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Analysis on Transporting Methods of Cultivation Unit for Vertical Cultivation in Plant Factory

Song Gu [1,2,*], Hanhan Ji [1], Yanli Yang [3], Qi Chu [3], Yi Yang [4], Houcheng Liu [5] and Xianping Jiang [6]

1 College of Engineering, South China Agricultural University, Guangzhou 510642, China; hanhanji@stu.scau.edu.cn
2 Key Laboratory of Key Technology on Agricultural Machine and Equipment, Ministry of Education, South China Agricultural University, Guangzhou 510642, China
3 Guangzhou Sky Mechanical & Electrical Technology Co., Ltd., Guangzhou 510642, China; yangy@cgz-sky.com (Y.Y.); chuq@cgz-sky.com (Q.C.)
4 College of Electronic Engineering, South China Agricultural University, Guangzhou 510642, China; yangyi2001@scau.edu.cn
5 College of Horticulture, South China Agricultural University, Guangzhou 510642, China; liuhch@scau.edu.cn
6 Guangdong Modern Agricultural Equipment Research Institute, Guangzhou 510635, China; jiangxianping2021@163.com
* Correspondence: sgu666@scau.edu.cn; Tel.: +86-020-85281-392

Abstract: Automatic transport can improve the operational efficiency in plant factory production and reduce the use of labor. However, a determination of a plant factory automation operation mode should comprehensively consider the economic strength of the enterprise, operation objects and operation mode, production scale, technical strength, labor costs, and other factors. In this study, a logistics transport system comprising a set of cultivation units was developed for plant factories, using a mode based on shelf-end delivery without power inside the shelf. Moreover, an analysis was conducted on four modes of common transportation methods for the cultivation units for vertical cultivation in plant factories. The results showed that, when comparing the progressive transport type and warehousing/reciprocating transport type for cultivation units, the transport productivity of the former is higher than that of the latter, and the difference in the two transport productivities is proportional to the capacity for cultivation units in each layer. When the capacities for cultivation units in each layer are 20 and 40, the transport productivity of the former is 115–200% and 130–250% higher than that of the latter, respectively. Moreover, the logistics transport system developed herein reaches an input (output) transport productivity of 330 (270) cultivation units h^{-1}.

Keywords: plant factory; vertical cultivation; cultivation unit; vertical transport; logistics equipment

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1. Introduction

Plant factories have advantages in regards to avoiding pollution in the planting environment, saving production materials, providing high yield and quality, and allowing for annual production [1,2]. However, the production investment cost is high, and the production benefit is not evident when compared with the conventional planting mode of crops [3,4]. Scientists have conducted various studies aiming to commercialize plant factories [5]. For example, cultivation experts have focused on artificial light [6–9], nutrient solutions, environmental control [10,11], energy saving [7,12,13], and planting modes [14,15]. In terms of production equipment, agricultural equipment experts have also studied automatic production in plant factories. Seeding and transplanting equipment have been widely used for hydroponic leaf vegetable production in plant factories [16]. However, for vertical cultivation in plant factories, the vertical transport of the planting units remains an important factor, as there is no economical and rational transport mode for large-scale production in plant factories [17].

In the 1990s, Chiba University of Japan began to study a vertical cultivation mode for plant factories [18]. Subsequently, Osaka Prefectural University [19,20] and certain Japanese industrial enterprises [21] developed plant factories based on vertical cultivation, aiming to produce hydroponic leafy vegetables. In the 2010s, North America and Europe also began to use abandoned industrial workshops to establish plant factories for the vertical cultivation of hydroponic leafy vegetables [22]. Some production areas of these plant factories reached 5000 square meters [23]; however, scissor lifts were mostly used for transporting the planting units in production [24]. In China, the Jingpeng company [25], Jiangsu University [26], etc., have developed a few types of vertical conveying equipment for planting units in small-scale vertical cultivation, using the logistics technology of industrial warehouses. Iron ox, Bowery, and Sananbio [27] have developed a set of planting robot systems, logistics systems for planting units with movable containers, and automated logistics production systems for hydroponic leafy vegetables [28,29].

However, there remain problems in constructing transport systems for scaled production in plant factories.

(1) Scissor lifts remain widely applied; however, the transport operation of cultivation units at such heights is dangerous [24], and the transport efficiency is not high.

(2) Most of the established automated transport equipment systems do not match the planting mode and/or planting scale; these generally provide a high automation level of the equipment but have low transport efficiency and require large investments.

In view of the above problems, this study proposes a vertical transport mode, and compares the transport performance with those of other common vertical transport modes.

2. Materials and Methods

2.1. Production Process of Hydroponic Leafy Vegetables

Many plants can be cultivated in plant factories, such as lettuce, vegetable seedlings, and medicinal plants. As a way of providing a research object with a short cultivation period and high productivity, a typical production process for hydroponic leafy vegetables was applied in this study, as shown in Figure 1. The production process of vertical cultivation mainly includes seeding, germinating, vertical cultivation of seedlings, seedling spacing, vertical cultivation of vegetables, harvesting, packaging, and clearing of the cultivation units. Moreover, each of the above operation steps is repeated daily.

