Generic approach for structuring of workflow processes in satellite operations

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In general Satellite missions can be classified due to their assignment into commercial, scientific and military missions. The main differences occur in their operational concepts with respect to manpower, step-by-step activities versus automation and quality of service (QoS). However, also the different phases inside each mission, such as routine and low earth and orbiting face (LEOP) operations have different concepts. LEOP and singular events are in need of more flexibility because of the complexity in this start-up phase of a satellite than routine operations that are dominated by regular and well known activities. The main objective during all phases is the reduction of risk, which could be based on technical, human or in inadequate processes in the operational concept itself.

This paper presents an approach to model workflow processes for space operations that considers risk evaluation and quality issues. Furthermore, it points out the structure of workflow processes in operations that occur between planning and execution. The workflow model will be illustrated with sample processes based on data from a communication satellite mission at German Space Operations Center.

I. Introduction

Satellite missions can be classified in general as commercial, scientific and military missions. Furthermore each mission can be structured in different operational phases like the launch and early orbit phase (LEOP), anomaly events and routine operations. The requirements of each mission and mission phase in terms of operations diverge with respect to quality of service (QoS) as for example manpower, step-by-step activities, automation concepts or the QoS itself.

The main subject of operations is to execute activities on ground or on the satellite which can be clearly defined by workflow processes. Parts of those are written down in so called flight procedures. For satellite operations a *non-failure* execution of the workflow is the most important requirement. To fulfill this requirement and especially to optimize it, a model of the workflow would be helpful for analysis and optimizations of the process structure, possible failure options and evaluate the overall QoS.

An approach is to consider the workflow processes in satellite operation comparable with known workflow processes in production, administration or software development. Thereby processes can be evaluated with common strategies taking into account cost efficiency and workload leveling, which are primary requirements in those areas, while they are secondary requirements for space operations. For those fields various tools are in use

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to support modeling and analyzing these processes and it is possible to use these tools and methods to optimize the processes.

As this paper will concentrate on the embedding and modeling of a space operation workflow with a workflow process, the upcoming chapter should enhance the general understanding of the philosophy to embed processes in space operations.
Satellite operations will be defined from a very high strategic level of an operational concept down to a command and telemetry level which builds the interface to the satellite respectively the monitoring and control system. Within this structure the activities will be defined as workflow processes or tasks and the tasks' elements will be defined as actions or work items.
Afterwards this process model will be extended to include the actual participating systems and tools during satellite operation. For further analysis and optimization strategies of the workflow processes which are not subject in this paper, these extensions are needed.

II. Workflow - General description and definitions

In the literature very useful and generic definitions for a workflow are already established. The following chapter should summarize the common understanding of a workflow.

One general definition of a workflow was found on the internet[1] "*A workflow consists of a sequence of concatenated (connected) steps. Emphasis is on the flow paradigm*". Compared to the field of satellite operations the words sequence and steps are typical used nomenclatures and wordings and show therefore a well coherence to the generic definition.

Medina-Mora[2] uses the definition for workflow as class of information objects for informational processes. These objects consist of basic elements and the workflow is defined as a *sequence of actions* built of them. He calls this concept Action Workflow™, and opens with that definition the correlation to the satellite operation again by combining the words action, sequence and workflow.

Ellis[3] defines also a workflow process similar by using the elements *process* and *activities*. Within that specification the workflow process will be defined as a *set of work steps with a partial ordering*. Activities are the body of work steps in a process. They can be elementary activities, compound activities or other sub-processes. Figure 1 shows a simple example for this kind of workflow process, with a time axis in downward direction. The process has a defined beginning and end (green boxes) where in between different work steps and compound work steps are located.

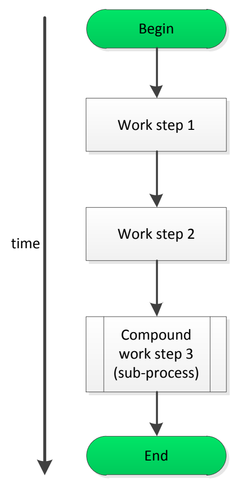

Figure 1 Simple example of a workflow process model

Elementary activities are a set of primitive work steps, executed by single participants. These descriptions fit with the commonly used processes in satellite operations such as procedures.

All definitions contain the key elements for workflow processes used in procedures for satellite operations:

- It is built by a sequence of elements.
- It contains a workflow path which orders the elements.
- It is executed by personnel.

