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Sustainable Plant Layout Design for End of Life Vehicle Recycling and Disassembly Industry Based on SLP Method, a Typical Case in China

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ABSTRACT End of life vehicle (ELV) is a significant renewable resource with enormous economic value and environmental value. New regulation promulgated by the State Council of PRC has been implemented since June 2019, allows main assemblies of ELV can be sold to remanufacture enterprises, which dramatically prompts more enterprises to invest in the recycling industry. According to the technological recovery characteristics of ELV, the system layout design (SLP) method is briefly applied to arrange the plant facility layout of ELV recycling and disassembly enterprise. The relationship between logistics and non-logistics was firstly analyzed, and the operating unit correlation diagram of location and area were presented correspondingly. Then, through further modification and adjustment, the feasible layout scheme was obtained, and the reasonable general layout of the plant area was determined by using the weighted factor method. As a critical functional unit of the factory area, the detailed planning and design of the disassembly and shredding workshop were further presented. A detailed facility layout and logistics route of the disassembly and shredding workshop are finally proposed according to the obtained correlation diagram of the operating unit area based SLP, which has been implemented in a recycling company in Changsha, a typical case in China. Combined with the theoretical techniques of statistics, intelligent algorithms, and logistics analysis under the background of modern green production and sustainable manufacturing, this work can provide a new approach for plant layout design and optimization for ELV recycling and disassembly industry.

INDEX TERMS End of life vehicle, recycle and disassembly, plant facility layout, sustainable design, SLP.

I. INTRODUCTION

End of life vehicle (ELV) is a significant renewable resource with substantial economic value and environmental value, and the efficient recycling of ELV has become the key to the green, sustainable and low-carbon development of the global vehicle industry [1]–[3]. Europe, Japan, Australia, and the US both have well-established ELV regulations and management systems, and the effective recycling and disassembly of ELV are to better follow-up related activities, such as remanufacturing [4]. As the early stage of the vehicle reverse supply chain effective operation, the implementation effect of ELV recycling and disassembly activities determines the material quality and remanufacturing development of vehicle remanufacturing, highlighting the importance of recycling disassembly [5]. A large volume of published studies focusing on micro-researches of ELV recycling and disassembly technology through the algorithm and experimental simulation of partially to optimize a link in the industry.

In terms of disassembly technology, Güngör and Gupta [6] firstly put forward the concept of disassembly line. Generally, there are two layout modes used to design the disassembly production line, namely, linear [7] and U-shaped [8]. The common feature is that the workstations are arranged sequentially, and the workpiece is operated and transferred on the workstation in turn according to the

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predetermined cycle time [9]. The disassembly line balance problem is correspondingly proposed with a specific definition and mathematical modeling, which can be understood as a planning problem divided into two categories: accurate methods and approximate methods [10].

The accurate method is based on mathematical programming techniques to solve the optimization problem [11]. Altekin *et al.* [12] established a linear programming model to determine the most profitable remanufacturing production plan. Additionally, the number of workstations, disassembly sequence, and cycle time of the disassembly line can be determined by the hybrid shaping algorithm [13], [14]. Aiming at minimum workstations in disassembly line balance, Koc *et al.* [15] established the accurate shaping planning and dynamic programming methods to help the AND/OR graph. Based on this method, a feasible disassembly sequence scheme can be obtained to improve the disassembly production quality dramatically [16].

The approximate method generally refers to the heuristic algorithm, which employs the predefined rule sets to return a suboptimal solution [17], [18]. The heuristic method has advantages over the accurate way in the solution's search space. However, the solution process will be faster by finding a satisfactory solution through appropriate guidance, such as establishing a set of heuristic rules based on penalty function to evaluate the disassembly process and providing a disassembly line balance algorithm suitable for multi-workpiece and different order time-integrated Petri and heuristic algorithm [19]. In particular, Ren *et al.* [20] proposed a broader application range to the meta-heuristic algorithm, such as genetic algorithm, simulated annealing algorithm, ant colony algorithm, artificial bee colony algorithm, bacterial foraging optimization algorithm, greedy algorithm, Lagrangian relaxation algorithm and so on [21]. Since the meta-heuristic algorithm provides a comprehensive framework for the heuristic algorithm, it can be applied to solve some complex problem, and for this point, almost all assembly line or disassembly line balance problems can be solved on heuristic or meta-heuristic algorithm [22].

In terms of facility layout of ELV disassembly plant, it plays a significant role with a complicated consideration of various factors. Friedrich *et al.* [23] combined the occupied area, handling distance, transportation cost, production time, and environmental factors in layout design. The commonly used facility layout methods include the systematic layout planning (SLP) method, mathematical model method, and integrated intelligent algorithms [24], [25].

SLP method was put forward in 1961, and it has been widely used in manufacturing, medicine, education, and other fields [26]. Liu *et al.* [27] combined SLP with the ranking weight method, modified the wood production line's transportation trajectory and material movement. Preceding research determined the distance between two facilities by considering the centers' distance, making a layout very different from the reality. Taifa and Vhora [28] focused on determining the location of input/output points and logistics design. Aiello *et al.* [29] divided typical plant layout problems into static, dynamic, and stochastic layouts. Aiello *et al.* [29] took the relationship degrees for the plant into account, and the linguistic pattern approach can be employed to determine the installing cost of each facility in each possible place in the form of fuzzy sets [30]. Multi-objective layout research has been carried out and achieved consistent results. However, it is not applicable to rely on only one optimization objective to obtain all the products. Garcia-Hernandez *et al.* [31] combined an adaptive strategy and a variable neighborhood search to help solve the plant layout design. At the moment, the multi-objective genetic algorithms with the consideration of several factors are significantly applied to address the facility layout problem [32]. Considering material handling cost and distance requirements, a multi-objective ant colony optimization algorithm is applied to figure out the plant facility layout problem [33]. Besides, the practical genetic approach acknowledging both material handling cost and decision-maker preferences was also put forward to deal with the layout design for the recycling and disassembly plant.

Aiming at the problem of balance and optimization of the disassembly production line and the plant facility layout, scholars have made significant progress [34]–[36]. However, ELV recycling and disassembly enterprises require a reasonable and actual facility layout, which directly relates to the disassembly efficiency of ELV and the quality of the recycling products by advanced disassembly technology. Currently, "The measures for the administration of recycling of ELVs" promulgated by the State Council of China have been implemented since June 2019, which stipulates that the five assemblies of ELV can be sold to remanufacture enterprises for recycling [37], which dramatically prompts more and more enterprises to invest in the recycling industry. To achieve economic benefits in the short term, a simple and effective plant layout is essential. In this paper, SLP was adopted to arrange the plant facilities layout of ELV recycling and disassembly enterprise, the relationship between logistics and non-logistics in the factory area is first presented, then the correlation diagram of operating unit location and the functional unit area was drawn. Consequently, the feasible layout scheme is further obtained through modification and adjustment, and the best general layout scheme of the plant area is determined by the weighted factor method.

