022
4	Expert D	Manager	August 19, 2022
5	Expert E	Senior manager	August 19, 2022
6	Expert F	Director	August 23, 2022
7	Expert G	Manager	August 23, 2022
8	Expert H	Manager	August 24, 2022
9	Expert I	Manager	August 25, 2022
10	Expert J	Manager	August 26, 2022
11	Expert K	Senior manager	August 26, 2022
12	Expert L	Manager	August 29, 2022
13	Expert M	Manager	August 29, 2022
14	Expert N	General manager	August 30, 2022
15	Expert O	Manager	August 30, 2022
16	Expert P	Manager	August 31, 2022
17	Expert Q	Manager	September 1, 2022
18	Expert R	Manager	September 1, 2022
19	Expert S	Manager	September 2, 2022
20	Expert T	Manager	September 2, 2022

(Source: Self-compilation of this article)

Table 4-2 For the first variable, experts are invited to provide the actual of strength rating scores - "Actual score" matrix.

Expert	For the charging time of wireless transmission
A	94
B	88
C	95
D	94
E	89
F	97
G	89
H	91
I	96
J	97
K	92
L	94
M	90
N	94

O	96
P	94
Q	94
R	97
S	83
T	96

(Source: Self-compilation of this article)

Table 4-3 For all variables after the second, experts are invited to provide the scores relative to the first variable: "Relative importance score" matrix.

Expert	The importance of the first variable	The relative importance of the second variable	The relative importance of the third variable	The relative importance of the fourth variable	The relative importance of the fifth variable	The relative importance of the sixth variable
A	1	2.0	1.8	1.9	1.0	1.5
B	1	1.8	1.5	1.9	1.3	1.5
C	1	1.9	1.9	1.5	1.3	1.7
D	1	1.7	1.2	2.0	1.8	1.8
E	1	1.6	1.7	1.8	1.4	1.9
F	1	1.8	1.1	1.4	1.7	1.9
G	1	2.0	1.1	1.9	1.7	1.6
H	1	2.0	0.9	1.5	1.5	1.4
I	1	1.8	1.6	1.6	1.1	1.6
J	1	2.0	1.2	1.6	0.9	1.7
K	1	1.8	1.6	1.3	1.5	1.5
L	1	1.7	1.5	1.6	1.6	1.3
M	1	1.8	0.8	1.5	0.8	1.7
N	1	1.8	1.8	1.8	1.0	1.9
O	1	2.0	1.1	1.5	1.1	1.7
P	1	2.0	1.1	1.3	1.2	1.9
Q	1	1.7	1.3	1.6	1.3	1.5
R	1	1.7	1.2	1.3	1.1	2.0
S	1	1.7	1.6	2.0	0.8	1.6
T	1	1.8	1.4	1.4	1.8	1.9

(Source: Self-compilation of this article)

Table 4-4 "Appraisal score" matrix (= Actual score matrix * Relative importance score matrix)

Expert	The protection mechanism of metal foreign body intrusion	The protection mechanism of metal foreign body intrusion	The protection mechanism of metal foreign body intrusion	The protection mechanism of metal foreign body intrusion	Feasibility of dislocation charging	Transmittable interoperability between different unmanned handling equipment

A	94	188	169	179	94	141
B	88	158	132	167	114	132
C	95	181	181	143	124	162
D	94	160	113	188	169	169
E	89	142	151	160	125	169
F	97	175	107	136	165	184
G	89	178	98	169	151	142
H	91	182	82	137	137	127
I	96	173	154	154	106	154
J	97	194	116	155	87	165
K	92	166	147	120	138	138
L	94	160	141	150	150	122
M	90	162	72	135	72	153
N	94	169	169	169	94	179
O	96	192	106	144	106	163
P	94	188	103	122	113	179
Q	94	160	122	150	122	141
R	97	165	116	126	107	194
S	83	141	133	166	66	133
T	96	173	134	134	173	182

(Source: Self-compilation of this article)

Table 4-5 The sum of the 'weight of Relative importance score' Matrix of the Six Variables

