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GENERAL MODEL OF A TRANSPORT-TECHNOLOGICAL GRAIN STORE ROUTE NODE FOR CONTROL SYSTEMS PROGRAMS

The paper concerns a problem to develop software for engineering control systems based upon standard industrial controllers and SCADA means at enterprises for grain storage and processing. The problem generalizing approaches to develop algorithms controlling equipment as a part of technological routes has been considered. A system to control transport-technological grain route at grain storage is the research object. Control of transport-technological equipment at a route level is the research subject.

The article considers thematically related publications in the field of conveyor transport management and shows the relevance of developing a general model of transport and technological route of grain in terms of simplifying the tasks of building control algorithms, programming, debugging and implementation of ACS in enterprises.

Purpose is to develop general control model for nodes of a network of transport-technological grain storage routes to formalize tasks of software creation for industry specific engineering systems.

Analysis, classification, and generalization of processing equipment have been carried out; approaches to implement functional structures of elevator routes have been studied. General model to control transport-technological grain storage route has been proposed in the form of a graph of states. Transitional conditions in the form of algebraic logic have been developed for this graph as well as algorithms to control certain mechanisms in terms of transitional states of the route.

The control model developed in the form of graph involving transitional conditions and algorithms of transitional states has obtained its software implementation; moreover, it has been introduced in the context of industry specific engineering control systems at operating enterprises of grain storage and processing. The introduction results have demonstrated the model stability under the conditions of different enterprises engaged in grain storage and processing from the viewpoint of its implementation in the system software.

The realized field experiments have demonstrated the system effectiveness, which allows to recommend it to solve the problems of software development for engineering control systems based upon standard industrial controllers and SCADA.

Keywords: transport-technological grain storage routes, general control model, graph of states, industrial controller, SCADA, route node

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ЗАГАЛЬНА МОДЕЛЬ ТРАНСПОРТНО-ТЕХНОЛОГІЧНОГО МАРШРУТУ ЗЕРНА ДЛЯ ПРОГРАМ СИСТЕМ УПРАВЛІННЯ

Робота присвячена проблемі розробки програмного забезпечення технічних систем управління, побудованих на основі стандартних промислових контролерів та засобів SCADA на підприємствах зберігання і переробки зерна. Розглянуто задачу узагальнення підходів до побудови алгоритмів управління обладнанням у складі технологічних маршрутів. Об'єктом дослідження є система контролю транспортно-технологічного шляху зерна при зберіганні зерна. Предметом дослідження є контроль транспортно-технологічного обладнання на рівні маршруту. Метою є розробка загальної моделі управління вузлами мережі транспортно-технологічних маршрутів елеватора для формалізації задач написання програмного забезпечення для профільних технічних систем.

У статті розглянуто тематично пов'язані публікації у сфері керування конвеєрним транспортом та показана актуальність розробки загальної моделі транспортно-технологічного маршруту зерна з точки зору спрощення задач побудови алгоритмів керування, програмування, відлагодження і впровадження АСУ на підприємствах.

Проведено аналіз, класифікацію та узагальнення технологічного обладнання елеватора, підходів до реалізації функціональних структур маршрутів елеватора. Запропоновано загальну модель управління транспортно-технологічним маршрутом елеватора у вигляді графу станів. Для цього графа розроблено умови переходів у вигляді системи рівнянь алгебри логіки та алгоритми керування окремими механізмами у перехідних станах маршруту.

Розроблена модель управління у вигляді графа з умовами переходів та алгоритмами перехідних станів реалізована програмно і впроваджена практично на профільних технічних системах управління на діючих підприємствах зберігання та переробки зерна. Результати впровадження показали сталість моделі в умовах різних підприємств зберігання і переробки зерна з точки зору її застосування у програмному забезпеченні систем.

Проведені натурні експерименти показали дієвість запропонованої моделі, що дозволяє рекомендувати її для вирішення задач розробки програмного забезпечення технічних систем управління транспортно-технологічними маршрутами на базі промислових контролерів та SCADA.

Ключові слова: транспортно-технологічні маршрути елеватора, загальна модель управління, граф станів, промисловий контролер, SCADA, маршрутна одиниця обладнання.

Introduction

Processes of grain receiving, unloading, and processing in Ukrainian granaries are closely connected with such transport-technological equipment as conveyors, elevators, valves, separators, hoppers etc. The equipment is a part of transport-technological routes (TTRs). Currently, the problem to develop general model of control over transport-technological grain storage equipment as TTR network nodes is quite a topical problem. Such a node should give means, controlling routes, the unified access interface for each node in terms of the route despite its operation features and technological function.

