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STUDYING THE INFLUENCE OF PRODUCTION CONDITIONS ON THE CONTENT OF OPERATIONS IN LOGISTIC SYSTEMS OF MILK COLLECTION

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Розроблено алгоритм узгодження змісту та часу виконання робіт у логістичних системах заготівлі молока з виробничими умовами. Обґрунтовано доцільність виконання одинадцяти управлінських операцій, що забезпечують узгодження заготівельно-транспортних робіт з добовими обсягами надходження молока-сировини у пункти його заготівлі. Проведені дослідження базуються на імітаційному моделюванні виконання заготівельно-транспортних робіт з різним їх змістом та врахування мінливості виробничих умов.

На підставі імітаційного моделювання виконання робіт у логістичній системі заготівлі молока із врахуванням мінливості виробничих умов та можливих варіантів змісту робіт виконано прогнозування їх функціональних показників в окремі періоди календарного року. Обґрунтовано, що із зростанням кількості робіт щодо заготівлі молока зростають кількісні значення показників виконання цих робіт та зменшується кількісні значення показників виконання транспортних робіт.

За результатами досліджень встановлено, що впродовж календарного року у заданій логістичній системі заготівлі молока зміст виконання заготівельно-транспортних робіт та виробничі умови значно впливають на показники цих робіт. Також обґрунтовано попередній висновок, що із зростанням кількості робіт щодо заготівлі молока зростають кількісні значення показників виконання цих робіт та зменшується кількісні значення показників виконання транспортних робіт. Зокрема, що кількісне значення цих показників впродовж календарного року змінюється у 1,2...3 рази. Це пояснюється зміною обсягів заготівлі молока впродовж календарного року. Отримані результати вказують на доцільність щодобового узгодження змісту виконання транспортних робіт із виробничими умовами у заданій логістичній системі заготівлі молока

Ключові слова: планування, зміст робіт, заготівля молока, логістичні системи, якість управління

1. Introduction

In solving the problem of providing the population with high-quality food, provision of the diet of people with milk and dairy products is essential. Compliance with quality standards for manufacturing milk products in Ukraine and the European Union [1, 2] requires adoption and implementation of effective management decisions in the processes of planning and organization of logistic systems for milk collection (LSMC).

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Under modern conditions, the issues of coordination of collection and transportation operations (CTO) in LSMC with daily volumes of arrival of raw milk material at collection points (CP) remain unresolved. This problem belongs to the tasks of operative planning of content and duration of CTO execution in LSMC and has its own characteristics. At that, the toolkit for executing such operations is imperfect. That is why development of an appropriate procedure and the algorithm of computer programs for performing CTO in LSMC is relevant and essential for taking into account the changeability of production conditions in these logistic systems. To improve the technical and economic indicators of efficiency of LSMC functioning, it is relevant to substantiate possible variants of the content and time of execution of respective CTO.

2. Literature review and problem statement

Many scientific studies address solving management problems in complex organizational and technical systems in various sectors of economy. In particular, papers [3, 4] proved that making managerial decisions under intra-organizational conditions of enterprises somewhat differs when compared with systemic decisions that apply to a set of objects that are located at separate territories. This indicates that it is necessary to coordinate the content of operations in LSMC for a set of CPs, located at the assigned administrative area with production conditions in a systemic way from the unified center. Such a center is mainly composed of milk processing shops (MS), in which management problems associated with LSMC operation are solved. It is noted in papers [4, 5] that increasing the efficiency of logistic systems in various sectors requires that specific models, methods and tools that would take into account their features should be developed. In papers [6, 7], it is stated that the basis of efficiency of operation of logistic systems is to study them at the level of particular operations (works). However, it is impossible to use the scientific results proposed in the above-mentioned papers in LSMC. This is due to the fact that they do not take into consideration the peculiarities of variability of volumes of milk collection and seasonality. In addition, each administrative region has a specific network of roads of different categories and conditions. That has a significant impact on efficiency of LSMC and should be considered when predicting the indicators for operations execution in these systems.

Research [8, 9] proved that it is impossible to plan effectively the activities for different applied spheres without the use of PC tools based on applied software. At the same time, it is noted in articles [10, 11] that the tools for planning must take into consideration stochastic processes that are inherent in systems with changing manufacturing conditions. That is, it is possible to say that the above-mentioned scientific papers are important to the theory of management of separate systems. However, they offered the tools that cannot be used in LSMC. This is due to the fact that they do not take into account specific features in the technology of execution the milk collection operations, which define the content of these operations, and specific, changing production conditions.

In papers [12–14], it is proposed to simulate transport operations to determine the indicators for their execution. However, it is impossible to use the results obtained in these papers in order to coordinate CTO at a given LSMC with production conditions. This is due to the fact that variability of the daily volume of milk collection at the assigned administrative territory over a calendar year and the specific features of the content of performed operations are not taken into account in the above papers. In addition, simulation, as one of the effective tools for forecasting indicators of operations execution under given production conditions, is not used either.

The specified drawback was eliminated in papers [15–17], which proposed to adjust the content and time of operations execution to production conditions. In this case, simulation is used as a tool to adjust the content and time of operations execution to production conditions. The main disadvantage of these scientific papers, according to the authors, is that the existing tools do not take into consideration the variability of production conditions and seasonality of milk collection. This, in turn, decreases quality in planning the implementation of milk collection processes [18, 19] and, at the same time, quality of collected milk as a result of ineffective planning [17].

It is advisable to use simulation processes to adequately predict production conditions in LSMC, as well as to represent operations execution in them [20]. However, for simulation of processes in LSMC, it is advisable to carry out preliminary specific studies concerning the feasibility of indicators of production conditions for particular administrative territories [17]. Changing production conditions of milk collection are taken into account in papers [17–19]. However, it is impossible to use their tools for operative planning of operations execution in LSMC, because the proposed models do not take into consideration possible variants of daily content and duration of operations execution in LSMC [18].

Thus, an analysis of results from previous studies by other authors reveals that it is possible to say that the issues on planning in various fields of activity have been given much attention to. However, it is impossible to use the existing tools for operative planning of CTO execution in LSMC. This is due to the fact that most of the above-mentioned papers do not take into consideration the peculiarities of variability of production conditions of milk collection and features of forming the content of operations in LSMC. That is, in the authors' opinion, the above papers on making managerial decisions in complex organizational and technical systems in various industries give a significant contribution to the theory of management. However, the problem concerning the impact of variability of production conditions on the content and time of operations execution in LSMC was left out of focus.

In turn, this creates the need for predicting variability of production conditions, which requires time-consuming calculations and, consequently, the use of simulation of processes. At the same time, the solution of the problem of operative planning in LSMC is impossible without the development of an algorithm and software. Therefore, the latter should be based on simulation of processes in LSMC and adequately reflect the variability of production conditions and the specifics of operations execution. This will ensure the solution to an urgent problem regarding the coordination of the content and time of operations execution with variability of production conditions.

3. The aim and objectives of the study

The aim of this research is to substantiate regularities of change in the indicators of operations execution in logistic systems of milk collection given their different content, taking into consideration the influence of variability of production conditions.

To accomplish the aim, the following tasks have been set:

– to develop an algorithm of coordination of the content of operations execution in logistic systems of milk collection with production conditions;

– to substantiate the structure of the simulation model of operations execution in logistic systems of milk collection;

– to assess quantitatively the indicators of operations execution in logistic systems of milk collection with their different content, taking into consideration the influence of variability of production conditions.

4. An algorithm for adjusting the content of operations execution in logistic systems of milk collection to production conditions

The following operations are performed on a daily basis at the territory of a particular administrative district in LSMC:

– cooling milk raw material at CP;

– loading into a tank truck at CP;

– drawing up forwarding documents at CP;

– transportation of milk raw material;

– unloading tank trucks at CP;

– drawing up forwarding documents at MS.

Effectiveness of the CTO execution in LSMC depends on their content and the time that are determined by daily volumes of collection of milk raw materials on the territory of the administrative district. In this case, the volume of collection of raw milk from individual dairy farms is changeable over a calendar year and its particular days [18]. To solve the task on adjusting the content of CTO execution to daily amounts of collection of milk raw materials at the territory of a particular administrative region, the appropriate algorithm was developed, shown in Fig. 1.

