E3S Web of Conferences **443**, 06014 (2023) https://doi.org/10.1051/e3sconf/202344306014
ETESD-II 2023

Conceptual basis for digitalization of specifications of transport and technological cycles of agricultural UAVs

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Abstract. The conceptual basis for digitalization of the specifications of transport and technological cycles of agricultural UAVs used in performing agrotechnical operations in smart agriculture is presented in the article. The basic properties of specifications have been studied. Methods for analyzing the main properties of specifications are considered and the relationship between specifications and the main stages of the life cycle of transport and technological cycles of UAVs is established. Based on GERT-oriented conceptual specification tools, a method for organizing conceptual specification tools based on GERT-like nodal logic is proposed in the article. Formalization of the GERT-network specification of transport and technological cycles of agricultural UAVs has been completed. The proposed approach to creating specifications for transport and technological cycles of UAVs in smart agriculture makes it possible to ensure full compliance of the specifications with the basic requirements for accuracy, clarity and completeness of description.

1 Introduction

The presence of a specification for transport and technological cycles (TTC) of unmanned aerial vehicles (UAVs) in smart farming is dictated by the need to describe the tasks performed by UAVs, because UAVs are capable of performing several different functions: from regular and detailed aerial photography to thorough spraying of chemicals, etc. [1-3]. The specification of transport and technological cycles implies a description of the tasks corresponding to the nodes of the cycle, which are solved using UAVs. The use of specifications plays an important role in planning agricultural operations, the effectiveness of which depends both on ground-based measurement and monitoring tools (fixing the state

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of crops, measuring fields, drawing up the structure of sown areas and crop rotations, etc.), and information management systems based on geoinformation technologies [4] and Earth remote sensing data (aerial and space images) [5]. It is noted in [6] that both UAVs and geoinformation technologies are also in demand for technical subsystems of agricultural enterprises (moving equipment, calculating mileage and cultivated areas, determining optimal crop delivery routes, repair schedules, etc.).

Thus, in our case the TTC specification is a description of the tasks corresponding to the TTC nodes, which are solved using UAVs. It is known that there are different approaches to the concept of specification and different names for a number of related concepts [7]. Work [2] examines the stochastic analysis of the TTC of UAVs at the current stage of development of the agro-sphere, associated with the use of precision farming technologies. It is shown that the UAV transport technological cycle for differentiated application of pesticides and fertilizers corresponds to a given field processing program and is described by a stochastic GERT model. Taking into account the proposed approach, different aspects of the specification concept on the basis of GERT-like nodal logic will be considered [8].

2 Methods for analyzing the main properties of specifications

To form conceptual means of specifications and methods of their organization, it is important to consider the main properties of specifications, which in [7] include: completeness, accuracy and understandability. In this case, it is necessary to take into account the main stages of the life cycle of the UAV TTC.

Completeness of a specification is an informal concept, but very important in content. Although this concept is difficult to formalize, it is intuitively clear to the specifier and designer. As a rule, completeness is achieved after repeated discussions of specification options drawn up by the specifier with the customer and other interested parties, making changes, additions, etc. It is important that the participants in the discussions come to the same understanding of the specification being discussed. It may often turn out that participants have different understandings of the task being described, and this is precisely what should become clear when discussing the specification, since it is a consistent representation of the task recorded on paper.

Specifications should be distinguished from less complete and precise requirements for UAV transport and technological cycle operations. The concept of “requirement” is more sketchy, that is, a preliminary description. It is the requirements that precede the specification in the overall TTC development process.

The accuracy of the specification implies its formalization and unambiguity. Formalization requirements can be quite strict, up to a completely formalized description, or they can be presented in natural language, which is usually considered an unsatisfactory description in terms of accuracy. Note that the choice of formalization means (means of achieving accuracy) in the specifications depends on the formalized model of the UAV TTC. In this case, the K. Nuemann notation is used [8], based on GERT-like node logic. That is, it is necessary to construct and define the concepts used in the specification as mathematical objects. Thus, accuracy can be identified with the mathematical nature of the specification. The degree of formalization may vary depending on the purpose of the description and its potential users. It is important to formalize the description no more than is necessary for unambiguous understanding.

The description must consist of reliable, clear, unambiguous concepts. Accuracy is achieved not only by notation, but also by the nature of the objects used in it. Mathematical objects arise from the mathematical practice of the GERT-network description of the TTC. The correctness of objects depends on the correct interpretation of the elements of the GERT-like nodal logic used to describe the TTC. In work [8] ready-made concepts and structures can be found for which formalized definitions and algorithms for converting GERT structures are given to optimize costs and time when implementing TTC.