The article research object is an engineering system to control transport routes of grain within a grain storage, barnyard, and grain processing plant.

Route control relates to the problems of technological operation use for grain; in this context, it may be formalized. Currently, the most of granaries are equipped with the automated control systems (ACS) to control TTRs or ACS conveyors in other words. To solve the problem, use of such standard facilities as serial sensors, control gear, industrial controllers and SCADA is quite sufficient. The solutions relate to the problems to develop control software and, hence, methods and algorithms.

The research subject is a process to control transport-technological equipment at a route level.

Practices of TTR ACSs implementation in the context of core enterprises show that a period of the required TTR determination involves a problem to control various technological facilities being of the different purposes, different modes of action as well as different number of input and outputs even in terms of facilities being of one and the same operation mode. The diversity originates unique solutions for the automated control both at the mechanism level and at route level. In turn, the abovementioned complicates programming as well as TTR ACS development based on industrial controllers, and SCADA means.

Purpose is to develop general model to control nodes of network of transport-technological grain storage routes to formalize software coding for industry specific engineering systems.

Related works

Generally, the articles in the public domain are of advertising, general or journalistic nature. As a rule, articles of scientific content list functions and technical features of ACS of TTM; however, their solutions have not developed at the level of functional structures [1] or is descriptive, which in principle can provide some structure [2]. At the same time, these systems have implemented in practice. This fact indicates about the nonappearance of the unified system approach to the problem of TTR control at a grain storage. Nevertheless, problems of the control of certain transport-technological route nodes have been solved quite sufficiently. Among other things, there is a description of tags of the automated objects; sources of the signals as well as their processing means are available [3].

If you look at other areas of conveyor transport application, then from the point of view of the presented scientific works the situation is different. There are publications of mine conveyor control systems of transport that are descriptive and give an idea only for their functions and structure of technical means [4, 5]. But presented and quite serious scientific works related to speed control [6], modelling and speed management of belt conveyors during the movement of cargo [7], regulation of freight flows of conveyor transport based on energy efficiency [8]. Modern research on substantiation and construction of a network of TTM equipment are also presented [9, 10]. However, in the context of modern operating grain storage, substantiation matter is not so topical one. As a rule, each route has been determined at a design stage of the grain storage depending upon a list of technological operations. Currently, it is more relevant to propose the overall concept of granary TTR control based upon the industrial controllers to simplify the tasks of the development of control algorithms, programming, adjusting, and ACS of TTM implementation at the enterprises. This, in turn, will allow the introduction of energy-efficient methods of grain movement by safely regulating the speed of transport and technological equipment, as the latter are justified and can be used only at the level of standard functional solutions ACS TTM [6, 7, 8].

On the other hand, today there are works that present the results of the synthesis of the functional structure of the ACS TTM [2, 4, 5, 11, 12]. Also, the analysis and classification of transport-technological equipment used in the grain storage have performed. As a result, systems of logic algebra equations for control of this equipment have developed [12] Both the functional structure and the systems of equations had implemented in practice when developing software for the grain storages of Ukraine. The results of these works allow us to continue the research of the process of control of transport and technological equipment at the level of the route to obtain a general model of control of the transport network nodes and technological routes of the grain storage.

Proposed technique

Consider the basic technological operations within a grain storage in the context of their use with technological equipment of the enterprise. Generally, any grain storage performs series of actions intended to receive grain, store it, and release it. In any case, the activities relate to grain transportation and processing. Consider grain receiving since the process involves the most of operations [13] with the use of transport-technological equipment.

If weighing, quality determination, and decision-making as for the grain batch formation, placement, and processing are ignored, then receiving may consist of:

1. Reloading from a vehicle (truck, trailer, railway hopper or gondola wagon, etc.);
2. Grain cleaning;
3. Grain drying;
4. Grain batch placement.

It is obvious that the operations involve standard equipment to transport grain; however, specific facilities may also participate (equipment aspiration, grain cleaning, dosing etc.). Nevertheless, the facilities [13] for grain transportation within an elevator may be divided into several groups depending upon their control principles:

1. Non-positional equipment to transfer bulk material: belt, scraper, and worm conveyors; bucket elevators; and unregulated two-position hopper latches;
2. Ventilation and aspiration equipment for elevators, covered transporters, separators, and hoppers;
3. Positional equipment to transfer bulk material: check valves, rotary tables and pipes, and unloading carts;
4. Equipment to determine the route efficiency: smoothly or stepwise adjusted latches, conveyors, and sometimes bucket elevators with velocity control;
5. Separators;
6. Equipment which may be represented as a hopper: operative hoppers or permanent storage hoppers, driers, intake pits, and unloading equipment.

