Assessment of the Response Time to Information Messages in the Conditions of a Farms Based on the Methodology of Real-Time Systems

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Abstract. As you know, modern farms equip many technological devices, the operation of which directly affects the volume of agricultural products, the period of readiness, their quality, shelf life, etc., in this regard, the issues of assessing the response time and reaction to information flows are relevant. The article presents the results of constructing a model based on real-time systems for assessing system stability and the response time of a subject (farmer) to information messages from IoT devices to the subject's smartphone, depending on the time of performing current, priority and critical technological operations, their relevance, as well as on the level of information noise and the availability of resources. The analysis of the model revealed that an increase in the number of control objects and information messages increases the system response delay time from 0 to 36.5 hours which will especially depend on the receipt of priority and critical messages. The article offers solutions to reduce the response time, in particular by dividing the message flow into production and personal, resource optimization, using digital technologies (IoT), databases and improving the information skills of farmers.

1. Introduction
The main trends in the development of digital technologies have led to a rapid expansion of the use in various fields, in particular in the conditions of a multifunctional farm, mobile devices based on remote IoT technologies and messaging over Wi-Fi [1-2] to control and monitor production processes and operations, technological equipment, health status of the cattle. Accordingly, the management of information flows in various systems becomes a priority task for both large enterprises and small enterprises, including farms [3-4]. IoT devices create a significant information flow in the online mode, which requires constant processing. It leads to the problem of assessing the response time to a variety of information messages coming from IoT devices to create a stable state of the system and correctly plan the sequence and time for performing certain tasks, projects, operational response to changing conditions in the organization of various types of activities, in particular in the conditions of a multifunctional farm.

2. Materials and methods
There are a number of methods for scheduling tasks depending on their importance and urgency. These methods include the Eisenhower matrix [5]. It allows for planning tasks based on the assessment of their importance, a clear classification (urgent and important; important but not urgent; urgent but not important; neither urgent nor important). The article presents the results of constructing a model based on real-time systems for assessing system stability and the response time of a subject (farmer) to information messages from IoT devices to the subject's smartphone, depending on the time of performing current, priority and critical technological operations, their relevance, as well as on the level of information noise and the availability of resources. The analysis of the model revealed that an increase in the number of control objects and information messages increases the system response delay time from 0 to 36.5 hours. The article offers solutions to reduce the response time, in particular by dividing the message flow into production and personal, resource optimization, using digital technologies (IoT), databases and improving the information skills of farmers.
not important; not urgent and not important), according to the degree of priority. The Story Mapping methodology [6] determines priorities in work based on their consistency and criticality and a number of other methods that are used business process organization and management. There is a huge number of models of technical and economic systems, based on the theory of Queuing system [7]. They are used to solve problems of optimal management, service, in particular in real-time, certain service requests (customers, requirements), including priority ones that form a queue.

However, these models and methods do not allow evaluating in full the response time and the performance of certain actions by the subject of control as a reaction to messages about the state of the control object, taking into account the interaction of the subject and the object with a system of various factors - informational, technological and organizational.

The model developed by the author for assessing the response time of the impact of control factors on the stability and development of various systems [4] was used as a base model for estimating the response time, which was built on the basis of the methodology of distributed real-time systems [8]. Such systems are based on the prompt performance of many tasks in compliance with strict time constraints, including for information exchanges with external processes, and the response time of the task in the simplest case is determined by the sum of individual tasks, taking into account the time, the priority of their implementation and the recursive feedback. The problem of estimating the response time of the subject to messages about the state of the control object can be solved on the basis of a model in the form of an open system with elements of an information feedback (figure 1).

**Figure 1.** Model of information flows in the object-subject system.

The model presents a control object, which in the conditions of a farm (for example, meat and dairy specialization) is determined by a set of cattle (cows) and equipment, which are remotely monitored on the basis of specialized IoT devices ($A_i$), Wi-Fi sensors. Changes in the state of objects generate a multiple flow of information messages ($m_{i,om}$) about the controlled indicators of objects. They are received by the computer (smartphone) of the subject of control, the decision-maker - the farmer, the specialist, managing the farm. The subject's smartphone receives an information flow of messages about situations, objects of the environment (personal, news messages and newsletters), as well as notifications about the smartphone operation and various applications ($m_{i,ex}$). The subject selects priority ($m_{i,pr}$) and critical messages ($m_{i,cr}$) from the multiple message flow. Responding to messages, the subject performs various control actions and technological operations, makes technological decisions ($u$) aimed at managing objects using various labor, material, financial and time resources ($b$). First of all, among all possible current actions and operations, the subject selects priority (urgent,
and critical (super-priority, $p_{cr}$) operations, their prompt or immediate performance ensures the interaction of basic subsystems (object and subject), by way of a feedback.