To form a database on the production conditions of milk collection, external and internal information relative to a given LSMC is used. External information includes the requirements of current standards concerning milk collection, characteristics of climatic and natural conditions in the area of milk collection, predicted demand and prices of dairy products, etc. Internal information includes availability and territorial location of dairy farms regarding CP in LSMC, predicted volumes of milk collection in each of the farms of an administrative district, characteristics and the state of the road network.

Information about the availability and territorial location of dairy farms, which supply milk raw material to CP is taken from reporting documentation of MS [18]. Information on the amount of collection of milk raw material from each of the dairy farms on a separate day of the calendar year, for which CTO are coordinated, is taken from producers of milk. The obtained information on volumes of collection of milk raw material is passed to MS where the operations are coordinated during operative planning through the telecommunication network.

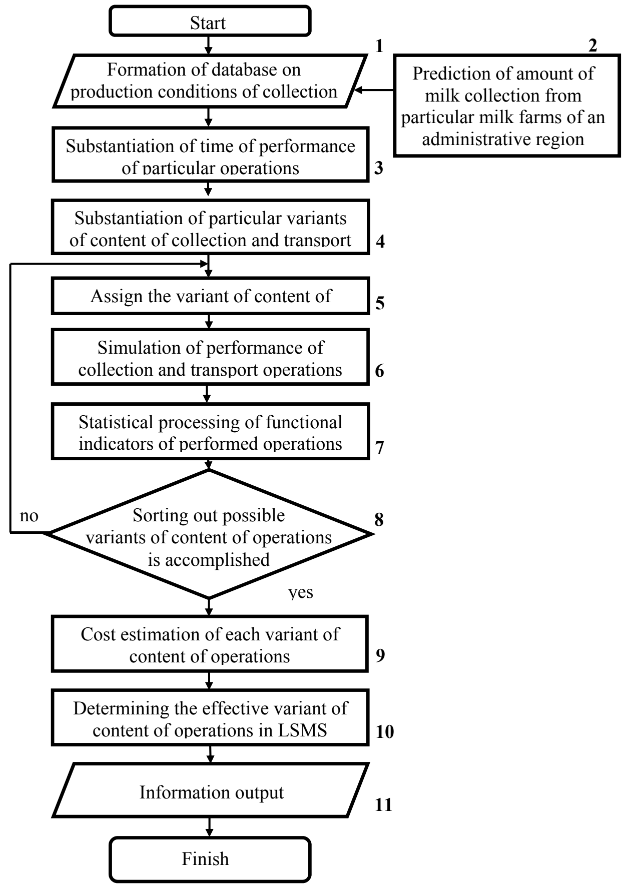

Fig. 1. Algorithm for adjusting the content of operations execution in LSMC to production conditions

The peculiarity of prediction of the volume (Q_d) of milk collection on the d-th day is that this volume is changeable and depends on the cows' lactation period. Lactation period lasts from 265 to 435 days (depending on the breed, age, and productivity of cows). Lactation period is shifted relative to the calendar year for particular cows, and milk collection is performed throughout the whole calendar year. However, the bulk of milk collection falls on summer months, during which transport vehicles are intensively used to perform the CTO.

The total volume Q_d^i of milk collection on the d-th day from the i-th farm is

$$Q^i = \sum_{j=1}^{n} Q_d^i \cdot z_d \cdot k, \tag{1}$$

where z_d is the number of cow milking within the d-th day; k is the coefficient of taking into account the share of milk raw material which was left by an enterprise for its own needs.

Daily volumes (Q_d^i) of milk collection from separate farms are different and changeable throughout the calendar year. If we know the value of annual volume (Q_{pi}) of milk collection from i farms, daily volumes (Q_d^i) are predicted using the source method [17]. In this case, the annual volume (Q_{pi}) of milk collection from i farms is determined based on statistical data taken from reporting documentation of i farms.

Duration of execution of particular CTO is determined based on industrial experiments in the assigned LSMC

[16]. To do this, photo-chronometric evaluation of separate operations is performed with the use of a stopwatch. These data determine specific duration of cargo handling works for vehicles available at MS. In addition, the sections of the route between the CP and between CP and MS and duration of their trip are recorded with the help of a speedometer of vehicles and the duration of their traffic is recorded with the use of a stopwatch. Based on these data, the average technical speed of tank trucks is determined.

Based on the experimentally obtained data under conditions of PAT "Brodivskyi ZSZM" (Lviv oblast, Ukraine) on the duration of separate cargo handling operations using CA Hyundai HD-65 STD+G6-OTA-3.9, the dependences of their duration on daily volumes ($Q_{\partial i}$) of milk collection were constructed (Fig. 2–4).

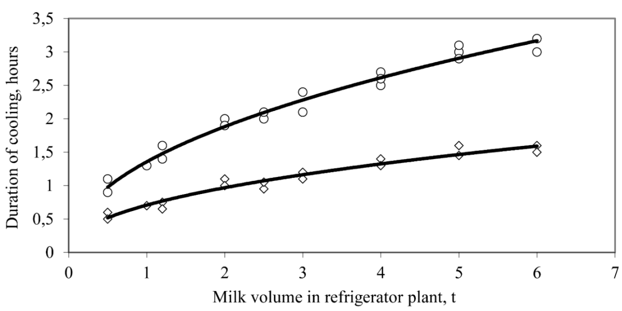

Fig. 2. Dependences of duration (t_o) of cooling milk raw material on its volume ($Q_{r.p}$) in the refrigerator plant during first (1) and second (2) milking

These dependences of duration of cooling milk raw material (t_o) on its volume in the refrigerator ($Q_{r.p}$) are described by the following equations:

– cooling milk raw material from first milking

$$t_o^1 = 1{,}355 \cdot Q_{r.p}^{0{,}473}, \ r=0.97; \quad (2)$$

– cooling milk raw material from second milking

$$t_o^2 = 0{,}707 \cdot Q_{r.p}^{0{,}452}, \ r=0.95. \quad (3)$$

Dependences (2), (3) indicate that at an increase in the volume of milk in the refrigeration plant, duration of its cooling increases in proportion. Correlative relations for the first and second milking are 0.97 and 0.95, respectively, indicating a direct link between the duration of cooling of milk raw material (t_o) and the volume of it in the refrigeration plant ($Q_{r.p}$).

Based on photo-chronometric evaluation of execution of collection and transportation operations, the dependences of duration of separate transport operations using CA Hyundai HD-65 STD+G6-OTA-3.9 on daily volumes ($Q_{\partial i}$) of milk collection were established (Fig. 3, 4).

The obtained dependences (Fig. 3, 4) are described by the following equations:

– tank truck loading at CP

$$t_l = 5{,}1 \cdot Q_M + 0{,}091, \ r=0.96, \quad (4)$$

where t_l is the duration of loading of milk raw material at CP, min; (Q_M) is the volume of milk raw material, t;

– tank truck unloading at MS

$$t_{unl} = 2{,}8 \cdot Q_M + 0{,}215, \ r=0.97, \quad (5)$$

where t_{unl} is the duration of unloading milk raw material at MS, min; (Q_M) is the volume of milk raw material, t;

– transportation of milk raw material

$$t_t = 0{,}037 \cdot L + 0{,}012, \ r=0.95, \quad (6)$$

where t_t is the duration of transportation of milk raw material, hours; L is the transportation distance, km.

