Modeling of sugar beet losses during storage in heaps

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Abstract. After harvesting root crops (beets, carrots, turnips) are stored in the fields or in the processing enterprises warehouse areas. Storage takes place in open space, and not always under shelters. Bulk heaps are formed from the collected root crops. Harmful microflora may occur in it under the influence of various weather conditions. This article discusses the root crops quality reducing issues. The raw materials quality deteriorates due to the development and increase in damaging fungal diseases. This leads to raw materials losses and a decrease in the processing plants productivity. The subject of the study is the storing root crops process. The fungal diseases six types distribution analysis results are presented. Its development patterns are revealed. The damage to root crops in bulk heaps intensity dynamics mathematical models are proposed in the article. Possible ways to normalize climatic conditions when storing root crops in heaps are given.

1 Introduction

Sugar is one of the main agricultural products. It is included as the main and necessary product in the every Russian resident consumer basket. Sugar is produced by special processing plants; the main raw materials for their functioning are root crops collected during the harvesting season. According to the state order, sugar Russian agro-industrial complex factories must provide the population with the necessary sugar amount. This is also important in the Western sanctions current conditions. When harvesting from fields it is given great importance creating optimal conditions for storing root crops and preventing the harmful microflora formation. However it is not possible to completely avoid the fungal diseases appearance and its spread [1].

Research conducted throughout the 2020 season showed that aphanomycete rot was most widespread in the beet growing areas fields. This disease appearance and development can be prevented only at an early stage of development by fungicidal treatment of root crop seeds. All further attempts to destroy it are useless. The beet root crops hybrid varieties selection is the one of the ways to combat the certain fungal diseases (for example, aphanomycete rot) occurrence and spread. Breeding gives positive results in preventing diseases, but such hybrid varieties have lower productivity. This leads to a decrease in yield per sown unit of fields. Here arises another task: how to find a balance between the hybrids productivity and sustainability?

Today the fungicidal treatment is still the most effective way to control and prevent fungal diseases even during sowing remains. Despite this, recent studies have shown disease resistance to this treatment type. Moreover, later cercospora blight appears and develops on beet leaves. The danger is that the leaf curls and the root crop dies. In addition, this fungus spreads quickly and retains its spores in the ground, which leads to damage to future plantings. The losses in this case can be from 30 to 40% the sugar beet roots yield [2].

Thus, all listed factors when obtaining raw materials for sugar production are important and interrelated. Scientists and agricultural workers cannot say what is the root cause of rot. This task is still relevant today and requires full attention.

The following solutions to this problem are proposed.

2 Field mapping method

The sugar beet field mapping method in heaps on roadside plantations plots can be used to reduce peak loads on the unloading beet point equipment during the beets mass acceptance period [3].

Heap is a certain sizes trapezoidal cross–sectionregular geometric shape sugar beet root crops mound (GOST R 52678-2006).

Beet root crops are generally stored without shelters, in the open air. Mound piles are available in all kinds of weather conditions. The beet tubers are so closely adjacent to each other that they rub and stick together before they are called for processing. A single whole is formed, with its own microflora inside the rope. Microflora is the basis for the appearance of such a disease as black rot. It is root vegetables, beets and carrots characteristic. The kelp rot process external

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manifestation is the white or grayish-ashy mold appearance. This mold type is caused by the fungus Botrytis cinerea in combination with other microorganisms.

This fungus is a typical aerobic that develops a multicellular colorless mycelium in the affected tissue. On the rotted root crops surface appears cotton-like, initially white, and then gray, and finally dark mycelium forms, which envelops whole root crops groups, fills the gaps between them, forming noble rot focus.

The most active fungus development and the abundant spores formation occurs at high relative humidity in the heap, closely to 100%, and at +25-+30°C temperature. This fungusconidia germination observed even at +5 ° C temperature. However, at +1-+3°°C temperature pathogen development is inactive [2, 3]. The authors experimental data [4, 5] are shown in Table 1. To maintain the root crops sugar content at an optimal level, the humidity during raw materials storage shouldn't fall below 90-95%.

