AHP comparative analysis of construction and demolition (C&D) waste recycling scenarios: The case of Beijing

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Abstract. As construction waste production in Beijing has increased significantly, there is an urgent demand to manage and dispose it in a more economical and environmentally-friendly way. As there are different benefits and limits between preliminary sorting/recycling on construction sites and centralized treatment on final disposal sites, three scenarios were formed. AHP was used to compare these scenarios from the aspect of technical feasibility, economic costs and environmental effects. AHP analysis results showed that the priority of three scenarios followed $D3 > D1 > D2$, indicating the optimal way for C&D waste in Chaoyang district is firstly going through primary recycling with a mobile treatment facility on the construction site and then transporting to a final disposal site.

1 Introduction

As efforts in Beijing's reconstruction and new construction of old city and new countryside construction intensify, the quantity of Beijing's C&D waste is on the increase. According to report, Beijing's C&D waste discharge amount in 2015 has reached 29.6 million tons, generating about 81,200 tons on average a day. Large quantities of continuously produced C&D waste have become a social issue, which pollutes the environment and bothers Beijing citizens as well [1-4].

The study of C&D waste management in foreign countries is very mature, and the management method has achieved good social and economic benefits in the enterprise [5-11]. However, there are still some problems in the management of C&D waste in China, such as the lack of attention to the management of C&D waste, the imperfections of relevant systems and standards, and the lack of application of renewable utilization technology of C&D waste. Even the management of C&D waste is relatively backward in big cities. There is no detailed and

2.2. Construction waste recycling and management

There are two approaches to recycle the C&D waste, on-site handling and centralized recycling. The C&D waste on-site handling adopts mobile equipment such as being flexible, movable and adaptable; however, under the condition of on-site operation with simple environmental control, its dust and noise pollution is relatively high. Mobile equipment can be temporarily used on the demolition site for preliminary crushing and screening, unnecessary to transport the C&D waste or

accurate data yet on Beijing's C&D waste recycling rate. There are few studies on the methods and modes of C&D waste management.

In this study, the recycling scheme of C&D waste in Beijing was studied. Based on the comparison of various C&D waste collection schemes, the optimal scheme was screened out. The research results can provide reference for the formulation of management plan of construction waste in Beijing.

2 Materials and methods

2.1 Construction waste compositions

The C&D waste was collected from construction waste sorting center in Beijing Chaoyang district. C&D waste usually consisted of 41% concrete blocks, 10% stone, 7% dust, 22% bricks, 9% grit, 4% metal, 4% Timber, 1% plastics and 3% others.

dump. It can also be used as a supplement to the fixed equipment to reduce the C&D waste volume and ensure C&D waste's qualities.

The C&D waste centralized recycling adopts fixed equipment whose process combination is complex. According to the properties of C&D waste, it commonly includes multiple-stage crushing, multiple-stage screening, manual sorting, winnowing, flotation, and magnetic separation as well as other combined-type equipment. It needs a fixed and large site to install a whole set of equipment to ensure adequate capacity, high efficiency and better control of the dust and noise

pollution, thus its disposal efficiency is relatively high and the products obtained from this is of high quality.

2.3. Scenarios

According to the generation and distribution status of C&D waste in Chaoyang District of Beijing, we proposed three different waste collection, transportation and recycling scenarios, as shown in Fig.1.

Fig.1. Construction waste recycling scenarios

2.4 AHP model establishment

In order to comprehensively compare three scenarios, we made a comparative analysis of the three situations from three aspects: technical indicators, economic indicators and environmental indicators. Technical indicators include equipment handling capacity, facility area, material adaptability, treatment effect and landfill residue; economic indicators include product value, transportation cost, investment cost and operating cost; and environmental indicators mainly refer to the scheme's impact on the environment, including noise and dust pollution. After comprehensively taking account of various indicators, the hierarchical structure chart was shown in Fig.2.

Fig.2. Hierarchy of C&D waste recycling.

