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Infrastructure and functions of a city logistics node for multi-floor manufacturing cluster

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Abstract—The multi-floor manufacturing cluster is widely used in the huge city with high-density population due to the limited areas for industrial development and the necessity of unloading transport streams. The article gives the conceptual understanding of the city logistics node for multi-floor manufacturing cluster. The analysis of an infrastructure and functions of the city logistics node for the multi-floor manufacturing cluster is performed that allows allocating the components and studying their role in maintaining the cluster production. One-way turnover of production freights of the city logistics node for their multi-floor manufacturing is defined.

Keywords: multi-floor manufacturing cluster, city logistics node, turnover of production freights, freight elevators.

I. INTRODUCTION

The tendency of huge cities development is being characterized by an increase of population density due to the increase of multi-floor buildings part for various purposes in the total construction volume [1, 2]. The growth in demand for goods and services developed together with population growth. A timely satisfaction of needs of huge cities population in terms of daily household items led to the appearance of multi-floor manufacturing in the urban environment [3, 4]. This phenomenon in huge cities was contributed by a range of factors, which are the following:

- high cost of land plots and a necessity to use rationally the land resources;
- intensive road traffic, limited opportunities of transportation lines and the necessity to settle environmental transport and logistics issues [1, 5];
- miniaturization of goods, the creation of innovative products for the huge cities and the efficient usage of natural resources;
- emergence of new information, production and management technologies [1, 5 and 6];
- usage of modular, lightweight technological equipment supplied in disassembled state and assembled in production premises [5, 7 and 8];
- change in quality of labor resources [5, 9].

Multi-floor manufacturing (Figure 1) is a multi-story building 1 with freight elevators 2, in the floors of which manufacturing of products for the population of the huge city are organized. On the ground floor and the upper floors are respectively the main stock and administrative and technical premises. On the other floors technological equipment 3 for

![Figure 1. Chart multi-floor manufacturing [8]](image-url)
manufacturing is installed. Delivery of materials and components for production on floors and shipment of finished products to the main stock are carried out by means of modular trolleys and freight elevators [8]. Modular trolleys can be used for transportation of bulk, liquid and solid-state aerypyns. Feature of modular trolleys is use of the unified details for its production that allows to make their modernization, re-equipment for transportation of various types of freights and goods in the conditions of flexible multi-floor manufacturing. The modular trolleys can be used in the multi-floor manufacturing at various levels of their organization: building, cluster, city, region, country, international level. It is important to use modular trolleys in flexible production as a tool of implementation of the "Kanban Cards" philosophy [10] in the multi-floor manufacturing, which reduces the storage time of freights and finished goods in warehouses and shortens the time of receipt of goods and services by customers [11].

The located group of multi – floor manufacturing on some territory of major cities that often interconnected by production networks can be integrated into clusters. The number of multi- floor manufacturing clusters in the major city depends on its size and economic expediency. The infrastructure of multi – floor manufacturing cluster includes production and non-production (social) infrastructure with different form of ownership that is necessary for its efficient functioning. Especially, there should be noted a logistics infrastructure that is designed for maintenance of systems of procurement, delivery, storage and supply of products to the consumer.

The growth of demand for multi – floor manufacturing of products within city limits led to the development of city logistics connected with storage of materials, components, goods and various technological, control and measuring equipment, as well as other facilities. The usage of huge warehouses and logistics centers on the outskirts of the huge city implied difficulties for timely satisfaction of needs of multi – floor manufacturing clusters located within the city limits that led to the emergence of City Logistics Nodes (CLN) in the cluster for their prompt service. It is obvious that the efficient cluster productivity connected with multi – floor manufacturing and limited land resources has led to the formation of City Logistics Nodes (CLN) in the type of multi – floor buildings with infrastructure and functions of 5PL provider. The City Logistics Nodes (CLN) with possibilities of 5PL provider have a form of enterprise or group of enterprises that is an intermediary between the manufacturers and its partners as a unified connection link with provision of services of net business, it manages the processes of delivery, including courier, forwarding and storage services based on unified software [12, 13, 14 and 15].