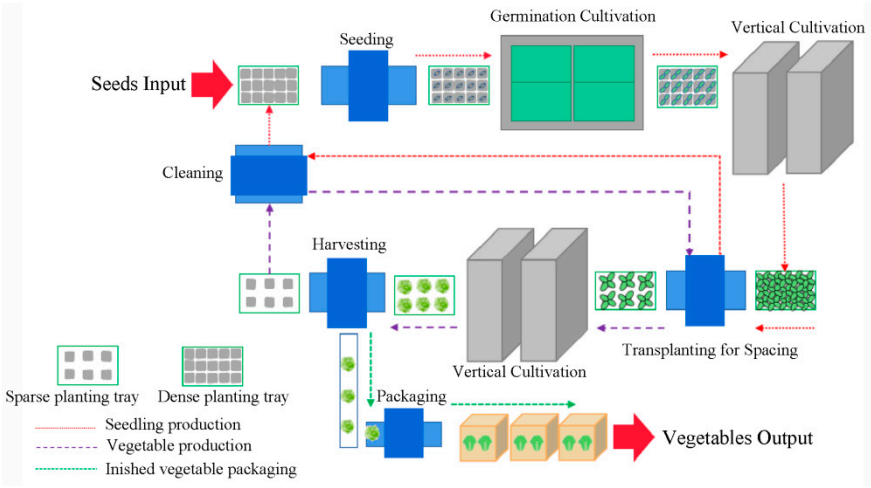


Figure 1. Flowchart of a type of vegetable production in a plant.

2.2. Cultivation Unit

As shown in Figure 2, the cultivation unit in this study is a transportable planting carrier. To place the cultivation units on the vertical cultivation shelf, the external dimensions of the cultivation units are set so as to be suited to the cultivating positions of the cultivation shelf; moreover, the number of cultivation units can be changed according to

cultivation demand, i.e., by changing the length of the cultivation shelf. The determination of the cultivation unit size should consider the following factors.

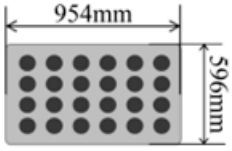


Figure 2. Cultivation unit.

(1) The cultivation unit load sizes are designed for their transport system and vertical cultivation shelf.

(2) The size of the cultivation unit should be as large as possible to ensure that a worker can hold it easily and transport it efficiently.

(3) The size of the cultivation units should be suited to the demands of seeding, space transplanting, and harvesting.

Based on the above factors, a 596 mm × 954 mm cultivation unit was selected in this study. Moreover, seedlings were transplanted with sponge cubes into 24 holes of each cultivation unit.

2.3. Transporting Methods of Cultivation Unit for Vertical Cultivation Shelf

Since Japan began research on vertical cultivation in plant factories in the 1990s [19], there have been multiple transport modes proposed for delivering cultivation units inside plant factories, such as manpower and ladder, manpower and scissor-lift car, manpower and transport equipment, and automated logistics transport systems. Currently, four types of logistics transport systems for the cultivation units of a vertical cultivation shelf are considered: shelf-end delivery without power inside the shelf, shelf-end delivery with power inside the shelf, warehousing logistics transport, and shelf-end delivery with a large unit load.

- Mode 1—Shelf-end delivery without power inside shelf

Mode 1 includes a ground convey line, input and output lift cart (IOLC), guided pushing vehicle (GPV), and GPV lift cart (GPVLC), as shown in Figure 3a. The IOLC and GPVLC are arranged at the two ends of the cultivation shelf, and the ground convey line is arranged along the moving path of the IOLC. During the input operation, the IOLC stops at the input position of the cultivation shelf, the ground convey line delivers cultivation units one-by-one to the position just under the IOLC, and the IOLC picks up, lifts, and places the cultivation unit into a target layer. The input operation is conducted in cycle by the IOLC with a cultivation unit quantity set by an operator. During output, the IOLC and the GPVLC stop at the output position of the cultivation shelf, the IOLC picks up a cultivation unit at a target layer and sends it to the ground convey line, and the ground convey line delivers the cultivation unit to another production spot. After the IOLC has taken out the first cultivation unit, on the other end of the shelf, the GPV exits the GPALC, enters the target layer, and pushes the entire line of the cultivation units to make the IOLC pick up the second cultivation unit. The output operation is also conducted in cycle by the IOLC, GPVLC, and GPV, with a cultivation unit quantity set by the operator.