It is obvious that six groups are too many to develop general node model. To simplify the classification, consider the adopted ACS structure of TTR to formulate the requirements for a program model of a technological equipment unit. Taking into consideration the available approaches to the development of ACS of grain storage TTR, it is possible to say that among other things their functional structures also involve three autonomous layers, i.e., functional levels [11, 12]. The levels are implemented programmatically:

1. Object coordination level where the initial processing of discrete, analog or Yes-No signals takes place; their norming and scaling; as well as program commutation in the form of tags to a level of the equipment control;
2. Equipment control level where program models of the facilities, performing automated control and diagnostics of the equipment state; and emergency protection according to the tags listed in point 1, are allocated. In turn, the level provides tags of the equipment state in terms of the route control level;
3. Route control level with the corresponding models and algorithms.

To achieve the purpose of research, it is advisable to use the third functional level.

Such a term as a *route* should be understood as a set of equipment units along which material objects transfer successively with changes in their properties. In this case, grain, waste, and air are the material objects. It is proposed to control the route according to a graph of states shown in Fig. 1.

The graph describes following states:

R0 being initial undefined state. It is available during the system start when tags from the mechanisms were not sent;

R1 being a state of the route readiness. All the route mechanisms are stopped and serviceable;

R2 being a state of the route starting. This is a transitional state when a certain part of the route mechanisms is started or in the process of starting, and some mechanisms are waiting their turn. Of course, the route is started follows the order being opposite to bulk material travel direction; however, this requirement is not obligatory for aspiration equipment;

R3 being normal operation of the route. All mechanisms are serviceable and work within the route;

R4 being the planned stop of route. It is the transitional state when the mechanisms are serially stopped. The sequence of stopping the route mechanisms corresponds to the direction of movement of bulk, while maintaining the time for the backfilling of grain from the mechanism or the extraction of dust by the aspiration element;

R5 being the abnormal stop of the route. It is a transitional state being available during the starting, operation, or planned stopping is the tag concerning the unexpected situation happening in one of the mechanisms if a tag relative to emergency is sent (i.e., emergency stop has happened or normal one if it was not scheduled). The abnormal mechanism, as well as all mechanisms, operating oppositely to grain movement, stops immediately and simultaneously to avoid the grain pouring. Other mechanisms perform their stopping successively like in a mode of the scheduled stop;

R6 being unavailable state. The route has stopped. In this case, it has faulty mechanisms which cannot be started; or one of these mechanisms launched, but as part of another route.

Fig. 1 misses R2-R4 transition; however, the scheduled route stopping without complete starting of all its mechanisms is not the obligatory condition to solve the considering problem.

The conditions of transition on the branches of the graph are determined. The control graphs of certain mechanisms required for the conditions of transfer along the branches of the graph in Figure 1 are considered in [11, 12] in the form of systems of equations. The described experiments use only the states being important as information criteria for the route level:

M0 is the initial undefined state of a mechanism. It is available during a system initiation similarly to R0 state when tags of sensors have not been received;

M1 is the initial state of a mechanism being serviceable and stopped;

M2 is the transitional state of a mechanism when is started;

M3 is the target state of mechanism, the mechanism is operating;

M4 is the transitional state of a mechanism, the mechanism is stopping;

M5 is the transitional state of a faulty mechanism; controlling influence for its stop is established.