The root crop damage by rot pathogens mathematical modeling was carried out based on known experiments (Table 1).The following models were obtained (1) - (6). The fungus growth modeling average relative error is 5-6%. Modeling was carried out by interactive identification system means [3, 5, 6]. Table 2 shows developed mathematical models coefficients (1) - (6).

Table 1. The temperature effect on the beet root intensity damage by rot pathogens.

The root crop destruction intensity on the 10-th day, %	**Air temperature, °C**									
	3	**5**	**10**	**15**	**18**	**20**	**22**	**25**	**28**	**32**
Ph.betae	0	0	2.5	7.5	10	15	12.5	7.5	5	0
A.tenuis	0	0	1.25	3.75	5	7.5	7.5	5	2.5	0
S.sclerotiorum	0	0	7.5	10	15	20	22.5	15	10	0
Fusarium sp.	0	0	3.75	5	7.5	8.75	10	11.25	10	0
B.cinerea	0	1.25	2.5	3.75	5	6.25	6.25	5	0	0
P.expansum	0	5	7.5	15	15	17.5	17.5	20	17.5	2.5

1) Growth model *Ph.betae:*

$$C_{Pb} = 1.3 \cdot 10^{27}/(t + a_9)^{a_2} \cdot \exp\left(\frac{-363.2 \cdot 10^{28}}{(t+a_1)^{a_4}}\right) + a_3 \cdot t + 10 \cdot a_5(t + a_1)^{a_8} + 100 \cdot a_6/(t + a_1) + 10 \cdot a_7 \quad (1)$$

2) Growth model *A.tenuis*:

$$C_{At} = 5.7251706 \cdot \frac{10^{29}}{(|t-9.95|)^{a_2}} \cdot \exp\left(\frac{-a_3 \cdot 10^{11}}{(t+a_1)^{a_4}}\right) + a_5 t + \frac{10^4 a_6}{(t+a_1)} + 100 \cdot a_7 + 1000 \cdot a_8 \cdot \sqrt{t + a_1} \quad (2)$$

3) Growth model *S.sclerotiorum*:

$$C_{Ss} = 10^4 \cdot \frac{a_1}{|t-14.457|^{a_2}} \cdot \exp\left(\frac{-a_3 \cdot 10^9}{|t-a_9|^{a_4}}\right) + a_5 \cdot t + 10 \cdot \frac{a_6}{|t-a_9|} + 100 \cdot a_7 + a_8 \cdot \sqrt{|t - a_9|} \quad (3)$$

4) Growth model *Fusarium sp.*:

$$C_{Fs} = 100 \cdot a_1/t^{a_2} \cdot \left(\exp(-a_3 \cdot 10^{-5} \cdot t^{a_4})\right)^{0.67} + 10^{-2} \cdot a_5 t^{2.74} + 100 \cdot a_6 + a_7/t + a_8 t \quad (4)$$

5) Growth model *B.cinerea*:

$$C_{Bc} = 607 \cdot 10^{27}/(t + a_9)^{a_2} \cdot \exp\left(\frac{-a_3 \cdot 10^{18}}{(t+a_1)^{a_4}}\right) + a_5 t + 10^4 \cdot a_6/(t + a_1) + 100 \cdot a_7 + 100 \cdot a_8/(t + a_1)^{0.38} \quad (5)$$

6) Growth model *P.expansum*:

$$C_{Pe} = 0.68 \cdot \frac{10^{23}}{(t+a_1)^{a_2}} \cdot \exp\left(\frac{-a_3 \cdot 10^3}{(t+a_1)^{a_4}}\right) + 100 \cdot a_5 \cdot t + 10^3 \cdot a_6 \cdot \sqrt{t + a_1} + 10^3 \cdot a_7 \quad (6)$$

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Table 2. The mathematical models (1) - (6) coefficients.

