System analysis of forest harvesting logistics

S M Bazarov*, V A Alexsandrov, Y I Belenky, G S Gasimov, A N Soloviev
Institute of Technological Machines and Forest Transportation, St. Petersburg State Forest Technical University, 5 Institutskiy Lane, St. Petersburg 194021, Russian Federation

*Corresponding email: s.bazarow@yandex.ru

Abstract. From the general position of logistics, forest harvesting technological complexes are multi-factor logistic flows formed by target operations of a complex production process. System analysis is included in forest harvesting logistics by constructing the functional time of the integrated connectivity of the operations performed. Minimum time of storage operations and maximum synchronization of operations in functional time are necessary conditions for optimizing logging production technologies.

1. Introduction
Under the market conditions, a sustainable development of forest industry enterprises largely depends on how much the basics of logistics, systems theory, analysis of multivariate operations, optimal management, mathematical economics, ecology, etc., are used in the formation and management of forest harvesting and transport taking into account the specifics of forest technologies.

Rational planning, organization, management and control of the processes of production and movement of material, energy, financial, information and other flows in their deep integrated connectivity is formulated by logistics. In view of the widespread use of the general principles of logistics in various areas of national economic activity, one distinguishes between the following types of logistics: military, industrial, forestry, business, economic, transport, customs, etc. [1-5]. In the logistic structure, the key element is production in its cohesive unity [6]. The aim of the study is to adapt the basic tools of logistics: time, optimality, minimum energy and financial costs, etc., to the production of specific logging complexes, which are important components of forest industry logistics [2].

2. Methods and Materials
In the mathematical modeling of logistic flows as deeply integrated systems, their presentation as algebraic structures is of decisive importance: the set of elements endowed with a property (objective function) and the mutual relation between them [7]. An important algebraic system is a group, when the binary relations between elements are of a group nature, which ensures integrity and harmony [8, 9]. With a systematic approach, the connectivity of logistics flows is investigated in the functional time of production associated with the dynamics of the production process [10].

In forest harvesting, as a coherent system of technological operations, material, energy and financial flows are characterized by dynamic parameters: capacity, technical power, cost and unit cost. With a systematic approach, the coherence of operations occurs in the functional time of production of a unit of the subject of labor, and of investment of a unit of energy and a monetary unit [10].
3. Results and Discussion
In the North-West of the Russian Federation, two characteristic processes for the production of assortments are applied:
- based on machine technology: harvester - forwarder - timber truck - sawmill;
- based on mechanized technology: chainsaw - forwarder - timber truck – sawmill.
In the functional time of the coherence of production operations, their effective capacity \( P \), power \( N \), cost \( C \), and unit cost are respectively equal to \([10]\)

\[
P = n/\sum_{i=1}^{n} P_i^i, \\
N = n^2/\sum_{i=1}^{n} N_i^i, \\
C = n^2/\sum_{i=1}^{n} C_i^i, \\
c = C/P,
\]

where, \( n \) is the number of sequentially performed technological operations by a complex of forestry equipment.

Based on the information provided by a forestry enterprise (FE), we perform a systematic analysis of these technologies.

Table 1 provides three-factor information of the FE on the production of assortments based on machine technology.

|       | Capacity, m³/h | Power, kW | Cost, Rub/h |
|-------|----------------|-----------|-------------|
| Harvester | 15              | 205       | 1614        |
| Forwarder | 15              | 205       | 1899        |
| Forest truck | 16              | 134       | 1225        |
| Sawmill | 4               | 28        | 480         |

System analysis is feasible for three options of continuous operation:
- without storage of assortments (table 2);

Table 2. Three-factor information on the production of assortments based on machine technology without storage of assortments.

|       | Capacity, m³/h | Power, kW | Cost, Rub/h |
|-------|----------------|-----------|-------------|
| Harvester | 15              | 205       | 1614        |
| Forwarder | 15              | 205       | 1899        |
| Forest truck | 16              | 134       | 1225        |
| 4 sawmills | 16              | 112       | 1920        |
- two hour storage of assortments (table 3);

**Table 3.** Three-factor information on the production of assortments based on machine technology with two hour storage.

|                | Capacity, m$^3$/h | Power, kW | Cost, Rub/h |
|----------------|-------------------|-----------|-------------|
| Harvester      | 15                | 205       | 1614        |
| Forwarder      | 15                | 205       | 1899        |
| Forest truck   | 16                | 134       | 1225        |
| 2 sawmills     | 8                 | 56        | 960         |