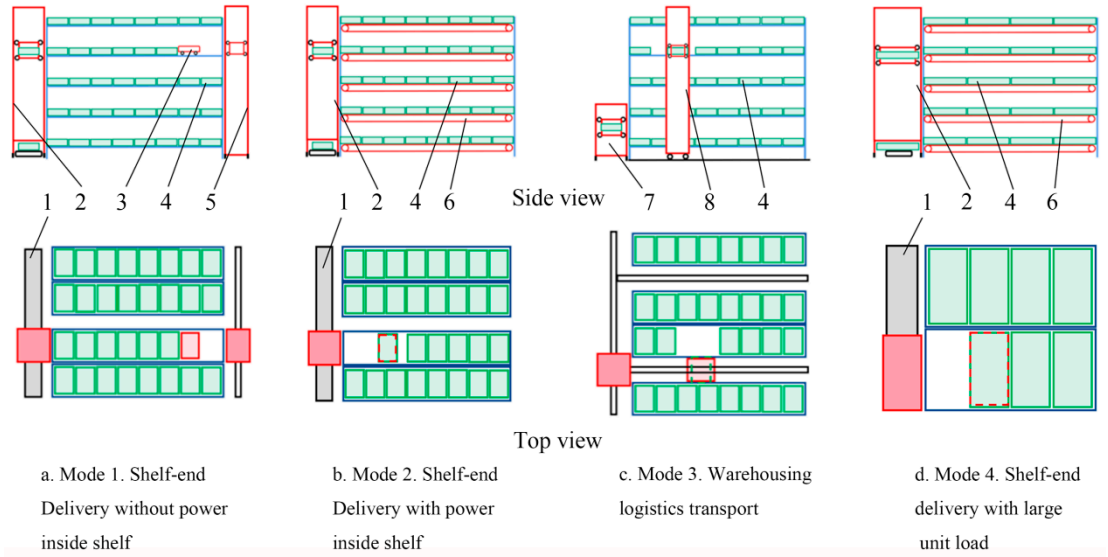


Figure 3. Four types of logistics transport systems for cultivation units in plant factory. 1. Ground convey line; 2. Input and output lift cart (IOLC); 3. Guided pushing vehicle (GPV); 4. Vertical cultivation shelf; 5. GPV lift cart (GPVLC); 6. Convey system of cultivation shelf (CSCS); 7. End delivery lift cart (EDLC); 8. Guided delivering vehicle (GDV).

Mode 1 applies a progressive transport type suitable for the culturing of plants. Moreover, there are no power drives or conveying mechanisms inside the cultivation shelf, thereby providing a lower cost and lower failure rate.

- Mode 2—Shelf-end delivery with power inside shelf

Mode 2 includes a ground convey line, IOLC, and conveyance system for the cultivation shelf (CSCS), as shown in Figure 3b. A CSCS is arranged in each layer of the entire cultivation system. The ground convey line is connected to the IOLC. During input, the IOLC stops at an input position of the cultivation shelf. The ground convey line delivers cultivation units one-by-one to the position just under the IOLC. The IOLC picks up, lifts, and places the cultivation unit into a target layer, and finally, the CSCS of the current layer moves the cultivation unit one unit distance toward the inside. The input operation is conducted in cycle by the IOLC, CSCS, and ground convey line, with a cultivation unit quantity set by the operator. The output operation is just a reversal of the input operation.

Mode 2 also applies a progressive transport type. However, compared with Mode 1, there is one less lift cart outside the cultivation shelf of Mode 2. The CSCSs inside the cultivation shelf may lead to high costs and high failure rates, because the CSCSs are arranged in each layer of the cultivation shelf.

- Mode 3—Warehousing logistics transport

Mode 3 includes an end-delivery lift cart (EDLC) and guided delivering vehicles (GDVs). The GDVs move outside of the cultivation shelves, as shown in Figure 3c. Moreover, there are other warehousing logistics transport modes, in which the GDVs move inside the cultivation shelves. During input, the EDLC stops at an input position of the cultivation shelf, and the GDV moves out of the EDLC and enters a rail between two cultivation frames of the cultivation shelf at the target layer. The GDV removes a cultivation unit from the cultivation shelf, then returns and places the cultivation unit into the EDLC; finally, the ELDC sends several cultivation units to a target position or to another delivery cart. The output operation is just the reverse of the input operation. A GDV can pass through different layers of different cultivation shelves using the ELDC, so as to input or output cultivation units with a cultivation unit quantity set by the operator.

Mode 3 can directly remove any cultivation unit in the whole cultivation shelf using the GDV. However, the delivery method using the GDV moving inside the cultivation shelf is a progressive picking type. Owing to its reciprocating transport type, the transport

efficiency of this mode is lower than that of the progressive transport types of Mode 1 and Mode 2. Moreover, most transport operations for the cultivation units are conducted one-by-one for scale plant production; therefore, Mode 3 is unsuitable for most cultivation scenarios, and is especially unsuitable for large-scale production.

- Mode 4—Shelf-end delivery with large container

Mode 4 applies the same delivery method of cultivation units as Mode 2; however, its cultivation container is many times larger than the cultivation unit of Mode 2. Thus, many cultivation units can be placed in the container. This method requires more space for transporting cultivation units and is suitable for scenarios demanding highly efficient and automated production.

2.4. Establishing an Efficient Logistics Transport System

In this study, according to the production process shown in Figure 1, as combined with the large-scale production demands of plant factories, a production system was designed. The production system providing daily batch repeated seeding, germination, seedling raising with vertical cultivation shelves, spacing of seedlings, transplanting of seedlings, cultivation with vertical cultivation shelves, and packaging. To reduce transport links, avoid requiring power inside the vertical cultivation shelves, and simplify the overall system, a progressive input-output logistics transport system was constructed for the cultivation units. The cultivation structure was a set of two vertical cultivation shelves, each with six layers and a total of 180 cultivation units (Figure 4). The operation mode of the logistics transport system was the same as that of Mode 1, as shown in Figure 3. The transport system included a ground convey line, an IOLC, GPV and GPVLC, as shown in Figure 4.