Throughout the entire life cycle of the UAV TTC, the main stages will be highlighted: design and development; verification (debugging, testing, and verification); operation and maintenance (adaptation, modification, etc.). In practice, these stages can be repeated and alternated. For example, identifying errors when testing the GERT model of a TTC may lead to the need not only to rework the model, but also to make changes to the specification, thus, the specifications depend on at which stage of the life cycle of the UAV TTC they are used.

Considering the design stage, the intermediate position of the specification between the draft requirements and transport and technological cycles ready for implementation is noted. The design and development stage can be considered complete when we have a specification written in a notation for which an effective interpretation is carried out or, in our case, automatic construction (synthesis) of a GERT model of the UAV TTC is possible. Note that the synthesis of a formal description of the TTC according to a ready-made specification is a labor-intensive process in which specialists from various fields are involved and the features of various agricultural production techniques, precision farming methods, and technological aspects of various agricultural operations performed using UAVs must be taken into account. Much depends on the skills of specialists and their ability to work with innovative tools and technologies. In fact, at the final stage of this process, the specification must be carried out using software and algorithmic support for the UAV TTC.

The specification can be either external (initial) or internal. The external specification is addressed to an external user, customer, consumer of precision farming services and technologies. An internal specification is a specification for an internal user, who is the developer of transport and technological cycles. This specification is often classified as an intermediate specification. It is this type of specifications that is provided, for example, in the method of formalized technical specifications [9].

3 Results

Taking into account the performed analysis of the properties of the specifications, let's move on to the conceptual means of specifying the transport and technological cycles of UAVs.

So, the practice of developing specifications encourages the creation of new conceptual tools that increase the expressiveness of specifications. Let us give a general idea of the wide variety of conceptual tools that can be useful and actually applicable in the process of developing specifications. Traditionally, the following conceptual means of specifications are distinguished:

- tabular tools;
- equality and substitution;
- logical means and axiomatic descriptions;
- operations, expressions and procedural means;
- means of modularization, typification, structuring;
- naming means;
- graph tools: graphs, networks, diagrams.

A more detailed description of the presented conceptual tools can be found in [7]. Graph tools, including graphs and networks, are of greatest interest, since the conceptual notation of K. Nuemann [8] is based on GERT-like nodal logic, which makes it possible to build a GERT network model of the TTC, implementing a graph-analytical approach to the specification of various agrotechnical operations performed using UAV [10].

Regarding graph tools, it is noted that they are mathematical concepts that operate with fairly simple types of connections between objects. Moreover, these types of connections, as a rule, have (or allow) a clear graphical representation, which makes it possible to use graphic-analytical methods to calculate model indicators [11]. Representation of connections and objects in the form of a graphic picture makes it possible to define relationships and interdependencies of objects. If object A consists of parts A1, A2, A3, then this can be represented by a picture where an arrow from point A to point Ai depicts the connection (relationship) "object Ai is part of object A". A condition can be also set: to perform action A1, we need the results of actions A2 and A3. It is important, however, to recognize that there are concepts behind the pictures. The representation of the same concepts may be different. Thus, a drawing, as noted in [7], is only an external way of representing concepts, that is, it is a form of concept syntax. It is important that for graph tools it is the most adequate.

As graph structures trees and labeled graphs with superstructures are noted. The latter include such substructures as finite state machine diagrams, syntax diagrams, generalized transition diagrams, Petri nets, functional networks, flowcharts, object-relationship diagrams and semantic networks. The GERT network also belongs to this type of substructure.

3.1 GERT-oriented conceptual specification tools

It can be noted that the "classical" network graphs used in the CPM and PERT network technologies are applicable as conceptual tools only in cases where each activity and each event are implemented once during the implementation of the corresponding network project. When specifying real TTCs, as a rule, a number of activities (including UAV operations) are carried out with a probability of less than 1. In addition, situations are possible when an event occurs at a time when not all, but only one of the leading activities for this event has been completed. Finally, it may happen that the TTC project, during its execution, will return to events that have already occurred previously (in other words, feedback is allowed). As a consequence, there are activities that are not executed, as well as events that are executed several times during one implementation of the TTC network model.

The above properties, which cannot be realized for building specifications in "classical" design networks, can be achieved through extensions such as weighting of arcs and the introduction of different kinds of nodes and loops in source-sink networks based on the "activity-on-arc" representation. The more general networks obtained in this way are called stochastic network graphs (in the specifications built on their basis, the evolution of the corresponding TTC is no longer uniquely determined). In the literature, they are also called GERT networks, and this name was introduced by A. Pritsker, who conducted a large amount of research in this area [12-14].

Since GERT networks describe graphs with a stochastic evolution structure and stochastic duration of operations, when forming specifications it is necessary to establish a basic probabilistic space. Let us define a sample space Ω, for which the set of all possible outcomes of a random experiment when specifying the desired TTC is identified with the set of all possible implementations of the TTC or, accordingly, the GERT network.

