Chapter 8 – GER-1: COGNITIVE AND COOPERATIVE ASSISTANT SYSTEM FOR AERIAL MANNED-UNMANNED TEAMING MISSIONS

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8.1 DATES

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8.2 LOCATION

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8.3 SCENARIO/TASKS

In future military helicopter missions a critical function is to get real-time surveillance and reconnaissance from several locations or targets at the same time without exposing humans to possible threats. Therefore, the deployment of multiple UAVs as remote sensor platforms in a Manned-Unmanned Teaming (MUM-T) scenario is investigated. The guidance of these will be realised by the commander aboard the mission leading helicopter, so the UAVs may be deployed flexibly and directly from where the surveillance and reconnaissance results are needed. This incorporates an operator to vehicle ratio smaller than one. Since the commander already works on many other tasks like mission management, system management, communication or supporting the pilot, the addition of the UAV guidance and mission management tasks will be very demanding for him/her, especially in situations when the environment requires the mission to be re-planned. On the other hand, when missions last a long time without need for action, the operator can become inattentive. These conditions may result in reduced performance or even accidents. Studies of accidents with ground-based UAV guidance attest that causes are not only technical malfunctions but also human error [1]. Furthermore, UAV guidance experiments at the Institute of Flight Systems show that operators produce errors which reduce mission performance [2]. These errors result from typical reasons like unbalanced workload conditions, interface handling problems, reduced situation awareness, degraded operator attention, vigilance decrements or complacency.

Therefore, the main objective is to reduce the workload of the helicopter commander to ensure mission success. The approach includes shifting UAV guidance from the typical waypoint-based level to a more abstract task-based level to reduce the workload of the operator and avoid overtaxing due to the multitude of various detailed system management and scheduling tasks [3],[4]. This is realised by an artificial cognition-based agent aboard each UAV, which understands the operator-given tasks and generates tactical sense making behaviours. Therefore, the commander provides single or a series of high-level tasks to each UAV via a graphical user interface based on a moving-map display. Ref. [5] describes this concept and the

experimental findings in some more detail. Furthermore, an adapted crew coordination concept is defined, which shifts some system management and communication tasks to the pilot flying. An assistant system for the pilot flying helps him/her to adopt the new tasks and also takes over the support of the pilot flying, which further reduces the workload of the commander. Finally, an assistant system for the commander shall be developed, which helps him/her in unbalanced workload conditions, improves situation awareness and attention [2],[6],[7] and eventually improves mission performance. The concept and evaluation of the commander assistant system will be presented in this article.

8.4 TECHNOLOGIES EXPLORED

Research on pilot assistant systems has been conducted at the Institute of Flight Systems since the early 1990s. Several prototypes (cf. CASSY, e.g., [8]; CAMA, e.g., [9]) have also been successfully tested in real flight. From this experience, Onken and Schulte describe the general approach to assistant systems in a broader context [10], which may in turn be applied to the multi-UAV guidance domain.

8.4.1 Work Process Analysis-Based Requirements for Assistant Systems

The general approach by Onken and Schulte describes assistant systems from a more abstract, work process oriented point of view. Figure 8-1 shows the structure of the physical entities performing a work process in a work system.

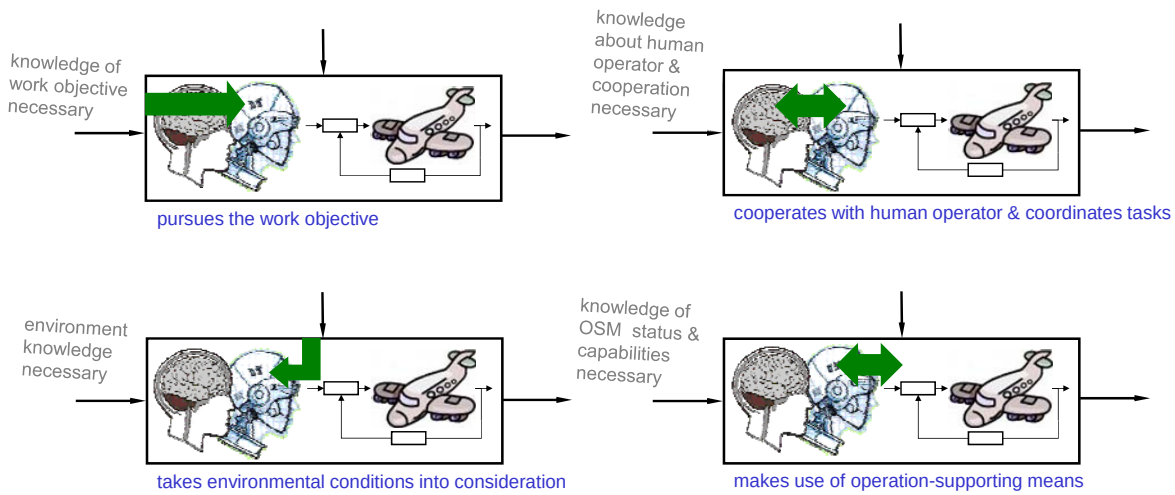

Figure 8-1: The Assistant System as Part of the Work System.