The CLN infrastructure may be divided into three blocks: 1. infrastructure of the resource maintenance of its operation: knowledge, information, innovation, capital, energy and materials; 2. infrastructure for CLN service: support of freight operations, storage and accounting, forwarding services, insurance, execution of orders, socio-economic and other services; 3. critical infrastructure – infrastructure based on the functioning of state-owned assets of CLN in the specific economic sector [16]. The outstanding interest is caused by infrastructure and functions of CLN designed for provision of services to the city multi-floor manufacturing cluster, most of which are connected by chain of virtual enterprises. The specifics of such CLN involves the provision of services of 5PL provider to the cluster of multi – floor manufacturing with a certain capacity of production that gives an opportunity to define a probable supply turnover of CLN, the number of floors under the simulated size of the land plot, including the adjacent territory for organization of freight operations. The studying of the peculiarities of infrastructure and functions of such logistics node as a component of the cluster of multi – floor manufacturing in huge cities is of interest for development of recommendations regarding its arrangement and functioning.

The purpose of this article is to develop some recommendations regarding the formation of infrastructure and functions of CLN for provision of services to the multi – floor manufacturing cluster in the huge city, considering the production capacities of multi – floor cluster manufacturing.

1. CONCEPTUAL UNDERSTANDING OF THE CLN FOR MULTI-FLOOR MANUFACTURING CLUSTER

The CLN for multi-floor manufacturing cluster is a special nodal point in the cluster, including different logistics facilities, where separate operators are providing number of services, connected to transportation, storage, trade through international, regional and local networks, covering products and goods inbound, outbound and in transit, maintenance, logistics and distribution in local, urban, regional and intermodal coverage. Despite the productive maintenance, the CLN provides different services to the cluster personnel in form of delivery of food and household items through the Internet orders or in the cluster shops.

Figure 2 shows the chart multi – floor manufacturing cluster with CLN. Cluster represents a part of the territory of huge city with its own area of activity that has well – defined physical boundaries. Cases, the cluster boundary can be expressed not clearly, which allows implementing its combined services provision by adjoining CLN. The cluster 1 includes multi-story and high-rise buildings 2 with multi-floor manufacturing, multi-floor CLN 3 with parking 4, local (internal) road system 5 and city (external) main route 6, connected with regional and/or multimodal transport routes. Areas of offloading and loading operations 7 and 8 of CLN are adjacent to the external city main route on the one hand, and on the other hand – to the chain of local traffic roads and cluster walkways. The arriving external freights by automobile transport to the area 7 are being processed by CLN and are being loaded by the automobile transport of cluster through area 8 that is for the local roads of the consumers of multi – floor manufacturing. The distribution of the finished products of the cluster is being performed in the reverse order, if it is being sold outside the territory of huge city. Within the boundaries of the huge city, the finished products of the cluster can be delivered by own transport to other CLN or city consumers.

The size of a multi-floor manufacturing cluster depends on the capacity of its CLN. Obviously, the more the throughput of
the CLN, the greater the size of the cluster. It is difficult to quantify the size of a multi-floor manufacturing cluster. It is possible to use such evaluation criteria as the number of working personnel, the total production area of all buildings of the cluster, one-way turnover of the CLN etc. We propose as a quantitative assessment of the size of a multi-floor manufacturing cluster to use such a criterion as the total number of floors of buildings in which production is organized.

Small and medium-sized multi-floor manufacturing clusters are clusters, the total number of production floors below certain limits. These limits may vary depending on the growth of the share of high-rise buildings in the total number of urban development, the development of production and transport technologies. In European countries, these limits can be set at 50-100 floors for small multi-floor manufacturing clusters, up to 200 floors for medium-sized multi-floor manufacturing clusters, and more than 200 floors for large clusters.