In production environments modeling and optimizing of workflow processes e.g. material workflow (Medina-Mora[2]), are used since many years. Also in the field of office work environment the workflow processes have been adopted to organize and coordinate informational processes (Ellis[3]). In both environments the aim of using them is to improve the flow of work in sense of higher cost effectiveness. Satellite operations is mainly driven by risk consideration and quality conditions (QoS), which opens the necessity of an extended model of a workflow process, because the common model mainly focus on cost efficiency aspects.

III. Approach to integrate and adapt the workflow process in satellite operations

In the previous chapter the workflow process has been described in general. To use this approach in satellite operations it must be integrated in the structure of operations and it has to be adapted to the special needs.

First a concept of an operational structure will be described with the embedded workflow process. Then an approach for modeling the work items is presented. In conclusion an extension of the workflow process which is necessary in order to be compliant with the special requirement for analysis of quality issues and risk evaluation will be explained.

A. Operational structure and embedding of the workflow process

The workflow process must be enclosed in the structure of satellite operations. In satellite operations on one side there are the mission objectives and requirements and on the other side is the interface with the command and control system. Somewhere between are the activities of the ground support team, which can be described as processes.

The structure used here (Fig. 2) gives also the possibility to take into account separate responsibilities and tasks due to different departments or different companies involved in operations. Since satellite operations are a diversified field, this paper focuses on the elements which are directly linked with the work on the satellite during operations.

The operational plan (strategic level) is the top and strategic level in this operational structure (see Fig. 2). On this level the mission objectives and mission requirements are integrated in operational activities. With this plan the mission requirements are translated to requirements of the activities.

An operational plan consists of the activities (tasks) and the execution schedule and is taking care on limiting conditions and considering the effects of the activities.

The tasks (workflow process) are the elements of the operational plan. They are connected with the strategic level by the task requirements and limits which are subject of the strategic planning. A look at the specification of tasks within this paper shows:

- Tasks are initiated by a defined starting situation or by the schedule.
- Tasks are executed by the operating staff.
- Tasks consist of a set of actions.
- Execution of a task follows a predefined path.
- The task ends with a predefined status.

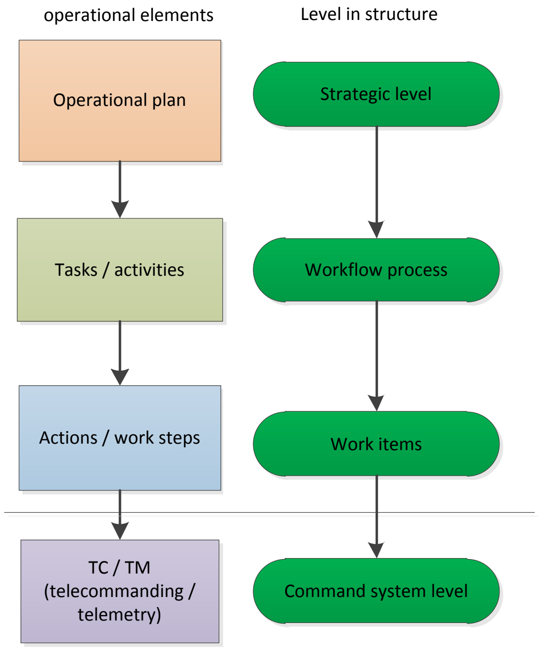

Figure 2 Structure of levels and elements in satellite operations

With these specifications and in respect of processes the tasks can be described as workflow processes. This offers the chance to use modeling tools and analyzing methods for workflow processes.
In space operation, the execution of tasks is often documented in the form of procedures as mentioned before. In the structure here procedures are not similar to tasks but they might be a part of the task. Tasks also include initiation and cleanup steps for procedures.

The actions (work item): The elements of tasks are the the individual actions. These actions describe the work to be done within the process contrary to the workflow path of the task. According to the definition of work units by Ellis[3], the actions are comparable with the elementary actions or the compound actions.
The actions can be simple work units like reading values from the telemetry system or sending telecommands (TC), but also compound actions like automated sequences of sub-actions or monitoring actions. A criterion to combine sub-actions to a compound action is the importance of interaction with the human operator.
An action is integrated in the workflow by its relationships with other actions. These relationships can be either manual interactions or a data transfer. An action always has one or more initiators and successors. This means it can depend on more than one previous action and cause also more than one following action.

Telecommanding and telemetry (TC / TM): As mentioned before actions might be “sending a telecommand” or “reading a parameter value” on telemetry. The content of these actions are therefore telecommands or telemetry values. Since actions request an interaction with the command and control system, the telecommands and telemetry values are the interface elements between actions within the workflow process and the command

and control system. Within the command and control system the TC will be processed. The further details of TC and TM are described by the CCSDS standard[4,5].