The work system is defined by the work objective (arrow from the left), which should be accomplished by the work process, thereby, providing a result (arrow to the right). The work system itself consists of the Operating Force (OF, left in figure), which always incorporates a human. In Figure 8-1 the OF is extended by the assistant system (robot head). To fulfil the work objective the OF applies Operation Supporting Means (OSM, right in figure), e.g., automation or in our case UAVs and a manned helicopter. Constraining factors to the work process are the environmental conditions (arrow from top). On this level the interaction between the OF and the OSMs can be described with the supervisory control paradigm [11]. Onken and Schulte [10] characterise some properties of the assistant system resulting from its integration into the work system,

e.g., the assistant system shall also pursue the work objective. These properties were refined to form a set of four properties as depicted below each work system in Figure 8-1. To fulfil them, the assistant system needs to have knowledge in four different areas (bold arrows), i.e., the *work objective*, the *environment*, the cooperation with the *human operator* and the *OSM*. Knowledge about the *OSM* can be further divided into knowledge about the *current state* and about *how to apply* them. Also, operator knowledge is split up into knowledge about the current *operator state* and about *interaction with* the *human operator*.

8.5 HUMAN FACTORS EXPLORED

Onken and Schulte [10] also characterise the mentioned cooperation between human operator and assistant system by the postulating basic behaviour requirements for assistant systems:

> "Requirement 1:
> The assistant system has to be able to present the full picture of the work situation from its own perspective and has to do its best by own initiatives to ensure that the attention of the assisted human operator(s) is placed with priority on the objectively most urgent task or sub-task.
>
> Requirement 2:
> If according to requirement 1 the assistant system can securely identify as part of the situation interpretation that the human operator(s) cannot carry out the objectively most urgent task because of overtaxing, then the assistant system has to do its best by own initiatives to automatically transfer this situation into another one which can be handled normally by the assisted human operator(s).
>
> Requirement 3:
> If there are cognitive tasks, the human operator(s) is(are) principally not capable to accomplish, or which are of too high risk or likely a cause of too high costs, these tasks are to be allocated to the assistant system or operation supporting means, possibly a supporting cognitive unit."

Based on these requirements a more detailed concept for the assistant system's intervention and cooperation with the operator will be derived in the next section. Afterwards, the corresponding types of intervention for the triggers will be defined, which are also derived by use of the requirements stated above.

8.5.1 Intervention Triggers

Referring to the introduction, an assistant system intervention should be triggered to prevent human overload and eventually human error, which may lead to reduced performance or accidents. Therefore, the identification of error causes is the trigger for an assistant system intervention. Several models for human error causes and prevention have already been stated, e.g., by Reason [12],[13] or Hollnagel [14],[15]. The basic requirements stated above also describe error causes and means to prevent these from a point of view which is very close to a system design. Therefore, the basic requirements were used to derive the following three intervention triggers:

1) *Attention Deficit*

   If according to the first requirement an assistant system should ensure attention to the most urgent task it has to intervene, if the operator does not pay attention to the most urgent task. This intervention is primarily meant to support the operator's situation awareness [16].

2) *Overtaxing*

   According to the second requirement an assistant system should intervene, if the operator is overtaxed in carrying out the most urgent task to balance the workload. From our point of view, overtaxing can

occur in every step of the human information process, which roughly consists of information acquisition and analysis, decision selection and action implementation (cf. Parasuraman, Sheridan and Wickens [17]). Since overtaxing as part of the information acquisition and analysis is already covered by the first intervention trigger, only overtaxing in the decision selection and action implementation process is used as an intervention trigger.

3) *Likely Inacceptable Costs*

Finally, according to the third requirement, an assistant system should become active, if the execution of a task by the operator would produce inacceptable costs. If he/she is not capable of accomplishing the task, this also means inacceptable task costs. This trigger is especially hard to detect because the system on the one hand has to decide upon the capabilities of the operator and on the other hand has to make a prediction about the future evolvement of the situation.

8.5.2 Intervention Types

After identifying the triggers when an assistant system should intervene, knowledge about how it should act is necessary. Intervention types basically represent different levels of automation and interaction. Here, several studies and theories have been published. Rouse and Rouse distinguish three levels of automation, i.e., “manual”, “management-by-consent” and “management-by-exception” [17]. Another theory is Sheridan’s ten levels of automation in decision and action support [18]. Endsley [19] first defined five levels of automation ranging from manual control to full automation and later refined them to ten levels of automation [20]. Onken and Schulte [10] also distinguish three different styles of cooperative assistance, i.e.,:

- **Alerting –** The assistant detects inadequate human behaviour and draws the attention of the human towards the corresponding task, if the human does not have situation awareness about this fact. It may give advice.
- **Associative** – The assistant continuously presents proposals but does not actively draw the attention of the operator. The operator can task the assistant to automatically carry out the corresponding task.
- **Substituting** – The assistant can either temporarily or permanently take over commitments of the human. Temporarily substituting assistance may be authorised by the human or intervene without waiting to be authorised. Permanently substituting assistance can be authorised in the beginning or built in by design.

Considering an attention deficit as an intervention trigger, assistance in situation awareness is needed. Here, alerting assistance was selected as an intervention type to interact with the operator. By guiding the attention, situation awareness about the most urgent task is transmitted to the operator. Inadequate behaviour not only incorporates the detection of necessary action in a certain task but also the conclusion that the action is urgent and more important than other tasks. Additionally to alerting assistance the system shall not only draw the attention towards the task but also improve situation awareness by telling the operator about the reason for the need for action. Advices in terms of decision aids should not be given directly but on request. When overtaxing is the reason for an intervention, the workload of the operator needs to be reduced by simplifying the task. Here, the intervention type associative assistance has been selected. The presentation of proposals shall reduce overload in decision selection, but in contrast to associative assistance these should not be given continuously but only in case of overtaxing. The automated execution of the task on request is also suitable for reducing overload in action implementation. Additionally to associative assistance, the assistant system should configure the user-interface for execution of the task to reduce overtaxing in action implementation through interface handling problems. Inacceptable task costs can only be avoided if the assistant carries out the task itself or passes it to an OSM. This intervention type is close to temporarily substituting assistance, which

intervenes without waiting to be authorised. Here, cooperation is still necessary in terms of letting the operator know, what the assistant system did. If this is not the case, situation awareness problems on the part of the operator could occur. Summing up, three different intervention types were defined corresponding to the three intervention triggers: *attention guidance*, *task simplification* and *task reallocation*.