3 Results and discussion

3.1 Lower criterion layer judgment matrix

Lower criterion layer consists of 11 comparison and judgment matrixes for Scenario D. Table 1 shows the judgment matrixes of C1 for 3 alternative scenarios, in which WC1 represents the weight of D1, D2 and D3 affecting C1, and the other 10 comparison and judgment matrixes have the same constructing method.

Table.1. Judge matrix C1-D1-3.

C1	D1	D2	D3	WC1
D1	1	2	1/2	0.2684
D2	1/2	1	1/6	0.1172
D3	2	6	1	0.6144

3.1.1. Single ordering weight of technical indicators

According to the calculation result of each judgment matrix, C₁-D hierarchy single ordering (0.2684, 0.1172, 0.6144)^T, in the three scenarios, the impact of equipment handling capacity on technical factors differs greatly. C₂-D hierarchy single ordering (0.309, 0.5816, 0.1095)^T, which indicates that the mobile type needs the least Facility Area. C₃-D hierarchy single ordering (0.309, 0.1095, 0.5816)^T, which indicates that mobile treatment facility mainly carries out preliminary crushing and preliminary screening for C&D waste. C₄-D hierarchy single ordering (0.4444, 0.1111, 0.4444)^T, which indicates that mobile treatment facility focuses on preliminary crushing and preliminary screening with a limited treatment effect while fixed treatment facility has a complete process, whose disposal of C&D waste is more refined, thus able to achieve a better effect. C₅-D hierarchy single ordering (0.2922, 0.0925, 0.6153)^T, which indicates that mobile treatment facility can only realize primary treatment and the amount of landfill residue is large, while fixed treatment facility, through a complex process, can furthest realize C&D waste recycling, and the amount of landfill residue is smaller.

3.1.2. Single ordering weight of economic indicators

According to the calculation result of each judgment matrix, C₆-D hierarchy single ordering (0.2583, 0.1047, 0.637)^T, product value among economic factors has the greatest impact on D3. C₇-D hierarchy single ordering (0.1172, 0.6144, 0.2684)^T, among economic factors, transportation cost has the greatest impact on D2. C₈-D hierarchy single ordering (0.2583, 0.637, 0.1047)^T, investment cost among economic factors has the greatest impact on D2; mobile equipment are relatively simple, and therefore the investment cost is lower, while fixed equipment have a complex process and involves more equipment, so the investment cost is higher; process combination requires fixed equipment and mobile equipment, and therefore the investment cost is the highest. C₉-D hierarchy single ordering (0.309, 0.5816, 0.1095)^T, operating cost among economic factors has the greatest impact on D2; mobile equipment focus on crushing and screening, and therefore the operating cost is low, while fixed equipment's operating cost is higher, and the process combination involves more processes, and therefore the operating cost is the highest.

3.1.3. Single ordering weight of environmental indicators

C₁₀-D hierarchy single ordering (0.637, 0.2583, 0.1047)^T, noise pollution among environmental factors has the greatest impact on D1. C₁₁-D hierarchy single ordering

$(0.637, 0.2583, 0.1047)^T$, dust pollution among environmental factors has the greatest impact on D1, which is because fixed equipment usually adopt sealing measures, and thus there is less dust pollution, while mobile equipment are relatively simple, and often cause more dust; when fixed and mobile equipment are combined, both situations exist, and therefore dust pollution is even more serious.

3.2. Upper criterion layer judgment matrix

Upper criterion layer constructs 3 comparison and judgment matrixes, B_1 -C₁₋₅, B_2 -C₆₋₉, and B_3 -C₁₀₋₁₁. Table 2 shows the judgment matrix constructed by technical factors, in which W_{B1} represents the weight of C₁₋₅ affecting B₁, and the rest judgment matrixes have the same constructing method. According to upper criterion layer judgment matrixes of B_1 -C₁₋₅, the weights of each affecting factor are obtained and the hierarchy single ordering $(0.0908, 0.0684, 0.0406, 0.3203, 0.4799)^T$ indicates the impact of technical indicators on the whole C&D waste recycling process.