The remainder of this paper is structured as follows. Sect. "Methodology" describes the methodology employed in this study. In Sect. "Case analysis", the described approach is applied to the typical case of a real ELV disassembly plant facility layout. The last section elaborates on the major contributions of this paper and gives a brief overview of possible extensions as part of future work.

II. METHODOLOGY

A. RECYCLE AND DISASSEMBLY MODE OF ELV

The recycling of ELV can not only save resources but generate significant profits. According to relevant estimates, China's future ELV disassembly market is expected to reach $ 110 billion each year, which means that China's ELV industry has the mass and potential to be the first in the world. Typical ELV disassembly and recycling mode is shown in Fig. 2.

Generally, some specific pollutants and fossil oil of ELV are firstly recovered after pre-processing, then the reusable components, the remanufactured parts, and the recyclable materials can be obtained after efficient disassembly, which can be sold again, thus re-entering the life cycle of a new product [38]. The materials obtained by sorting can be recycled once the ELV body wreckage is shredded, and the reusable materials can also be extracted from the residues after shredding through sorting carefully. The remaining materials are recovered through energy and then treated as harmless landfills to maximize ELV resources' recycling while taking both economy and environmental sustainability into account.

Recycling refers to the separation of useful resources from waste after restoration or in the form of raw materials to re-enter the product life cycle process to produce value, while the trash failed to be recycled treated innocuously. As far as ELVs are concerned, according to the economy of recycling, they are divided into five recovery levels of reuse, remanufacturing, recycling, energy recovery, and landfill.

1) REUSE

Reuse refers to recycling from the structural and functional parts of ELV that are reused according to the original function. The reused parts generally have good quality, not easy to damage, high reliability, and so on. This study is not considered to change the component's original function and apply it to other scenarios.

2) REMANUFACTURING

Remanufacturing refers to recycling for some parts with high market demand, high manufacturing cost, or technical difficulty, which are repaired by technological means, and the quality after the repair is equal to or better than that of the prototype new products. In principle, remanufactured products are prohibited from entering the new car manufacturing process. At present, the domestic remanufacturing industry's market conditions are not mature, consumers do not fully recognize remanufactured products, and the quality of remanufactured products still lacks a perfect guarantee mechanism. Remanufactured parts from ELV are challenging to be widely used in the automobile maintenance industry.

3) RECYCLING

Recycling refers to a way of recycled materials from ELV in the form of raw materials. However, many materials in ELV are challenging to be disassembled and sorted, and they can only be utilized with degrading due to the lack of purity and performance during the recycling process. For example, recycled plastics from ELV are generally used for unimportant accessories or other daily necessities.

4) ENERGY RECOVERY

For the materials of ELV that failed to be recovered and reused, the total recovery and utilization rate can be improved by energy recovery. Not only can the heat energy be obtained by incineration, but also the chemical energy can be derived utilizing thermal cracking, gasification, chemical conversion, and so on. At present, more and more attention has been paid to the production of hydrogen energy by pyrolysis and gasification.

5) LANDFILLING

Landfilling refers to the materials in ELV that cannot be treated by the above recycling methods as a means of harmless disposal of solid waste. However, landfilling sites for benign removal are increasingly scarce in various countries. Therefore, for the ELV recycling and disassembly industry, improving the recycling utilization rate and reducing landfills is the long-term solution for sustainable development.

B. SLP METHOD

Richard Muther put forward Systematic Layout Planning (SLP) in 1961 [39], which made a significant challenge to the traditional empirical design method of industrial facility layout. SLP is a set of methodical, step-by-step techniques for the layout of design projects, which are suitable for almost all kinds of layout issues. The basic procedure model can be implemented conveniently to the facilities layout or adjustment in new construction, expansion, or reconstruction project. The efficient design of plant layout is an iterative, step-by-step refinement process, which often depends on the correct design procedure. For the SLP method, the research problem's basis and entry point can be summarized into five essential elements of product P, production Q, production line R, auxiliary service department S, and production plan T. Among them, P and Q are the basis of all other conditions.

The primary task of using the SLP method for general layout is to obtain the relationship table of operating units after comprehensively analyzing the relationship between operating units, including the relationship between logistics and non-logistics. The distance between the operating units is determined according to the close degree of the relationship between the operating units in the interrelation table. Establish the operating unit correlation diagram once the position of each operating unit is arranged. Consequently, the operating unit area's correlation diagram is also presented by combining the actual occupation area with each operating unit's position correlation diagram. Eventually, several feasible layout schemes are proposed through the correction and adjustment of the operating unit area correlation diagram, and then the best strategy is selected by using a specific evaluation method to evaluate each scheme, as shown in Fig.1.

III. CASE ANALYSIS

A. BACKGROUND AND DATA COLLECTION

This study's enterprise mainly carries on the materials recycling utilization of waste batteries, which sites in Changsha, Hunan Province. The previous main plant area was put into production with water, electricity, other infrastructures, and wastewater purification and treatment facilities. The land for

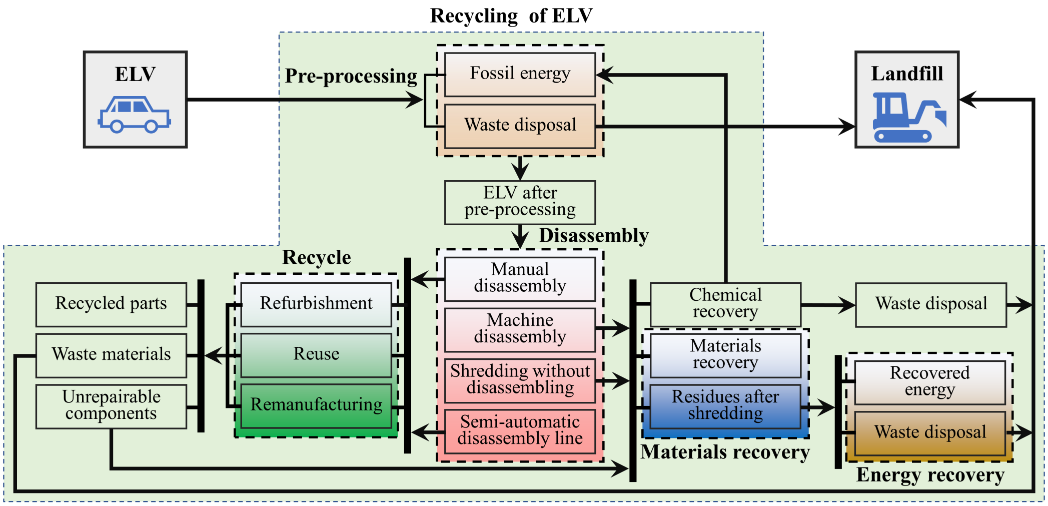

FIGURE 1. Typical mode of ELV disassembly and recycling.