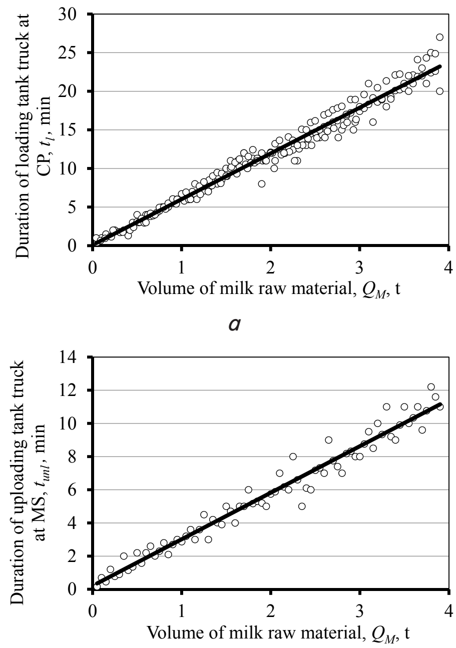

Fig. 3. Dependences of duration of loading at CP (a) and unloading at MS (*b*) of CA Hyundai HD-65 STD+G6-OTA-3,9 on daily volumes ($Q_{\partial i}$) of milk collection

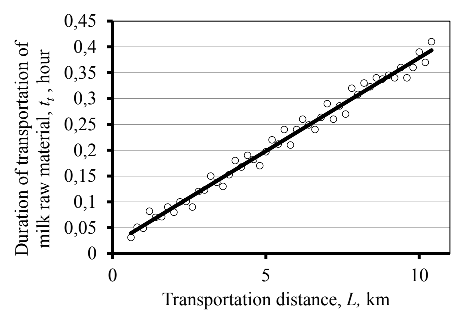

Fig. 4. Dependences of duration (t_t) of transportation of milk raw material by CA Hyundai HD-65 STD+G6-OTA-3.9 on transportation distance (L)

The duration of drawing up forwarding documents at CP and MS do not depend on the volumes of milk raw material that was loaded at CP and, respectively, unloaded at MS. The data on duration of drawing up forwarding documents at CP (t_{on}) and at MS (t_{OM}) are shown in Table 1.

Statistical processing of the data made it possible to determine the numerical characteristics, as well as to substantiate the theoretical laws of distributions, which are the Weibull distributions. The theoretical curve of distribution is described by the following equations:

– the duration of drawing up forwarding documents at CP

$$f\left(t_{on}\right)=0{,}548\left(\frac{t_{on}-1{,}5}{2{,}73}\right)^{0{,}49}\times\exp\left[-\left(\frac{t_{on}-1{,}5}{2{,}73}\right)^{1{,}49}\right],\qquad(7)$$

– duration of drawing up forwarding documents at MS

$$f\left(t_{OM}\right)=0{,}281\left(\frac{t_{OM}-3{,}1}{4{,}22}\right)^{0{,}18}\times\exp\left[-\left(\frac{t_{OM}-3{,}1}{4{,}22}\right)^{1{,}18}\right].\qquad(8)$$

Table 1

Experimental data on duration of drawing up forwarding documents at CP (t_{on}) and at MS (t_{OM})

Indicator	Numerical values									
Duration of drawing up forwarding documents at CP (t_{on}), min.	0,5	1,5	1,6	1,6	1,7	1,7	1,8	1,9	2,0	0,06
	2,1	2,2	2,3	2,4	2,5	2,5	2,6	2,6	2,7	0,07
	2,8	2,8	2,9	2,9	3,0	3,1	3,3	3,4	3,4	0,07
	3,5	3,7	3,7	3,8	3,9	4,0	4,2	4,2	4,3	0,08
	4,4	4,0	4,5	4,7	4,7	4,9	5,0	5,2	5,3	0,08
	5,3	5,4	5,5	5,8	6,0	6,2	6,3	6,5	6,7	0,09
	7,1	7,3	7,6	7,7	–	–	–	–	–	0,09
Duration of drawing up forwarding documents at MS (t_{OM}), min	3,1	3,1	3,2	3,2	3,3	3,4	3,4	3,4	3,5	0,18
	3,5	3,5	3,7	3,8	3,9	4,2	4,2	4,3	4,4	0,21
	4,6	4,7	4,9	4,9	5,0	5,0	5,1	5,1	5,2	0,23
	5,2	5,3	5,5	5,7	5,8	5,9	6,0	6,2	6,4	0,25
	6,6	6,6	6,8	6,8	7,0	7,0	7,1	7,2	7,4	0,27
	7,4	7,5	7,7	7,8	8,4	8,7	8,8	9,0	9,2	0,29
	9,4	9,6	9,9	10,3	10,6	10,8	11,4	11,9	12,4	0,33
	13,6	14,1	15,2	16,3	17,5	18,4	–	–	–	–

The following main statistical characteristics of distribution of duration of drawing up forwarding documents at CP (t_{on}) and at MS (t_{OM}) were established. In particular, assessment of mathematical expectation of these durations is 3.9 and 7.1 min, respectively. Estimation of root mean square deviation of these durations is 1.66 and 3.42 min, respectively. Confidence interval of these durations is 1.5...8.4 min and 3.1...18.6 min, respectively.

The adequacy of obtained distributions was verified by χ^2-Pearson criterion. The obtained calculation values of criteria χ^2 were compared with the table $(\chi^*)^2$ values. For distributions of durations of drawing up forwarding documents at CP (t_{on}) and at (t_{OM}), the values of criteria χ^2 are

$$\left(\chi^2=1{,}56\right)<\left(\left(\chi^*\right)^2=2{,}25\right)\text{ and }\left(\chi^2=2{,}5\right)<\left(\left(\chi^*\right)^2=7{,}81\right),$$

respectively. This indicates that the obtained theoretical curves of Beibull distributions adequately display empirical data of durations of drawing up forwarding documents at CP (t_{on}) and at MS (t_{OM}).

The obtained dependences and distributions of duration of execution of separate CTO are the basis for simulation of these operations for the purpose of quantitative assessment of their indicators for their different content, taking into consideration the influence of variability of production conditions.

Based on the analysis of the content and duration of execution of collection operations in existing LSMC, their possible variants were established (Fig. 5). In particular, the operations regarding delivery of milk raw material from the CP to MS can be carried out by the following patterns – one, two or three times a day. This is mainly caused by the physiological features of cows and peculiarities of organization of collection operations. As far as physiological features of cows are concerned, in winter months cows are milked twice a day because the duration of the light daytime is short. In all other months of the year cows' milking is organized three times a day. This indicates that it is possible to organize operations of milk collection on a single day not exceeding the number of milking of cows on this day.

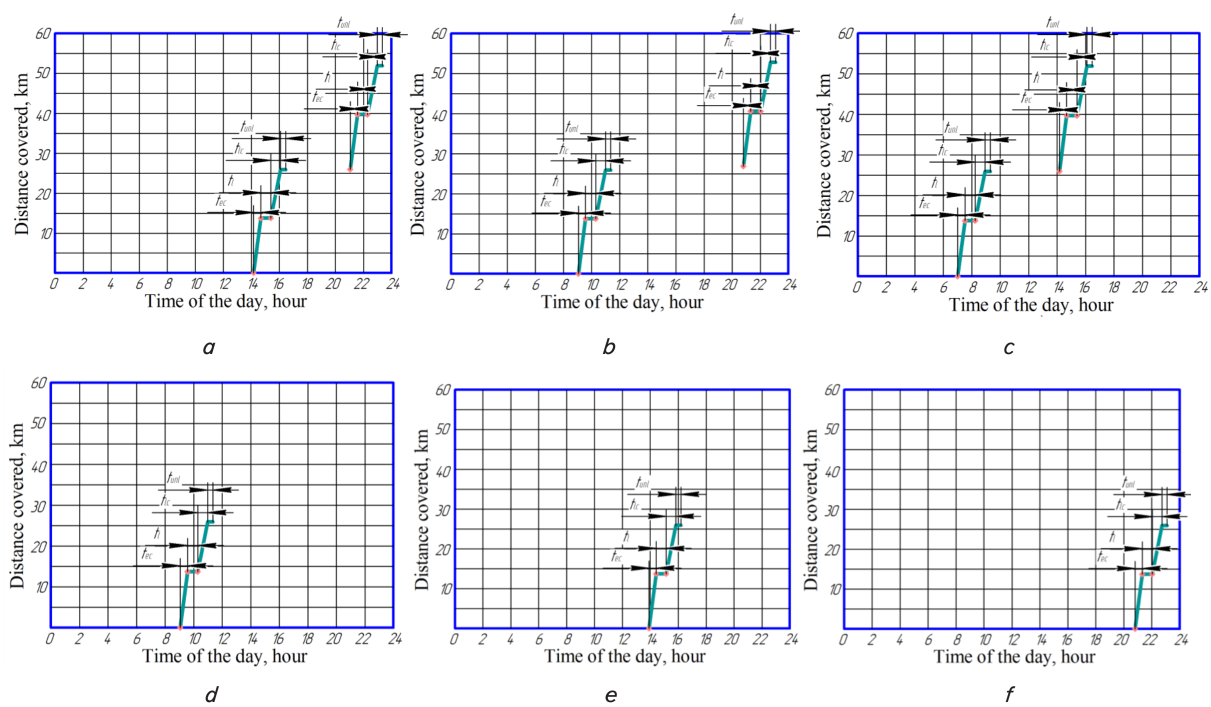

Fig. 5. Schedule of CTO execution: *a–c* – twice a day; *d–f* – once a day

If milk is collected three times a day, it is necessary to plan three trips of tank trucks at each CP. If milk is transported twice a day, there are several options for content and time of CTO execution:

1) the milk stored in the morning and in the afternoon is transported in the afternoon, the milk stored in the evening is transported in the evening (Fig. 5, *a*);

2) the milk stored in the morning is transported in the morning, the milk stored in the afternoon and in the evening, is transported in the evening (Fig. 5, *b*);

3) the milk stored in the evening of the previous day and in the morning of the current day is transported in the morning and the milk stored in the afternoon is transported in the afternoon (Fig. 5, *c*).