The following ratio (developed on the basis of the methodology of real-time systems) is proposed to be used to estimate the response time of the system $R$ or, in other words, the total response time of the subject to the appearance of information messages ($m_i$) by performing operations ($c_i$) (formula 1):

$$R(y_i) = \frac{U_i}{\beta_u \mu_u} + \sum_{j=1}^{m} \frac{p C_i(c_{i}, D_i)}{\beta_c \mu_c} + \frac{p C_j(c_{i}, c_{pr}, D_j)}{\beta_c \mu_c} + B_i$$  \hspace{1cm} (1)

Where $C_i$ – is the execution time of many current technological operations; $C_j$ – is the time of fulfillment of the priority and critical operations; $p$ – is the coefficient that defines the relationship (feedback) between the actions of the subject and the reaction of the object; $B_i$ – is the delay (blocking) time of operations fulfillment - time (period) of waiting for the appearance of necessary labor, time, material resources; $U_i$ – is the execution time of previous operations; $D_i$ – is the deadline for performing technological operations or the time when the operation (task) remains relevant; $\beta_u, \beta_c$ – are the coefficients determining the delay in the appearance of control solutions; $\mu_u, \mu_c$ – are the coefficients determining information noise - the delay in processing messages by the subject (reading, deleting, ranking priority and critical messages). The execution of any operations ($c_i$) is guaranteed if the total response time $R_i < D_i$ and the execution time of any operations $C_i < D_i$ and $C_j < D_j$ is less than the time (time period) when the task remains relevant.

3. Results
Let us estimate the response time of the system - subject (farmer, decision-maker), to the flow of information messages from the control object by evaluating the possible values of the variables in Formula (1) – the execution time of current, priority, previous operations, the time of blocking operations and coefficients.

The following initial conditions were used for modeling: a set of remote devices ($A_i$) that perform round-the-clock monitoring (period - 120 days) to identify cows (objects) in estrous period and inseminate them at the optimal time. The devices send daily messages about the health status of the cattle to the farmer's computer (smartphone). Taking into account that the frequency of estrous period in cows is about 20 days \[9\], then in 120 days, the farmer will receive 6 messages from one device (priority messages) requiring rapid response, and the total number of priority messages from 80 devices will be 480 for a period (table 1).

| Number of internal / external / priority messages per day, pcs. | Number of messages for the period: total/ priority/ critical, pcs. | Information noise (per number of messages): priority/ critical, pcs. | Work execution time: total / current / priority, hours | Delay time: message processing / response / total, hours |
|---|---|---|---|---|
| 20/0/1 | 2400/120/2 | 20/1200 | 7.7/6.2/1.5 | 0.1/0/0.1 |
| 20/20/1 | 4800/120/2 | 40/2400 | 7.7/6.2/1.5 | 0.3/0/0.3 |
| 20/40/1 | 7200/120/2 | 60/3600 | 7.7/6.2/1.5 | 0.5/2.7/3.2 |
| 40/0/2 | 4800/240/4 | 20/1200 | 16.2/13.2/3 | 0.3/8.2/8.5 |
| 40/20/2 | 7200/240/4 | 30/1800 | 16.2/13.2/3 | 0.5/8.2/8.7 |
| 40/40/2 | 9600/240/4 | 40/2400 | 16.2/13.2/3 | 0.8/14.2/15 |
| 80/0/4 | 9600/480/8 | 20/1200 | 31.2/25.2/6 | 0.8/23.2/24 |
| 80/20/4 | 12000/480/8 | 25/1500 | 31.2/25.2/6 | 1/23.2/24 |
| 80/40/4 | 14400/480/8 | 30/1800 | 31.2/25.2/6 | 1.3/35.2/36.5 |