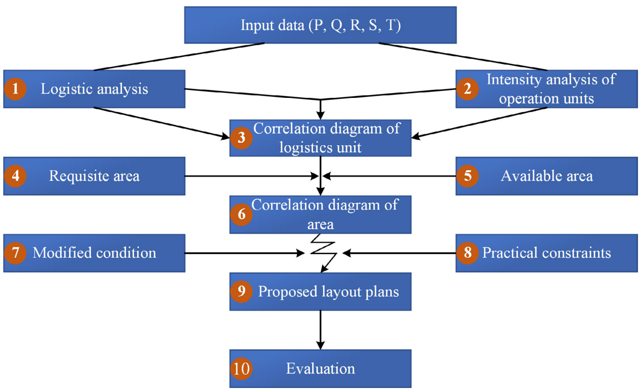

FIGURE 2. SLP procedure.

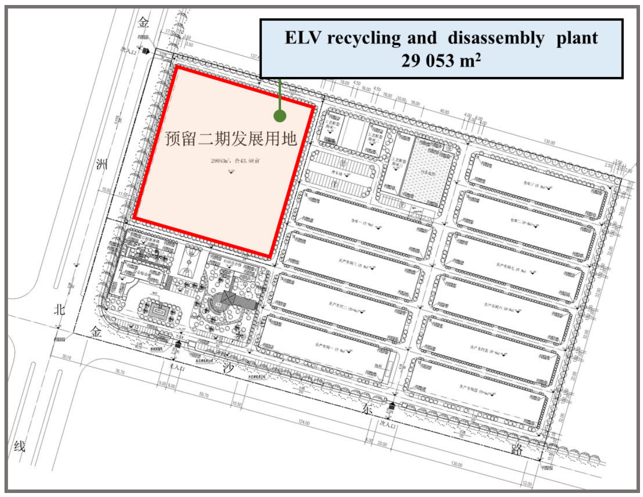

FIGURE 3. Schematic diagram of the study area.

the recycling and disassembly plant of ELV has been reserved in the company's general layout planning, which sites in the northwest of the plant, with an area of 29 053m^2, as shown in Fig. 3. The west side of the reserved land is the city's main road, which leads to the entrance of the expressway, and the north side is close to other plants. This plant's main production tasks are collecting ELVs, disassembling entire vehicles and assembly finely, shredding processing, and storing parts and waste. The recycling and disassembly production capacity is about 20 000 ELVs every year.

The general layout shall be determined after technical and economic comparison based on the overall planning according to the scale, production process, transportation, environmental protection, requirements of fire prevention, safety, construction, and maintenance of industrial enterprises, combined with the natural conditions the site. In this study, the layout design conforms to the Chinese new standard's the requirements of GB 22128-2019 "Technical specification for end of life vehicle recycling and disassembly enterprises". The layout design should also comply with the provisions of the current national standards and norms on fire prevention, safety, health, transportation, and environmental protection.

Therefore, the ELV recycling and disassembly plant layout should meet the following requirements: (1) buildings and other facilities should be arranged in multiple layers on the premise of meeting the production process, operation requirements, and equipment functions; (2) the reasonable width of the logistic passageway according to functional zoning; (3) the plant area, functional zone and the shape of buildings should be organized; (4) the layout of various facilities in the functional zone should be compact and reasonable.

B. DISASSEMBLY PROCEDURE OF ELV

The vehicle comprises five engine assemblies: transmission, steering gear, front, rear axle, and chassis. For this similar structure, a general operating procedure of ELV recycling and disassembly can be presented, strictly following environmental protection and recycling principles. Once the ELVs are delivered to the plant, the fundamental procedures are carried out according to several working operations, such as inspection and registration, environmental pre-processing,

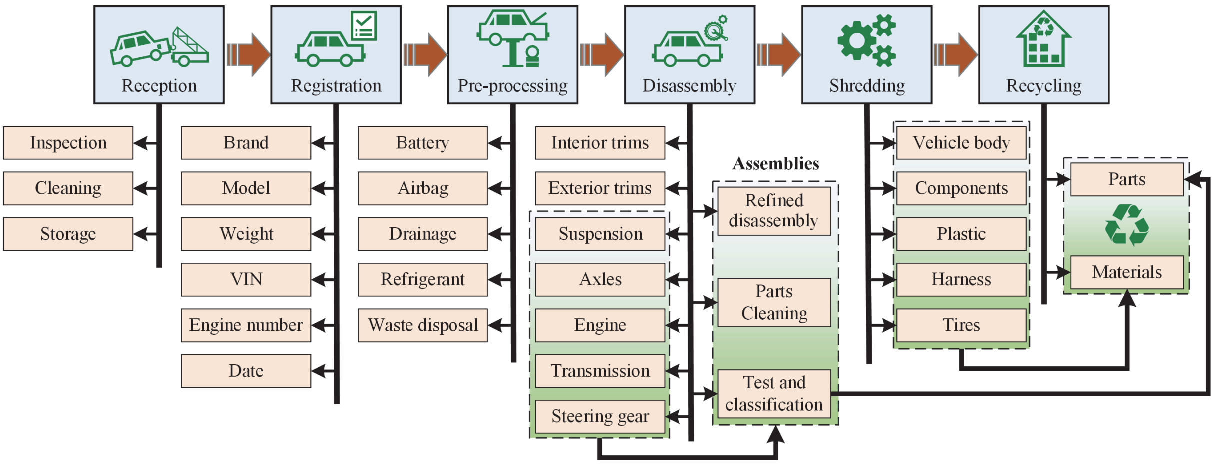

FIGURE 4. General disassembly procedure of ELV.

ELVs storage, refined disassembly, classified storage, and management of various materials, as shown in Fig.4.

The ELVs transported to the plant are stored in a temporary warehouse after thoroughly cleaning, waiting for inspection and registration. Some essential information of ELV is registered, which includes brand, model, weight, vehicle identification number (VIN), engine number, and receipt date. Moreover, a label with primary information of ELV should be affixed in a prominent position on the body. Pre-processing should be carried out before disassembly. Each station's primary operations are as follows, removing the battery, trigging airbag, drainage fluid, recovering refrigerant in air conditioner, and waste disposal.