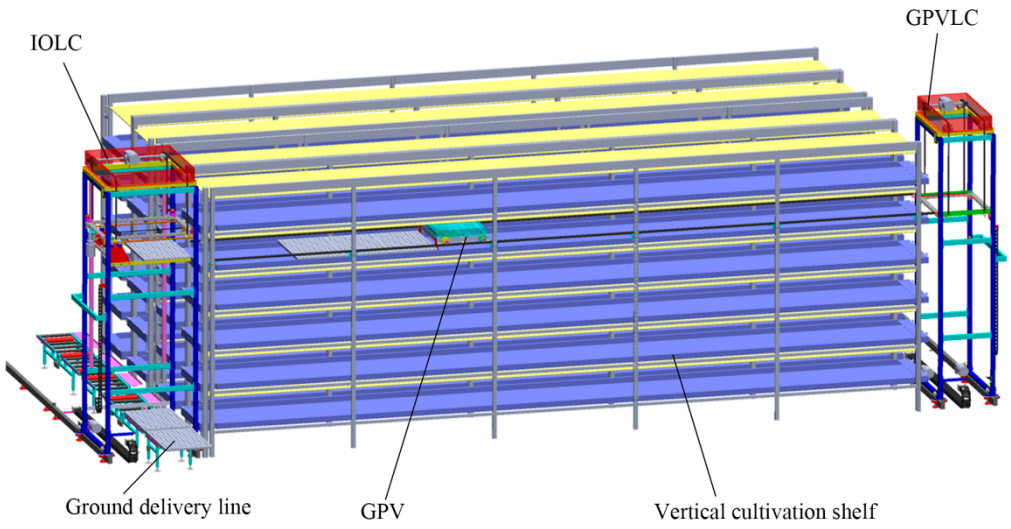


Figure 4. Vertical transport system of cultivation units without power inside shelf.

The system was only equipped for two vertical cultivation shelves, each having six layers with 30 cultivation units in each layer; each cultivation unit was 596 mm × 954 mm. Through transport tests of the cultivation units, the operation speed of the key operation links could reach the speeds shown in Table 1, therefore, the transport system reached 330 cultivation units h-1 for the input transport productivity, and 270 cultivation units h-1 for the output transport productivity. As an extension, its transport capacity was 51,840 hydroponic leafy vegetables in 8 h per day, with a cycle of 13.3 s for transporting one cultivation unit. Therefore, it could be expanded into a larger operational area as a unit. The established logistics transport system is shown in Figure 5.

Table 1. Operation parameters of key operation links for delivering cultivation units.

Machines	Items	Values
Input and output lift cart (IOLC)	Mean vertical speed (m/s)	0.6
	Mean horizontal speed (m/s)	0.5
	Time for putting cultivation unit in or outs (s)	6.5
Guided pushing vehicle (GPV) lift cart (GPVLC)	Mean lift speed (m/s)	0.6
	Mean horizontal speed (m/s)	0.5
GPV	Mean moving speed (m/s)	0.5

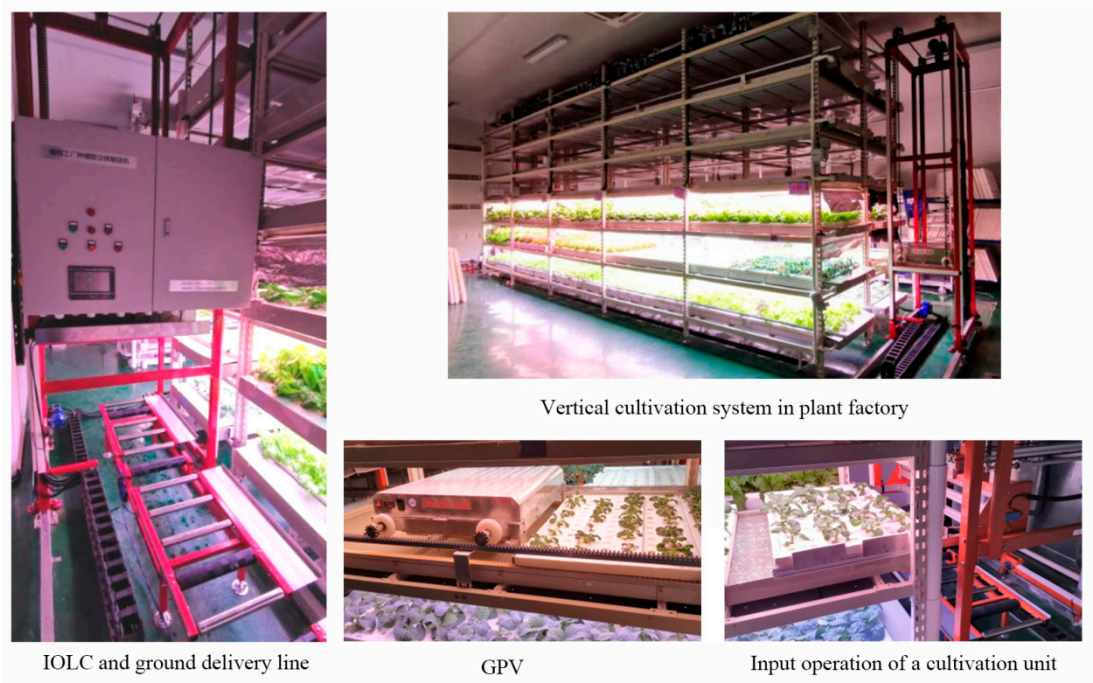


Figure 5. Equipment of the vertical transport system of cultivation units without power inside shelf in plant factory.