8.5.3 Prioritisation

The defined triggers and corresponding types of intervention now form three different assistant functions derived from the three basic requirements. Since there can be several assistance needs at a time, the additional workload posed on the human operator by several interventions at once may overtax him/her. Therefore, the operator is supposed to handle only one intervention concurrently, which means that the different functions must be prioritized.

First a prioritisation is defined in case the same function is triggered multiple times at once. If the operator's attention should be guided towards several urgent tasks, not only the urgency but also the importance of tasks is considered by the assistant. Within the same task (e.g., the operator has to define the next mission task for UAV1 and UAV2 concurrently) the urgency is taken as a basis for deciding upon the higher priority. In contrast to this, between tasks of different types the task the output of which can have/has an effect on the other task's input is prioritized higher. Tasks with a lower priority will be processed afterwards. If the operator is working on several (not urgent) tasks in parallel and is overtaxed, only the task which the operator is really currently working on shall be assisted. Task reallocation however can always be executed directly, since the operator is not actively involved. Yet, the information dialog about the intervention needs to be queued, if the assistant already conducts other dialogs with the operator.

The following prioritisation was defined between the different assistant functions:

1) Task reallocation;
2) Attention guidance; and
3) Task simplification.

Since task reallocation can and also needs to be executed directly because of the criticality for the mission and for safety, this function has the highest priority. Finally, the second requirement states that the assistant system shall only trigger a task simplification, if the operator already works on the most urgent task. Therefore, attention guidance to the most urgent task has a higher priority than task simplification.

8.5.4 Operator Interactions

Only the assistant system takes the initiative for an intervention and starts dialogs with the operator. However, the operator has different possibilities to react upon the interventions by interacting either with the operation supporting means or the assistant system. In case of an attention guidance the operator has the following three reaction possibilities:

1) The operator accepts the advice and *switches to the respective task*. The assistant system recognizes the respective task as the current operator task and the dialog disappears. In the end the task should be accomplished. Otherwise the advice reappears.
2) The operator *requests support* in the task from the assistant. The assistant system switches to the task simplification intervention type and offers decision and action support.

3) The operator does not accept the advice and *ignores the dialog*. Here, he/she needs to tell the assistant to ignore the need for action, which is also remembered by the assistant.

In case of a task simplification intervention the operator has similar options:

1) The operator *accomplishes the task* and the dialog disappears. Here, it is not relevant whether the proposed solution or a different one is executed. Only the result that the task is accomplished is important.
2) The operator *requests automated execution* of the task from the assistant. The assistant system switches to task reallocation intervention type.
3) The operator does not want to work on the task anymore and *ignores the dialog*. As soon as the operator switches to a different task, the dialog disappears. Again the reaction is remembered by the assistant.

In case of a task reallocation intervention no further interaction of the operator is possible. The assistant only sends a dialog to the operator telling which actions were performed. However, the operator can interact with the assistant in advance to prohibit task reallocation for certain tasks.

8.5.5 Specific Assistant Knowledge

According to the defined concept Figure 8-2 shows the specific knowledge needed by an assistant system and relates it to the knowledge areas.