							The sum of the 'weight of Relative importance score'	Ranking
y_1	20	10.98138	15.414987	12.59299	16.4396102	12.065259	*87.494*	⑥
y_2	36.6	20	28.354659	23.07705	30.1361641	22.101129	*160.269*	①
y_3	27.4	15.10694	20	17.07928	22.5678536	16.562222	*118.716*	④
y_4	32.4	17.82003	24.70091	20	26.7647113	19.608342	*141.294*	③
y_5	25.9	14.25267	19.97805	16.35751	20	15.650805	*112.139*	⑤
y_6	33.6	18.47243	25.934863	21.24613	27.6481439	20	*146.902*	②

(Source: Self-compilation of this article)

Step 2: For all reference important factors (variables) after the second, experts are invited to provide the importance rating scores relative to the first variable to establish the "Relative importance score" matrix.

Step 3: According to the research method/third stage/step 1 description in Chapter 3, the "Appraisal score" matrix

can be obtained. That is, the "Actual score" matrix in Table 4-2 and the "Relative importance score" matrix in Table 4-3 are multiplied to form the "Appraisal score" matrix in Table 4-4.
"Appraisal score" matrix
= "Actual score" matrix * "Relative importance score" matrix
= Table 4-2 * Table 4-3
= Table 4-4

Step 4: According to the description of Research Method/Third Phase/Step 2 in Chapter 3, the matrix of "summation of weights of relative importance" among the variables can be obtained.

The Stage 4 of the tEWM-AR Model - Recycling, Statistics and Analysis of Feedback Opinions From Experts

Regarding the statistical results of after the "Expert Questionnaire" was collected (see Table 4-5), this article went back to interview the same batch of 20 experts again, and invited them to provide "Feedback Opinions From Expert" (see the table in Appendix B format) to express whether the experts themselves agree with the statistical results that have been released.

After summarizing the "Feedback Opinions From Expert" * 20 copies, and then analyzing the results, the research method of the *t*EWM-AR model can be determined, which can indeed highlight the professional evaluation of the "Relative importance score" among the variables -(proposed by experts); in other words, such a result is naturally closely related to the future trend of the global "wireless charging" demand market. (See Table 4-6 below for details)

Table 4-6 Proportion of 'Experts express whether it is reasonable or not on the ranking results of "the sum of the weights of relative importance"

The names of the six reference important factors (variables)	Ranking	Reasonable	No comment	unreasonable
*y*2 : Transmission distance (the wireless charging sensing range)	①	100%	-	-
*y*6 : Transmittable interoperability between different unmanned handling equipment	②	95%	5%	-
*y*4 : The protection mechanism of metal foreign body intrusion	③	90%	10%	-
*y*3 : Shielding effects of obstacles	④	55%	30%	15%
*y*5 : Feasibility of dislocation charging	⑤	50%	20%	30%
*y*1 : The charging time for wireless transmission	⑥	75%	25%	-

It can be seen from Table 4-6 that the top three ranking data show that: (1) the proportion of reasonable approval is ≥ 90.0%, (2) especially the reasonable approval of "transmissible distance (wireless charging sensing range)" The

ratio = 100%. Furthermore, the "statistical results" of the proportion distribution in Table 4-6 also highlight the following two derivative focuses worthy of discussion.

Statistical results: In line with the trend of the "wireless charging" demand market compiled by "expert opinions".

Statistical results: It shows that the relationship between "AMR and wireless charging technology" is positively correlated with the global development trend.

Conclusions and Discussion

Conclusions

According to the "statistical results" of the proportion distribution in Table 4-6, the following two derivative focuses that are worth discussing can be clearly highlighted:

Statistical results: In line with the trend of the "wireless charging" demand market compiled by "expert opinions".

"Expert Opinions" have summarized the trend of the demand market; that is, the demand market has gradually listed "transmission distance (wireless charging sensing range)" as "building a wireless charging system for handling equipment (AMR, AGV)" 'The highest planning principle (proportion = 100%). At the same time, it is expected to be able to purchase a "wireless charging system" (proportion = 95.0%) that has the ability to wirelessly communicate and transmit power between different handling equipment at the same price. As for the evaluation of the Wireless Charging system's protection mechanism against the intrusion of metal foreign objects, it is also highly anticipated, far exceeding other important reference factors (proportion = 90.0%). In other words, there has been a trend in the demand market to look forward to choosing a robot that transforms the handling equipment from a simple fixed-point automated operation to an intelligent arbitrary movement.