It was located in the plant factory of South China Agricultural University.

2.5. Productivity Simulation Using Flexsim

Transport productivity is an important factor in transport systems. Therefore, in this study, each of the four transport modes were simulated, so as to compare their productivities under different operating conditions using Flexsim 20.02 (Flexsim Software Products Inc., Salt Lake City, UT, USA). Flexsim is a complex multi-objective system software for simulating logistics transport and can output the running results of different parameter combinations of multiple objectives for calculation and comparison [30]. The transport operations of the four modes of the cultivation unit transport system were simulated using Flexsim simulation software according to the basic data shown in Table 1.

In this study, the transport productivities of the four types of cultivation unit logistics modes for the same vertical cultivation shelves were compared, as shown in Figure 6. As mentioned above, each cultivation shelf had six layers. Each cultivation unit had the specifications and size as described in Section 2.2. According to the transport process of each conveying equipment operation of the vertical cultivation shelf in the cultivation area of the plant factory, the operation area was divided for the simulation layout. Four simulation models were obtained (as shown in Figure 6) after selection of the resource type of each conveying equipment, corresponding parameters and their attributes, space positions, and corresponding entity models [31]. According to the operation velocities of

the conveying machines shown in Table 1, the four types of logistics transport systems were simulated using Flexsim software, and the simulated transport productivity was simulated under different cultivation unit capacities in one layer and different total numbers of transport cultivation units. The level values of the cultivation unit number in one layer and the total number of transport cultivation units are shown in Table 2; these values are common for scale production. The simulation results for the transport productivity are shown in Figure 7.

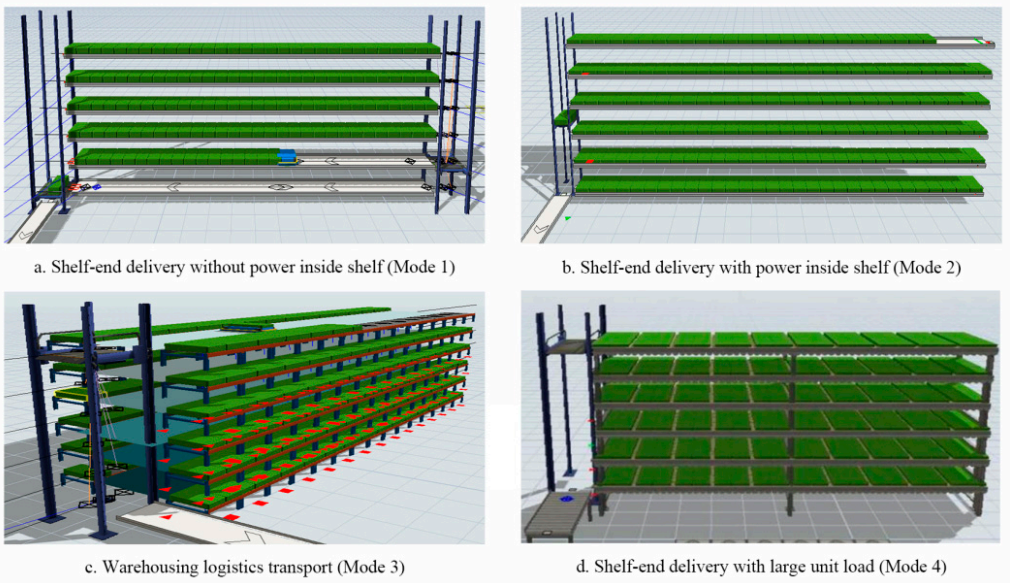


Figure 6. Simulation models of four transport modes.

Table 2. Level values of simulation experiment with Flexsim.

Level	Transport Mode	Capacity for Cultivation Units in One Layer/Unit	Total Delivery Number of Cultivation Units/Unit
1	Mode 1	20	40
2	Mode 2	30	80
3	Mode 3	40	120
4	Mode 4		160
5			200
6			240