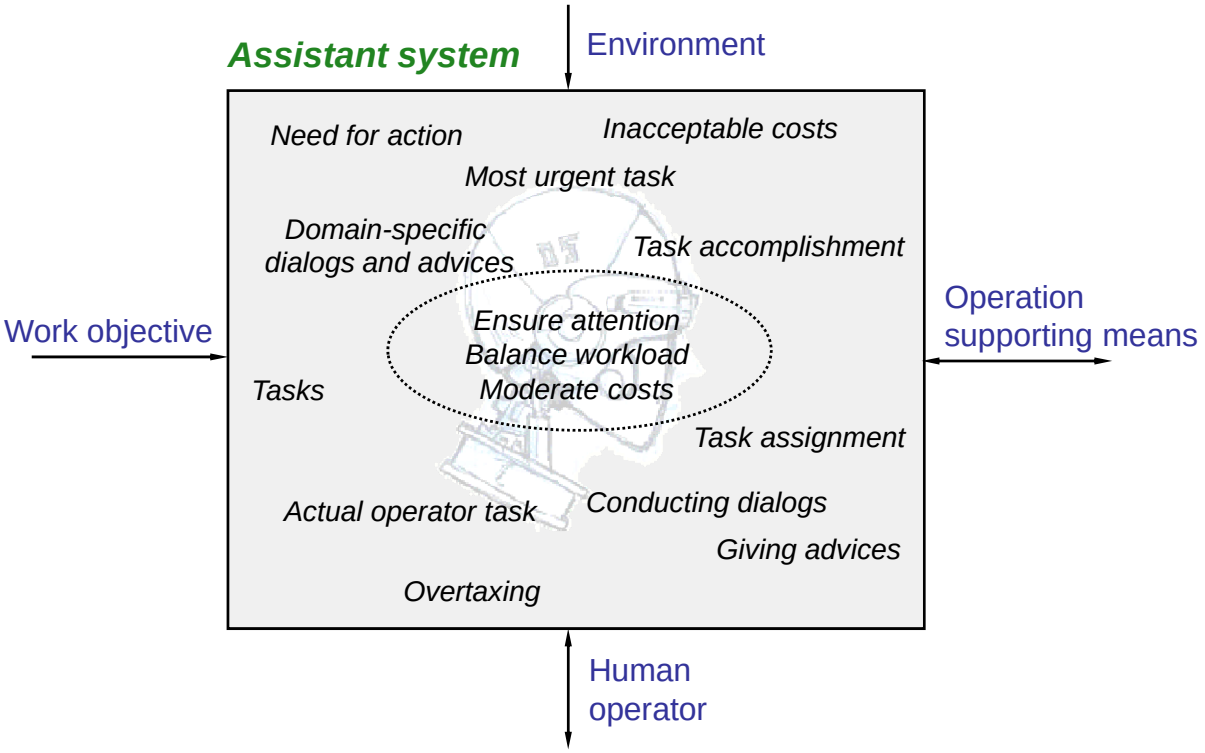

Figure 8-2: Specific Knowledge of the Assistant System as Part of the Work System.

First of all to ensure operator attention the assistant needs to know the currently *most urgent task*. For knowledge of the most urgent task it has to know which tasks have a *need for action*. After that it can determine the urgent matters and the most urgent one. For this it is also necessary to know, which *tasks* have to be generally worked on as part of the work process. This knowledge can be derived from the *work objective* and the available *OSMs*. Since the system shall only assist tasks, which are assigned to the operator and not to the automation, knowledge is required about the current *task assignment* between human and automation. After recognizing the most urgent task, the assistant needs to know, if the operator's attention is placed on this task, that means it needs to know the *actual operator task*. For balancing the workload, it is essential to detect *overtaxing* of the operator. To be able to offer appropriate help, it also needs knowledge about the actual operator task, which causes the overtaxing. Finally, to keep the costs on a moderate level, the assistant system should recognize if there are tasks which likely produce *inacceptable costs*, if they stay assigned to the operator. Of course this knowledge is always connected with a distinct uncertainty since on the one hand the system predicts operator behaviour and on the other hand it defines an arbitrary cost limit above which it intervenes. If the assistant system decides that an intervention is necessary, it has to know how to *conduct a dialog* with the operator and how to *give hints* on the user-interface to present the situation. Moreover it needs *domain-specific* knowledge about which *dialogs and advices* are useful for the operator. Finally, to reallocate a task the system needs to know which commands have to be sent to the OSMs to *accomplish tasks*.

The derived knowledge shown in Figure 8-2 is still quite unstructured. Therefore, the next section will introduce a knowledge-based implementation technology also proposed in [10], which allows a more structured modelling of the knowledge which is also closer to an implementation.

8.5.6 Cognitive Modelling

The assistant system for the UAV operator is implemented as an Artificial Cognitive Unit (ACU) to realize goal-driven behaviour. For this, the "Cognitive Process" (CP) by Putzer was used, which implements the knowledge-based level of the human performance model stated by Rasmussen [21]. The CP has been developed as a model of human information processing, which is suitable for generating human like rational behaviour [22] in technical systems. The behaviour is completely defined by explicitly represented knowledge, which is split up into goals the ACU shall fulfil [1], action alternatives it can choose from, schedules to implement them and environment models to build up a situational understanding. The CP was implemented with the Cognitive System Architecture (COSA), described in detail in [10].

In this section the specified knowledge for an assistant system is structured according to the cognitive process (cf. Figure 8-3). The aim is to derive specific knowledge classes for a cognitive implementation of an application independent knowledge package "Assistance".