If transport operations are organized once a day, the following variants of content of time of execution of these operations are possible:

1) the milk stored in the afternoon and in the evening of the previous day and in the morning of the current day is transported in the morning (Fig. 5, *d*);

2) the milk stored in the evening of the previous day and in the morning and in the afternoon of the current day is transported in the afternoon (Fig. 5, *e*);

3) the milk stored in the morning, in the afternoon and in the evening of the current day is transported in the evening (Fig. 5, *f*).

The obtained diagrams (Fig. 5) were plotted based on simulation of execution of transport operations. To do this, we used the simulation model of operations execution in LSMC, which is substantiated below.

Thus, there are seven variants of the content and duration of CTO, among which it is necessary to determine the most effective. The effective variant of the CTO was determined based of their simulation for the assigned production conditions in LSMC.

5. Substantiation of the structure of the simulation model of operations execution in logistic systems of milk collection

Simulation of CTO execution in LSMC is carried out with the aim of quantifying the indicators of execution of specified operations for their different content, taking into consideration the influence of changeability of production conditions. These indicators include:

1) technological demand for tank trucks at CP;

2) time consumption to perform separate CTO and service particular routes (t_μ);

3) covered distance (L_μ) and performed cargo freight (W_μ) for separate routes of transportation of milk raw material;

4) consumption of electric power by refrigerating equipment and of consumptions of water for its washing.

Simulation of CTO execution was carried out by stages:

1. The block diagram and the algorithm for statistical simulation, as well as software for its implementation on PC, were developed.

2. Previous simulation was performed and the adequacy of the model of actual duration of execution of the CTO for the conditions of PAT "Brodivskyi ZSZM" was verified.

3. Computer experiments (simulation of CTO execution) for different variants of the content of operations were performed.

4. The results of simulation were analyzed and dependences of indicators of execution of the specified operations for their different content, taking into consideration the impact of changing production conditions, were substantiated.

The block diagram and the algorithm for simulation of the CTO execution for different variants of their content were developed based on substantiated methods, models and procedures of coordination of CTO with daily volumes of milk arrival [17]. The block diagram consists of 12 blocks (Fig. 6).

Based on revealing the content of the blocks shown in the block-diagram, we developed the algorithm for simulation of execution of CTO, consisting of 14 steps.

Each of the steps of the proposed algorithm means the following:

1. Entering initial data for simulation to PC memory:

– number of CP performing milk collection – *n*;

– number of days, for which the volumes of milk collection are predicted – *d*;

– number of variants of content of CTO *d*1;

– loading capacity of tank truck *a*1;

– average technical speed of tank track motion *vr*;

– specific duration of operations execution at CP *ptz*;

– specific duration of operations execution at MS *ptr*.

2. Formation of arrays of characteristics of production conditions, specifically;

– daily volumes ($Q_{d\text{i}}$) of milk collection at the *i*-th CP

$$MK := (Q_{dij})_{n\times d}, \qquad (9)$$

where (Q_{dij}) is the volume of milk collection at the i-th CP of the *d*-th day throughout the calendar year, t.; *n* is the number of CP, units; *d* is the number of days of prediction of volumes of milk collection, units.

$$MV := (V_{ij})_{n\times n}, \qquad (10)$$

where (V_{ij}) is the distance between the i-th and the *j*-th settlements, km.

3. Allocation of space in PC memory for the arrays of:

– indicators (*MN*) of execution of transport operations on each route:

$$MN := (\psi_{ij})_{k\times n}, \qquad (11)$$

where ψ_{di} is the indicator of execution of transport operations at the i-th CP on the *d*-th day; *k* is the number of indicators of execution of transport operations, units.

– volumes (*MD*) of milk collection at CP for different variants of the content of collection and transportation operations

$$MD := (Q_{nid})_{\omega\times n}, \qquad (12)$$

where (Q_{nid}) is the volume of milk accumulation at CP at the *i*-th CP on the *d*-th day; ω is the number of variants of content of collection and transportation operations, units;

– results (*MR*) of determining the indicators of execution of collection and transportation operations for their different content

$$MR := (\psi_{ij})_{\omega\times n}, \qquad (13)$$

where ψ_{id} is the indicator of collection and transportation operations at the i-th CP on the *d*-th day; ω is the number of variants of the content of collection and transportation operations, units