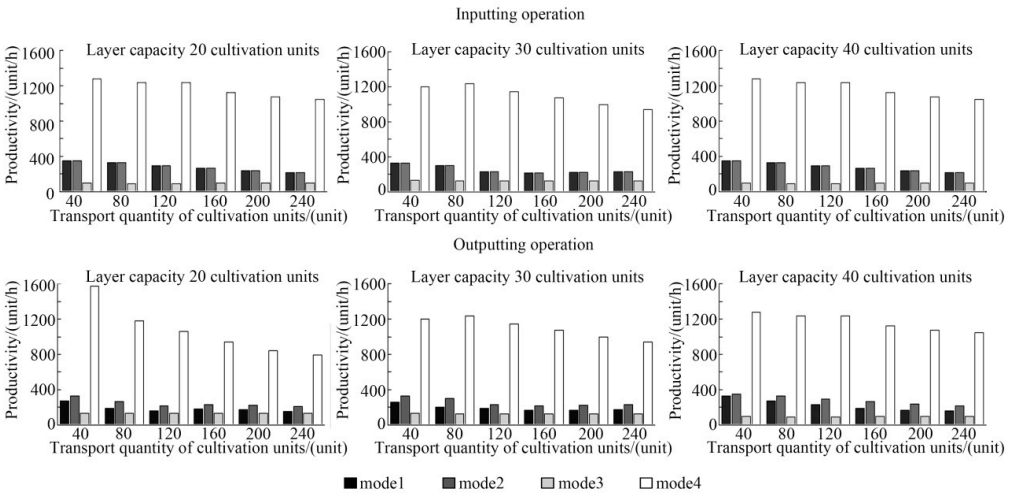


Figure 7. Productivity simulation results of different transport modes using Flexsim software.

3. Results and Discussion

Determining a transport method for a cultivation unit for vertical cultivation is very complex, and requires consideration of the transport productivity, investment, and area covered by the equipment. Through analyses of the transport productivity and other relative factors, the advantages and disadvantages of the four transport models were compared, as discussed below.

3.1. Productivity

Productivity is the first consideration of a transport system of cultivation units and affects whether the production enterprise can conduct large-scale production in plant factories. Moreover, it determines whether the cost of adding the equipment to the transport system and labor cost of the labor replaced by the equipment can offset each other, and the recovery cycle of the equipment.

As shown in Figure 7, the productivity of Mode 4 is the highest. However, its large transport equipment (i.e., the cultivation unit container) leads to an increase in the cost of the transport equipment and the area covered by the transport equipment. In addition, the transport capacity of the cultivation unit should match the processing capacity of the other operations, such as seeding, transplanting, and harvesting, which may have lower productivity relative to transport operations. In this case, the transport productivity of the cultivation units is excessively fast, which has little significance. Compared with other transport modes, the productivity of Mode 3 is the lowest, as it uses a reciprocating transport type. Moreover, the longer the cultivation unit stays in a single layer, the longer the reciprocating transport path, which lowers the transport productivity; therefore, the improvement in Mode 3 is limited to increasing the cultivation unit quantity in each layer.

In the four transport modes, only the transport productivities of Mode 1 are different when the input productivity is approximately 10% higher than the output productivity. The reason is that the input operation can place the cultivation unit into the cultivation shelf without waiting, whereas the output operation must pick up the cultivation units one-by-one, as combined with pushing by the GPV under no power inside the vertical cultivation shelf. However, the transport productivity of the cultivation unit remains much higher than that of transplanting and harvesting [32,33].

As shown in Figure 7, when comparing the progressive transport mode and warehousing reciprocating transport mode for cultivation units, the transport productivity of the former is higher than that of the latter, and the difference between the two transport productivities is proportional to the layer capacity for cultivation units of the vertical cultivation shelf. When the capacity for cultivation units in each layer is 20 units, the transport productivity of the progressive transport mode is 115–200% higher than that of the reciprocating transport mode; when the capacity for cultivation units in each layer is 40 units, the transport productivity of the former is 130–250% higher than that of the latter.

3.2. Investment

The equipment investment determines whether production enterprises can undertake and implement the construction of a logistics transport system. In addition, the equipment investment determines the payback period of the equipment. Transport machinery is a conventional industrial technology and equipment, and most logistics transport systems are integrated from this type of equipment; there is almost no price difference. Conventional industrial technology and equipment can meet the demands of plant production for vertical cultivation in plant factories, depending on the production process of the plant. The reasons for a high price for a logistics transport system may arise from two aspects. One is the application of high-tech products such as high-tech robots and wireless navigation vehicles, and the other is the use of a power driving mechanism in each layer of the entire vertical cultivation shelves; in the latter case, the large number of structural materials and drive components increase the investment.

According to Figure 7, the transport productivity of Mode 1 is not the highest. However, because there is no power in the vertical cultivation shelf, the structure for transporting the cultivation units inside the cultivation shelf is simple, and the failure rate is low. Compared with other modes, the investment cost of Mode 1 is the lowest, making it a better choice for large-scale plant factories.

3.3. Area Covered

The area covered by the transport equipment is ineluctable; however, the larger the area, the smaller the cultivation area for the plant factory [22]. The logistics transport system of Mode 4 (with a larger container transporting cultivation units) occupies a larger ground area, reducing the cultivation area for vertical cultivation in plant factories; therefore, Mode 4 is not suitable for small-scale production. The delivery vehicle does not occupy a fixed position, rather, it occupies a passageway. However, the operation of the delivery vehicle requires transmitting the para-position and obstacle avoidance, thereby requiring manipulation by high-level technicians. The use of high-level technicians leads to an increase in labor costs. An approximately fixed delivery line of a cultivation unit is a simple and faster way to transport cultivation units relative to a delivery vehicle. Therefore, delivery of cultivation units using a fixed delivery line occupying some area or a moving vehicle without rails should be considered, depending on the demands of users.