B. Overview of actions / elements of work item in process

As described in the previous chapter the actions are the work units of the tasks. Each action represents one work item. In order to model the process, different types of actions are used as visual representation of different types of work. According to the process model of Ellis[3] the action type can be described as attribute. Similar the relationships to other actions also can be defined as attributes. The relationships represent the connecting transactions between different action elements. Some actions and their visual impression used in this paper are presented below:

- Manual action / element
- Sup-process (automatic process)
- Data element
- Selection element
- Continuous monitoring

In the following the work items are presented more in more detail with their relationship to other work items and their visual expression.

Manual actions: They are the main elements of the process and describe a manually executed work item (see Fig. 3).

In Fig. 3 the element can contain one or multiple **inbound relationships** with previous elements. In case there are more than one inbound transactions all transaction have to be filled before starting the action (AND condition).

The **outbound transaction** is executed after the action is finished. It can contain the delivery of data but it also can be only the process path.

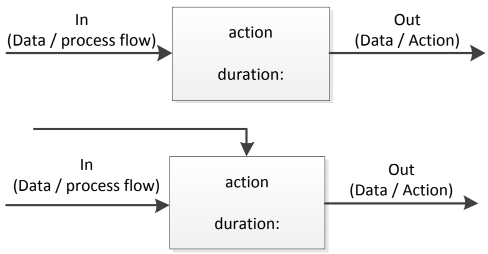

Figure 3 Graphic of the work item "manual action"

Sub-process (automatic process): The element in Fig. 4 is used for sub-processes which are not modeled in detail here. Often the sub-processes are executed automatically without user interaction. Or the sub-process element is used in case of actions containing multiple sub-steps, which are not modeled in detail due to their low relevance. An example for a sub-process here would be starting a program with choosing a file. Its status at the end is completed or not.

In Fig. 4 the **inbound transaction** might contain input data for the automatic action, but not necessarily.
The **outbound transaction** contains at least the completion status of the sub-process. But it might also contain additional data.

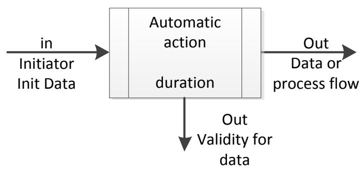

Figure 4 Graphic of the work item "sub-process"

Data element: Data elements of Fig. 5 represent data sources, which offer data like telemetry values, program values or action values to another work action.

The data element in Fig. 5 is triggered (**inbound transaction**) by another action element. For example the start of a program triggers the data element with a certain value.
It delivers the current data for **outbound transaction**.

Figure 5 Graphic of the work item "Data element"

Selection element: Selection elements in Fig. 6 are used in case the process path continues to be dependent on a verification of data or a situation. The selection can be rather easy if only a telemetry value needs to be verified or it can be complex if a situation bases on verification of multiple data.

The decision contains one or multiple **inbound transactions** with data (e.g. TM values) as in Fig. 6 and at least two **outbound transactions** if the conditions are true or false.

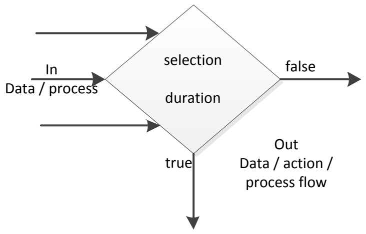

Figure 6 Graphic of the work item "selection element"

Continuous monitoring: This element in Fig. 7 is used for actions in case the work of the operator is monitoring the progress of an automated process for a longer period and reacting on upcoming anomalies.
The monitoring element is a special case of the selection element since it contains a decision if an error has occurred or not.

The monitoring is characterized by multiple **inbound transactions** of data and usually a longer duration of this action.
In the nominal case the process path will continue with the standard path (Fig. 7), only in case of anomalies the flow will continue with the sub-process for the anomaly cases.

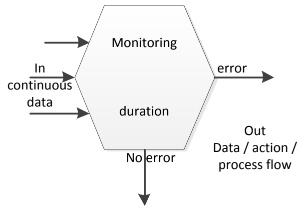

Figure 7 Graphic of the work item "continuous monitoring"

With the elements introduced so far the workflow process for satellite operation can be modeled. But the target of the model is to analyze the process with respect to risk evaluation. Therefore the model must be extended.