Model's name	Mathematical models coefficients								
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
Ph.betae	6.18	17.40	27.31	21.70	-1.02	7.03	-0.27	1.23	11.54
A.tenuis	11.10	23.22	0.25	6.21	-8.48	0.14	-4.88	0.11	-
S.sclerotiorum	0.64	2.45	0.14	6.08	-5.45	6.80	-0.80	44.23	0.70
Fusarium sp.	-1.97	0.14	0.22	3.97	-0.83	1.44	80.40	-0.14	-
B.cinerea	100.8	17.00	0.25	7.78	-5.58	-6.74	6.74	-0.45	0.14
P.expansum	8.04	8.50	0.15	0.59	-0.22	0.17	-0.49	-	-

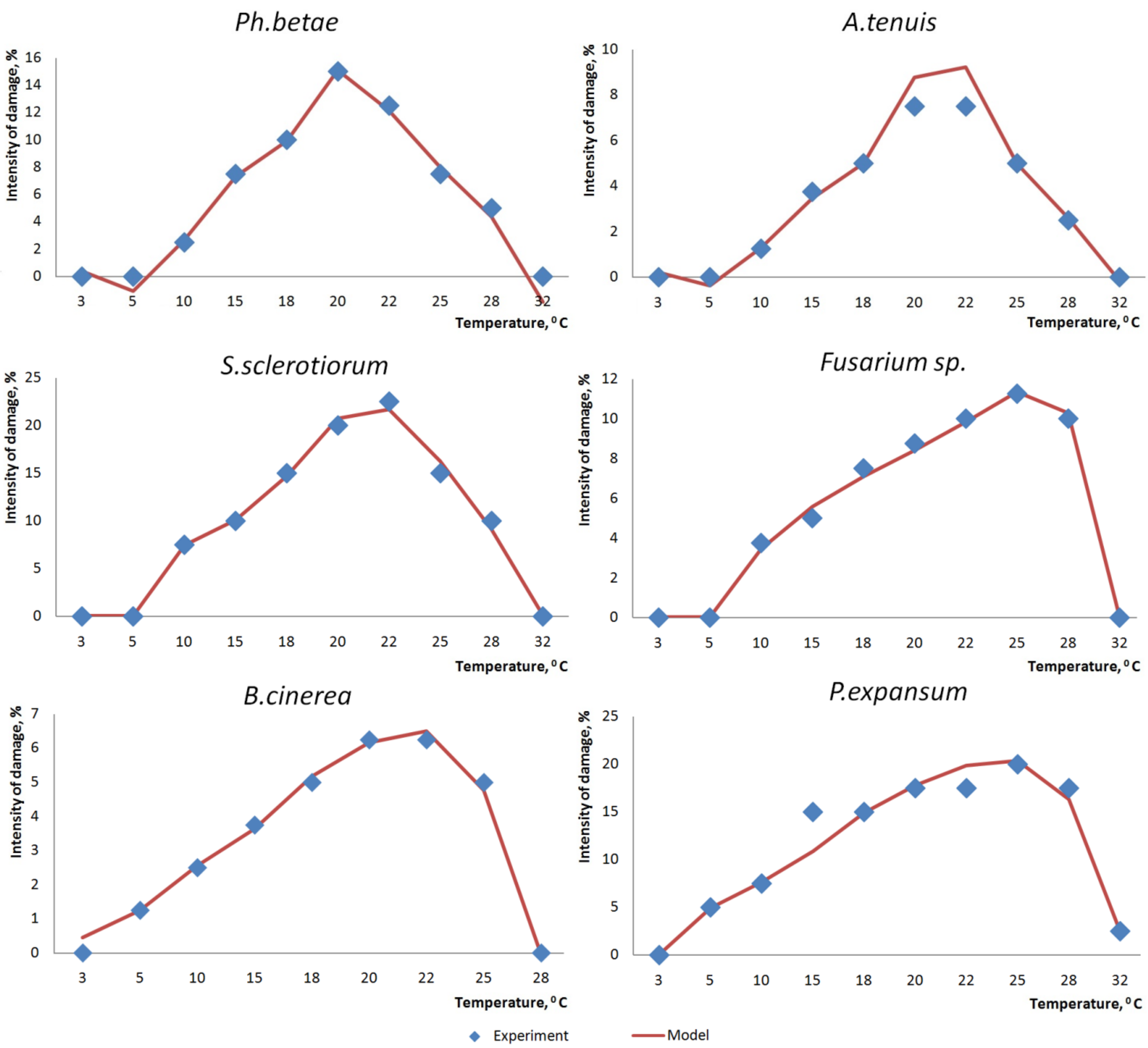

Fig. 1. Root crop damage intensity by fungus.

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Figure 1 shows experimental and model root crop damage intensity dependences from temperature by all fungus. The negative damage intensities resulting at the graphs ends are equated to zero in the models.

Regardless of its causative agent, the root crops physiological state plays an important role in the noble rot emergence and development. The roots weakening may be due to diseases suffered during the growing season, withering, freezing and mechanical damage.

This indicates the need to prevent the low temperatures influence on root crops in order to preserve the raw materials high quality [7].

The compliance with optimal beets in heaps storage conditions is one of the combating sugar beet root noble rot methods. This condition can be organized by automated information system means (Figure 2).

If the temperature increase in heap is not related to the outside air temperature, it means that there is a beet destruction inside the heap. The destruction development can also be judged by the wet spots appearance on the heap surface and the fog formation over the affected area, especially in the morning with a decrease in outdoor temperature.