3.4. Automatic Level of Transport System

From the small-scale plant factories in Japan in the 2000s to large-scale plant factories in the USA, Europe, and China in the 2010s, there are several automation levels for logistics transport systems [22]. Some have used normal logistics equipment [34,35], and some have used high-tech robots and unmanned transport vehicles [27,35,36]. However, high-tech automation equipment requires massive capital investments to build and highly skilled labor to operate and maintain, both of which increase the financial burden on production enterprises [24,37]. Moreover, it is not easy to convince highly skilled technicians of automatic technology to work in plant factories for agricultural production. Owners of plant factories should understand the objectives when implementing automation production using a logistics system. A simple and efficient logistics system is a better way to reduce labor costs and investment. From comparing progressive types such as Mode 1, Mode 2, and Mode 4 and reciprocating types such as Mode 3, it can be observed the latter is more flexible, e.g., for transporting any cultivation unit in a vertical cultivation shelf. However, the construction of the corresponding transport equipment is complex, and the long driving line inside the cultivation shelf leads to a high failure rate and lower transport productivity. The former is a simple structure with a lower failure rate and higher transport productivity. However, its transport flexibility is limited. Overall, the key point should be matching the transport performance, cultivation mode, and automation level of the transport system, under the premises of reducing the amount of manual labor and improving productivity [24].

3.5. Integration of All Production Links

Plant factory production is a system, in that it includes not only transport equipment, but also production equipment [26]. Therefore, the cultivation unit should also be suitable for use with the production equipment of all sections, such as those for seeding, harvesting, transplanting, and washing. The objective of logistics transport in plant factories is not only to transport cultivation units for vertical cultivation shelves, but also to connect the seeding, transplanting, harvesting, and washing machines [22]. Moreover, these machines should be integrated as a whole production system for all production links, so that their transport and production productivity match each other [26].

3.6. General Analysis

The industrialization of plant production is a trend in agricultural development [38,39]. The production operation object of plant factories is plants, and there is a significant difference between plant production and industrial production. The plant production environment is extremely complex. The automated equipment faces a wet, watery, and dusty working environment, and tender and irregular operation objects with individual differences in growth [22]. In addition, the technical levels of equipment operators are generally not high [24]. Automatic transport can improve the operational efficiency and reduce the use of labor in plant factory production [1,22,26]. However, it requires not only very high capital maintenance, but also skilled technicians, which can increase labor costs [22]. Therefore, the determination of a plant factory automation operation mode should comprehensively consider the economic strength of the enterprise, operation object and operation mode, production scale, technical strength, labour cost, and other factors. The construction of vertical cultivation logistics systems for plant factories needs to consider the productivity, investment, area covered, automation level, and so on. However, different people have different opinions when choosing transport modes with different emphases [38,40]. Therefore, to rank the importance of each factor, we consulted experts, including senior managers and a production manager of a large-scale plant factory without automatic transport equipment, senior technology managers of large-scale greenhouse planting enterprises, engineers of logistics equipment manufacturing enterprises, engineers of logistics equipment-integrating enterprises, and university researchers of plant factory technology.

The results are shown in Figure 8. The managers of large-scale planting enterprises all pay more attention to the operational productivity, capital investment, and operational difficulty of logistics transport equipment. Unexpectedly, they are not too concerned with the area covered by logistics transport equipment. Moreover, owing to the different work positions in planting enterprises, their views on the matching of automation equipment with the cultivation process and other production operations are different. The views of the engineers of logistics equipment manufacturing and integrating enterprises are similar to those of the managers of large-scale planting enterprises, reflecting engineers' understanding of the practical demands of planting enterprises depending on the development experience regarding the automatic equipment for planting enterprises. University researchers generally give higher weight to equipment productivity, and lower weight to the difficulty of equipment operation. Moreover, the consistency of their views is not significant. The reason is that researchers have different understandings of the actual production situation, and the researchers in different research fields are used to focusing on the relevant factors in their respective field, resulting in different views on the various factors concerning the specialized subjects of the researchers, including engineering and horticulture.

The planting enterprise is the terminal user of the transport equipment, and the view of the equipment engineering group is close to that of the planting enterprise manager group; in contrast, the views of the University expert group are scattered. Therefore, the average results from the planting enterprise group can be used an example for evaluating the automatic transport mode of cultivation units. Accordingly, the weights of the capital investment, productivity, equipment operation difficulty, matching of the transport equipment and cultivation process, matching of the transport equipment and other automatic production equipment, and area covered by transport equipment are 22%, 20%, 20%, 20%, 13% and 5%, respectively.

According to the above evaluation weights, Mode 1 is the best suited to the demands of plant factory production enterprises, owing to its higher productivity and simpler structure. However, the final selection should be determined according to the specific requirements of the planting enterprises.