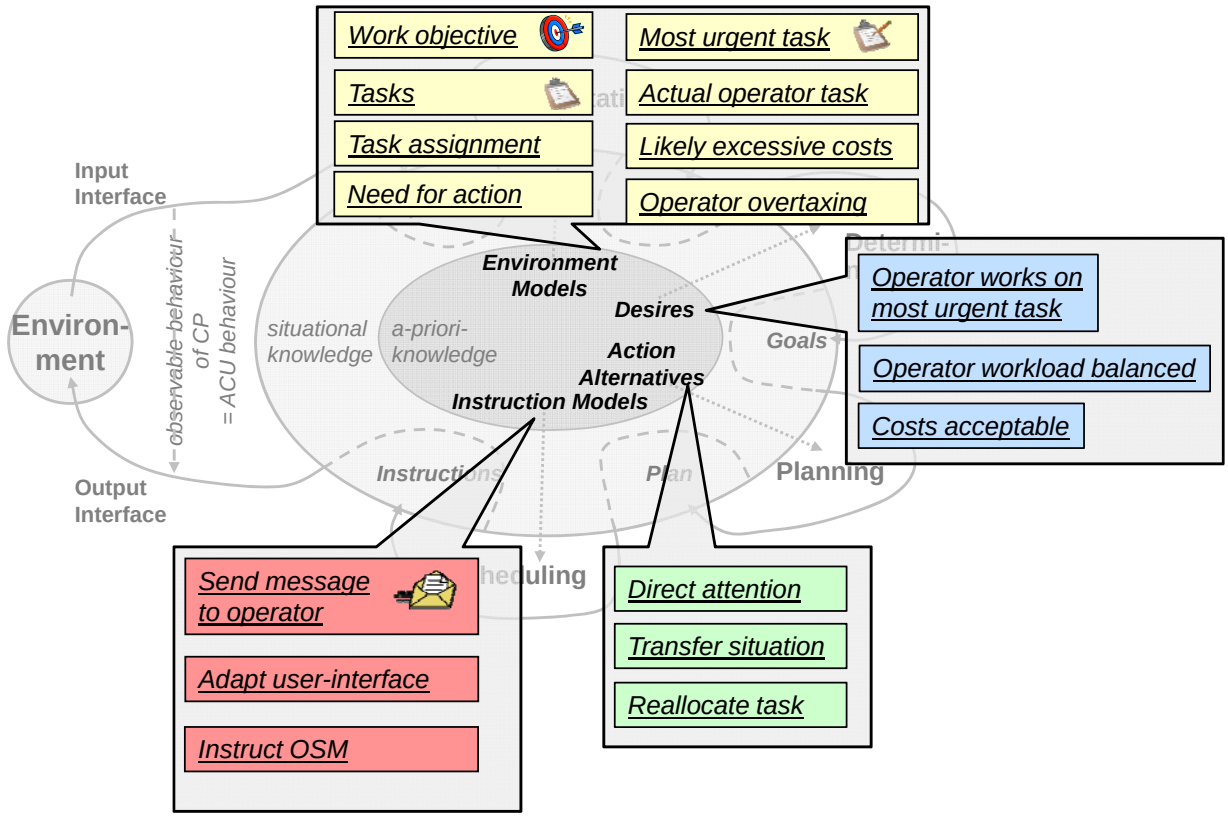

Figure 8-3: Application-Independent Knowledge Package "Assistance".

The application of the different knowledge classes to an assistant system should start with a definition of the DESIRES to be achieved [22]. A desire is a state of the work process that shall be achieved. If the state is different, the desire becomes an active goal. In our case the intervention triggers describe states, where the state is not satisfying for the assistant. Therefore, the goal of the assistant is to achieve the opposite state, i.e., *the operator works on the most urgent task*, *the operator's workload is balanced* and *the costs are acceptable*. The next step in deriving knowledge classes is to figure out, which abstract ACTION ALTERNATIVES could be applied to fulfil the desires. These alternatives correspond to the intervention types specified earlier. Therefore, if the operator is not working on the most urgent task, the assistant system should *direct the attention* of the operator. In case the operator workload is unbalanced, the assistant system *simplifies the task* by offering partial automation to the operator. If the task costs would become inacceptable, the assistant shall *reallocate the task*. To execute the action alternatives, INSTRUCTION MODELS are used, which describe the technical output of the system. According to the knowledge areas illustrated above, the output can be either to the operator or the OSM. Outputs to the operator may be to start a dialog by *sending a message* or *adapting the user-interface* to give additional hints or to configure the display. Outputs to the OSM would result in *sending instructions to the OSM* to execute tasks. To understand the situation, be able to check, if the above mentioned desires are met and also to send appropriate messages and instructions, an assistant system needs ENVIRONMENT MODELS. In this case they correspond to the specific knowledge stated above (e.g., work objective, tasks, task assignment, actual operator task, need for action). For a complete knowledge-based modelling also rules are necessary, which instantiate these knowledge classes and change their attributes. The desire "operator works in most urgent task" is instantiated, if there is an instance of a "most urgent task" but no instance of an "actual operator task" which links to the same task. The action alternatives are instantiated

according to the prioritisation defined above and activate the corresponding instruction models. The environment models in this package are actually abstract classes, which are inherited by domain-specific classes in a separate knowledge package "Mission". For example in a troop transport mission there is an instantiation of a "work objective" class, which contains that the troops have to be at a certain position at the end of the mission. The "Mission" package also contains instruction models, e.g., a message for guiding the attention of the operator towards the identification of a certain object or commands to the UAVs for adding or deleting mission tasks.

8.5.7 MUM-T Specific Assistant Functions

The assistant functions are defined on the one hand by the different intervention types in the application-independent knowledge package and on the other hand by the application-specific tasks in the "Mission" package, which shall be supported. Therefore, a task analysis for the commander in a manned-unmanned teaming domain was performed. Tasks in the area of communication and system management were not considered because in the crew coordination concept these tasks were intentionally shifted to the pilot flying by experimental design. Results are shown in Figure 8-4.

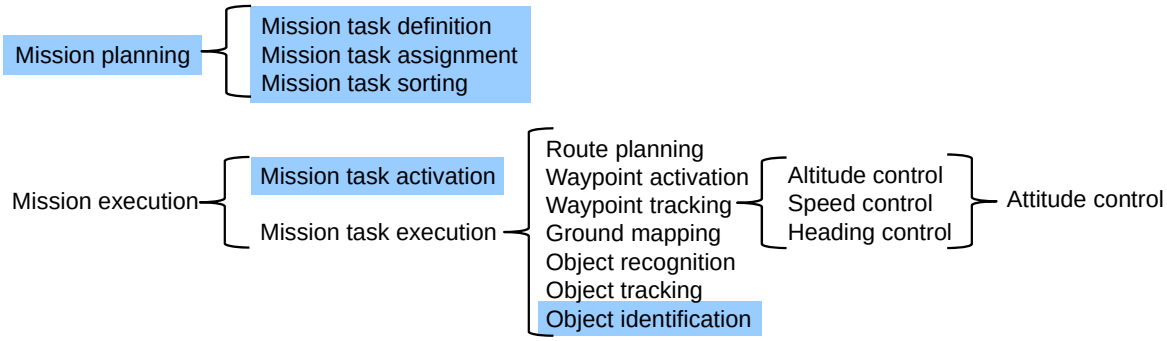

Figure 8-4: Task Analysis for the Helicopter Commander in a Manned-Unmanned Teaming Domain.