The heap rot control existing methods analysis allows us to propose the heaps modernization way [7]. The proposed system technological scheme is shown in Figure 3. The heap itself is subject to modernization. The changes are aimed at maintaining optimal microclimatic storage conditions for sugar beet.

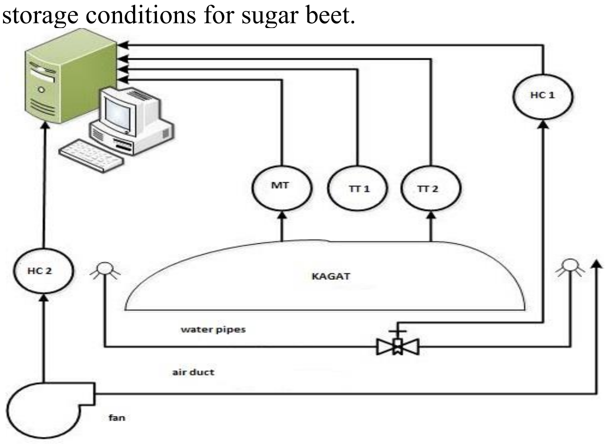

Fig. 2. The automated information system technological scheme: MT - a device for measuring relative air humidity, TT - instruments for measuring temperature (TT1 measures the air temperature, TT2 - the temperature inside the coil), HC - position sensors (HC1 determines the degree of opening of the valve on the water supply, HC2 - the state of the fan motor (on/off).

At the same time, a prerequisite for these conditions is the droplet moisture absence, which contributes to the fungal mold development intensification.

The automated information system (AIS) looks like [6]. Firstly, the heaps need to be equipped with sensors that will read basic microclimatic parameters such as humidity, ambient temperature and air temperature outside. Secondly, ventilation holes and air ducts are located inside the heaps to ventilate the root crops and prevent the environment humidity increase. For proper ventilation the air ducts should be connected to the fans. In addition, in order to prevent the reverse drying process, in addition to ventilation openings, it is necessary to provide a water supply circuit through the water supply system through humidifying nozzles.