**Figure 2. Chart multi-floor manufacturing cluster with CLN**

The vast majority of large cities have long-established infrastructure and their modern development is mainly due to the accession of the surrounding areas. Therefore, the organization of a multi-floor manufacturing cluster in an urban environment is possible outside the historical part of the huge city and tourist and recreational areas. The existing infrastructure of huge cities limits the possibility of placing CLNs with high capacity due to the limited necessary for their effective functioning of the adjacent territories. It is obvious that the closer to the central part of the huge city is a multi-floor manufacturing cluster, the smaller the cluster can be implemented in practice. Urban agglomeration with one huge city can be divided into three relatively large concentric zones, each of which contains clusters of the same size. Large multi-floor manufacturing clusters are located in the zone of the greatest distance from the huge city center. On the periphery of this zone are located city logistics centers, connected with CLNs and ensuring the functioning of all clusters of agglomeration. In the other two zones, as we approach the center of the huge city, there are medium and small floor manufacturing clusters. In the case of polycentric agglomeration with several equivalent core cities, it is quite difficult to form such three zones. Therefore, in conditions of conurbations around such core cities, small and medium-sized multi-floor manufacturing clusters can be formed.

The close location of CLNs with adjacent multi-floor manufacturing clusters allows them to integrate into their activity and form a city logistics cluster. In this case, a group of multi-floor manufacturing clusters associated with the city logistics cluster can form a multi-floor manufacturing mega cluster.

Figure 3 shows the chart of the multi-floor manufacturing mega cluster. Mega cluster 1 includes small 2 and medium 3 multi-floor manufacturing clusters with multi-floor CLNs 4 that form the city logistics cluster 5. The multi-floor manufacturing clusters 2 and 3 relate to the city logistics cluster 5 by an intermodal transport system that provides the possibility of cargo transportation by road 6, railway 7 and river 8 transport.

**Figure 3. Chart multi-floor manufacturing mega cluster with city logistics cluster in huge city**

II. INFRASTRUCTURE AND FUNCTIONS OF THE CLN FOR MULTI-FLOOR MANUFACTURING CLUSTER

The CLN infrastructure includes:
- adjacent external and internal road systems;
- freight terminals in the external and internal areas of offloading and loading operations along the walls of CLN;
- a multi-floor warehouse terminal with system, including freight and passenger elevators, technical and office floors;
- container freight stations for one-time storage 10 000 TEU;
- places for storage of unit loads, including the oversize;
- internal road system and tote roads;
- automobile transport for provision of forwarding services within the limits of cluster and for delivery of finished products to the consumers on the territory of city;
- engineering infrastructure facilities (heat supply, water supply, and electricity supply systems, disposal of sewage, etc.)

The CLN for multi-floor manufacturing cluster consists of two parts, one of them is designed for processing of freights for cluster manufacturing and another one is designed for freights that are necessary for life activity of cluster personnel (food products and different household goods).

Figure 4 shows separate elements of CLN infrastructure, including the chain of external 2 and internal 3 motor roads, automobile transport of cluster 4, offloading and loading external 5 and internal 6 terminals on the ground floor, floors for segregating supplies, package and storage of materials, products and items 7, floors for storage of equipment and instruments 8, floors for location of different enterprises that provide services for cluster (maintenance actions, checkout of the delivered equipment, receipt control of products, metrological services, project design work, software and etc.), administrative 10 and technical 11 floors.

Acceptance and pre-packing of products is being performed by a logistics operator with the help of management system of CLN. In this case, the heavy goods and goods that are in great demand placed on the lower floors. All freights and goods in CLN are being moved by internal transport (freight elevators, freight elevators on the floors, loading machines, modular trolleys). External freights and goods arrive in containers or in the set of modular trolleys assembled in the form of multi-modular trolleys (Figure 5 shows the chart of assembling of modular trolleys in the form of multi-modular trolleys) [4, 11]. The products of multi-floor manufacturing pre-packed in the modular trolleys suppliers are coming to the stock (ground floor of the manufacturing building), where the modular trolleys form multi-modular trolleys for the further dispatch by the automobile transport of the cluster to consumers in the huge city or in CLN in case of products dispatch to the regional or international consumers.