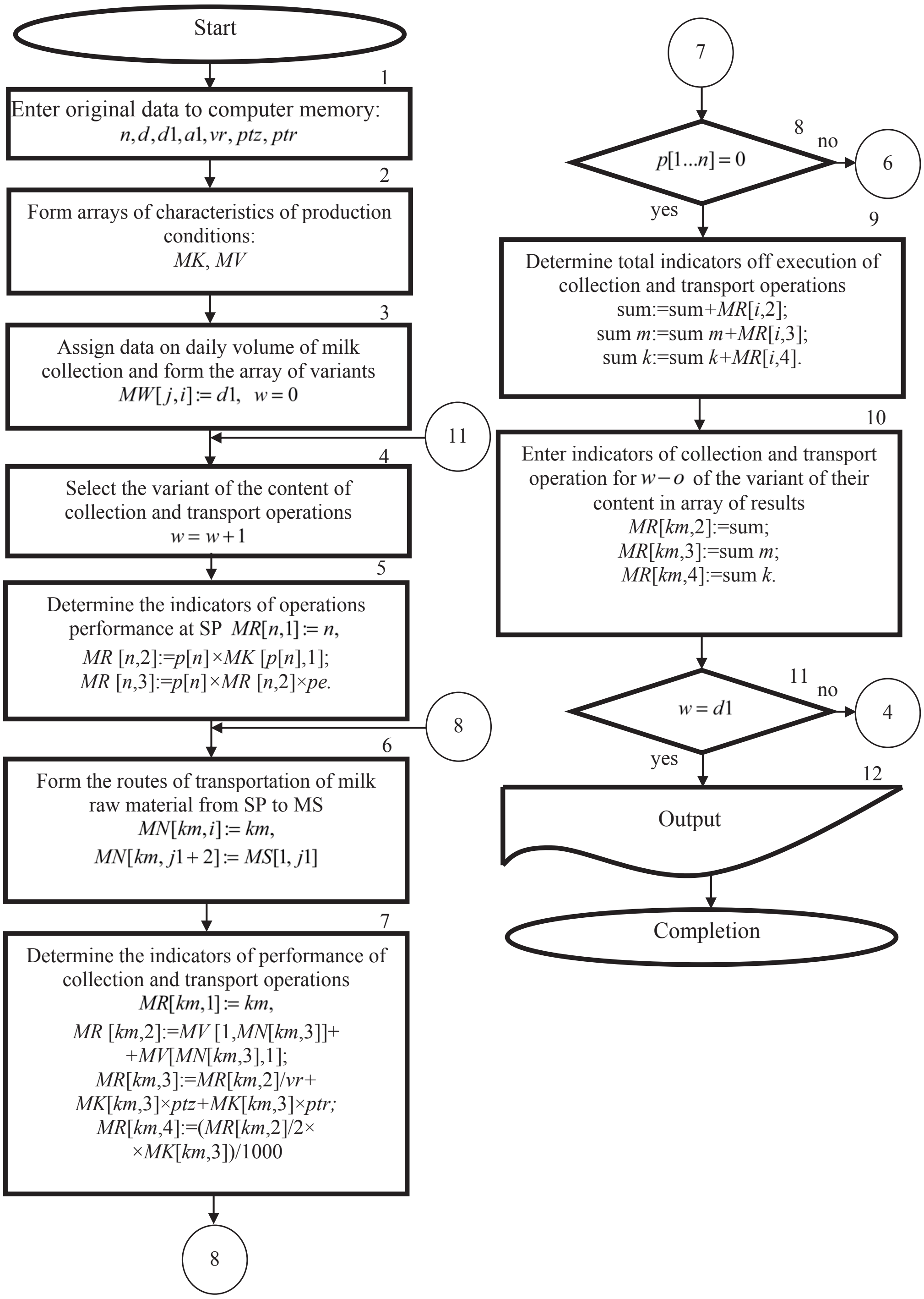

Fig. 6. Block diagram of the algorithm for simulation of CTO execution

4. Preparing the data on daily volume ($Q_{\partial i}$) of milk collection at i CP and formation of arrays of variants of the content of collection and transportation operations

$$MW := (Q_{\partial i})_{\omega \times n}. \quad (14)$$

5. Selection of a variant of the content of collection and transportation operations and assigning the value

$$\omega = \omega + 1. \quad (15)$$

6. Determining indicators for the execution of collection operations at CP, specifically

– recording the number of CP

$$MR[n,1] := n; \quad (16)$$

– determining the duration of milk cooling at CP, using dependences (2) and (3) and entering numerical values to the array of results (*MR*):

$$t_o^1 = 1{,}355 \cdot Q_{r.p}^{0.473},$$

$$t_o^2 = 0{,}707 \cdot Q_{r.p}^{0.452}, \quad (15)$$

$$MR[n,2] := t_{oi}; \quad (17)$$

– determining the volumes of consumed electricity at CP and entering numerical values to the array of results (*MR*):

$$Q_{ei} = q_e \cdot Q_{r.pi} \cdot t_{oi}, \quad (18)$$

$$MR[n,3] := Q_{ei}, \quad (19)$$

where ($Q_{r.p}$) is the volume of milk raw material in the refrigeration plant, t

7. Formation of routes of transportation of milk raw material from CP to MS for the assigned variant of the content of collection and transportation operations with recording:

– the route number

$$MN[km,i] := km; \quad (20)$$

– the order of arrivals at CP along the route

$$MN[km, j1+2] := MS[1, j1]. \quad (21)$$

8. Determining the indicators of execution of transport operations along a separate route and entering numerical values to the array of results (*MR*), specifically:

– transportation distance

$$L_{\mu ij} = L_{zx} + \sum_{i=1}^{n_\mu} L \; + L \;, \quad (22)$$

where $L_{\mu d}$ is the distance covered by a tank truck along the μ-th route of bringing milk from CP to MS on the *d*-th day, km; L_x, L_{ij}, L_z are, respectively, the distance covered by a tank truck to the first CP, from the i-th to the *j*-th CP and from the last CP along the route to MS along the route, km.

$$MR[km,2] := L_{\mu j}, \quad (23)$$

– duration of servicing the route is determined based on formulas (4)–(8)

$$t_{\mu j} = t_x + \sum_{i=1}^{n_\mu} t_{li} + \sum_{i=1}^{n_\mu} t_{oni} + \sum_{i=1}^{n_\mu} t_{ti} + t_{Mi} + t_{unl} + t_{OM}, \quad (24)$$

where t_x is the duration of motion of tank trucks from the first CP along the route, h; t_{li}, t_{oni} are, respectively, the duration of loading milk raw material and drawing up forwarding documents at the *i*-th CP, h; t_{ti}, t_{Mi} are, respectively, the duration of transportation of milk raw material between the *i*-th CP and from the last CP along the route to MS, h; t_{unl}, t_{OM} are, respectively, the duration of unloading milk raw material and drawing up forwarding documents at MS, h.

$$MR[km,3] := t_{\mu j}, \quad (25)$$

– freight turnover performed along the route

$$W_{\mu j} = \sum_{i=1}^{n_\mu} Q_{Mi} \cdot L_{ij} + Q_{Zi} \cdot L_{Zi}, \quad (26)$$

($W_{\mu d}$) is the freight turnover performed by a tank truck on the μ-th route of collecting milk from CP to MS on the *d*-th day, t. km; Q_{Mi}, Q_{Zi} are, respectively, the volume of milk in a tank truck after loading at the *i*-th CP, as well as after loading at the last CP along the route, t; L_{ij}, L_{Zi} are, respectively, the covered distance by a tank truck from the *i*-th to the *j*-th CP from the last CP along the route, km.

$$MR[km,4] := W_{\mu j}. \quad (27)$$

9. Checking the condition of milk availability at CP

$$P[1...n] = 0. \quad (28)$$

If the condition is not met, proceed to step 7.

10. Determining total daily indicators of execution of transport operations for the assigned variant of their content, specifically:

– total distance covered along the routes

$$MR[i,2] := L_\partial = \sum_{\mu=1}^{n_\mu} L_{\mu j};$$

$$\text{sum} := \text{sum} + MR[i,2]; \quad (29)$$

– total duration of servicing the routes

$$MR[i,3] := t_\partial = \sum_{\mu=1}^{n_\mu} t_{\mu j};$$

$$\text{sum}m := \text{sum}m + MR[i,3]; \quad (30)$$

– total freight turnover performed along the routes

$$MR[i,2] := W_\partial = \sum_{\mu=1}^{n_\mu} W_{\mu j};$$

$$\text{sum}k := \text{sum}k + MR[i,4]. \quad (31)$$

11. Entering characteristics of execution of collection and transportation operations for the $w-o$ variant of their content in the array of results:

MR [km,2]:=sum,

MR [km,3]:=sum m,

$$MREZ[km,4]\text{:=sum } k. \quad (32)$$

12. Checking the condition of selection of all the variants of the content of collection and transportation operations

$$w = d1. \quad (33)$$

If the condition is not met, proceed to step 5.

13. Output the results for printing.

14. Finish.

Based on the presented algorithm, the software program of simulation of CTO execution in PascalABC language was developed, the volume is 38 Kb.

The next step was to perform preliminary simulation in order to verify the adequacy of the model of actual duration of execution of the CTO for conditions of the PAT "Brodivskyi ZSZM". The developed simulation model of CTO execution was tested for adequacy using a paired *t*-criterion. The original data for verification of the simulation model for adequacy are given in Table 2.

Table 2

Original data for verification of the simulation model for adequacy

Route	Data on duration of servicing CP along separate routes, hour		Difference $x_{2n}-x_{1n}$
	Production experiment x_{1n}	Computer experiment x_{2n}	
1	1.57	1.6	0.03
2	1.83	1.777	–0.053
3	3.37	3.36	–0.01
4	3.91	3.94	0.03
5	4.26	4.32	0.06
6	5	5.1	0.1
7	6.29	6.18	–0.11
8	6.89	6.91	0.02

During verification of its adequacy, the experimental and simulated values of durations of servicing separate routes ($t_{\mu i}$) by tank trucks Hyundai HD-65 STD+G6-OTA-3.9 were compared. Deviation of the obtained quantitative values of durations ($t_{\mu i}$) of performing separate routes based on simulation of CTO execution and their obtained experimental values does not exceed 2.9 %. This testifies to the adequacy of the developed simulation model of CTO execution in LSMC.

6. Regularities in change in the indicators of operations execution in logistic systems of milk collection

In order to identify the influence of the content and duration of CTO execution on their systemic indicators, their simulation was performed. To do this, the computer program in the PascalABC language, based on the algorithm substantiated above (Fig. 3), was developed at the Department of information systems and technologies at Lviv National Agrarian University (Ukraine). Simulation of CTO execution was carried out according to the previously substantiated options for the content of these operations for predictable changing production conditions of PAT "Brodivskyi ZSZM" (the town of Brody, Lviv oblast), the characteristics of which are shown above.