The entire system is connected by an information management system, which is located on the workstation. It combines and aggregates all data and generates based control signals. It is necessary to use wireless sensors and control devices for the entire system convenience and mobility. Humidity analyzers measure the sugar beet moisture content in the heap and transmit it to the workstation.

Temperature sensors measure the temperature inside the heap in several places and outside, and also transmit information to the workstation. Further, the noble rot reproduction intensity is determined according to(1)-(6). AIS aggregates data and generates signals to control fans and nozzles. ThecontrolalgorithmisshowninFigure3.The regulating device will generate a signal to turn on the fans and cool the heap from the inside if the inside heap temperature increases without changing the external air temperature, and if the temperature deviates from optimal values.

The regulating device will generate a signal to turn on the fans and cool the heap from the inside if the inside heap temperature increases without changing the external air temperature, and if the temperature deviates from optimal values. When the sugar beet in the heaps humidity decreases below the optimal values, the AIS includes humidifying nozzles for wetting the products. If the humidity increases above the optimal values, the system will stop the water supply and turn on the ventilation.

The proposed model should contribute to the raw materials physics and chemical properties preservation at the right level. It will increase the "healthy" beet pulp amount sent for processing. Note that this model hasn't been tested in an active experiment. Undoubtedly, a task of this scale requires study in the real conditions during the sugar beet harvesting and storage periods.

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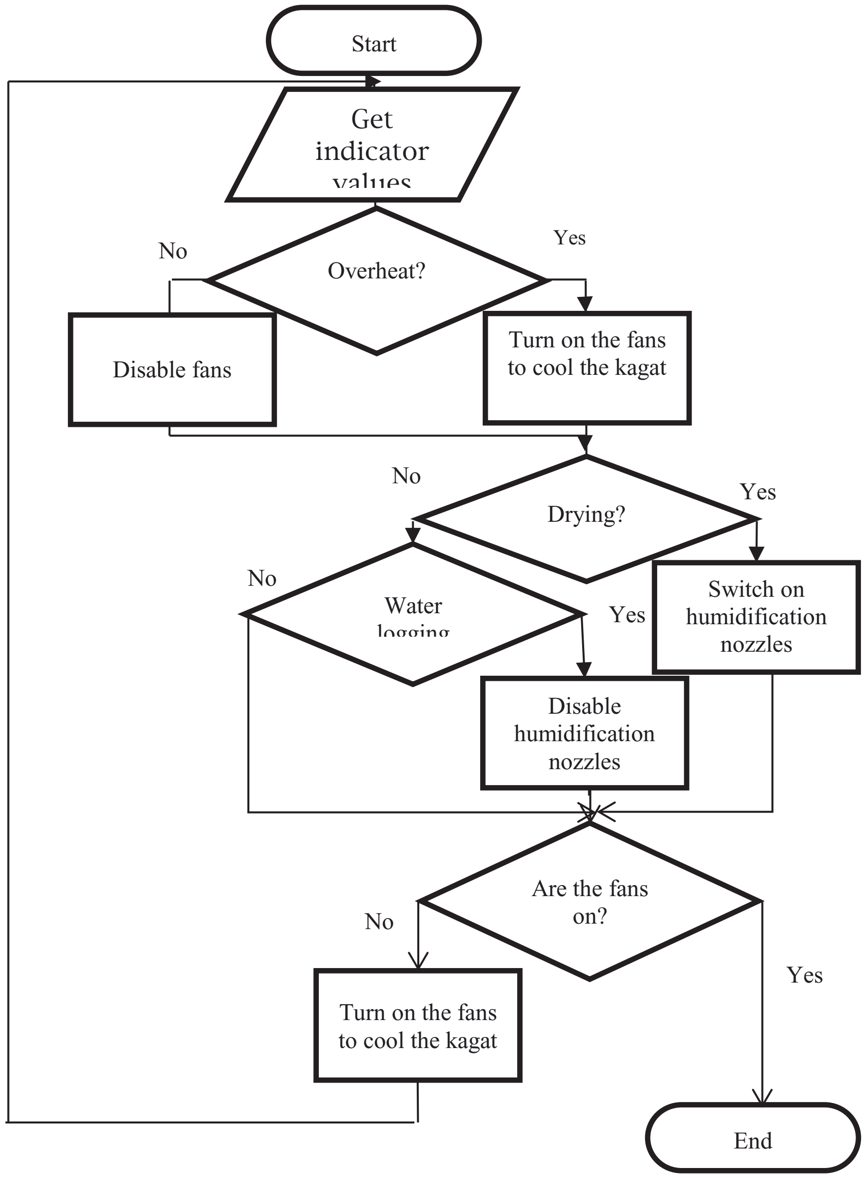