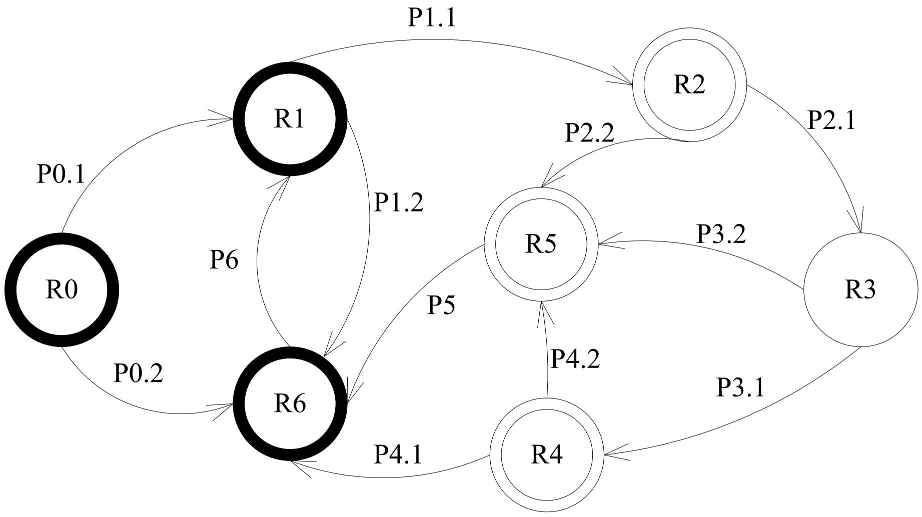


Fig. 1 Graph of states to control transport-technological grain storage route

According to point 6, the equipment, represented as a hopper, is absolutely passive. It has either one sensor or several or provides another tag that prohibits downloading. The model may show that as an emergency sensor of from a group, mentioned in point 1, or as a tag of a command by operator as for the scheduled route stop depending upon the specific technological task.

Control of non-positional equipment of transition, ventilation, aspiration, separators is reduced to the mechanism on and off. Its control graphs are similar. Hence, finite-state machine with the predetermined states [12] from a group, mentioned in point 1 is applied.

Now, consider positional equipment to transfer of bulk in terms of point 3. From the viewpoint of a route control, the moment when check valve, rotary table, and unloading cart are in the motion, they cannot be used for their main purpose, i.e., for grain moving. Thus, despite the control graph looks like when the devise is moving, its position for the route in R2 state should be M2 only. M3 initiates if the mechanism is at the required position; its drives are stopped; and its route state corresponds to R2-R5 range. Hence, from the viewpoint of a route, the group from point 3 is reduced to the same group from point 1 in terms of information identifiers of state. However, exceptions are possible in some cases. For instance, there are technological schemes where check valve or route reloading latch of a scraper conveyor is used to load either dryer or separator. If they are filled up, the latch should be closed to prevent the grain pouring out, or the valve should vary its position right during the operation to redirect the grain flow towards an operative tank. Under the conditions, despite the current state of positional mechanisms of the route within R2-R5 state, its mode will always be M3 if a command to stop the mechanism or accident tag is not received.

The equipment, determining route efficiency in terms of point 4, is also reduced to non-positional uncontrolled one in terms of point 1, by moving the control task for the functional level of route management. It is correct since the route effectiveness may be restricted of drier and/or separator low efficiency or incorrect conveyor choice.

Thus, each class of elevator mechanisms was described by means of multipurpose digital control box corresponding to point 1 classification. The equations of states of this a control box are given in [12]. Its use makes it possible to transfer to equation system (1) describing transition conditions of the graph shown in Fig. 1.

$$P0.1 = \bar{p} \wedge_{i=1}^{n} M1_i$$

$$P0.2 = \bar{p} \vee_{i=1}^{n} \overline{M1_i}$$

$$P1.1 = p \vee_{i=1}^{n} M1_i \cdot \vee_{i=1}^{n} M2_i \cdot \wedge_{i=1}^{n} \overline{M3_i} \cdot \wedge_{i=1}^{n} \overline{M5_i}$$

$$P1.2 = \bar{p} \vee_{i=1}^{n} \overline{M1_i}$$

$$P2.1 = p \wedge_{i=1}^{n} M3_i$$

$$P2.2 = p \bigvee_{i=1}^{n} M1_i \cdot \bigvee_{i=1}^{n} M2_i \cdot \bigwedge_{i=1}^{n} \overline{M3_i} \cdot \bigvee_{i=1}^{n} M5_i$$

$$P3.1 = \bar{p} \bigvee_{i=1}^{n} M1_i \cdot \bigwedge_{i=1}^{n} \overline{M3_i} \cdot \bigvee_{i=1}^{n} M4_i \cdot \bigwedge_{i=1}^{n} \overline{M5_i}$$

$$P3.2 = p \bigvee_{i=1}^{n} M1_i \cdot \bigwedge_{i=1}^{n} \overline{M3_i} \cdot \bigvee_{i=1}^{n} M5_i$$

$$P4.1 = \bar{p} \bigwedge_{i=1}^{n} M1_i$$

$$P4.2 = \bar{p} \bigvee_{i=1}^{n} M1_i \cdot \bigwedge_{i=1}^{n} \overline{M3_i} \cdot \bigvee_{i=1}^{n} M4_i \cdot \bigvee_{i=1}^{n} M5_i$$