Based on simulation, CTO execution for each of the variants of their contents and duration of execution, the following systemic total indicators were determined:

– daily duration of cooling milk raw material at CP;
– daily volume of water consumption at CP;
– daily distance covered by tank trucks;
– daily duration of tank trucks operation;
– daily freight turnover performed by tank trucks.

The quantitative values of the basic indicators of CTO execution were obtained by the results of simulation and shown in Table 3.

Table 3

Results of determining the basic indicators of CTO execution in LSMC within separate days of milk collection season (*d*) for different variants of the content of their execution

Variant of content of operations	Day of milk collection season (*d*)											
	21	49	77	105	133	161	189	217	245	273	301	329
1	2	3	4	5	6	7	8	9	10	11	12	13
Total daily duration of cooling milk at CP (t_{oc}), h												
1	155	179.3	203.2	234.7	332.1	349.3	336.3	340.2	337.2	323.7	286.6	231.3
2	283.3	305	326.2	354.1	440	455.2	443.7	447.1	444.5	432.7	399.9	351
3	283.6	305.3	326.5	354.5	440.7	455.9	444.4	447.8	445.2	433.3	400.5	351.4
4	282.9	304.4	325.5	353.3	439	454.1	444.8	448.2	445.5	433.7	400.8	351.7
5	370.2	390.1	409.5	435	663.1	746.8	694.6	720.6	695.5	638.4	480.4	435.1
6	370.7	390.6	410.1	435.8	664.5	748.3	693.2	719.1	694.1	637.1	479.5	434.4
7	371.2	391.2	410.8	436.5	665.8	749.9	691.8	717.7	692.7	635.9	478.6	433.7
Total daily volume of water consumption at CP (Q_B), m^3												
1	18	18	18	18	18	18	18	18	18	18	18	18
2	12	12	12	12	12.84	13.1	12.9	12.94	12.9	12.68	12.28	12
3	12	12	12	12	12.68	13	12.74	12.84	12.84	12.58	12.24	12
4	12	12	12	12	12.74	13.1	12.94	13	12.94	12.68	12.28	12
5	6	6	6	6.1	8.61	9.44	8.91	9.19	8.94	8.34	6.55	6.1
6	6	6	6	6.12	8.61	9.47	8.89	9.19	8.91	8.31	6.55	6.1
7	6	6	6	6.12	8.61	9.47	8.89	9.19	8.89	8.31	6.5	6.1
Total daily volume of electricity consumption at CP (Q_{BC}), kW·h												
1	1,395	1,614	1,614	2,112	2,989	3,144	3,027	3,061	3,034	2,914	2,579	2,081
2	2,550	2,745	2,745	3,186	4,657	5,007	4,733	4,807	4,741	4,471	3,832	3,159
3	2,553	2,748	2,748	3,191	4,554	4,939	4,629	4,739	4,711	4,405	3,804	3,163
4	2,546	2,740	2,740	3,180	4,573	4,995	4,782	4,855	4,790	4,481	3,841	3,166
5	3,332	3,511	3,511	4,096	7,508	8,435	7,901	8,188	7,955	7,235	5,285	4,097
6	3,336	3,516	3,516	4,140	7,523	8,496	7,842	8,172	7,895	7,178	5,275	4,091
7	3,341	3,521	3,521	4,147	7,539	8,513	7,826	8,156	7,836	7,164	5,185	4,084
Total daily distance covered to CP (L_c), km												
1	966	966	1,090	1,158	1,454	1,554	1,460	1,488	1,460	1,522	1,262	1,158
2	672	694	777	884	1,114	1,243	1,139	1,147	1,139	1,162	993	912
3	672	686	831	864	1,122	1,244	1,128	1,157	1,128	1,176	964	876

Continuation of Table 4

1	2	3	4	5	6	7	8	9	10	11	12	13
4	672	694	819	892	1,114	1,231	1,139	1,172	1,139	1,152	993	920
5	386	437	490	536	827	857	852	849	878	834	735	536
6	386	474	490	546	827	873	852	849	852	842	735	527
7	392	516	488	546	827	873	843	878	843	836	735	527
Total daily freight turnover performed by tank trucks (W_c), t·km												
1	1,056	1,438	1,441	1,576	2,268	2,770	2,373	2,476	2,398	2,523	1,848	1,500
2	786.6	1,022	1,109	1,272	1,737	2,138	1,808	1,875	1,824	2,023	1,539	1,357
3	786.6	1,012	1,290	1,280	1,799	2,148	1,856	1,953	1,872	1,940	1,541	1,366
4	778.4	1,012	1,261	1,316	1,721	2,115	1,826	1,886	1,842	1,851	1,557	1,393
5	628.2	644.8	820.8	925.5	1,340	1,499	1,453	1,439	1,463	1,473	1,258	927.8
6	635.7	830.1	834.3	934.3	1,358	1,487	1,432	1,419	1,446	1,379	1,243	878.1
7	643.1	836.9	801	950.9	1,376	1,509	1,408	1,470	1,420	1,408	1,228	862.1
Total daily duration of execution of transport operations (t_{TC}), h.												
1	27.6	27.6	33.3	35.2	48.0	50.8	48.2	48.9	48.2	49.9	40.3	35.2
2	19.9	20.5	24.3	28.1	38.3	42.7	39.7	39.9	39.7	39.6	33.4	28.9
3	19.9	20.3	25.9	27.6	38.5	42.7	38.7	40.2	38.7	40.0	31.8	27.9
4	19.9	20.5	25.5	28.3	38.3	42.3	39.7	40.6	39.7	39.4	33.4	29.1
5	12.5	13.9	16.1	18.2	30.8	32.4	31.5	31.4	32.2	30.3	26.0	18.2
6	12.5	15.0	16.1	18.5	30.8	32.8	31.5	31.4	31.5	30.5	26.0	17.9
7	12.6	16.9	16.1	18.5	30.8	32.8	31.2	32.2	31.2	30.3	26.0	17.9

The obtained data (Table 3) were processed with the use of Microsoft Excel 2010 program, which made it possible to construct dependences of the key indicators of CTO on the day of the milk collection season (d) and the variants of their content (Fig. 4). These dependences are described by equations that are shown in Table 4.

Thus, the obtained dependences (Fig. 7, *a*) indicate that the total daily duration of milk cooling at the CP decreases at an increase in the number of trips of tank trucks from the CP to MS. The total daily volume of water consumption at the CP (Fig. 7, *b*) is constant throughout a year and makes up 18 m^3 provided milk is transferred from the CP to MS three times a day. The total daily amount of water consumption at the CP depends on the variant of CTO execution and the volumes of milk collection if milk is transported from the CP to MS once and twice a day. The total daily amount of water consumption at the CP increases at an increase in the volume of milk collection.

It was found (Fig. 7, *c*) that the total daily volume of electricity consumption at the CP decreases at an increase in the number of trips of tank trucks from the CP to the MS. At the same time, (Fig. 7, *d*), the total daily distance covered by tank trucks increases at an increase in the number of trips of tank trucks from the CP to the MS.