Fig. 3. Generating discrete control actions algorithm

3 Transportation information module

Currently, there is no single sample information module that is suitable for making a queue for transporting sugar beet from the fields and the necessary software development is carried out by organizations independently [7].

It is necessary to automate the raw materials from the heap to the production place transporting process in order to reduce the delivery unevenness and waiting time in the queue. This article proposes an information system software module for the sugar beet delivery to enterprises. The module implements an algorithm for drawing up a recommended schedule for the sugar beet delivery to a processing enterprise. The module is intended for the logistics department dispatcher. Developing the module it was assumed that contracts for the sugar beet delivery from the fields were concluded according to schedule [6, 7].

The holding transport agency logistics department is engaged in the delivery schedule development. The dispatcher mainly participates in the transportation organization and his duties include the following functions:

1) request acceptance from the dispatch center and its processing for delivery;

2) accompanying documents registration;

3)checking the workload at the factories, promptly making changes to the data for the route delivery and making changes related to a long queue, raw materials shortage, etc.;

4) goods unloading supervision and documentary acceptance.

The company's logisticians most effective work is possible only with modern information technologies usage. Raw materials loading, transportation and

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delivery standard processes complex automation is very relevant for Russian enterprises [7].

The functional model construction for the organization logistics system module begins with whole system functioning description using IDEF0 in the Raw materials delivery context diagram form (AS-IS) (Figure 4).

The diagram clearly illustrates the information and material flows relationship with the organizational structure, control actions and all processing enterprise activities. The diagram presented in Figure4 is used for the business process "Raw materials delivery" initial analysis [6, 7]. It describes the business process in the set of functions, incoming and outgoing flows form, and it is the IDEF0 approach basis and the center for the all other modules construction. Functional modeling involves a gradual transition from the general to the particular due to decomposition.

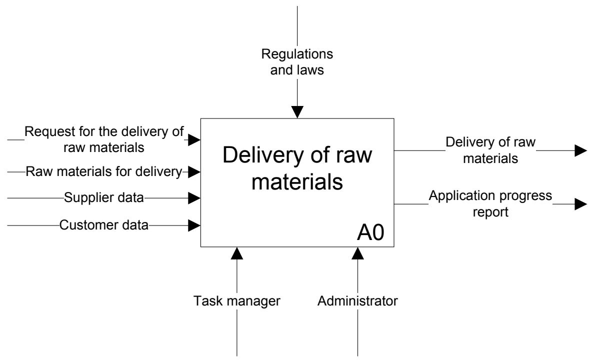

Fig. 4. Raw materials delivery context diagram.

The real business process context diagram decomposition (Figure 3) is shown in Figure 5.