When the pre-processing is completed, the specific disassembly operations can be employed as follows. All kinds of electronic components should be removed first, including dashboards, stereos, navigation equipment, starter, generator, wires, cables, and other interior trims. Next, it is not only the wires and pipelines connected between the vehicle body and the chassis which need to be dismantled but the kinds of connectors such as the controls of the steering system, transmission, clutch and throttle, and so on. Then, the remaining vehicle body is shifted to the disassembly section for assembles, and the chassis is placed to specialized support when all the connectors between the body and the chassis are disconnected. Afterward, the parts such as the air filter and muffler are removed and sent to respective storage places, while the wheel assemblies are delivered to the decomposition station. Various control parts of transmission, clutch, brake, throttle, and others mounted to the chassis's upper is removed. After that, the driveshafts are delivered to the decomposition station. Disassemble the circuit, pneumatic and hydrostatic transmission components, intake, and exhaust pipes connected between the engine assembly, gearbox assembly, and other assemblies. Deliver the engine and gearbox assembly to a refined disassembly station when installing fixed parts are removed. The components obtained from the fine disassembly station are cleaned and sent to the inspection room to determine whether they are reusable parts, repairable parts, or scrapped parts. The different types are delivered to the recycling warehouse, remanufacturing workshop, shredding station, and waste disposal station. Finally, the chassis' accessories are disassembled and stored in reusable containers, respectively, according to the type of material, i.e., steel, copper, plastic. The front and rear axle and suspension are delivered to the refined disassembly station after disassembling, and the remaining parts are further removed and sent to storage containers, respectively. The rest of the chassis assembly is hoisted to the refined disassembly station.

The disassembled body, chassis, harness, plastic parts, tires, and irreparable parts are shredded to obtain the original materials for sale according to customers' needs. Based on the disassembly procedure of ELV, five workers are employed to the disassembly time consumption under the same condition approximately, and a specific statistical result is shown in Table 1.

TABLE 1. Disassembly time consumption of main components.

Objective	Time					
	I	II	III	IV	V	Mean
Doors and hoods	4'2''	4'39''	4'17''	3'48''	3'56''	4'84''
Fender	1'12''	2'8''	1'41''	1'47''	2'11''	1'47'
Bumper	1'35''	1'29''	1'40''	1'41''	1'26''	1'34''
Windshield	3'43''	3'55''	3'31''	3'03''	3'57''	3'37''
Light	1'41''	1'36''	1'27''	1'33''	1'28''	1'33''
Tires	1'54''	2'08''	1'43''	2'11''	1'55''	1'58''
Radiator	1'36''	1'40''	1'30''	1'32''	1'29''	1'33''
Starter and generator	3'11''	3'01''	3'04''	2'57''	2'59''	3'02''
Gearbox	2'19''	2'05''	2'08''	2'09''	2'11''	2'10''
Safe-belts	1'54''	1'46''	1'34''	1'47''	1'43''	1'44''
Exhaust pipe	2'46''	2'50''	2'53''	2'46''	2'50''	2'49''
Rear axle	3'58''	3'49''	3'55''	3'54''	3'56''	3'54''
Transmission	1'32''	1'49''	1'43''	1'52''	1'36''	1'42''
Front axle	5'12''	5'33''	5'19''	5'54''	5'28''	5'29''
Suspension	3'18''	3'34''	3'55''	3'41''	3'47''	3'39''
Steering system	4'34''	4'38''	4'59''	4'47''	4'41''	4'43''
Brake system	3'18''	3'10''	3'12''	3'16''	3'13''	3'14''
Dashboard	3'38''	3'20''	3'05''	3'41''	3'19''	3'25''
Total	53'16''					

It is necessary to perform a reasonable permutation and combination according to the disassembly time in each process and divide it into different stations. After consideration, the five stations were proposed, and each station's time is about 12 minutes. Different ELV has different degrees of damage, which will cause the disassembly time to fluctuate. Therefore, the disassembly time is divided into working time and rest time during the specific disassembling process. The free time is used to tool arrangement. Accordingly, the necessary floating time should be added at each station. The design-time quota for completing ELV disassembly is shown in Table 2.

TABLE 2. Disassembly time of ELV.

Workstation	Objective	Time /min	Planned workers	Planned time/min	Station time/min
Preparation	Ready	1	1	2	
The first: external disassembly	Engine hood	2	2	25.5	12
	Battery	1			
	Front lights	2			
	Trunk hood	2			
	Trunk decoration	2			
	Rear lights	2			
	Doors	4.5			
	Tires	4			
	Front windshield	3			
	Rear windshield	3			
	Forward	0.5			
The second: disposal of hazard liquid	Lifting	0.5	1	10	12
	Fuel oil	2			
	Lubricating oil	1			
	Final drive shaft	1			
	Cooling fluid	1			
	Refrigerator	1			
	Brake fluid	1			
	Glass water	1			
	Landing	1			
	Forward	0.5			
The third: internal disassembly	Air bags	4	2	25.5	12
	Steering wheel	2			
	Seats	6			
	Dashboard	3			
	Evaporator	2			
	Heating blower	1			
	Interior trim parts	2			
	Wiring harness	2			
	Handling systems	1			
	Forward	0.5			
The fourth: turning vehicle	Lifting	0.5	1	10	12
	To turn platform	0.5			
	Turning	0.5			
	Cutting	3			
	Underfloor parts	3.5			
	Turning	0.5			
	Lifting	1			
	Forward	0.5			
The fifth: assemblies disassembly	Engine	4	2	22	12
	Connectors	5			
	Lifting	1			
	Power assembly	3			
	Air-condition Parts	2 3			
	Brake	2			
	ELVs body	2			

C. FUNCTIONAL AREA DIVISION AND SETTING

According to the production plan, a vehicle with an engine displacement of 1.6 L is used as the standard recycling and disassembly enterprise model. The daily disassembling production of ELVs disassembly plant is 80, and 6 units per hour can disassemble a single disassembly line. The actual number of vehicles disassembled in a day can be obtained as

$$Z = Z_1 \times \alpha \times \beta$$

where Z_1 is the designed daily disassembly production with the work time of 8 hours, α is the work time efficiency considering the loss of working hours for accidents or production stoppage, β is the attendance rate of workers considering sickness, leave, etc.

Assume the attendance rate is 95% and the working hours' efficiency is about 90%, and the number of disassembly lines is 2, then the actual daily disassembly number is about 82. According to the disassembly task, the designed daily weight of disassembled components of the ELV disassembly plant is shown in Table 3.

TABLE 3. The daily weight of disassembled components.

Disassembly workstation	Objective	Weight /kg	Quantity /pcs	Production /pcs	Logistics /t
External	Engine	200	1	80	1.60
	Battery	15	1	80	1.20
	Light	3	4	80	0.96
	Trunk hood	10	1	80	0.8
	Door	10	4	80	3.2
	Tire	9	4	80	2.88
	Windshield	23	2	80	3.68
Internal	Airbag	3	4	80	0.98
	Steering wheel	1	1	80	0.08
	Seats	18	4	80	5.76
	Dashboard	5	1	80	0.4
	Evaporator	60	1	80	4.8
	Heating blower	45	1	80	3.6
	Wiring harness	30	1	80	2.4
Assembly	Compressor	6	1	80	0.48
	Power assembly	325	1	80	26
	Transmission	53	1	80	4.24
	Brake valves	10	1	80	0.8
	Vehicle body	1	420	80	33.6

1) ESTIMATE OPERATING UNIT AREA

It is not easy to calculate the operating unit's space requirements in the site selection of facility planning, but it is imperative. In general, the period of facility planning and layout can reach 5-10 years, including many uncertain factors: changes in demand, technological progress, product transformation, etc. The more uncertainties to consider, the more difficult it will be to forecast demand space. After investigating and analyzing, and predicting necessary data, Table 4 estimates the area of the storage area and disassembly area of the ELVs disassembly plant.