$$P5 = \bigvee_{i=1}^{n} M1_i \cdot \bigwedge_{i=1}^{n} \overline{M4_i} \cdot \bigvee_{i=1}^{n} M5_i$$

$$P6 = \bar{p} \bigwedge_{i=1}^{n} M1_i$$

$$i = \overrightarrow{1,\ 2, .., n}, M1, M2, .., M5 \in \{0; 1\}, p \in \{0; 1\}, \quad (1)$$

where p is a command by an operator to start the route, and $\bar{p} = 1$ may mean both stop command or prohibit further operation from the end point of the route (for example, from a silo storage if its upper-level sensor responses); i are order numbers of mechanisms within the route; and n are the quantity of mechanisms within the route.

To make the controlling model complete, it is also required to determine output control influences. At the level of routes, these influences at the tops of the graph of Fig. 1 are tags as switch on/off ith mechanism where $mi \in \{0; 1\}$. The changes in the tags may take place within the transitional graph states (Fig. 1) following a strict sequence stipulated by a technique of the route starting and stopping.

To demonstrate this technique, it is expedient to represent processes of controlling influence on the route mechanisms in the form of schemes of algorithms for transient nodes of graphs R2, R4, and R5 as it is shown in Fig. 2.

Schemes of algorithms in fig. 2 are generalized schemes. Like the graph in Fig. 1, they do not reflect some specifics of software coding for industrial controllers.

Experiments

The model has been implemented in LAD language for industrial controller of SIMATIC S7-1200 series. Together with this controller, OBEH Mx110 means of the distributed input/output have been applied to make the development cheaper. The model was applied separately for each grain storage TTR in the context of general processing cycle.

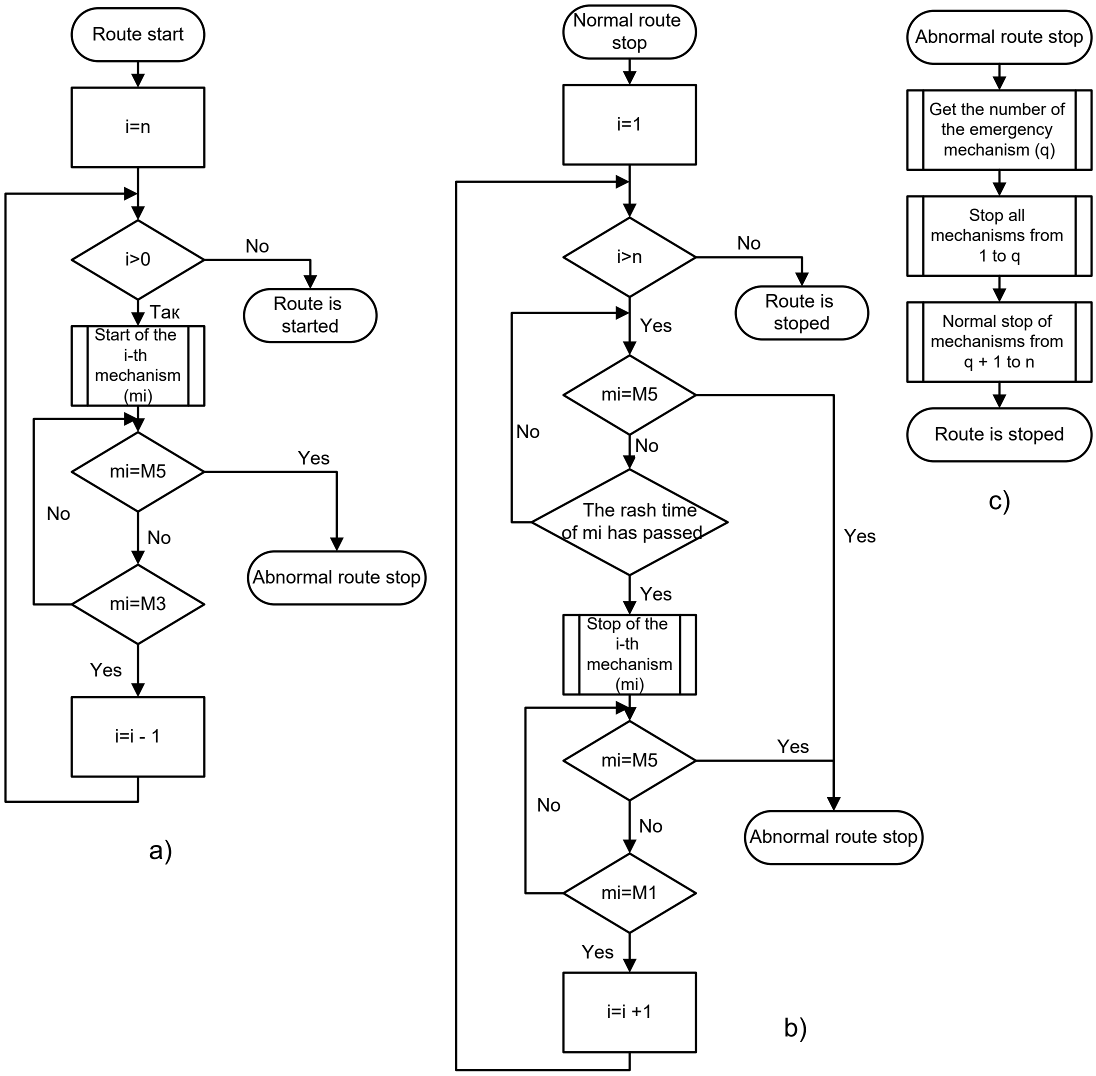
The software, implemented in terms of the model, was introduced at the three operating enterprises: Ahronadia ltd elevator (village of Rivchak-Stepanivka, Nosivka District, Chernihiv Region); Boryslav farm (village of Starostyntsi, Pohrebyshche District, Vinnytsia Region); and Druzhba ltd (village of Orly, Pokrovsk District, Dnipropetrovsk Region). Table 1 demonstrates results of the implementation experiments.