Statistical results: It shows that the relationship between "AMR and wireless charging technology" is positively correlated with the global development trend.

In February 2022, Global Information, Inc., GII released a research report on "Global Market for Automatic Guided Vehicles (AGV) and Autonomous Mobile Robots (AMR)": In 2027, there will be a market opportunity of more than $18 billion and an installed base of more than 2.4 million robots." (Please refer to https://prtimes-jp.translate.goog/main/html/rd/p/000002721.000071640.html?_x_tr_sl=ja&_x_tr_tl=zh-TW&_x_tr_hl=zh-TW&_x_tr_pto=sc)

At the same time, in the 2022 market report, GII predicts that the "global wireless charging market size" will reach US$12.26 billion in 2022 from US$9.58 billion in 2021, growing at a compound annual growth rate of 27.96%. . In addition, the market size will reach US$34.77 billion by 2026, growing at a compound annual growth rate of 29.77%.
(Please refer to https://www.giichinese.com.tw/report/tbrc1127383-wireless-charging-global-market-report.html)

Recommendations

In recent years, with the rapid development of smart mobile devices and the continuous improvement of product functions, the issue of jointly stimulating the battery life of smart mobile products has attracted more and more attention.

In fact, whether it is the "Transportation and Electricity System Coupling Framework" theory developed by the Cornell University research team in 2022, or the multinational car manufacturer Stellantis N.V. Group building in Italy in 2021 The above results all show that the "global wireless road charging system" has begun to demonstrate the advantages of "wireless charging roads" equipped with "energy storage systems" in the past two years.

In other words, the previous discussion has clearly expressed the development trend of "incorporating the road wireless charging system into the real-time power market". If such a development trend can be promoted commercially within one or two years, based on the basic theory of the Pareto Principle, this paper believes that, in addition to consumer electronics and electric vehicles, "the Wireless Charging" demand market will be greatly expanded to industry, aviation and military (such as wireless charging for drones), medical (implantable medical devices), ... and so on. Among them, it is especially matched with the "wireless charging required for handling equipment (AMR, AGV)" required for smart manufacturing systems.

Finally, it is expected that the wireless charging technology of "autonomous mobile robot (AMR)" can overcome the cost problem in the short term, and truly achieve a positive correlation with the global development trend. In this way, the results of the "Statistics of Efficiency Evaluation" obtained in this article will be helpful in two ways: 1) It will not only help the establishment goal of "comprehensive digital transformation into "smart factories, factories with lights off"" ; 2) At the same time, it can also provide "relevant decision-makers" with another high-efficiency operating strategy of "unmanned economy and lower labor costs".

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《Appendix A》

Expert Questionnaire

✧ Research Topic: "Efficiency Evaluation of Wireless Charging Model for Autonomous Mobile Robots (AMR)"

✧ 6 important factors related to the research topic of this paper:

1. The charging time for wireless transmission.
2. Transmission distance (the wireless charging sensing range).
3. Shielding effects of obstacles.
4. The protection mechanism of metal foreign body intrusion.
5. Feasibility of dislocation charging.
6. Transmittable interoperability between different unmanned handling equipment.

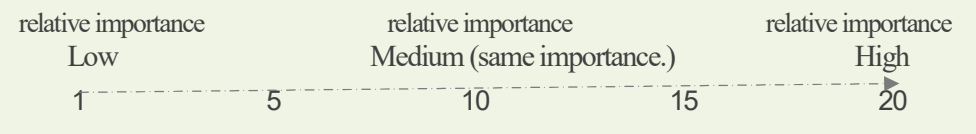
The 6 questions in this Expert Questionnaire are as follows:

Q_1. Entrepreneur Xiaohu is now planning to purchase and build a smart production plant; in order to enhance the strategic benefits of "unmanned economy and reduce labor costs", please focus on the above-mentioned "the first important factor for reference" "Wireless transmission charging time" ", Provide your 'professional perception' 'strength' rating score". : _

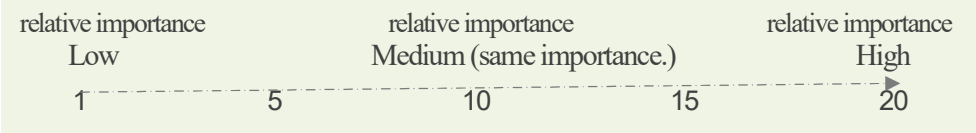
points.