TABLE 4. **Overview of the operation area.**

Item	Description	Area/m^2
Freight elevator no.1	Semi-finished products delivery	50
Freight elevator no.2	Finished product delivery	50
Quick disassembly area	Quick and basic disassembly	504
Storage area of ELVs	Storing ELVs	By demand
Shredding area	Shredding, shattering, sorting, and delivery of ELVs wreckage	2106
Disassembly area of ELVs	Non-destructive disassembling	1053
Storage area of ELVs body	Storing ELVs bodies	300
Refined disassembly area	Refined disassembly of assembly	2106
Disassembly area of tires	The recycling process of the tires	567
Shattering area of plastic and wiring harness	Recycling Process of plastic and wire harness	324
Cleaning area	Cleaning ELVs before disassembly	10.5
Disassembling platform	Disassembling of engine and transmission	1.8
Storage area of tires	Storing disassembled tires	112
Storage area of recycling components	Storing recycling components	By demand

2) ESTIMATE THE STORAGE SECTOR AREA

It is mainly aimed at the warehouse of recycling parts and the ELVs when estimates the storage department's area. Also, the number and size of stored items, the storage, transportation methods, and the aisle's width are all factors to be considered. The following is the calculation process:

The area occupied by the storage of an ELV is about 10 m^2 (width: 2 m, length: 5 m), and 100 to 150 vehicles are planned to be stored. According to the plant area and layout plan, the total area is 2 088 m^2 (length: 65 m, width: 24 m).

There are two kinds of recycling warehouses considered in this study. The No.1 mainly stores assembly components and parts that pass the inspection after disassembly. The entire warehouse is divided into several storage areas, including engine parts, transmission parts, steering assembly parts, suspension and brake assembly parts, dashboard parts, and electrical equipment. Besides, the recycling warehouse No.2 is mainly used for remanufacturing development reserved areas. To avoid excessive storage costs, the storage amount is twice daily disassembled parts. The detailed calculation of the storage information is shown in Table 5.

Volume of transfer bin No.1, No.2 and No.3 is 0.048 m^3 (length: 600 mm, width: 400 mm, height: 200 mm), 0.162 m^3 (length: 900 mm, width: 600 mm, height: 300 mm), 0.3 ^{3} (length: 1000 mm, width: 1000 mm, height: 300 mm) respectively. The required storage area of recycling warehouse is calculated in Table 6.

According to the results, the theoretical area of the recycling parts warehouse is 2009.6 m^2. Taking the specific requirements of the infrastructure construction into account, therefore, the actual site is designed to be 2268 m^2.

3) ESTIMATE PRODUCTION AREA

Since the disassembly procedure of different models of ELV is pretty similar, the product design principle can be employed to deal with the layout issues. The reasonable arrangement of personnel and equipment forms a unified production line according to the disassembly procedure mentioned previously. The specific disassembly sequence of ELV is shown in Fig 5.

TABLE 5. **Calculation of storage information.**

Objective	Demand /pcs	Transfer bin	Capacity /pcs	Estimated /pcs	Required /pcs
Engine	80	No.3	2	160	80
Battery	80	No.1	5	160	32
Gearbox	80	No.3	5	160	32
Steering assembly	80	No.1, No.2, No.3	5	160	100
Suspension and brake assembly	80	No.1, No.2	10	160	80
Dashboard	80	No.2	10	160	80
Electrical equipment	80	No.1, No.2	10	160	160

TABLE 6. **Storage area of recycling warehouse.**

Transfer bin	Demand /pcs	Unit area /m^2	Quantity /pcs	Container area /m^2	Passage area /m^2	Total /m^2
No.1	315	0.24	8	855.5	300	855.5
No.2	29	0.54	4	368.3	240	808.3
No.3	220	1.00	6	445.8	100	345.8

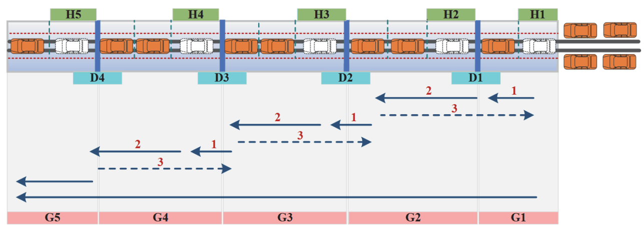

FIGURE 5. **The disassembly procedure of single line.**

Taking the disassembled vehicle's operation process as an example, the disassembled vehicle's transportation process is described.

(1) At workstation G1, the transshipping platform D1 transfers the vehicle to be disassembled from the buffer station H1 to the workstation G1 to perform external disassembly. After that, D1 moves the vehicle without external assembly to H2, and the D1 returns to H1 again.

(2) At workstation G2, the disassembled vehicle from the buffer station H2 is transferred to workstation G2 by the transshipping platform D2. The vehicle is lifted to a certain height to complete the waste liquid drainage, the disassembled vehicle without waste liquid is transferred to the buffer station H3 by D2.

(3) At workstation G3, the transshipping platform D2 lifts the disassembled vehicle from the buffer station H3 and transfers it to the G3 for internal disassembly. Then, D2 returns to H2 again.

(4) At workstation G4, the transshipping platform D3 transfers the disassembled vehicle without interior decoration from the G3 to the buffer station H4. The vehicle is transferred to the vehicle body overturning platform, which

can turn the vehicle's side 90 degrees to suitably perform related disassembling and cutting operations for some chassis connecting components. Then, D3 returns to H3 again.

(5) At workstation G5, the D3 transfers the vehicle that has completed disassembly operation at G4 to G5 to disassemble the connecting components of engine assembly, transmission assembly, and others. The vehicle chassis is obtained when the necessary disassembly operations are completed. The transshipping platform D4 transfers the vehicle wreckage to the temporary storage area and then returns to the buffer station H5 to prepare for the next wreckage transfer.

ELVs disassembly line consists of 5 workstations (Fig. 5), including external disassembly, liquid drainage, interior disassembly, vehicle body overturning, assembly disassembling. The disassembly time of each workstation is different, and it is challenging to keep the average disassembly cycle time. Therefore, a buffer area is reserved between the two adjacent workstations, and the vehicles that have not been disassembled in time can be temporarily stored in this area. For G2, G3, G4, each workstation's disassembly time is more than G1 and G5. To obtain more buffer time, the length of space occupied is designed as 20 m, which can place three vehicles freely. The size of space occupied by G1 and G5 is 12 m, then the total length of the disassembly line is 84 m.

