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RESEARCH ON UNMANNED TECHNOLOGY UNDER DISTRIBUTION LOGISTICS

This paper takes China DJI's UAV as the research object and establishes three evaluation dimensions: safety and security, transportation efficiency, and management application. Through the entropy value method, a comprehensive evaluation of UAVs in distribution logistics is carried out to provide appropriate reference for the innovation and future development of the distribution logistics industry.

Keywords: *Distribution logistics, last mile, unmanned aerial vehicle, entropy value method, logistics, digital technology*

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ИССЛЕДОВАНИЕ БЕСПИЛОТНЫХ ТЕХНОЛОГИЙ В РАСПРЕДЕЛИТЕЛЬНОЙ ЛОГИСТИКЕ

В данной статье в качестве объекта исследования взят китайский БПЛА DJI, и определены три параметра оценки: безопасность и надежность, эффективность транспортировки и применение в управлении. С помощью метода энтропийных значений проводится комплексная оценка БПЛА в распределительной логистике, что дает соответствующие рекомендации для инноваций и будущего развития отрасли распределительной логистики.

Ключевые слова: *распределительная логистика, последняя миля, беспилотный летательный аппарат, метод энтропийных значений, логистика, цифровые технологии*

Along with the gradual improvement of the application of digital technology, the distribution logistics industry has ushered in new development opportunities [1]. The "last mile" is the pain point of distribution logistics [2]. To reduce the cost of the supply side and improve its efficiency, the "last mile" needs to be optimized by more intelligent means [3]. Since the timeliness and service experience of end-of-line distribution are particularly important, using unmanned distribution in the right scenario will increase efficiency by 60–70 % and save more than 60 % in cost.

The Web of Science Core Collection was searched with the subject term "distribution logistics technology," and 889 core documents were counted between 2019 and 2023. The keyword co-occurrence network was obtained by using the CiteSpace visualization and analysis function. The keywords that appear more frequently in the figure are the hot topics of research in recent years. The current research on logistics issues such as "big data," “supply chain,” “unmanned distribution,” “system," and so on is in full swing (Figure 1).

In recent years, China's civil UAVs industry has been developing rapidly, and the overall market size of the industry in 2015 was only 6.64 billion yuan, while the market size in 2024 will reach 207.5 billion yuan. As the potential of "unmanned +" is constantly being tapped, the distribution logistics market is becoming more and more receptive to the application of UAVs products in the logistics industry, and the demand of the logistics industry is showing a blowout trend [4]. The research objective of this paper is to solve the "last mile" problem of distribution logistics, and the deep integration of digital transformation and logistics industry provides an innovative solution to the current problems. In this paper, through the results of the characterization of UAVs applied in distribution logistics, combined with the mutual influence factors of UAVs and distribution logistics, an evaluation model is established, to obtain the evaluation results of the comprehensive capability of UAVs applied in distribution logistics, and to promote the application of digital technology for distribution by logistics companies.

For the evaluation research applied to logistics and distribution UAVs, this paper divides the direction of evaluation into three dimensions to facilitate the formation of a scientific and comprehensive evaluation index system. [Table 1]

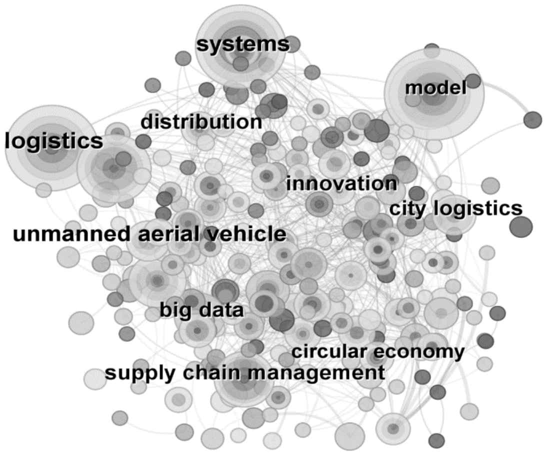

Fig.1. Keyword Co-occurrence Network

Note – source: Author's generalization

Table 1

Distribution logistics UAV evaluation index system

Dimension	Code	Name	Unit
Safety and security	A1	Maximum wind speed	m/s
	A2	Operating Temperature	°C
	A3	Obstacle Sensing Range	m
	A4	Field of View (FOV)	°
Transport efficiency	B1	Maximum loading weight	g
	B2	Maximum flight speed	m/s
	B3	Maximum flight duration	min
Management application	C1	Maximum range	km
	C2	Battery Capacity	mAh
	C3	Unit Price	RMB
	C4	Maximum Hover Time	min