C. Exemplarily process with the integration of affected systems

The workflow model is extended by implementation of the affected systems (see Fig. 8). The workflow process follows the predefined path of work units (actions). Normally the responsible department or the system (tool), which executes the work unit, is an attribute of the work unit but not modeled separately. In satellite operation often the process needs multiple tools and multiple people. The workflow often transfers activities or data from one tool to another. As a general approach all occurrent systems are modeled as "affected systems".
The description "affected" is used, because the system which is the source for the data or the workflow executes the action item (work unit). For example a data element shall be read by a program. This will be modeled with the work item "data element" as part of the affected system "tool" and work item "reading" as part of the receiving system "the operator". An example of the visual representation of affected systems is shown in Fig. 8.

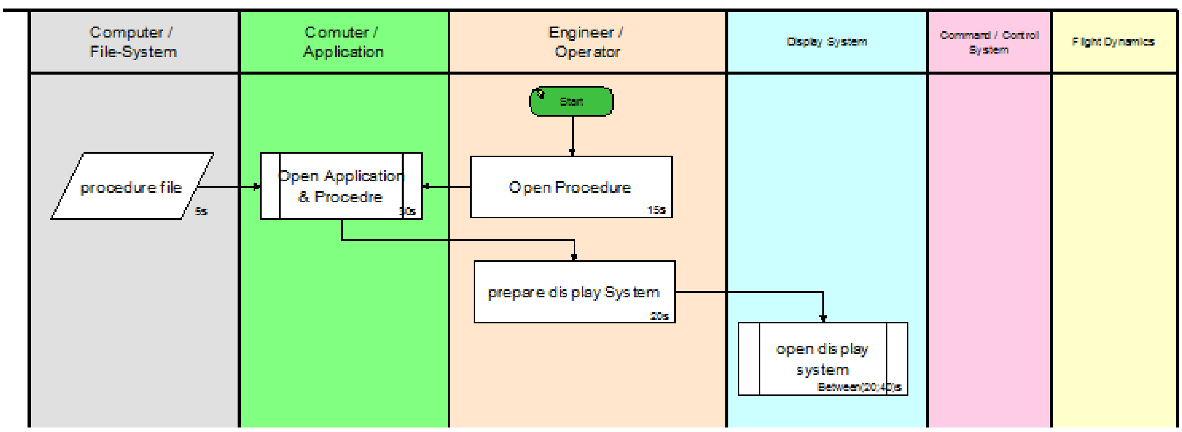

Figure 8 Example of a Diagram with a simple workflow process model, including the affected systems.

The figure shows the beginning of a simple process opening and preparing the work environment for execution of a flight procedure. The workflow is modeled with the action elements previously presented. To illustrate the attribute of the affected systems they are modeled as vertical lanes. The action items are allocated to the system they regard to. The actions of the operator are allocated to the system *operator* where starting of programs are allocated to the system of the program. The affected systems can be arranged in any order. However an adequate order helps on the analysis to make the alternations of the affected system better visible. In Fig. 8 one alternation is modeled when the workflow path changes from system *computer / application* to the *display system* via the *operator*. These alternations can be used for further analysis and process optimization which are not part of this paper. But already the visual representation shows whether a process is working steadily on one system or whether it is alternating the system very often.

IV. Conclusion and perspective

The approach to model activities of a satellite operation scenario as a workflow processes was the clear major content of this paper. The workflow process was defined first as the operating elements between the overall strategy of mission planning on one hand and the interface with the command and control system on the other hand. The resuming process describes the execution of the step-by-step procedure which will be finally executed by human operators. Different workflow processes can be modeled by using the presented work items (actions) which are defined in this paper. Those items are the basic input for various tools which are available for a generic modeling, such as the well-known Microsoft Visio or IgrafX Flowchart / IgrafX Process. By means of modeling the workflow it is already possible to harmonize the various processes or to identify their comparable parts. The design can be changed to reuse the comparable sub-processes in miscellaneous workflow processes, in order to reduce the amount of different sequences.

The used extension of the workflow model gives already an impression which systems are affected by the process and how often the system will alter. This will become more relevant for the analysis and optimization of the process. The purpose of modeling the various processes this way is to use these models for risk reduction by optimization of the processes and improvement of the reliability of service without increasing the stress on the personnel.

For the risk evaluation the impact of the process on the executing personnel shall be used in further studies by transferring ergonomic principals to the process analysis. These analyses will use characteristic values for reviewing processes and sub-processes. As exemplarity implementation of the described approach, a well-known operations environment which is currently operated at GSOC in routine operations was used.

V. References

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