On top level tasks can be divided into mission planning and mission execution. Mission planning consists of defining mission tasks (e.g. departure, transit, route/area reconnaissance or surveillance), assigning them to either a manned helicopter or a UAV and sorting them into the agent's agenda. To execute mission tasks, they have to be activated first. Most of the time activation is done in the order given by the agenda. Mission task execution for the manned helicopters mainly consists of flight management tasks like route planning, waypoint activation and waypoint tracking. Since the UAVs have cameras as a payload, ground mapping, object recognition, tracking and identification also needs to be done for reconnaissance tasks. Since the helicopter is controlled by the pilot and the UAVs are guided on a task-based level [3], only the highlighted tasks have to be performed by the commander/UAV-operator. These tasks are also supported by the assistant system. According to the intervention types (attention guidance, task simplification, and task reallocation) each task can be assisted in three different ways. The only exception is the object identification task, where a task reallocation in terms of an automated identification seems hardly feasible with the current state of the art.

8.6 UNMANNED SYSTEM USED

The UAVs used in the simulation are generic vehicles with a flight performance close to the manned platform, so they are able to fly in a common mission in loose formation.

8.7 SUMMARY OF ANY NATO COMMUNICATIONS/COLLABORATIONS/ INTERACTIONS

The MUM-T focus is on specific requirements of the German Armed Forces. Still, it is of great interest to discuss the system concept, experimental design and results with NATO partners.

	Planning/Design	***Execution***	***Analysis***
Communication	*X*	*X*	*X*
Coordination			
Collaboration	*X*		

8.8 SUMMARY OF TD RESULTS

In May 2011, during an experimental campaign for the MUM-T research at the UBM the benefit and cooperation aspects of the described assistant system were evaluated. One of the experimental missions used in this campaign was also shown as a tech demo for the NATO-HFM group in September 2010.

8.8.1 Experimental Setup

The primary objective for the test persons was to successfully complete a helicopter troop transport mission into hostile territory. To achieve this, they had additional three UAVs, which were guided on a task-based level. The UAVs implemented capabilities like route/area reconnaissance and surveillance in order to secure the routes/landing sites/objective for the helicopter and the troops. Each mission started at a main operation base in friendly territory. Here, the commander was mainly busy entering a mission plan for the helicopter and the UAVs. After activating the take-off and passing the corridor into insecure territory the UAVs started with the reconnaissance and the commander had to observe the progress and identify objects preselected by the UAVs. During the mission also three events for a major mission re-planning occurred: identification of hostile troops at the primary drop zone, detection of a SAM-site at the primary egress corridor and a follow-up troop transport mission after completion of the first troop transport. The experimental run was finally stopped after 30 to 45 minutes when the helicopter returned to friendly territory.

Each test person had to complete one mission with and one mission without support by the assistant system. To prevent expectations about the mission development, missions differed concerning the mission area and the threat configurations.

Eight German Army helicopter pilots participated as test persons at an average age of 37 years (min 28 years, max 51 years. Their flying experience ranged from 830h up to 5100h with an average of 1815h. The test persons were grouped into fixed crews consisting of two members (alternating in the roles of commander and pilot flying). Each test person had two days of training for the commander’s workstation. The training began with an instructed phase and continued with a free training phase. Furthermore subjects had the possibility to observe other subjects in their training (passive training).

The experiments took place in the helicopter simulator of the UBM, which was refined to support a manned-unmanned-teaming mission including UAV-guidance from the commander's seat. This workstation provides two displays with various formats especially for UAV tasking and object identification as well as one control and display unit (in this case) especially for entering mission goals and constraints and activating automated helicopter mission planning. The commander was equipped with a headset for communication within the cockpit, with other external entities (e.g., tower, AWACS) and with the assistant system.

During each mission, the simulation was paused three times in order to measure the crew's workload (with NASA TLX [23]) and the situation awareness (with SAGAT [24]). The first pause was made while the helicopter was still in friendly territory, the second in hostile territory outside the operation area (only NASA-TLX) and the third inside the operation area. Video and audio recordings were taken and all relevant simulation data was logged, which included the system interactions of the commander and the pilot flying. After the experimental runs the test persons were interviewed about acceptance of the assistant functions and possible impacts on situation awareness and workload.

The measured data shall prove that the employment of the assistant system can increase mission performance, reduce workload and increase situation awareness of the commander. Also the interventions should be considered reasonable and be well accepted by the test persons.

8.8.2 Experimental Results

First of all, mission performance, which is dependent from both the commander, the pilot and from the corresponding assistance configuration, is presented. Afterwards, the individual situation awareness and subjective workload are examined. Finally, the objective individual behavior of the commander and subjective ratings of the assistant system functions by the test persons are presented.

Performance – Mission planning for the UAVs and the helicopter as well as punctual activation of UAV mission tasks had an effect on performance. If the commander did not recce the helicopter route with the UAVs in time, the helicopter either had to wait until the route was recced or fly across insecure territory. To measure the performance impacts in case the helicopter waited, mission delays were assessed by generating a standard solution for each mission offline and comparing it to the measured mission durations. Then the frequency of mission delay in segments of 2.5 minutes each was counted.

Here, in the unassisted configuration, excessive mission delays, which exceeded 7.5 minutes, occurred in four cases, whilst this could be observed only once in the assisted configuration (cf. Table 8-1). Furthermore, the duration was measured in which the helicopter had a geographical position (2D) that had not been photographed by a UAV before. In the configuration without assistant system, this exposure time was three times higher ($t(14) = 1.74$, $p = 0.1$).

Table 8-1: Comparison of Mission Delay for the Helicopter.