Note – source: Author's generalization

Safety and security dimension. UAVs are used in the "last mile" distribution, to ensure that they can operate normally under adverse climatic conditions, there will be no body failure, or transmission signal problems; secondly, to ensure the normal flight of UAVs in dense urban buildings, it is also necessary to ensure that they can recognize and make timely avoidance of obstacles of all kinds, rather than crashing into buildings. Avoidance, and will not crash into the building and other harmful accidents.

Transportation efficiency dimension. According to Amazon's data statistics, UAVs with a cargo capacity of more than 2 kg can cover more than 86 % of cargo distribution; therefore, the maximum capacity of UAVs is an important factor in improving their transportation efficiency. In addition, long-distance intra-city co-location distribution should also be considered. In addition, the final distribution is often the "last mile" to consumers, and the ability of distribution logistics UAVs to deliver goods to customers in a timely and rapid manner has become a key link.

Management application dimension. Logistics UAVs can distribute freely and flexibly in a wide range; secondly, to reduce the operating difficulty of the operator, they can be flown for a long time after charging, and they can stop at any time in the city to minimize the landing time and improve the work efficiency; finally, it is important for the logistics company to purchase a distribution logistics UAV with a high cost-effective price (Figure 2).

Fig.2. Three Dimensions of Evaluation Orientation

Note – source: Author's generalization

The entropy value method is used as the evaluation method, and through the research object of China DJI Enterprise, a total of five UAVs suitable for application in the distribution logistics link are screened out by taking the distribution logistics demand as the criterion from its existing aerial photography UAVs, agricultural UAVs, photographic UAVs, and other varieties of models. Due to the complexity of most of the product names and models, this paper respectively takes UAV1-UAV5. Due to the complexity of most product names and models, they are represented as UAV1-UAV5 in this paper (Table 2).

Table 2

Metrics initial data for five UAV products

	A1	A2	A3	A4	A5	B1	B2	B3	C1	C2	C3	C4
UAV1	10.7	0~40	0.38-23.8	72	58	595	19	31	18.5	3500	6499	30
UAV2	12	-10~40	0.5-20	90	105	895	21	45	32	5000	23100	38
UAV3	10	-20~40	0.7-30	60	54	810	26	27	7	4280	19999	27
UAV4	10	0~40	0.7-7	70	20	1375	16	30	25	5870	9999	25
UAV5	13.8	-10~40	0.5-18	56	71	795	15	20	16.8	2000	5399	16

Note – source: Author's generalization

A2 and A3 are the two indicators; the assignment is an interval; it is not easy to participate in the comparison and calculation; and because of the models of the A2 and A3 indicators of the interval, they basically overlap, so this paper directly selected the two indicators of the range of the difference in accordance with the larger the temperature span, the larger the range of detection; that is, for the data to be evaluated, the data is processed, and the entropy value of the calculation of the initial matrix D1 is established.

$$D1=\begin{bmatrix} 10.7 & 40 & 23.4 & 72 & 58 & 595 & 19 & 31 & 18.5 & 3500 & 6499 & 30 \\ 12.0 & 50 & 19.5 & 90 & 103 & 895 & 21 & 45 & 32.0 & 5000 & 23100 & 38 \\ 10.0 & 60 & 29.3 & 60 & 54 & 810 & 26 & 27 & 7.0 & 4280 & 19999 & 27 \\ 10.8 & 40 & 6.3 & 70 & 20 & 1375 & 16 & 30 & 25.0 & 5870 & 9999 & 25 \\ 13.8 & 50 & 17.5 & 56 & 71 & 795 & 15 & 20 & 16.8 & 2000 & 5399 & 16 \end{bmatrix}$$