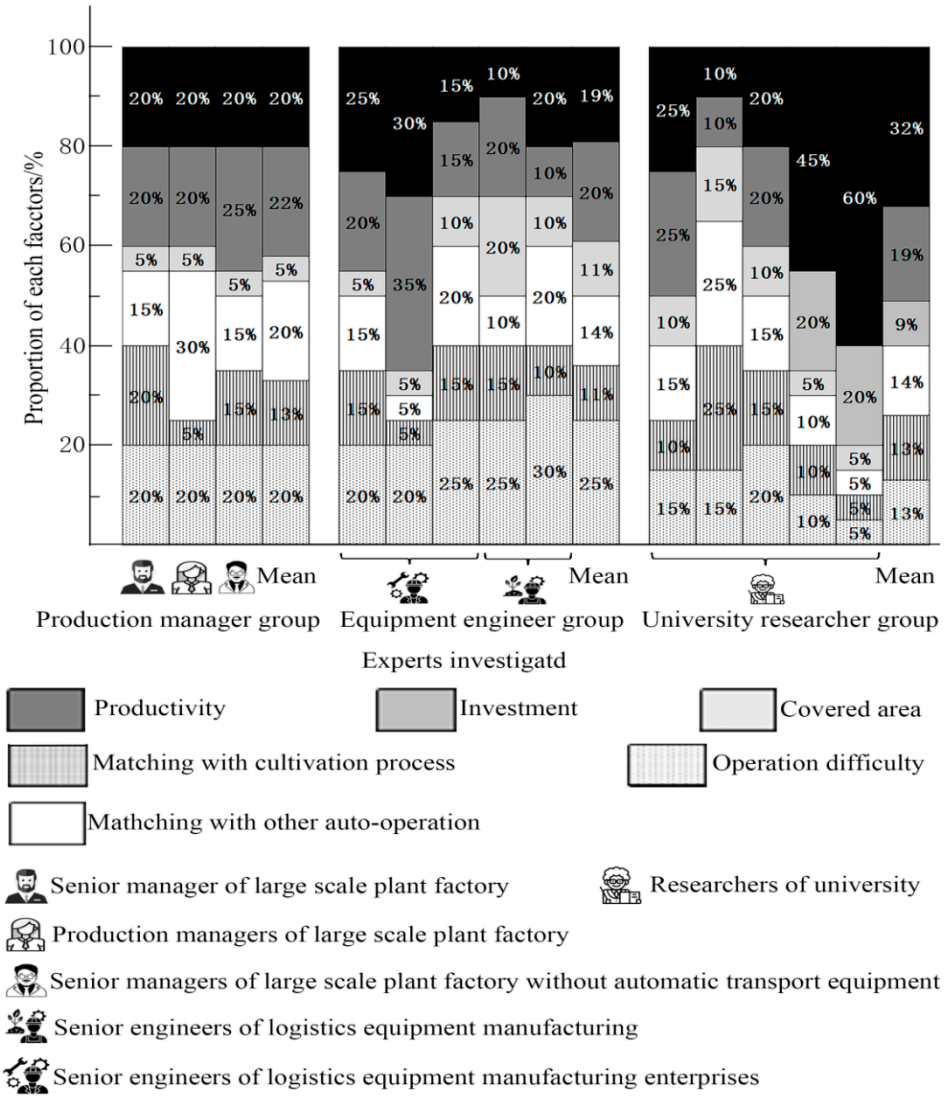


Figure 8. Views of experts investigated on the factors of plant factory construction.

4. Conclusions

1. In this study, a set of logistics transport systems for cultivation units was developed for plant factories, using a mode comprising shelf-end delivery without power inside the shelf. The system had low investment costs, a simple structure, and expandable units. From comparing the progressive transport type and warehousing reciprocating transport type for cultivation units, the transport productivity of the former is higher than that the of the latter, and the difference between the two transport productivities is proportional to the capacity for the cultivation units in each layer for the vertical cultivation shelf. When the capacity for cultivation units in each layer is 20, the transport productivity of the former is 115–200% higher than that of the latter. When the capacity for cultivation units in each layer is 40, the transport productivity of the former is 130–250% higher than that of the latter.
2. In regards to the construction of logistics transport equipment systems for cultivation units in plant factories, plant factory planting enterprises pay more attention to the capital investment, productivity, equipment operation difficulty, matching of transport equipment, and cultivation process. The automation operation of a plant factory involves many complex factors, and it is difficult to set fixed selection criteria. The selection criteria must be comprehensively considered according to the production quantity demand per day of the plant factory, financial ability, operator technician

level, operation automation level demand, and other factors. The capital investment, productivity, equipment operation difficulty and matching of the transport equipment are considered mainly for setting up a plant factory.

3. In this study, the logistics transport system developed for cultivation units for a vertical cultivation shelf using shelf-end delivery without power inside the shelf; the system reached 330 cultivation units h-1 for the input transport productivity, and 270 cultivation units h-1 for the output transport productivity. The cultivation construction comprised set of two vertical cultivation shelves, in which each shelf had six layers with 30 cultivation units in each layer. The size of each cultivation unit was 596 mm × 954 mm.

5. Patents

Invention patent application No.CN202010221482.9;
Authorization Announcement No.CN111422781B.

Author Contributions: S.G.: study design, methodology, funding acquisition, funding acquisition, data analysis, writing—review and editing; H.J.: study design, software, data interpretation, data interpretation, writing—original draft preparation; Y.Y. (Yanli Yang): date validation, original draft preparation, supervision, investigation; Q.C.: original draft preparation, data analysis, investigation; Y.Y. (Yi Yang): date validation, literature search; H.L.: literature search, Figures; X.J.: investigation, supervision. All authors have read and agreed to the published version of the manuscript.

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