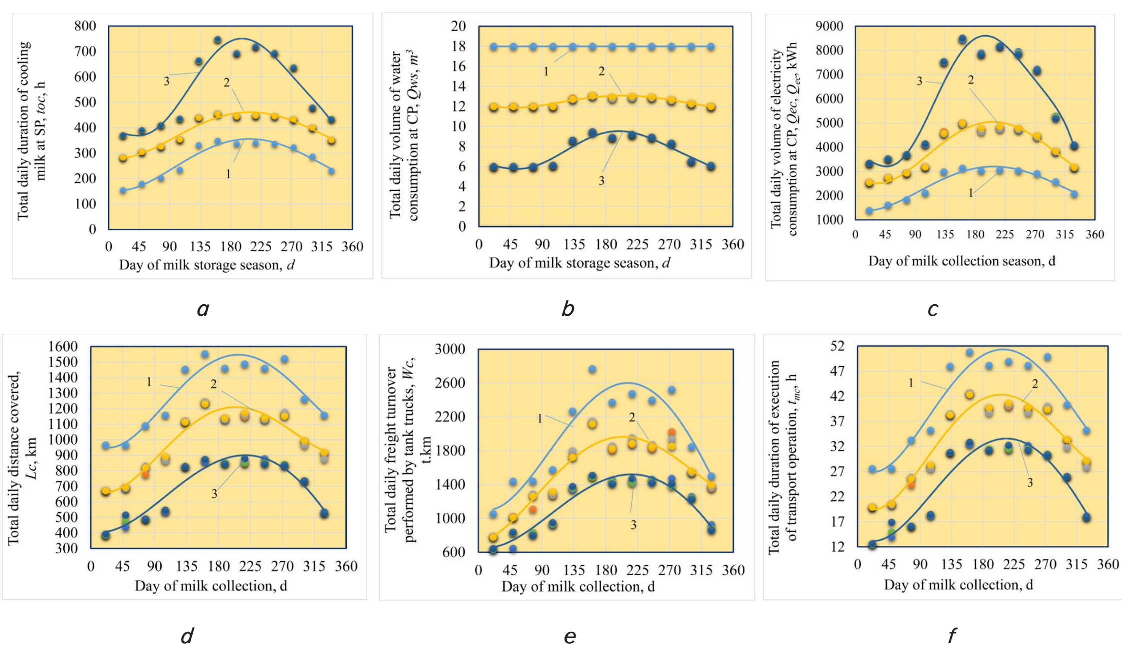

Fig. 7. Dependences of total daily indicators of CTO execution on the day of milk collection season (*d*) at transportation from CP to MS three times a day (1), twice a day (2) and once a day (3): *a* — duration of milk cooling at CP; *b* — the volume of water consumption at CP; *c* — the volume of electricity consumption at CP; *d* — distance covered to CP; *e* — freight turnover at CP; *f* — duration of execution of transport operations

It was found (Fig. 7, *e*) that total daily freight turnover of tank trucks increases at an increase in the number of their trips from CP to MS. Similar tendencies are observed for total daily duration of execution of transport operations (Fig. 7, *f*), which increases at an increase in the number of trips from CP to MS.

Table 4

Equations of dependences of indicators of CTO execution on the day of milk collection season (*d*) and the variant of their content

Indicator	Content of CTO execution		
	once a day	twice a day	three times a day
Total daily duration of milk cooling at CP (t_{oc})	$t_{oc1}=2\times10^{-7}d^4-$ $-1\times10^{-}d^3+2,76\times10^{-2}d^2-$ $-0,75d+158,55$, $r=0,95$	$t_{oc2}=1\times10^{-7}d^4-$ $-1\times10^{-4}d^3+2,44\times10^{-2}d^2-$ $-0,67d+286,44$, $r=0,95$	$t_{oc3}=6\times10^{-7}d^4-$ $-5\times10^{-4}d^3+0,11d^2-$ $-7,56d+494,27$, $r=0,92$
Total daily volume of water consumption at CP Q_{BC}	$Q_{BC1}=7\times10^{-9}d^4-$ $-6\times10^{-6}d^3+1,4\times10^{-3}d^2-$ $-9,8\times10^{-2}d+7,66$, $r=0,91$	$Q_{BC2}=-3\times10^{-7}d^3+$ $+9\times10^{-5}d^2-2,7\times10^{-3}d+$ $+11,92$, $r=0,85$	–
Total daily volume of electricity consumption at CP Q_{ec}	$Q_{ec1}=8\times10^{-6}d^4-$ $-6,8\times10^{-3}d^3+1,62d^2-$ $-104d+4997$, $r=0,92$	$Q_{ec2}=3\times10^{-6}d^4-$ $-2,4\times10^{-3}d^3+$ $+5,7\times10^{-1}d^2-$ $-31,14d+3005$, $r=0,94$	$Q_{ec3}=1\times10^{-6}d^4-$ $-1,1\times10^{-3}d^3+$ $+2,4\times10^{-1}d^2-$ $-6,76d+1427$, $r=0,95$
Total daily distance covered to CP (L_c)	$L_{c1}=2\times10^{-7}d^4-$ $-2\times10^{-4}d^3+5,1\times10^{-2}d^2-$ $-1,27d+413,3$, $r=0,91$	$L_{c2}=6\times10^{-7}d^4-$ $-4\times10^{-4}d^3+9,1\times10^{-2}d^2-$ $-3,18d+691,4$, $r=0,94$	$L_{c3}=6\times10^{-7}d^4-$ $-5\times10^{-4}d^3+0,1d^2-$ $-4,44d+1001$, $r=0,91$
Total daily freight turnover by tank trucks (W_c)	$W_{c1}=4\times10^{-7}d^4-$ $-24\times10^{-4}d^3+$ $+8,9\times10^{-2}d^2-$ $-1,91d+664,6$, $r=0,94$	$W_{c2}=7\times10^{-7}d^4-$ $-6\times10^{-4}d^3+0,1d^2+$ $+1,45d+716,2$, $r=0,92$	$W_{c3}=8\times10^{-7}d^4-$ $-8\times10^{-4}d^3+0,1d^2-$ $-4,58d+1133$, $r=0,88$
Total daily duration of execution of transport operations (t_{TC})	$t_{TC1}=1\times10^{-8}d^4-$ $-1\times10^{-5}d^3+2,9\times10^{-3}d^2-$ $-0,11d+14,4$, $r=0,91$	$t_{TC2}=2\times10^{-8}d^4-$ $-2\times10^{-5}d^3+$ $+3,9\times10^{-3}d^2-0,15d+21,1$, $r=0,95$	$t_{TC3}=2\times10^{-8}d^4-$ $-2\times10^{-5}d^3+$ $+3,9\times10^{-3}d^2-$ $-0,15d+28,53$, $r=0,88$

Note: d is the day of milk collection season

Therefore, the key indicators of CTO execution in LSMC depend on the variants of their organization and the day of milk collection season. The obtained results of the research are the basis for determining cost indicators of CTO execution in LSMC. In particular, the effective variant of the contents of CTO in LSMC is selected on their basis.

7. Discussion of results of studying the influence of production conditions and the content of execution of collection and transportation operations on their indicators

The developed algorithm of coordination of the content of operations in logistic systems of milk collection with production conditions implies the execution of eleven grounded management operations (Fig. 1). Unlike existing approaches to planning of operations execution in logistics systems, the proposed algorithm takes into consideration the changing daily volumes of milk collection from separate farms. In addition, it takes into consideration stochastic durations of CTO execution. The variants of their content were substantiated. The proposed algorithm for coordination of the content of operations execution in logistic systems of milk collection with production conditions implies the formation of the database to perform calculations from different sources. Information about the availability and geographical location of dairy farms, which supply milk raw material to the PS, is taken from reporting documentation of MS. Information on the volumes of preparations of milk raw materials on each of dairy farms on a separate day of the calendar year, for which the CTO is coordinated, is taken from producers of milk. Information on the volumes of collection of milk raw material is passed to the MS, where the operations are coordinated during operative planning through the telecommunication network.

The peculiarity of the prediction of daily volume of milk collection is that it implies taking into consideration its variability during the period of lactation of cows, which lasts from 265 to 435 days. This period depends on the breed, age and productivity of cows. It was taken into account that the lactation period is shifted relative to a calendar year for separate cows and milk is stored throughout the whole calendar year. It was established that the bulk of milk collection falls on summer months, during which transport vehicles are used intensively to perform CTO.

Based on the data that were experimentally obtained for conditions of PAT "Brodivskyi ZSZM" (Lviv region, Ukraine), the dependences of durations of the CTO execution on daily volumes of milk collection were constructed (Fig. 2–4). It was found that dependences of the duration of cooling milk raw material on its volume in the refrigeration plant for the first (1) and second (2) milking are described by power dependences. At the same time, according to the duration of loading at CP and unloading at the MS of CA Hyundai HD-65 STD+G6-OTA-3.9 on daily volumes of milk collection (Fig. 3) and the dependence of the duration of transportation of milk raw material on transportation distance (Fig. 4) are described by linear equations. The correlation coefficient is observed within 0.95...0.97, which indicates a strong correlation between the studied indicators

It was established that the duration of drawing up forwarding documents at the CP and at the MS do not depend on the volumes of milk raw material loaded at the CP and unloaded at the MS. Statistical processing of these data made it possible to determine the numeric characteristics, as well as to substantiate the theoretical laws of distributions, which are the Weibull distributions. The main statistical characteristics of the distribution of durations of drawing up forwarding documents at the CP and at the MS are the following. Estimation of mathematical expectation of these durations is 3.9 and 7.1 minutes, respectively. Estimation of root mean square deviation of these durations is respectively 1.66 and 3.42 minutes. Confidence interval of these durations is respectively 1.5...8.4 minutes and 3.1...18.6 minutes.