Normalize all values to form a new data matrix D2.

$$D2=\begin{bmatrix} 0.184 & 0.000 & 0.744 & 0.164 & 0.563 & 0.308 & 0.417 & 0.481 & 0.460 & 0.388 & 0.747 & 0.636 \\ 0.526 & 0.500 & 0.574 & 0.343 & 1.000 & 0.574 & 0.583 & 1.000 & 1.000 & 0.775 & 0.000 & 1.000 \\ 0.000 & 1.000 & 1.000 & 0.040 & 0.524 & 0.499 & 1.000 & 0.333 & 0.000 & 0.589 & 0.066 & 0.500 \\ 0.000 & 0.000 & 0.000 & 0.141 & 0.194 & 1.000 & 0.167 & 0.444 & 0.720 & 1.000 & 0.570 & 0.409 \\ 1.000 & 0.500 & 0.487 & 0.000 & 0.689 & 0.485 & 0.083 & 0.074 & 0.392 & 0.000 & 0.803 & 0.000 \end{bmatrix}$$

Substituting the data in the initial matrix D2 obtained after normalization into the formula $P_{ij}=\frac{UAV_{ij}}{\sum_{i=1}^{n} UAV_{ij}}$, the contribution ratio of each indicator is calculated to obtain the matrix D3.

$$D3=\begin{bmatrix} 0.089 & 0.000 & 0.212 & 0.083 & 0.190 & 0.102 & 0.173 & 0.157 & 0.144 & 0.130 & 0.195 & 0.187 \\ 0.253 & 0.167 & 0.163 & 0.176 & 0.337 & 0.191 & 0.241 & 0.325 & 0.312 & 0.260 & 0.000 & 0.293 \\ 0.000 & 0.333 & 0.284 & 0.021 & 0.176 & 0.166 & 0.414 & 0.108 & 0.000 & 0.198 & 0.017 & 0.147 \\ 0.000 & 0.000 & 0.000 & 0.073 & 0.065 & 0.332 & 0.069 & 0.144 & 0.225 & 0.336 & 0.149 & 0.120 \\ 0.481 & 0.167 & 0.138 & 0.000 & 0.232 & 0.161 & 0.034 & 0.024 & 0.122 & 0.000 & 0.210 & 0.000 \end{bmatrix}$$

Substitute D3 into the formula $e_j=-k\times \sum_{i=1}^{n} p_{ij}\ln(p_{ij})$ where k>0, ln is the natural logarithm, and $e_j\geq 0$. First compute the product of each element with that ln (element) to form the new matrix D4.

$$D4=\begin{bmatrix} -0.215 & 0.000 & -0.329 & -0.206 & -0.315 & -0.233 & -0.303 & -0.290 & -0.279 & -0.266 & -0.319 & -0.313 \\ -0.348 & -0.299 & -0.296 & -0.306 & -0.367 & -0.316 & -0.343 & -0.365 & -0.363 & -0.350 & 0.000 & -0.360 \\ 0.000 & -0.366 & -0.358 & -0.080 & -0.306 & -0.298 & -0.365 & -0.241 & 0.000 & -0.321 & -0.070 & -0.282 \\ 0.000 & -0.000 & 0.000 & -0.190 & -0.178 & -0.366 & -0.185 & -0.280 & -0.335 & -0.366 & -0.283 & -0.254 \\ -0.352 & -0.299 & -0.274 & 0.000 & -0.339 & -0.294 & -0.116 & -0.090 & -0.257 & 0.000 & -0.327 & 0.000 \end{bmatrix}$$

In the formula, the constant $k = \frac{1}{ln(m)}$ (m represents the sample size), since the sample size is 5, so the value of $k = 0.621$, so as to ensure that $0 \leq e_j \leq 1$, the maximum value of 1, the value of k and the new matrix D4 each column and multiply, to obtain the 12 products for all the programs on the index UAV_{ij} contribution to the index of entropy value of the indicators e_j.