Note: * - execution of priority ($c_{pr}$) and super priority (critical) operations ($c_{cr}$).
The rest of the messages about the health status of cattle, as well as personal, news messages and newsletters, as well as notifications about the smartphone operation and applications operation (from 0 - no messages to 40 - intense message flow) are information noise. Taking into account that the client uses a smartphone for about 2.5 hours a day, and to work with communication applications, including mail, contacts, text messages - 40-60 minutes [10], then with messages about the health status of cattle (20, 40 , 80), the time for processing messages and determining priority (the onset of estrous period in cows) will be 0.1-1.3 hours per day. The object (farmer) performs current operations three times a day (feeding, milking cows, removing manure), spending an average of 10-20 minutes per cow per day ($C_i$), as well as other operations for cattle care, equipment and documentation maintenance, in the amount of about 10-30% of the working time - 1-2 hours ($U_i$). The full cycle of insemination of one cow takes about 1.5 hours. During the production process, critical situations may arise - illness, cattle losses, calving, equipment failure and others that are difficult to predict, require an urgent response and, conditionally, constitute one critical situation per 10 cattle for a period (120 days) and a lead time of about 1.5 hours per operation ($C_j$).

An integral part of the total response time of the subject (farmer) is the delay time, which depends on the values of the coefficients $\beta_u$, $\beta_c$, $\mu_u$, $\mu_c$ and the indicator $B_i$, and is determined by the search time (processing) of priority and critical messages in the information noise, and upon the receipt of such messages by the delay time in making a control decision to perform certain operations ($C_i$). The total execution time of operations, based on priority of operations for 20 objects, does not exceed the 8 hour workday, but the appearance of a priority message (a priority operation) increases the time spending by 18.7% (1.5 hours, $\mu_c = 0.84$; 11.25 minutes for 1 hour of working time), and the appearance of a critical message (performing a critical operation) at any time leads to an increase in the delay in the response time to messages by another 18.7% (3 hours, $\mu_c = 0.73$), and the system goes into an unstable state. As a result of increasing the number of objects to 80 and increasing information noise, the total execution time increases by 4.2% ($\mu_c = 0.96$), and the delay time (36.5 hours, $\mu_c = 0.46$) can significantly exceed the total execution time of current operations (25.2 hours) with the simultaneous appearance of priority (4 items) and critical messages (8 items).

The $\beta_c$ coefficient can vary from 1 - prompt decision-making to 0.7 – delayed decision-making with a lack of information or production experience. The $\beta_u$ coefficient will also decrease due to the lack of necessary resources (indicator $B_i$) - in the absence of an opportunity to make an operational decision. That is, a significant time delay arises due to a lack of resources, primarily temporary and labor, which with an increase in the number of objects you need to have in excess.

The results of modelling show that an increase in the number of control objects generates an intensive information flow of messages and increases the response time for priority and, especially, critical messages from 0 to 36.5 hours (reducing $\mu_c$ to 0.46). At the same time, some of the priority messages, especially in the conditions of agricultural production, in a relatively short period lose their relevance, increase the execution time, and delay time, whereas the subject (farmer) must have a mandatory reserve of time, labour and material resources.

4. Discussion

The developed model based on the methodology of real-time systems shows the need to search for priority and critical messages in a significant information flow and perform appropriate actions, which is close to the methodology for scheduling tasks based on the assessment of their importance, classification, priority and criticality [5-6]. However, in contrast to these models, the developed model will constantly generate critical situations connected with a simultaneous need to perform current and priority and critical operations at the same time, despite the fact that the subject (farmer) knows all production operations in advance. That is, if a priority message about the estrous period of a cow comes during working or non-working hours (at night, weekends) and there is a delay in performing operations or there are no necessary resources, then the current or other priority operations will be postponed to another time. Providing the fact that the optimal period for insemination of cows is on average about 10 hours [9], the inability to perform this operation in the current period causes a loss of
relevance of the message, a time delay and postponement of the insemination operation to the next priority message, and their total number will continuously increase (theoretically up to 80 priority messages per day), each time the response time increases by 18.7%. And the appearance of any critical message, for example, about a cattle disease, will result in a sharp increase in response time that will cause a delay in the performing of current operations. At the same time, the subject (farmer), as a rule, does not interrupt the execution of one priority operation (insemination of cows), if it is necessary to inseminate another cow, but if the priority operation is relevant for a long time (10 hours), such an operation can be interrupted when a critical message is received (for example, about cattle disease) due to possible irreversible consequences.