Table 1

Results of the experiments

Enterprise	Number of routes	Number of equipment units involved in the route	Total number of equipment units	Period of program scan, ms
Lab debugging	1	20	20	13
Ahronadia ltd	59	from 6 to 14	62	86
Boryslav farm	53	from 6 to 16	68	79
Druzhba ltd»	10	from 6 to 13	34	27

As a result, no principal changes were made in the graph, controlling routes, and algorithms, controlling mechanisms, despite differences in methods and equipment types. Changes concerned the number of mechanisms and routes; and composition of the mechanisms in terms of specific routes. The changes were described only in structures of databases, and algorithms of the data preparation. The algorithm, implemented by means of the method, experienced no changes.



ig. 2. Schemes of algorithms to control mechanisms within a route: a – starting, R2; b – scheduled stopping, R4; and c – unscheduled stopping, R5

Results

According to the experiment results, the model has demonstrated stable behaviour under the conditions of different enterprises engaged in grain storage and processing; in terms of response time, its program implementation with the help of means of industrial controllers did not exceed 100 ms. Such a response period is good enough for granary enterprises. The fact, the model implementation did not experience any changes in terms of different technological schemes demonstrates its versatility making it possible to recommend the model as the general one to control TTR nodes as well as TTRs themselves for the core enterprises.

The model implementation involves rendering of list of the mechanisms as well as description of an enterprise TTR to the corresponding structure of industrial computing means data. The abovementioned makes it possible to organize common interface to configurate mechanisms and routes and integrate them in the general system of an enterprise control.

Conclusions

According to the purpose, set at the beginning of the paper, the authors managed to obtain general model to control nodes of a grain storage TTR network. Following problems have been solved during the research:

– TTR equipment has been classified according to a control principle;

– functional level of ACS has been selected to implement the model to control TTR nodes;

– TTR control graph has been developed as a model where conditions of its transitions are described by means of equation system as well as performance algorithms of control influence within transition states of the graph;

– The control model in the form of individual programs for engineering systems to control TTR of real objects has been implemented;

– Invariance of the model has been demonstrated resulting from its use at different profile objects.

A method to represent states of transport and technological grain storage routes in the form of general graph to control the routes has been proposed. Implementation of the method makes it possible to formalize a problem to control transport and technological routes involving different number of nodes with various technological purposes.

Scientific novelty is in the granting of general approach to develop software of engineering systems of a grain storage TTR control to manage the equipment for grain moving at the level of routs.

Practical significance is to simplify design, coding, and implementation of software for technical control systems of a grain storage TTR by formalizing approaches to add technologically sound routes to those controlled automatically.

Prospects for future researches are to create methods of adaptive dynamic routing of grain flows depending upon a set of scheduled technological operations, the level of involvement and modes of operation of the equipment

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