Also, for the sake of reducing equipment cost, the G2 and G3 share D2. For the specific disassembly sequence of ELV, the area estimation results of the particular operation area are shown in Table 7.

TABLE 7. The estimated size of the individual production line.

	Description	General area/m^2	Operation area/m^2	Overall area/m^2	Total /m^2
Lift	Lifting ELV to a certain height	2.79	36	38.79	
Disassembling platform	Disassembling assembly parts	3.6	30	33.6	
Tire disassembler	Separate the tire and the wheel hub	6.15	15	21.15	362.3
Overturning platform	Turning ELV and disassembling the parts of chassis	35.9	35	70.9	
Transshipping platform	Transferring vehicle	49.2	147.6	196.8	
Liquid drainage system	Draining the waste liquid	0.14	1	1.14	

4) OVERALL AREA CALCULATION

According to the relevant environmental protection requirements about ELV, the plant area of the recycling and disassembly enterprise should be divided into five different functional areas, which include management area, ELV storage area, disassembly operation area, recycling product storage area, and pollution control area with the collection, storage, and disposal of all kinds of waste. Correspondingly, each functional area's size and division should be suitable for the disassembly capacity and marked clearly. Every except management area should have a waterproof floor and oil and water collection facilities. Moreover, the operation area, the recycling product storage area, and the pollution control area shall be equipped with rain-proof and wind-proof facilities. The occupation area of each operating unit is shown in Table 8.

TABLE 8. Overall area estimation results.

Sequence	Operating unit	Function description	Area/m^2
1	ELVs warehouse	Storing in tiled or stacked ways for different ELV	2088
2	Disassembly and shredding workshop	Disassembling and shredding the ELVs	8424
3	Recycling warehouse No.1	Qualified external assembly after disassembly	2268
4	Recycling warehouse No.2	Qualified internal assembly after disassembly	1440
5	Office building	Office and sale	552
6	Sewage station	Sewage treatment system	170
7	Solid waste warehouse	Storing the discarded parts	150
8	Liquid waste warehouse	Storing the waste liquids	60
9	Power station No.1	Voltage control	60
10	Power station No.2	Power management	30
		Total	28828

D. LOGISTICS CORRELATION ANALYSIS

According to the technological process of ELV recycling and disassembling and the designed daily weight of disassembled components, the specific logistics process of different operating units is shown in Fig. 6.

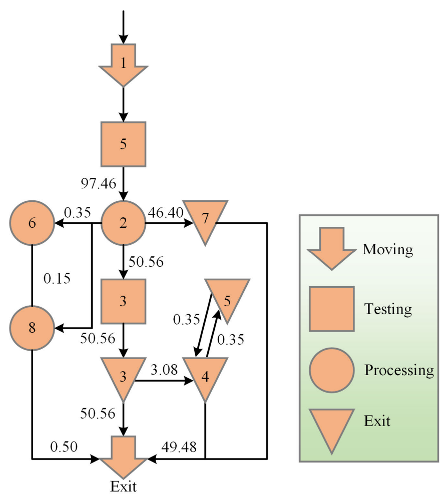

FIGURE 6. The logistics processes.

The standard for measuring the flow rate is the daily weight of the logistics. The minimum 0.01 t is recorded as the weight 1. Table 9 shows the distribution ratio of logistics intensity.

The logistics intensity grade is divided according to the logistics intensity distribution ratio, and the logistics related table of the operating unit in the plant area is drawn, as shown

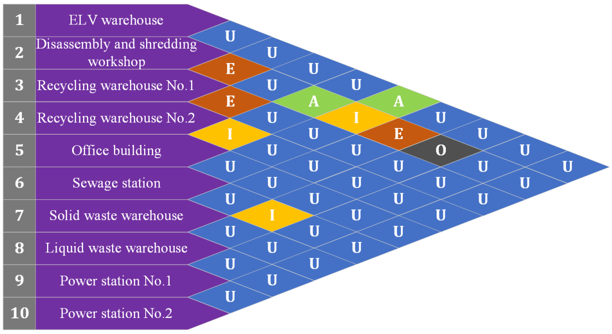

FIGURE 7. Logistics-related map of ELVs dismantling plant.

TABLE 9. The distribution ratio of logistics intensity.

Operating unit set	Logistics intensity	Rank
1-5	9746	A
5-2	9746	A
2-3	5056	E
2-7	4640	E
3-4	3080	E
4-5	70	I
2-6	35	I
6-8	35	I
2-8	15	O

in Fig. 7. The logistics intensity is represented by the symbol A, E, I, O, U, and the logistics intensity is gradually reduced in order.

E. COMPREHENSIVE RELATIONSHIP ANALYSIS

A comprehensive relationship needs to be given after determining the relationship between logistics and non-logistics between operating units. The logistics relationship between ELV disassembly units is dominant in the plant layout design, and some researchers believe that the relative importance of determining the relationship between logistics and non-logistics is relatively 2:1. The correlation degree of logistics and non-logistics should be quantified, in this study, we take $A = 4, E = 3, I = 2, O = 1, U = 0, X = -1$. According to the quantized grade and weighted ratio, the comprehensive interrelationship value is calculated by

$$CR_{ij} = mMR_{ij} + nNR_{ij},$$

where MR_{ij} represents logistics relationship score, NR_{ij} represents non-logistics relationship score. Take $m = 2$, $n = 1$, and correspond to the six levels of A, E, I, O, U, and X. Therefore, the comprehensive interrelationship of operating units is presented, as shown in Table 10.

The correlation degree and proportions of comprehensive logistics are shown in Table 11.

Starting from the comprehensive correlation diagram, the extensive proximity degree of operating units is obtained. that is, the sum of the quantified correlation level between the operating unit and all others is obtained, and the operating units are sorted according to their status is shown in Table 12.

In SLP, the plant's layout does not directly consider each operating unit's geometry or the building's floor space. Instead, it starts with the tightness between the operating units and then further arranges each operating unit's relative position. High-density relationship units are close, and low-density relationship units are far away. Besides, the higher the tightness between the operating units, the closer the distance between them, and vice versa, resulting in the working unit's position-dependent graphics. The chart below is based on the overall proximity of the operating unit location map. The interrelationship level and correlation diagram of the operating units are shown in Table 13 and Fig. 8, respectively.

TABLE 10. The comprehensive interrelationship of operating units.

Operating unit set	Correlation degree				Comprehensive interrelationship	
	Logistics (Weight 2)		Non-logistics (Weight 1)			
	Rank	Score	Rank	Score	Score	Rank
1-5	A	8	A	4	12	A
5-2	A	8	A	4	12	A
2-3	E	6	E	3	9	E
2-7	E	6	E	3	9	E
3-4	E	6	I	2	8	E
4-5	I	4	O	1	5	I
2-6	I	4	U	0	4	I
6-8	I	4	U	0	4	I
2-8	O	2	U	0	2	O

TABLE 11. Correlation of comprehensive logistics.