Delay	Unassisted	Assisted
d < 2.5 min.	3	3
2.5 min. ≤ d < 5.0 min.	1	2
5.0 min. ≤ d < 7.5 min.	0	2
7.5 min. ≤ d	4	1
Overall	8	8

Finally, performance of the commander in the object identification task was measured. Throughout all sixteen experimental missions 113 objects were located by the UAVs' ATR functionality and had to be identified consequently (53 without / 60 with commander assistant system). Identification correctness was equally good (only one error in each configuration) but not analyzed because it was not supported by the assistant system. Instead a closer look was taken into critical events, where the helicopter came close to the unidentified object (15 without / 10 with assistant system) and fast task completion times were important. In the assisted configuration the assistant system guided the attention of the commander towards the object identification task and additionally offered task simplification in terms of display configuration. Attention guidance reduced mean duration from ATR recognition until the commander started the object identification from 46.8 seconds unassisted to 18.2 seconds assisted, which shows weak significance ($t(23) = 1.79$, $p = 0.087$). The automated display configuration, which was used five times reduced the mean time for object identification itself from 17.3 seconds to 7.5 seconds, but no significant effects could be verified ($t(21) = 0.771$, $p = 0.45$). The overall time from ATR recognition to task completion of the identification was reduced from 66.1 seconds unassisted to 27.7 seconds assisted, which also shows weak significance ($t(21) = 1.96$, $p = 0.063$).

Situation Awareness – Situation awareness was measured objectively using the SAGAT [24] method. During the simulation pauses, subjects had to estimate positions of own and hostile forces in an electronic map display. Civil forces were not counted, since subjects very often considered them not relevant and omitted them intentionally. The estimated positions were compared to the true positions at this time. Each object was awarded with two points if distance between specified and actual position was less than 0.75 nm, with one point if distance was less than 1.5 nm, and no points if distance was larger or the object was missing. In the unassisted configuration 108 out of 154 points were gained (70.1%), while in the assisted configuration 105 were gained (68.2%), which shows nearly no difference.

Moreover, subjects were interviewed about the current situation (threats, reconnaissance status, next communication task, current and subsequent tasks of UAVs and helicopter). Correct and nearly correct answers were awarded with two points, still acceptable answers with one point, and wrong or missing answers with no points. Again, for every test, the points were summed up and divided by the maximum number of points to receive a percentage. In the interview the subjects gained significantly better results in the assisted (95.4%) than in the unassisted configuration (90.0%) ($t(14) = 2.49$, $p = 0.026$). It is also worth mentioning that the test results were showing very high absolute values in both configurations.

Subjective Workload – Subjective workload was measured using the NASA-TLX [23] subjective workload assessment tool, which divides workload into the following six categories: Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Performance (P), Effort (E) and Frustration (F).

Workload across all phases and subjects shows a non-significant decrease in mean from 42.3% (unassisted) to 38.8% (assisted) ($t(43) = 0.714$, $p = 0.48$). The NASA-TLX scores did not produce significant results, because the individual utilization of the scale varies more than the differences between the system configurations. However, the main difference between these two values was caused by a significant decrease in temporal demand from 13.7% (unassisted) to 8.3% (assisted) ($t(43) = 2.28$, $p = 0.027$). Changes in other workload dimensions range only from 0.3 – 1.6 % and are not significant.

Behavior – The commander's interaction with the assistant system was evaluated by video analysis of the assistant system interventions (system- or user-initiated) and the corresponding commander's reactions. User-initiated attention guidance was not possible by design. Also, not in every task knowledge for system-initiated task simplification or task reallocation was implemented (cf. Table 8-2).

Table 8-2: Assistant Interventions and Commander's Reactions.

	Object Identification		Single Mission Task Planning (UAV)		Mission Task Activation (UAV)		Mission Planning		**Overall**		
	System	User	S	U	S	U	S	U	S	U	**Overall**
Attention Guidance	**12**		**20**		**15**		**27**		**74**		**74**
Accepted	*12*		*11*		*11*		*21*		*55*		***55***
Not Accepted	*0*		*9*		*4*		*6*		*19*		***19***
Task Simplification		**5**	**12**	**6**	**0**	**4**		**2**	**12**	**17**	**29**
Accepted		*5*	*8*	*3*		*4*		*2*	*8*	*14*	***22***
Not Accepted		*0*	*4*	*3*		*0*		*0*	*4*	*3*	***7***
Task Reallocation				**8**	**5**	**4**		**2**	**5**	**14**	**19**
									91	31	**122**

Across all experimental runs 74 times the assistant system intervened with attention guidance. 55 times the commander complied with the advice by switching to the respective task. In the remaining cases subjects did not work on the respective task directly after the advice. Thus according to the test persons, in about 75% of the cases attention guidance was correct. Task simplification was evaluated by analyzing, if the subjects used the decision selection and action implementation support offered by the assistant. Since the assistant could not offer a solution for object identification, here, only the configuration of the user-interface to prevent interface-handling problems was evaluated. 22 out of 29 times (about 75%) task simplification was used by the subjects. Only single mission task planning proposals were not accepted several times, but still more than 60% (11 out of 18) of the proposals were accepted either by requesting automated task reallocation or manually inserting the mission task into the UAV's agenda. System-initiated task reallocation was only implemented for a safety critical situation, when a UAV came close to a threat and therefore was stopped by the assistant. Here, the commander could not react, but the intervention could be regarded as correct, since no UAVs came under fire in the assisted configuration compared to five times without the assistant. Also, in the interviews all test persons stated that the intervention was necessary.

Ratings – In the following, the most important results of the questionnaires, which were given to the test persons during the corresponding mission debriefings, are presented (cf. Figure 8-5).