In the simulated system (as in real conditions of monitoring the health status of cows), there are a lot of priority messages about the need to perform peer-to-peer priority operations (for example, simultaneous insemination of many cows). This situation is modelled using the theory of queuing systems (QS) [7], when, in a particular case, priority operations form a queue for service. As in the QS, in the constructed model, the message flow increases and instability arises when the response time \( R_i > D_i \) is longer than the time (time period) when the operation remains relevant, that is, the object (farmer) does not have time to respond to incoming messages and is required to maintain the technological process of attracting additional resources. In the QS, the queue is serviced on the basis of strictly defined parameters, in particular, the rejected operation is transferred to the end of the queue and will be performed after a certain time, while the QS completely excludes the subjective factor of choosing an object for service (conditionally, the cashier cannot refuse to serve the client if the cashier does not like him). In contrast to the QS in the developed mode, the subject (farmer) can independently (subjectively) choose an object (cattle) for management, or choose more priority operations and change the decisions, and in certain situations, the subject may not respond to any messages at all, including priority ones, for example, sell a cow and not inseminate it. That is, in the QS, in contrast to the presented model, there is no need for a mandatory response to internal and external priority messages (for example, personal) or to external critical messages (for example, about weather emergencies), which also increases the response time.

It should be emphasized that for the developed model it is not properly correct to use the methodology for estimating the response time of the system in the "hard real time" mode for technical systems [8]. Nevertheless, in agricultural production, a significant part of livestock and crop production operations cannot be stopped or terminated by external command without damage and negative consequences. These operations are specifically regulated in time (keeping cows, growing plants, etc.). Therefore, the assessment of the subject's response time to information messages obtained in the developed model fits into the strict deadlines for the implementation of technological processes and is closely related to the sustainability and efficiency of the organization of agricultural production and resource management.

The analysis of the resulting model showed that reducing the response time of the subject to the appearance of internal and external information messages and maintaining the stability of the system is becoming an important problem. Obviously, in order to reduce the response time (\( R \)), it is necessary to increase the coefficients (\( \beta \) and \( \mu \)), as well as to reduce the execution time of current, priority and critical operations, the delay time (\( U_i, C_i, C_j, B_i \)), including at different stages of information exchange.

Reducing the execution time of operations (\( U_i, C_i, C_j \)), especially in a farming environment, can only be achieved by introducing modern, innovative, energy-efficient production processes and equipment, mechanization, automation and computerization of technological operations, including increasing the number of equipment by based on IoT devices and the use of digital technologies.

Modeling showed that the arrival of critical messages and the need to perform extra urgent operations have a significant impact on the increase in response time. To reduce the response time (\( R \)) in a farm setting, specialized databases should be used for regular, long-term recording of the health status of cattle, priority and critical operations, their number and execution time. The use and analysis of the database will allow to optimize the use and distribution of resources, planning of production activities, including taking into account critical operations. It should be noted that despite the active
introduction of digital technologies in agriculture, the overall level of information competencies of farmers remains low. Accordingly, the value of the decision-making delay time coefficient ($\beta$) is closely related to the lack of sufficient experience of the farmer with various specialized applications, information systems and technologies in the farm. Increasing the coefficients ($\beta$), as well as reducing the delay time ($B_i$), is based on improving the qualifications of the subject (farmer) in the fields of information technology, obtaining skills in production management, planning the use of time and labor resources, including using the methodology of real-time systems.

Increase of coefficients ($\mu$) (a reduction in information noise - a delay in processing messages by a subject (farmer)) faces a certain psychological problem - a constant increase in the time and frequency of using a personal smartphone (computer) [10]. Therefore, in order to reduce information noise (increase the coefficients ($\mu$)), it is necessary to regulate the time and periods of viewing and processing messages and, if possible, to separate internal (production) and external (personal) messages by using several devices (smartphones). It is advisable to use special software for work scheduling (organizers), as well as disable secondary notifications about the operation of a smartphone, various applications and Internet resources.

5. Conclusion
The assessment of the system stability and response time to information messages in the conditions of a farm showed that the response time significantly depends on the time of execution of current, priority and super priority (critical) operations, and the time (period) of their relevance. In this case, there is the problem of delay (blocking) in the execution of technological operations arises, including due to the delay in making management decisions, due to information noise and the lack of a sufficient amount of time and labour resources.

The developed model makes it possible to estimate the response time and stability not only of agricultural systems, but also of other similar production and social systems in the presence of information interaction between the object and the subject of management. Reducing the response time of the system, in particular, is achieved by using modern digital technologies and devices, reducing the level of information noise, organizing resource planning, as well as by increasing the information and organizational literacy of farmers, specialists, and farm managers.

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