Score	Rank	Operating unit sets	Proportion （%）
11-12	A	2	2.04
9-10	E	2	4.08
4-8	I	4	10.21
1-3	O	1	22.45
0	U	0	0
-1	X	0	0
	Total	9	100

TABLE 12. Comprehensive proximity of operating units.

Operating unit	1	2	3	4	5	6	7	8	9	10
1			A/4		O/1	I/2				
2										
3	A/4			O/1				I/2		X/-1
4			O/1		O/1			O/1	O/1	O/1
5	0/1			O/1		O/1				
6	I/2				O/1		O/1			
7						O/1				
8			I/2	O/1					I/2	
9				O/1				I/2		
10			X/-1	O/1						
Comprehensive proximity	7	3	5	5	4	6	1	5	10	0
Rank	2	10	5	6	9	3	11	7	1	13

F. AREA CORRELATION DIAGRAM OF OPERATING UNITS

The process of drawing an operating unit location-related diagram should be systematic and transparent, which generally follows the steps below. An appropriate drawing scale should be selected, here, we set the scale to 1:1000, and the drawing unit is mm. Then, enlarge the relevant picture of the operating unit's position onto the coordinate paper, leaving as much space as possible between each work unit symbol

TABLE 13. Interrelationship level.

Level	Symbol	Coefficient value	Line number
Absolutely important	A	4	////
Very important	E	3	///
Important	I	2	//
General important	O	1	/
Unimportant	U	0	
Unwilling to close	X	-1	....

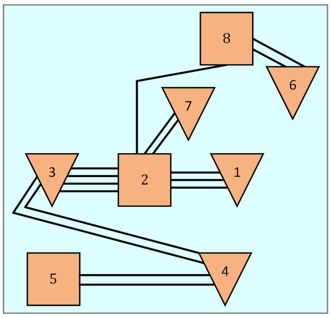

FIGURE 8. Correlation diagram of the operating units.

to arrange the operating unit's establishment. Only essential relationships are marked, such as A, E, I, and X connections. According to the order of a comprehensive approach, each unit is arranged in order of size. The operating unit's shape is drawn with the operating unit's symbol as the center during drawing. The operating unit buildings are generally rectangular, and the body's rotation angle can obtain different layout drawings. When the reserved space is insufficient, the position of the operating unit needs to be adjusted correspondingly. However, we must change the position symbol to meet the requirements of the unit position correlation diagram. The following correlation diagram of the operating unit area is finally obtained after continuous adjustment and redrawing, shown in Fig. 9.

G. CORRECTION

The area correlation diagram that has been drawn should be corrected according to some actual situations, and several correction factors are considered in this design, which is as follows.

(1) The status of the original industrial construction. Some factories have been completed in the early stage, and two factories have been set up in the south.

(2) Pollution and noise. Substations and sewage treatment areas may release irritating odors and generate vibration and noise. To do this, these areas should be arranged in the corner of the plant with adequate ventilation. As far as noise is concerned, the office area should be kept as far away from the central operating unit as possible.

(3) People flow management. This design set the office at the exit, and the main reason is that it is an area with the most traffic. Placing the office at the entrance can better reduce people's distance and people's flow in the workshop.

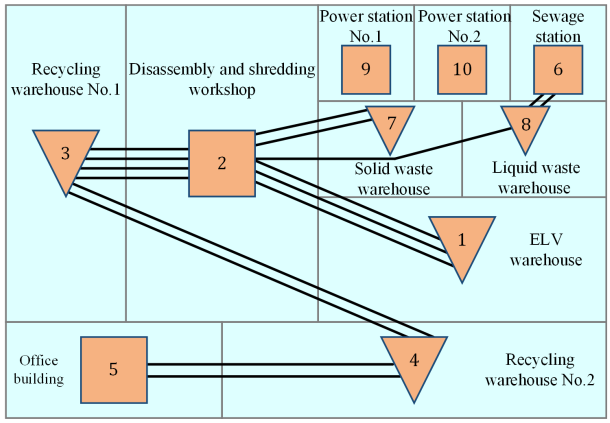

FIGURE 9. Area correlation diagram of the operating units.

(4) Channel conditions. In addition to the operating unit's channels, to meet the needs of logistics personnel flow, appropriate channels should be set up between the various operating units; to prevent discontinuities, the channels are generally arranged in a ring or orthogonal mode.

(5) Safety and fire protection. The disassembly and shredding section of the vehicle requires fire protection arrangements, including fire extinguishers, fire hydrants, and emergency fire passages. There are many flammable and dangerous items in this section. Proper fire protection arrangements should also be placed in the remaining workshops.

The above correction factors should be considered in the layout design. However, there should be other factors that limit our layout. For the workshop, the shape, the available area, the building's cost, and the price should be considered. When determining the layout plan, the impact of these factors should be considered at the same time. Further adjustment plan is based on these restrictions, which is shown in Fig.9. Furtherly, according to the disassembly process of ELV, a detailed facility layout and logistics route of the disassembly and shredding workshop are proposed, as shown in Fig.10. The ELV warehouse is located on the east side, far away from the office building and recycling warehouse No.1, reducing the corporate environmental image's negative impact. It is conducive to the establishment of a clean environment in the factory area. Simultaneously, it is located in the downwind direction of the factory area, preventing the odor and dust from the site from affecting the plant area's environmental hygiene.

The recycling warehouse No.1 is arranged on the west side, forming an isolation barrier to the outside. The disassembly and shredding workshop's qualified parts can be conveniently transferred to the recycling warehouse No.1 for storage and centralized logistics.

The workstations such as the whole vehicle disassembly, refined disassembly, wreckage shredding, and rapid disintegration of the vehicle are arranged together (Fig. 11), saving construction costs and facilitating operation logistics cycle between the operating units is more compact