The internal transport includes: load-carrying vehicles of the cluster, elevators, freight elevators, loading machines, modular trolleys and other equipment. The freight elevators and maintenance terminals are advisable to be set up on the external sides, as the goods will be directly sent from the floor of acceptance to the floor of storage. The internal elevators are designed for relocation of employees and clients. The freight elevators are being used for the relocation of light goods and constitutive elements in small amounts on the storage floors of CLN. The outbound and inbound freights may be also represented by technological equipment, instruments for cluster manufacturing or demounted production equipment designed for re-engineering or utilization. The separate types of technological and metrological equipment, measurement and cutting instruments etc. may be kept in CLN and may be given in a rent to the manufacturing enterprises of cluster as the circumstances require. The technological and metrological equipment is being delivered in disassembled state as separate parts of assembly modules with the possibility of their transportation by CLN and multi-floor manufacturing freight elevators. The assembly and disassembly of such equipment is being implemented in the manufacturing or metrological premises.

Besides the well-known functions [15] in CLN a set of works is carried out related to the maintenance of multi-floor facilities and the satisfaction of the social needs of the personnel of the cluster. Such services are provided by virtual enterprises located above the CLN storage floors (positions 8, 9 fig. 2). The ratio of floors intended for warehouses and virtual enterprises should ensure CLN maximum profitability.

The production services provided by virtual enterprises are related to:
Infrastructure and functions of a city logistics node for multi-floor manufacturing cluster

- delivery or rent of technological equipment, its installation and replacement, maintenance, repair, replacement and utilization;
- delivery or rent of metal-cutting tool, press tools, control measuring tools and metrological measuring;
- incoming verification of materials and constituent parts, delivered to multi-floor manufacturing cluster, and storage;
- information resources, software support of CLN and multi-floor manufacturing work;
- marketing services, selection of goods, discovery of sales markets, their capacity, the search for consumers;
- organization of performance of project work and the formation of production;
- sale of undistributed stocks, its recycling.

The social spectrum of services is related to the supply of goods and food products at the request of the personnel of the cluster, organization of the information resources, shops, training centers, recreation centers, fitness centers, parking etc.

CLN administration, which is located on the upper floors, conducts overall management of the node. The duties of the administration include issues related to concluding contracts with virtual enterprises, attracting investments, capital, human resources, information support for the work of units, the introduction of innovations, ensuring safety and labor protection, etc. In this case, the CLN ownership form can be state, private, joint stock, cooperative, corporate, etc.

III. TURNOVER OF MANUFACTURING FREIGHTS OF THE CLN FOR MULTI- FLOOR MANUFACTURING CLUSTER

Turnover of the manufacturing freight of the CLN for multi-floor manufacturing cluster depends on productivity of multi-floor manufacturing cluster, number of floors of industrial buildings, capacity of the freight elevators, internal transport, floor-by-floor differentiation of manufacturing, technological processes and operations. Based on the provisions proposed in [4, 8], it is possible to determine the one-way annual turnover of manufacturing freight of the CLN for the multi-floor manufacturing cluster using expression:

$$G_{W|V|C} = 4800t \sum_{i=1}^{n} \frac{K_{E,i}Q_{W|V|C}S_{E,i}}{\frac{q_{i}K_{C,i}f_{i}F_{S_{E,i}}^{2}}{1 - \varepsilon_{i}S_{E,i}}}$$

where: $G_{W|V|C}$ – one-way annual turnover of production freight of CLN for multi-floor manufacturing cluster, m$^2$; $t$ – working hours per year, h; $Q_{W|V|C}$ – the rated load (volume) of freight elevator in the i-th multi-floor manufacturing building, m$^3$; $K_{E,i}$ – load factor of freight elevators in the production processes for i-th multi-floor manufacturing building; $V_{i}$ – the rate speed of the freight elevator, m/s; $S_{E,i}$ – the actual areas occupied by the freight elevator for the i-th multi-floor manufacturing, m$^2$; $q_{i}$ – the numbers of the freight elevators for the i-th multi-floor manufacturing; $Q_{i}$ – average numbers of the manufacturing cells on each floor of the i-th multi-floor manufacturing; $K_{C,i}$ – the coefficient of losses of time cycle of a work of the freight elevators in the i-th multi-floor building; $f_{i}$ – the interfloor distance in the i-th multi-floor building, m; $F_{i}$ – the number of production floor of the i-th manufacturing part of the building; $n$ – number of the multi-floor manufacturing buildings in the cluster.