GERT-like node logic underlies the development of UAV TTC network specifications. Various types of GERT nodes are used. Six different types of nodes used in GERT networks are defined, which are formed by combining three different input and two output characteristics of a node, that is, each node has an input and output side, differing in the type of input and output characteristics (i.e., their combination).

Let's consider three types of input for node i. If, during the execution of the network, event i occurs at exactly the time when all activities leading to node i terminate at the first iteration, then node i has an AND input. This AND input is used in CPM and PERT networks. The IOR input corresponds to the situation when event i occurs exactly at the time at which the first (in time) operation leading to node *i* is terminated at the first iteration. The occurrence time of event *i* is the earliest of the first completion times of the incoming activity.

Node *i* is said to have an EOR input if event *i* occurs every time at which one of the activities leading to node *i* stops. It can be noted that a node with an AND input or an IOR input can, by definition, be activated at least once during one implementation of the design network, while nodes with an EOR input can be activated several times during one implementation of the network. If $r > 1$, that is, the number of operations that activate a node and lead to a node with an EOR input, occur at the same time *t*, then, by definition, the node is activated *r* times at time *t*. In [8], some assumptions are formulated that prove that various activations of a node with an EOR input occur one after another.

Two types of output characteristics of node *i* can be considered. If all operations originating from node *i* occur when an event of network *i* occurs during the execution of the network specification, then node *i* can be considered to have a deterministic output. This type of node output characteristic is used in CPM and PERT networks.

If only one of the activities associated with node *i* is carried out when event *i* has occurred, then we should talk about stochastic output. During the formation of the specification of the TTC network model, when we are interested in completing the cycle as early as possible, we should be guided by the condition that each type of activity begins at its earliest start time. In a TTC specification with queuing UAV operations over a GERT network, some activities may be delayed due to limited UAV capacity or limited resources that are required to implement the TTC.

From the definition of AND and IOR input, it can be seen that nodes of this type are of any interest only if there are at least two arcs entering the node. In addition, using a deterministic output for a node is relevant if there are at least two outgoing arcs.

As already mentioned, in CPM and PERT networks, each node has an AND input and a deterministic output. The type of GERT network node that is most easily processed and is a node with EOR input and stochastic output is called a STEOR node. The remaining five types of nodes are called non-STEOR nodes. The STEOR node is a kind of transit node: whenever an incoming activity is completed, one outgoing activity is carried out. A GERT network, all nodes of which are STEOR nodes, is called a STEOR network. We speak of an AND node (or IOR or EOR node, respectively) if the node has an AND input (or IOR input, or EOR input, respectively). Likewise, a node with a deterministic output (or stochastic output, respectively) is called a deterministic node (or stochastic node, respectively).

In fact, a GERT network is a source-sink network graph based on an activity-on-arc representation, where each node belongs to one of the six node types considered (introduced in [8]) resulting from a combination of three inputs and two outputs characteristics of the nodes, with a weight vector assigned to each arc when the initial distribution of the network is specified.

3.2 GERT-network specification UAV TTC

The GERT network specification of the UAV TTC describes graphs corresponding to the transport and technological cycle, which have a stochastic evolution structure and a stochastic duration of transport and technological operations. The sample space Ω (the set of all possible outcomes of a random experiment when performing a TTC) is identified with the set of all possible implementations of a TTC or, accordingly, implementations of a GERT network.

When creating a specification, it is necessary to distinguish between the concepts of execution of a TTC and implementation of a TTC (or, accordingly, execution of a GERT network and implementation of a GERT network). The execution of the TTC corresponds to the execution of the main random experiment, while the implementation of the TTC represents the result of this experiment. In addition, we must distinguish between the concepts of "TTC event" and "random event". The occurrence of network events, however, is a special random event in the case of a GERT network.

Let us introduce the following notation. The random event "i-th node is activated" will be denoted by A_i, and the random event "i-th node is not activated" will be denoted by - A_i. For each arc, we introduce the parameters P_{ij} and F_{ij}, the combination of which in [8] was called the weight vector (WV). This WV is assigned to each activity (TTC operation) on the arc <i, j>. The first component of the WV P_{ij} is the conditional probability that the TTC operation <i, j> is carried out provided that the initial event i has occurred (that is, the probability of the operation <i, j> being performed). Then we can write P_{ij} := P (<i, j> is carried out | i happened).

When specifying a TTC with stochastic evolution of the GERT structure, it should be taken into account that some operations can occur and some activities on the arcs can be carried out several times during the same execution of the transport and technological cycle. Let D^a_{ij} be the non-negative duration of the a-th execution of the activity on the arc <i, j>. Then the second component of the WV F_{ij} is the conditional distribution function (CDF) D^a_{ij}, provided that the activity is carried out during the a-th time. For it we have:

F_{ij}:= $P(D^a_{ij} \leq t$ | <i, j> is carried out during the a-th time) for $t \geq 0$.