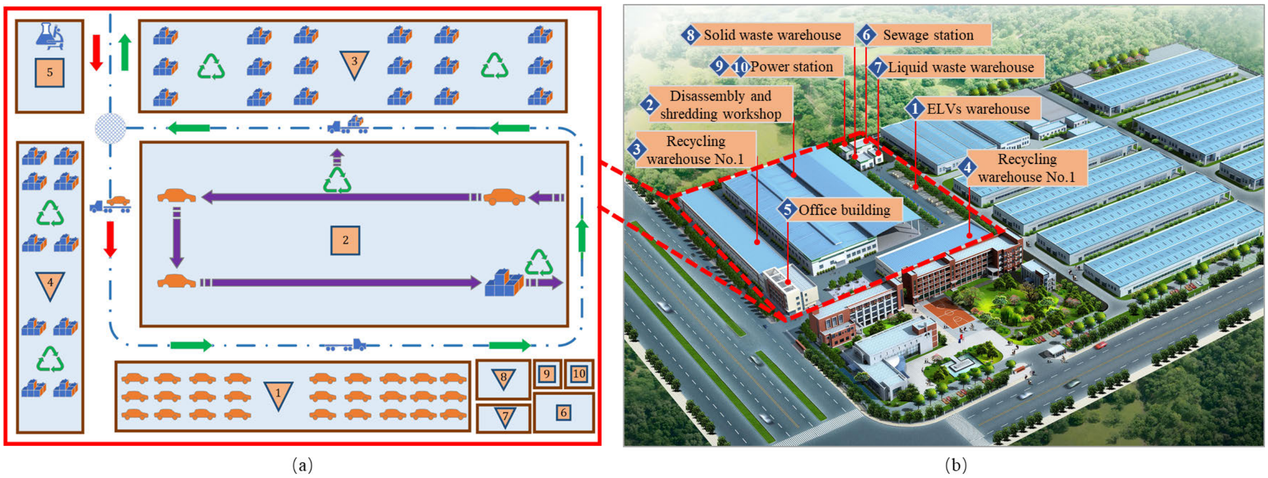

FIGURE 10. The general layout of ELV recycling and disassembly plant: (a) general layout; (b) aerial perspective.

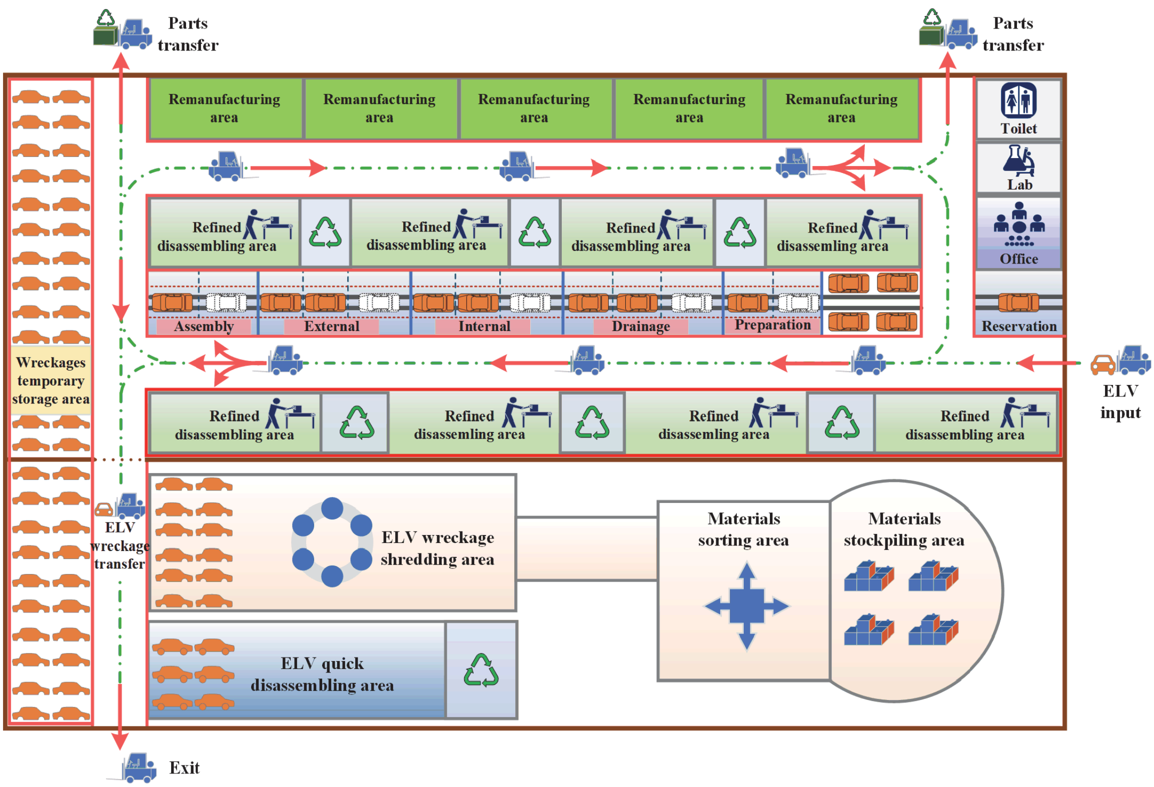

FIGURE 11. Facility layout of disassembly and shredding workshop.

and succinct. Sewage station, solid waste warehouse, liquid waste warehouse, ELV warehouse, and the auxiliary equipment and places are arranged on the plant's east side, which is adjacent to the main workshop. Also, these operating units are in the direction of minimum wind frequency to reduce the pollution to other operation areas. The pollution area is far away from the living area, the layout of each workshop is compact, the management is convenient, and the logistics channel is smooth.

The width of the road between the disassembly and shredding workshop, the ELV warehouse, and the cycling warehouse No.1 is 10 m to ensure the smooth passage of vehicles in the factory area. The trunk road in the plant is arranged in a ring, which meets the requirements of transportation and fire protection; the trunk road connects the main entrances and exits of the plant area, and the logistics route design comprehensively considers the vertical and horizontal logistics. At present, the layout scheme of the recycling and disassembly plant designed in this study had been implemented, and the appropriate supporting equipment and facilities, especially the semi-automatic disassembly line and special recovery equipment of in disassembly and

(a) (b) (c)

FIGURE 12. Some work scenarios of the recycling and disassembly plant; (a) recovered ELVs in warehouse; (b) semi-automatic disassembly line in disassembly workshop; (c) ELVs wreckage to be crushed in shredding workshop.

shredding workshop, have been installed. Some work scenarios are shown in Fig. 12.

IV. CONCLUSION

The practical facility layout of the ELV recycling and disassembly plant plays a significant role in remanufacturing development, and it is a complex decision-making problem, including multiple influencing factors. However, for a new ELV recycling and disassembly plant intended to enter the recycling market, a fast and effective plant layout scheme can help it change its profitability smoothly. In this work, a straightforward and practical approach called SLP is adopted to determine the performance of the ELVs recycling and disassembly plant layout alternatives, and its application is shown. The above methods were performed in a merging recycling company in Changsha, a typical case in China. The facility layout scheme obtained by the SLP method fully met the production process requirements and the operating unit, realized the scientific design of the plant layout of the plant, and greatly improved the plan's efficiency and quality. Therefore, the SLP method's application in the general layout of ELV recycling and disassembly plant is of great significance to ensure the production, which will also be widely used in the vehicle remanufacturing industry and will achieve satisfactory results.

The future work will focus on moving from the existing assessment method to integrating the evaluation procedure into a computer-assisted design support system for the ELVs disassembly plant layout alternatives. Moreover, the information of experts has an uncertain and imprecise feature. Some multi-criteria decision-making methods integrating tentative theory for ELVs disassembly plant layout alternatives need to be developed in the future.

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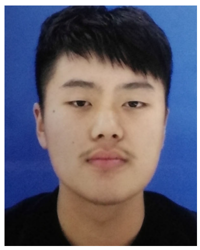

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