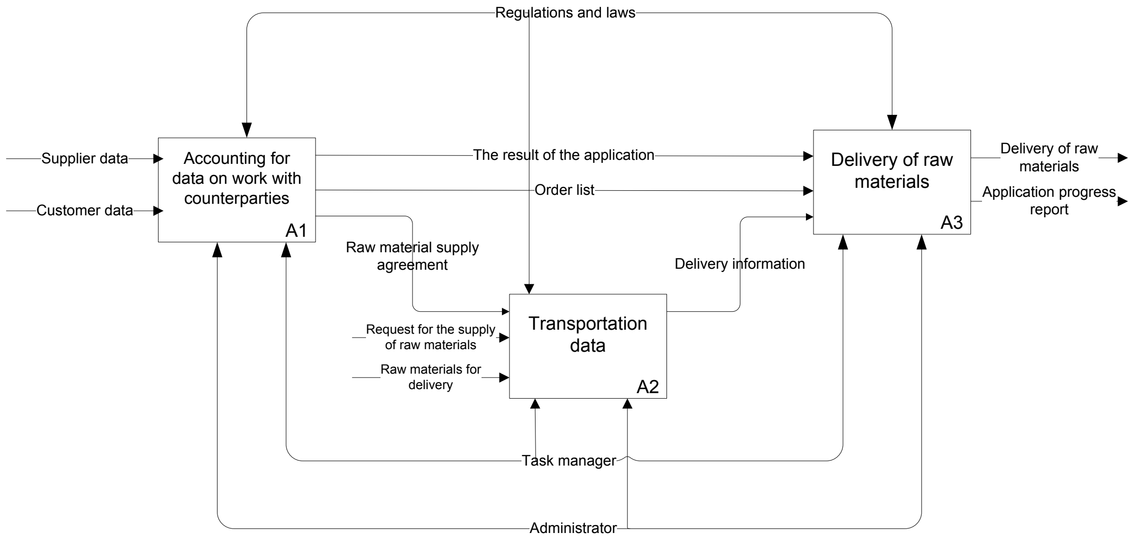

Fig. 5. First level decomposition diagram (AS-IS).

Taking into account all the shortcomings, the TO-BE model was developed (Figure 6). The decomposition diagram shows three processes.

1. "Work with contractors data accounting" (the process is designed to account for work with suppliers, customers and requests). The input data for this process are Suppliers data and Customers data. At the output, the Application results (information about the application status) and a factories list (replenished company database) are obtained.

2. "Transportation data" (the process is intended for transportation parameters calculating). For the "Transportation Data" process the input data are raw materials supply contract, cargo transportation application, and a cargo for transportation. At the output we have – Delivery information (field, heap, beet point, driver location information and the route).

3. "Raw materials delivery" (the process is designed to track the raw materials transportation and accounting documents formation). The input data for the accounting documents formation are Delivery information, Application results, Factories list. At the exit we have Cargo delivery and Application execution report.