- four hour storage of assortments (table 4);

**Table 4.** Three-factor information on the production of assortments based on machine technology with four hour storage.

|                | Capacity, m$^3$/h | Power, kW | Cost, Rub/h |
|----------------|-------------------|-----------|-------------|
| Harvester      | 15                | 205       | 1614        |
| Forwarder      | 15                | 205       | 1899        |
| Forest truck   | 16                | 134       | 1225        |
| 2 sawmills     | 4                 | 28        | 480         |

The first option (table 2). The productivity of the harvester-forwarder-timber truck system is 15.2 m$^3$/hour, with continuous synchronized operation of the entire system four frames are needed, in this case in the system: the functional capacity is 15.5 m$^3$/hour; functional power of 147.8.0 kW; functional cost of 1666.7 Rub/hour; accordingly, the efficiency coefficient of technological capacity is 0.25; coefficient of efficiency of technological power is 0.23; coefficient of efficiency of technological costs is 0.25; and the unit cost is 107.5 Rub/m$^3$.

The second option (table 3). With two-hour storage of assortments, two frames are necessary; in this case in the system: the functional capacity is 7.8 m$^3$/hour; functional power is 108.0 kW; functional cost is 1333.3 Rub/hour; accordingly, the efficiency coefficient of technological capacity is 0.14; efficiency coefficient of technological power is 0.19; efficiency coefficient of technological costs is 0.23; and the unit cost is 171.0 Rub/m$^3$.

The third option (table 4). With four-hour storage of assortments, one frame works: the functional capacity is 4.0 m$^3$/hour; functional power is 70.2 kW; functional cost is 1000.0 Rub/hour; accordingly, the efficiency coefficient of technological capacity is 0.08; efficiency coefficient of technological power is 0.12; efficiency coefficient of technological costs is 0.19; and the unit cost is 250 Rub/m$^3$.

The calculation results of the three options for machine technology are summarized in table 5.

**Table 5.** Three factor information on the technical and economic efficiency of assortment production based on machine technology.

| Options                   | 1       | 2       | 3       |
|---------------------------|---------|---------|---------|
| Capacity, m$^3$/hour // efficiency coefficient | 15.5 // 0.25 | 7.8 // 0.14 | 4.0 // 0.08 |
| Power, kW // efficiency coefficient | 147.8 // 0.23 | 108.0 // 0.19 | 70.2 // 0.12 |
| Cost, Rub/hour // efficiency coefficient | 1666.7 // 0.25 | 1333.3 // 0.23 | 1000.0 // 0.19 |
| Unit cost, Rub/m$^3$ | 107     | 171.0   | 250     |

Based on the information provided by the FE (table 6), we perform a system analysis of the mechanized technology of production of assortments.
Table 6. Three-factor information on the procurement production of assortments based on mechanized technology.

|                  | Capacity, m³/hour | Power, kW | Cost, Rub/h |
|------------------|-------------------|-----------|-------------|
| Chainsaw         | 3                 | 3.4       | 588         |
| Forwarder        | 15                | 205       | 1899        |
| Forest truck     | 16                | 134       | 1225        |
| Sawmill          | 4                 | 28        | 480         |

System analysis is feasible for three options for continuous operation:
- without storage of assortments (table 7);

Table 7. Three-factor information on the production of assortments based on machine technology without storage of assortments.

|                  | Capacity, m³/hour | Power, kW | Cost, Rub/h |
|------------------|-------------------|-----------|-------------|
| 5 chainsaws      | 15                | 17        | 2940        |
| Forwarder        | 15                | 205       | 1899        |
| Forest truck     | 16                | 134       | 1225        |
| 4 sawmills       | 16                | 112       | 1920        |

- two hour storage of assortments (table 8);

Table 8. Three-factor information on the production of assortments based on mechanized technology with two hour storage of assortments.

|                  | Capacity, m³/hour | Power, kW | Cost, Rub/h |
|------------------|-------------------|-----------|-------------|
| 5 chainsaws      | 15                | 17        | 2940        |
| Forwarder        | 15                | 205       | 1899        |
| Forest truck     | 16                | 134       | 1225        |
| 2 sawmills       | 8                 | 56        | 960         |

- four hour storage of assortments (table 9);

Table 9. Three-factor information on the production of assortments based on mechanized technology with four hour storage of assortments.