B_2 -C₆, C₇, C₈, C₉ hierarchy single ordering $(0.1054, 0.1894, 0.5158, 0.1894)^T$ indicates the impact degree of economic efficiency of each sub-indicator on the whole C&D waste recycling. Among them, capital investment among economic indicators has the greatest impact. B_3 -C₁₀, C₁₁ hierarchy single ordering $(0.75, 0.25)^T$ indicates the degree of impact of the two environmental indicators on the whole C&D waste recycling. Among them, dust pollution has the greatest impact.

Table.2. Judge matrix B₁-C₁₋₅.

B ₁	C ₁	C ₂	C ₃	C ₄	C ₅	W_{B1}
C ₁	1	2	3	1/6	1/7	0.0908
C ₂	1/2	1	2	1/4	1/6	0.0684
C ₃	1/3	1/2	1	1/7	1/8	0.0406
C ₄	6	4	7	1	1/2	0.3203
C ₅	7	6	8	2	1	0.4799

CR=0.0427, B₁=technical factors, C₁=Equipment Handling Capacity, C₂=Facility Area, C₃=Material Adaptability, C₄=Treatment Effect, C₅=Landfill Residue, W_{B1} is the weight of C₁, C₂, C₃, C₄ and C₅ to B₁.

3.3. Target layer judgment matrix

The affecting factors of the target layer and the lower layer include technical factors, economic factors and environmental factors, and the comparison and judgment matrixes constructed are shown in Table 3, in which W_A represents the weight of B₁, B₂, B₃ affecting A. Hierarchy single ordering $(0.6491, 0.279, 0.0719)^T$ of judge matrix A-B₁₋₃ in the target layer indicates that, among factors of B₁, B₂ and B₃ affecting C&D waste recycling process, technical factors have the largest impact.

Table.3. Judge matrix A-B₁₋₃.

A	B ₁	B ₂	B ₃	W_A
B ₁	1	3	7	0.6491
B ₂	1/3	1	5	0.279
B ₃	1/7	1/5	1	0.0719

CR=0.0624, A=Best scenario, B₁=technical factors,

B₂=economic factors, B₃=environmental factors, W_A is the weight of B₁, B₂ and B₃ to A.

3.4. Comparison of scenarios

According to the results of all hierarchical orderings, the score of each alternative scenario is calculated in Table 4. The score index of the three scenarios is $(0.3342, 0.2640, 0.4018)^T$. The priority of three scenarios follows $D_3 > D_1 > D_2$. That indicates the optimal process scenario for C&D waste recycling in Chaoyang District is: C&D waste go through primary recycling with a mobile treatment facility on the construction site or nearby, before they are transported to Gao'antun for centralized disposal, which is the most ideal choice.

Table.4. Hierarchy sequence.

B	W	C	W	D ₁	D ₂	D ₃
B ₁	0.6491	C1	0.3115	0.2684	0.1172	0.6144
		C2	0.2079	0.309	0.5816	0.1095
		C3	0.1439	0.309	0.1095	0.5816
		C4	0.0589	0.4444	0.1111	0.4444
		C5	0.0539	0.2922	0.0925	0.6153
B ₂	0.279	C6	0.0528	0.2583	0.1047	0.637
		C7	0.0528	0.1172	0.6144	0.2684
		C8	0.0444	0.2583	0.637	0.1047
		C9	0.0294	0.309	0.5816	0.1095
B ₃	0.0719	C10	0.0264	0.637	0.2583	0.1047
		C11	0.0181	0.637	0.2583	0.1047

Conclusions

(1)AHP analysis and comparison results show that, when fixed treatment mode is adopted, C&D waste needs to be all transported from the source to treatment plant, transportation cost of which is high. But the treatment process is complete and the treatment effect is better. And its noise and dust pollution control is more desirable.

(2)When mobile treatment mode is adopted, C&D waste needs to first go through preliminary crushing and screening at the source, which saves the transportation cost.

(3)When mobile at the source +fixed equipment is adopted, technically it can furthest realize C&D waste recycling, ensure treatment effect and maximization of product value.

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