It was substantiated that there are seven variants of the content and duration of CTO, among which it is necessary to determine the effective one. The obtained dependences

(Fig. 5) of the variants of CTO execution were constructed based on the simulation of execution of transport operations. To do this, we used the simulation model of operations execution in LSMC. They are the basis for determining the effective variant of the CTO under the assigned production conditions in LSMC.

The proposed simulation model of execution of the CTO in LSMC was developed at four stages. The block diagram and the algorithm for statistical simulation were developed at stage 1. For this, we used the predictable changeable daily volume of milk collection from selected farms, the substantiated dependences of the duration of CTO execution on the volumes of milk collection, as well as possible variants of their content. At stage 2, the preliminary simulation was carried out and the model for adequacy was verified with the use of the paired t-criterion. To do this, experimental and simulated values of durations of servicing separate routes by tank trucks Hyundai HD-65 STD+G6-OTA-3.9 were compared. Deviations of the obtained numerical values of durations of execution of individual routes based on simulation of the CTO execution and obtained experimental values do not exceed 2.9 %. Computer experiments (simulation of the CTO execution) for different variants of content of operations were carried out at stage 3. Stage 4 made it possible to process the results of the simulation and substantiated the dependences of indicators of performing the CTO of different content, taking into consideration the impact of changeable production conditions.

It was established that the key indicators of the CTO execution in LSMC depend on the variants of their organization and the day the collection season. The obtained results of the research are the basis for determining the cost indicators of CTO execution in LSMC. In particular, the effective variant of the content of CTO in LSMC is based on them.

The shortcomings of the proposed approach to coordination of the content and duration of operations execution with daily volumes of milk collection is the need to perform specific and time-consuming production experiments for quantitative estimation of characteristics of production conditions. To eliminate this drawback, it is necessary to create an information system of supporting managerial decision making in LSMC. The information system will greatly facilitate the process of the formation of the database on changeable production conditions and, respectively, quantitative estimation of their indicators. This will increase the quality, accuracy and efficiency of making managerial decisions regarding the coordination of the content and duration of operations execution with changing production conditions.

Analysis of functioning of the existing LSMC revealed that there are seven variants of content and duration of the CTO execution, each of which has its own specifics. It was established that milk collection operations include duration of cooling, volume of energy and water consumption. Respectively, transportation operations include the distance covered by tank trucks, duration of their use and performed freight turnover.

The use of the simulation model of CTO execution in assigned LSMC makes it possible to perform iterative selection of substantiated variants of the content and duration of CTO execution.

Several constraints were accepted in the course of the study.

The number and geographical location of milk collection points, availability of farms, as well as characteristics of the network of roads were accepted as constant as of 01.01.2019 for the conditions of PAT "Brodivskyi ZSZM" (the town of Brody, Lviv oblast, Ukraine). The previously substantiated regularities of a change in indicators of using vehicles of one brand – tank trucks Hyundai HD-65 STD+G6-OTA-3.9 were used in the research.

The performed studies based on simulation of CTO execution in LSMC made it possible to determine the numerical values of the indicators of execution of these operations for different content in separate periods of the calendar year (Table 3).

It was established that at an increase in the number of operations concerning milk collection, the quantitative values of indicators of execution of these operations (duration of cooling milk raw materials, consumption of electricity and water) increase. In turn, the quantitative values of the indicators of execution of transport operations decrease. In this case, the indicators of execution of collection operations at the CP of the assigned LSMC fluctuate within certain limits for different variants of content of operations execution during the calendar year. In particular, for the conditions of PAT "Brodivskyi ZSZM" (the town of Brody, Lviv oblast), the total duration of cooling milk raw material fluctuates within 155...750 hours. Total daily electricity consumption within 1395...8513 kW·h. Total daily water consumption within 6...18 m^3. Total daily distance covered by tank trucks – within 386...1,554 km. Total daily duration of using tank trucks within 12.5...50.8 hours. Total daily freight turnover – within 628...2,770 t·km.

Analysis of specific variants of the content and duration of CTO execution in the assigned LSMC reveals that for the two-time transportation of milk raw material, compared with the one-time transportation, a decrease in the total daily duration of cooling milk raw material by 1.2...1.65 times is ensured. At the same time, the total daily energy consumption increases by 1.28...1.7 times and the total daily water consumption – by 1.38...2 times. In this case, an increase in total daily mileage of tank trucks by 1.31...1.73 times; the total daily duration of the use of tank trucks by 1.22...1.61 times; the total daily execution of freight turnover by 1.31 ... 1.57 times is ensured.

If the three-time transportation of milk raw material is organized, in comparison with one-time transportation, it ensures a decrease in total daily duration of milk cooling by 1.67...2.4 times, an increase in total daily consumption of electricity and water by 1.96...2.71 and 1.9...3 times, respectively. The indicators of execution of transport operations of total daily mileage of tank trucks increased by 1.69...2.46 times; total daily duration of the use of tank trucks – by 1.52...2.19 times; total daily execution of freight turnover – by 1.5...1.84 times.

The obtained dependences (Fig. 4) are the basis for substantiation of the effective variant of the content and duration of CTO execution in the assigned LSMC. Cost indicators of CTO execution in LSMC are determined on their basis. Specifically, the effective variant of the content of CTO in LSMC is chosen.

Thus, the conducted studies take into consideration the variability of daily volumes of milk collection from separate farms, stochastic durations of CTO execution, as well as the substantiated variants of their content. The obtained results will be useful for managers, who are involved in planning in LSMC and their designing. Substantiated regularities of the change of indicators of the CTO execution will accelerate the implementation of the managerial decision-making process and enhance its quality. Subsequent research should be carried out in relation to the development of information decision support system in LSMC. This will offer the opportunity to solve the managerial problem of coordination of CTO with daily volumes of inflows of delivery of milk raw material to the CP under different production conditions (particular regions of different countries).

8. Conclusions

1. The developed algorithm to adjust the content of operations execution in LSMC to production conditions implies the execution of eleven substantiated management operations (Fig. 1). The research that was based on it, in contrast to previous studies, take into consideration the predictable variability of daily volumes of milk collection from separate farms, stochastic durations of CTO execution, as well as the substantiated variants of their content.

2. The proposed simulation model is based on the developed block diagram and the algorithm for simulation of CTO execution for different variants of their content. The block diagram consists of 12 units, which are based on the substantiated methods, models and procedures of coordination of the CTO with daily volumes of milk delivery. Units 1–3 ensure the database formation, unit 4 – the selection of variants of the CTO, unit 5 – determining the indicators of operations execution at CP, units 6–9 – determining of indicators of implementation of transport operations, units 10–12 – saving and output of the simulation results. The simulation model implies the prediction of changeable daily volumes of milk collection from separate farms. The model is based on the substantiated dependences of duration of the CTO execution on volumes of milk collection, distributions of durations of CTO execution, as well as possible variants of their content. The proposed model was verified for adequacy with the use of the paired t-criterion. Experimental and simulated values of the durations of servicing of certain routes do not exceed 2.9 %, which indicates the adequacy of the developed model to the actual processes of milk collection.

3. Based on the simulation of CTO execution in LSMC, their indicators were established. These indicators include the duration of cooling milk at the CP and the duration of transport operations, the volume of water and electricity consumption by the CP, the covered distance and freight turnover performed by tank vehicles. Their quantitative values depend on the content of operations execution and seasonality of milk collection. It was established that the content of CTO execution and production conditions significantly affect their indicators, the quantitative values of which change by 1.2...3 times in a given LSMC throughout the calendar year. This proves the appropriateness of daily coordination of the content of execution of operation within a given LSMC with production conditions.

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