|                  | Capacity, m³/hour | Power, kW | Cost, Rub/h |
|------------------|-------------------|-----------|-------------|
| 5 chainsaws      | 15                | 17        | 2940        |
| Forwarder        | 15                | 205       | 1899        |
| Forest truck     | 16                | 134       | 1225        |
| Sawmill          | 4                 | 28        | 480         |

The first option (table 7). The performance of the system five chainsaws - forwarder - timber truck is 15.5 m³/hour, with continuous synchronized operation of the entire system, four frames are needed, in this case in the system: the functional capacity is 15.5 m³/hour; functional power is 49.4 kW; functional cost is 1904.8 Rub/hour; accordingly, the efficiency coefficient of technological capacity is
0.25; efficiency coefficient of technological power is 0.23; efficiency coefficient of technological costs is 0.25; and the unit cost is 38.6 Rub/m$^3$.

The second option (table 8). With two hour storage of assortments, two frames are needed, in this case in the system: the functional capacity is 7.8 m$^3$/hour; functional power is 43.5 kW; functional cost is 1538.5 Rub/hour; accordingly, the efficiency coefficient of technological capacity is 0.14; the efficiency coefficient of technological power is 0.11; efficiency coefficient of technological costs is 0.22; and the unit cost is 35.4 Rub/m$^3$.

The third option (table 9). With four hour storage of assortments, one frame works: the functional capacity is 4.0 m$^3$/hour; functional power is 35.7 kW; functional cost is 1111.2 Rub/hour; accordingly, the efficiency coefficient of technological capacity is 0.08; efficiency coefficient of technological power is 0.09; efficiency coefficient of technological costs is 0.17; and the unit cost is 31.1 Rub/m$^3$.

The results of the calculations of mechanized technology are summarized in table 10.

| Options | 1   | 2   | 3   |
|---------|-----|-----|-----|
| Capacity, m$^3$/h // efficiency coefficient | 15.5 / 0.25 | 7.8 / 0.14 | 4.0 / 0.08 |
| Power, kW // efficiency coefficient | 49.4 / 0.23 | 43.5 / 0.11 | 35.7 / 0.09 |
| Cost, Rub/h // efficiency coefficient | 1904.8 / 0.25 | 1538.5 / 0.22 | 1111.2 / 0.17 |
| Unit cost, Rub/m$^3$ | 38.6 | 35.4 | 31.1 |

4. Conclusion

The technical and economic efficiency of the three-factor flows of logging production (material, energy and financial), as a deeply integrated dynamic structure, is formed in the functional time of the flow of related operations of the technological process. The operation of storing the subject of labor reduces the productivity of the complexes, the optimization of technology is achieved by maximizing the synchronization of the dynamic parameters of production flows in the functional time of the operations performed.

References

[1] Omel’chenko et al. Industrial Logistics 1997 [in Russian – Promyshlennaya logistika] ed A A Kolobov (Moscow: Moscow State University) pp 3-4
[2] Salminen E O, Borozna A A and Tyurin NA 2001 Forest industry logistics [in Russian – Lesopromyshlennaya logistika] (Saint Petersburg: SPbFTU) pp 3-4
[3] Semenenko A I 1997 Entrepreneurial logistics [in Russian – Predprinimatel’iskaya logistika] (Saint Petersburg: Polytechnica) pp 24-29
[4] Smekhov A A 1995 Basics of transport logistics [in Russian – Osnovy transportnoj logistikii] (Moscow: Transport) pp 8-11
[5] Stakhanov D V and Stakhanov V N 2000 Customs logistics [in Russian – Tamozhennaya logistika] (Moscow: PRIOR) pp 3-4
[6] Protosenko O P and Protosenko I O 2012 Logistics and supply chain management - a look into the future [in Russian – Logistika i upravlenie cepyami postavok – vzglyad v budushchee] (Moscow: DELO) pp 6-10
[7] Gurov S V 2008 Theory of systems analysis and decision making [in Russian – Teoriya sistemnogo analiza i prinятиya resheniya] (Saint Petersburg: SPbFTU) pp 7-9
[8] Faure R, Kaufmann A and Denis-Papin M 1964 Mathematiques nouvelles (Paris) pp 68-69
[9] Fried E 1972 Absztrakt algebra (Budapest) pp 27-28
[10] Bazarov S M, Belenky Y I and Soloviev A N 2018 Fundamentals of a systems analysis of production processes [in Russian – Osnovy sistemnogo analiza proizvodstvennyh processov] (Saint Petersburg: SPbFTU) pp 5-8