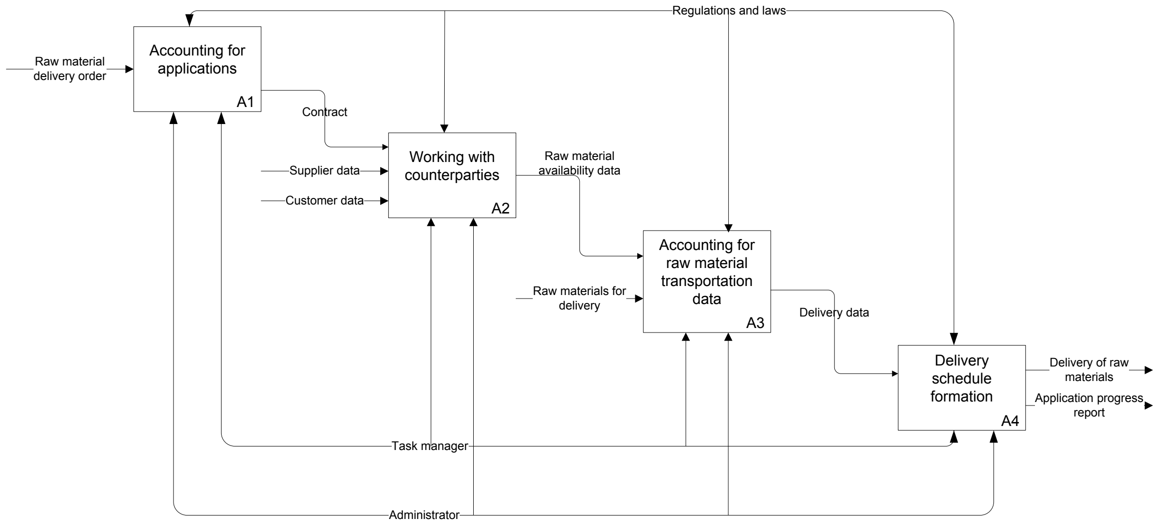

Fig. 6. First level decomposition diagram (TO-BE).

The existing process organization disadvantages are:

• logistics process management low efficiency, such as: supplies, transportation, storage, etc.;

• slowly logistics process planning, including needs forecasting and material requirements planning;

• requirement to coordinate actions, operations and logistics processes throughout the all promotion chain;

• large number of errors when filling out documents manually due to the human factor;

• irrational transportation and increase in transport costs as a consequence;

• monitoring and control absence over the logistics operations progress. Continuous monitoring will create a basis for regulating processes in order to increase their continuity;

• transport difficulties due to poor road conditions.

The presented diagram (Figure 6) shows an increase in the information flows number. They cover all the Raw materials delivery business process key stages [7, 8]. In addition to the quantity, these streams quality has also changed. Now these documents are presented in electronic form and can be printed at any time on demand. Figure 7 shows four processes:

1) "Applications registration" (the process is designed to applications to the dispatcher receipt account). The input data for this process is Raw materials delivery application (this is information about customer, location and necessary raw materials volume). The output data is the Contract.

2) "Work with contractors" (the process is designed to account for work with suppliers, customers and requests). The input data for this process are the Contract, Customer Data, and Supplier Data. The output data are Raw materials availability data (information about the raw materials from suppliers, and in the fields availability).

3) "Raw material transportation data accounting" (the process is designed to track and account for the raw materials transportation). Input data are Raw materials for delivery, Raw materials at a certain point availability data; output is Data for delivery.

4) "Delivery schedule formation" (the process is intended for the separate documents about delivery schedule formation). Input data is Data for delivery; output data are Applications execution report and Raw materials delivery.

4 The automated information system software module

The automated information system software module is developed in the 1C:Enterprise environment and contains the following objects [6, 7]:

Subsystems:

– regulatory and reference information (contracts, employees, contractors);

– delivery (factories, fields, distance between points, transport, the plant daily needs, route formation);

– service (working with a table, file uploading data, employees, warehouses).

Reference books:

– transport;

– fields;

– factories;

– contracts;

– employees;

– contractors.

Documents:

– route formation (delivery schedule for field);

– routes (delivery schedule for factory).

Data register: Distance from fields to factories.

Accumulation register: Queue for unloading.

The proposed solutions implementation makes it possible to improve the processing enterprise transport and logistics system [7, 8]. The software module allows to calculate the recommended route with the nearest time for unloading at the processing plant. With the recommended schedule help, we can create all the necessary documentation (product delivery schedule, raw materials acceptance and transfer acts, etc.).

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5 Conclusion

The paper proposes sugar beet nobal rot most common fungi growth mathematical models. A models modernization method is proposed on the automated information system development example, aimed at maintaining optimal microclimatic conditions for storing beet pulp in heaps. The developed software module will simplify the employees work, improve the processing enterprise logistics department work quality and will reduce processing information for decision-making time. The developed software product advantages also include the ability to quickly access to the necessary information and ease of use.

The software module implementation will increase the processing enterprises productivity by reducing the transport downtime and timely raw materials delivery. In addition, the developed module implementation will significantly reduce the creating the necessary documentation cost, which compiled and calculated earlier manually, thereby increasing the information reliability and integrity and reducing its loss likelihood.

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