Values of the $K_{E,i}$ parameter can be established based on the analysis of the share of freight traffic of freight elevators of the i-th multi-floor manufacturing in the production process using the following expression:

$$K_{E,i} = \frac{\sum_{j=1}^{x} (C_{j,i} - P_{j,i})}{\sum_{j=1}^{x} C_{j,i}}$$

where: $C_{j,i}$ – total number of rides of j-th freight elevator of the i-th multi-floor manufacturing; $P_{j,i}$ – number of rides of the j-th freight elevator of the i-th multi-floor manufacturing, related to the differentiation of production processes.

The greatest value of the $K_{E,i} = 1$, if all manufacturing technologies of products are made on the floors of the multi-floor manufacturing without moving workpieces or components between floors or between manufacturing buildings. In this case, the floor-by-floor concentration of the technological processes of production is maximum and the manufacture of products begins and ends on each floor of the i-th multi-floor manufacturing. Such concentration of the technological processes of manufacturing is typical for the cellular types of the production process organization [4, 17].

The conditions under which the value of the $K_{E,i} < 1$, arise at the floor-by-floor differentiation of the technological processes of manufacturing, as well as in the differentiation of the technological processes of production between manufacturing buildings. In these cases, the production of the product begins on one floor of the building, continues other floors or manufacturing buildings. Such differentiation of the technological processes of manufacturing is typical for network or technological types of the production process organization [4, 18 and 19].

The daily turnover of the CLN for the multi-floor manufacturing cluster is an important indicator for determining the need for calculating of the necessary amount of its storage space. The one-way daily turnover of the CLN can be found based on the expression:

$$G_{W|V|D} = 38400 \sum_{i=1}^{n} \frac{h_{i}K_{E,i}Q_{W|V|D}S_{E,i}}{\frac{q_{i}K_{C,i}F_{S_{E,i}}^{2}}{1 - \varepsilon_{i}S_{E,i}}}$$

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where: \( G_{W(V).D} \) – one-way daily turnover of production freights of CLN for multi-floor manufacturing cluster, \( t (m^3) \); \( T_{W(V).D} \) – the rated load (volume) of modular trolleys in the i-th multi-floor manufacturing building, \( t (m^3) \); \( h_i \) – the number of work shifts per day in the i-th multi-floor manufacturing; \( n_i \) – the numbers of the modular trolleys in the freight elevator for the i-th multi-floor manufacturing.

The equation (3) is valid if the following condition is satisfied:

\[
Q_{W.i} \geq n_i T_{W.i} \tag{4}
\]

The total number of modular trolleys required for daily maintenance of the multi-floor manufacturing cluster is:

\[
N_D = \frac{G_{W(V).D}}{T_{W(V).D}}, \tag{5}
\]

where: \( N_D \) – the total number of modular trolleys required for daily maintenance of the multi-floor manufacturing cluster; \( T_{W(V).D} \) – the rated load (volume) of modular trolleys.

The obtained dependencies can be used in planning the throughput of the CLN for multi-floor manufacturing cluster.

CONCLUSION

The article presents the concept of the multi-floor manufacturing cluster of the huge city, carry out analysis of the infrastructure and functions of CLN for the multi-floor manufacturing cluster, which makes possible:

1. To present a conceptual understanding of the structure and basic elements of the multi-floor cluster, the role and importance of CLN in its effective work.
2. To determine the infrastructure and functions of CLN for the multi-floor manufactures and its organizational structure.
3. To propose floor-by-floor distribution of warehouses, considering the weight of manufacturing freights as well as virtual enterprises serving multi-floor manufacture and personnel of the cluster.
4. To determine approaches for calculation the one-sided annual turnover of the manufacturing freights of the CLN considering the weight or volume productivity of the multi-floor manufacturing cluster and to identify the daily needs of the cluster in the trolleys and light or medium trucks.
5. To determine the influence of the forms of organization of the multi-floor manufacture on the turnover of the manufacturing freights of the CLN cluster.

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