□ Very weak	□ Weak	□ Normal	□ Strong	□ Very strong
1 ~ 20	21 ~ 40	41 ~ 60	61 ~ 80	81 ~ 100 分

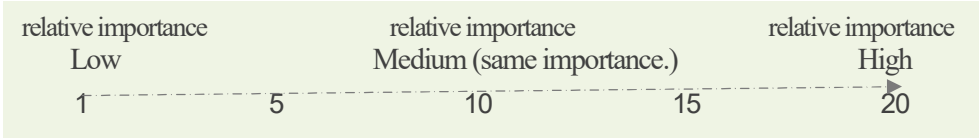
Q 2. In addition, please also rate the importance score of the second reference important factor "Transmission distance (the wireless charging sensing range)" relative to the first "wireless transmission charging time" construction reference: points.



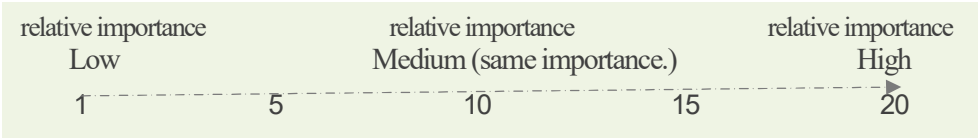
Q 3. Please rate the importance rating score of the third important reference factor the shielding effect of obstacles relative to the first reference for the construction of wireless transmission charging time: _____ points.



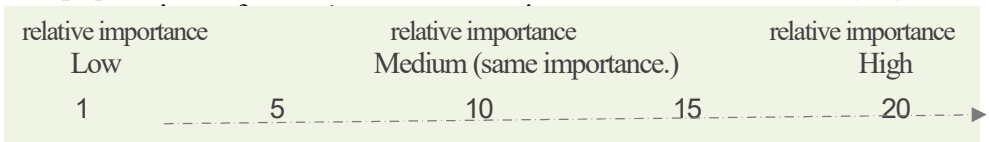
Q 4. Please rate the importance score of the "4th reference important factor "The protection mechanism of metal foreign body intrusion" relative to the first "wireless transmission charging time" construction reference": Points.



Q5. Please rate the importance rating score of the fifth reference important factor "Feasibility of dislocation charging" relative to the first "wireless transmission charging time" construction reference: _____ points.



Q 6. Please rate the importance score of the '6th reference important factor "Transmittable interoperability between different unmanned handling equipment" relative to the first "wireless transmission charging time"



《Appendix B》

This article revisited 20 experts and invited them to provide a professional "Feedback Opinions From Expert" blank form

Ranking	The names of the six reference important factors (variables)	Is it reasonable?
①	The charging time for wireless transmission	○Reasonable ○No comment ○unreasonable
②	Transmission distance (the wireless charging sensing range)	○Reasonable ○No comment ○unreasonable
③	Shielding effects of obstacles	○Reasonable ○No comment ○unreasonable
④	The protection mechanism of metal foreign body intrusion	○Reasonable ○No comment ○unreasonable
⑤	Feasibility of dislocation charging	○Reasonable ○No comment ○unreasonable
⑥	Transmittable interoperability between different unmanned handling equipment	○Reasonable ○No comment ○unreasonable

(The original data of the "relative importance" evaluation score provided by ? expert)

(provided by ? expert)	
evaluation score	(evaluation score) Resulting relative rank

Statistical results of Table 4-5		
The names of the six reference important factors (variables)	the sum of the weights of relative importance	Ranking
*y*2 : Transmission distance (the wireless charging sensing range)	***160.269***	①
*y*6 : Transmittable interoperability between different unmanned handling equipment	***146.902***	②
*y*4 : The protection mechanism of metal foreign body intrusion	***141.294***	③
*y*3 : Shielding effects of obstacles	***118.716***	④
*y*5 : Feasibility of dislocation charging	***112.139***	⑤
*y*1 : The charging time for wireless transmission	***87.494***	⑥