From the condition $t < 0$ it follows that F_{ij}:= 0.

The introduced definitions for P_{ij} and F_{ij} assume that these values do not depend on how many times the i-th TTC operation occurred, and whether this activity on the arc was carried out previously. For the TTC specification, it is important to indicate the duration of activity <i, j>, which we denote by DJI, and which corresponds to the duration of any execution of activity <i, j>. We assume that for each TTC operation the expected duration E(DJI) is finite and, thus, P(DJI < ∞) = 1.

In fact, E(DJI) represents the conditional mathematical expectation of the duration of the TTC operation at the time of implementation <i, j>.

Let us denote by T_i the activation time of node *i* if node *i* is activated no more than once, and $T_i = \infty$ if node *i* is not activated. Then $A_i = \{ T_i < \infty\}$ and, accordingly, $^{-}A_i = \{ T_i < \infty\}$.

The structure of the UAV TTC specifications is conveniently specified in the form of tables reflecting the elements of the UAV states (GERT-model nodes). For example, in [2], to analyze the TTC taking into account the risk of UAV downtime at the stages of loading and transporting cargo, a specification is presented that reflects the existing processes and operations of the transport technological cycle of an individual UAV. Table 1 presents a generalized specification for 4 possible UAV states. Loading/unloading operations of UAVs are carried out at ground loading points (GLP), and transportation operations are carried out within the framework of the cultivated field (CF).

Table 1. GERT specification of UAV states (GERT model nodes).

Possible UAV states, *i*	**UAV loading operation (A_i/$^{-}A_i$)**	**UAV position (item/field)**
1	No ($^{-}A_i$)	GLP
2	Yes (A_i)	GLP
3	Yes (A_i)	CF
4	No ($^{-}A_i$)	CF

Next, to generate the specifications of the arcs <i, j> corresponding to the UAV idle operations in the GERT network model, as shown above, a weight vector assigned to each activity (TTC operation) on the arc is introduced. UAV downtime for elements of a single transport cycle, like random variables, is subject to a certain distribution law. Chronometric analysis of downtime in the cycle of the DJI Agras T30 agricultural UAV, carried out in [2], allows us to establish the conditional distribution functions of downtime Fij and the probability Pij of its occurrence. A fragment of the generalized GERT specification of arcs (UAV idle operations) is presented in Table 2.

Table 2. GERT specification of arcs (UAV idle operations).

Idle operation <i, j>	**Description of idle operation**	***Pij***	**CDF *Fij***	**Type of CDF**
<1, 1>	Waiting for GLP loading	0.35	$\mu_{1,1} = 8$ $\sigma_{1,1} = 1.25$	NO
<1, 2>	Idle operation during UAV loading	0.15	$\alpha_{1,2} = 3$	E
<2, 3>	Idle operation when moving a loaded UAV to CF	0.15	$\alpha_{2,3} = 2.85$ $b_{2,3} = 0.09$	GA
<3, 3>	Waiting for processing to begin CF	0.45	$\mu_{1,1} = 7$ $\sigma_{1,1} = 2$	NO
<3, 4>	UAV idle operation during processing CF	0.03	$\alpha_{1,2} = 2$	E
<4, 1>	UAV movement from CF to GLP	0.09	$\alpha_{2,3} = 2.35$ $b_{2,3} = 0.05$	GA

Here, the type of CDF indicates the type of distribution, respectively: NO – normal; E – exponential; GA – gamma. The values of μ, σ, α, b correspond to the parameters of the moment generating function [11].

4 Conclusion

The considered approach to creating specifications for transport and technological cycles of UAVs in smart agriculture ensures that the specifications meet the basic requirements for accuracy, clarity and completeness of description. The GERT network structure, which forms the basis of the specifications, as the analysis shows, is a subset of a broad class of graph structures, including trees and labeled graphs with superstructures. It is important that this type of specification has a set of conceptual tools.

It is shown that there are different approaches to the concept of specification and different names for a number of related concepts. The work examines the basic properties of specifications and the relationship of specifications with the main stages of the life cycle of UAV transport and technological cycles. An analysis of the conceptual means of specification of transport and technological cycles of UAVs is presented. In particular, it is shown that the UAV transport technological cycle for differentiated application of pesticides and fertilizers corresponds to a given field processing program and is described by a stochastic GERT model.

The method of organizing conceptual tools presented in the article is based on GERT-like nodal logic and allows you to build a network model of the specification in the form of a network graph with sources and sinks representing activities on the arc, and each network node corresponds to one of the considered types of nodes. This makes it possible to build a GERT network model of the transport and technological cycle, implementing a graphical-analytical method for specifying various agricultural operations performed using UAVs. The correctness of the description depends on the correct interpretation of the elements of the GERT-like nodal logic used to describe the transport and technological cycles of the UAV.

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