After obtaining the entropy value, the entropy value is substituted into the formula $c_j=1-e_j$, which results in the coefficient of variation of each indicator, and then the obtained coefficient of variation is substituted into the formula $w_j = \frac{c_j}{\sum_{i=1}^{n} c_j}$ (j =1,2,...m), which results in the weights of the number of each indicator, and finally, the comprehensive score is obtained. [Table 3]

Table 3

Entropy value, coefficient of variation and weights

Indicator	A1	A2	A3	A4	A5	B1	B2	B3	C1	C2	C3	C4
Entropy (e_j)	0.57	0.60	0.78	0.49	0.93	0.94	0.81	0.79	0.77	0.81	1.01	0.75
Coefficient(c_j)	0.43	0.40	0.22	0.51	0.07	0.06	0.19	0.21	0.23	0.19	-0.01	0.25
Weights(w_j)	0.16	0.15	0.08	0.19	0.02	0.02	0.07	0.08	0.08	0.07	0.00	0.09

Note – source: Author's generalization

The weights of the indicators were obtained through the above steps and the composite scores of the 5 VAUs were calculated (Table 4)

Table 4

Combined scores of five distribution logistics UAVs

	VAU1	VAU2	VAU3	VAU4	VAU5
Score	0.2230	0.3335	0.1988	0.1578	0.1705

Note – source: Author's generalization

According to the comprehensive scores of the five drones, the highest score was 0.3335 for UAV2, and the lowest score was 0.1578 for UAV4. As the newest product of DJI, UAV2 is a better choice for distribution logistics, except for some shortcomings in the C3A3 index data, and the other indexes are better. Overall, if the logistics company has a sufficient procurement budget, the UAV2 model is undoubtedly the best choice for distribution logistics. In addition, UAV4 has the lowest rating, with the main gap reflected in the B and C indicators. UAV3 is at the bottom of the B2, B3, and B1 data, which indicates that its range is not good, its transportation speed is not satisfactory, and it is able to carry fewer cargoes, which greatly affects its transportation efficiency. The rest of the UAVs score relatively close to each other, with the main differences focusing on B1 and C3.

Summarizing the above evaluation results, the three most important indicators are A1, A4, and B2. First, the weights of the first two are greater than 0.1, which indicates that these two indicators are very important and belong to the A dimension. When this paper studied the weights of dimension A, it was found that the sum of the weights of the indicators was as high as 0.6; therefore, the UAV company should pay extra attention to the A indicators when designing and manufacturing the distribution logistics UAVs, to ensure that the distribution logistics UAVs will not have major safety accidents in the process of work. Secondly, A1 and B2 can reflect the flight capability of the UAV, which are also more important indicators. When designing the logistics and distribution UAV, if the UAV company needs to sacrifice part of its performance, it should choose C1 and A3, because the importance of these two indicators is not very high, and most of the UAVs are able to satisfy the existing demand in these two aspects, and in general, the change in size has the least reference value for the UAV. Finally, the weights of B and C are 0.17 and 0.24, respectively, which are relatively close to each other, indicating that the importance of the two is similar. Although they are far away from the A indicator, the effect of their interaction has reached a balanced state with the A indicator, and the A indicator needs to be emphasized while the B and C indicators need to be balanced.

Conclusion. When the current distribution logistics UAVs are applied in the industry, the safety and security of the UAVs should be regarded as the primary direction, while the direction of transport efficiency and management application should reach a balanced state, which is a realistic situation when the UAVs are applied in the field of distribution logistics at present. This is a realistic situation when UAVs are applied in the field of distribution logistics. For UAV research and development enterprises, when carrying out distribution logistics UAV research and development, they need to think about the current design of UAVs with no obvious focus on their load capacity and, in the case of ensuring safety and security, improve their load capacity to become a breakthrough direction for the practical application of distribution logistics UAVs. At present, the main factor restricting the application of UAVs in distribution logistics is the applicability of performance standards. Which indicators are the key indicators of logistics and distribution, and what are the reasonable standards of the indicators that have become constraints on the application of UAVs in the field of distribution logistics. Therefore, this paper argues that there is an urgent need to establish UAV application standards in the logistics industry to expand the application of digital technology in the field of distribution logistics.

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