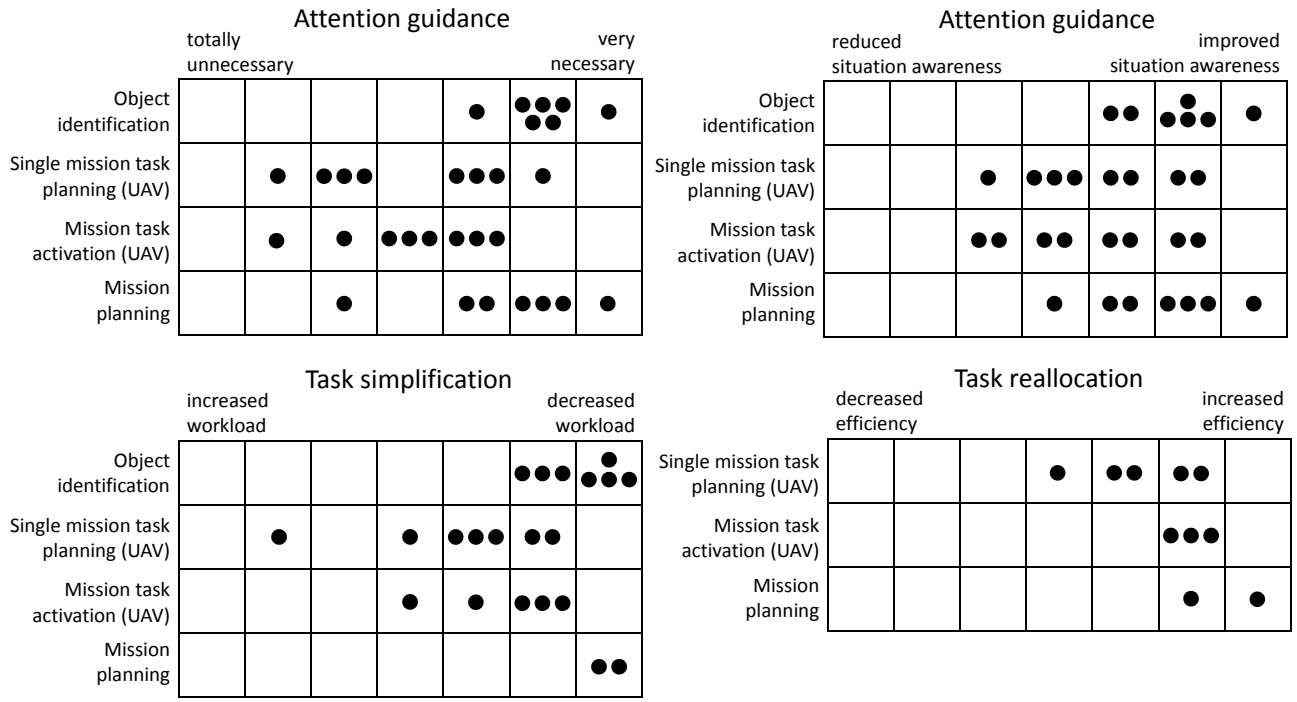

Figure 8-5: Rating of Different Intervention Types Across the Corresponding Commander Tasks.

Most of the test persons accepted the attention guidance for object identification and mission re-planning as necessary and stated that it improved their situation awareness. Attention guidance for activation and planning of single UAV-tasks produced more or less indifferent results. This was because test persons sometimes wanted to employ the UAVs differently from the assistant which led to the understanding that the attention guidance was too early and not necessary. According to the subjects' statements, the task simplification in terms of automated display configuration for the object identification task reduced workload. Task simplification for activation and planning of single UAV-tasks were also found to reduce operator workload slightly. For task simplification in mission re-planning, which was not used very frequently, the subjects attested a strong relief in workload. Task reallocation was also not used by all test persons, but was rated to increase efficiency.

8.9 LESSONS LEARNED

An interesting finding was that test persons followed different strategies in mission planning. For example some test persons wanted the UAVs to secure the operation area and wait there until the helicopter arrive, while others sent them directly back to recce the route to the main operation base. Also some test persons recced alternate routes whilst others focused on reconnaissance of the main route. This made it difficult for the assistant to propose mission plans which were in accordance with the individual test person's view. So, test person's strategies are highly individual, which might be the consequence of too little training on the particular job or too little developed procedures, since multi-UAV guidance from the cockpit is a novel task to German Army helicopter pilots.

Another surprising point was that although tasks were strictly divided upon commander and pilot flying in terms of a crew coordination concept, task assignments were shifted. The commander even acted as an

assistant for the pilot flying upon pilot errors although this should not have been necessary because the pilot was also supported by another assistant system. Since the commander assistant system did not have knowledge about these tasks it did not have the full situational picture and in one case triggered attention guidance to a currently less urgent object identification task.

8.10 STUDY CONSTRAINTS/LIMITATIONS

The results are based on a simulated environment and not a real-world campaign. Therefore some aspects like e.g., data link losses were not regarded. Since there was only the possibility to simulate one manned aircraft, only intercom between pilot flying and commander and radio communication to airport towers or the mission leader was simulated. Radio communication to other aircraft was missing. This caused reduced workload for the helicopter crew / UAV-operator.

8.11 CONCLUSIONS

A generic approach for the development of a knowledge-based assistant system was presented. The approach was adapted to the domain of manned-unmanned-teaming, i.e., guidance of multiple UAVs from the commander's workplace in a helicopter cockpit aided by an assistant system. The approach was evaluated by conducting experiments in the helicopter simulator of the UBM. The introduction of the assistant system improves human factors related variables like situation awareness and workload, improves performance and safety and is well accepted.

8.12 FUTURE RESEARCH NEEDS AND PLANS IN THIS AREA

The next steps to further improve the assistant system performance and acceptance should be to refine the knowledge models for operator overtaxing estimation, current task recognition and cost prediction. In addition the action and decision support for tasks, which include several steps should be refined. Finally, the cooperation and variable task assignment between commander and pilot flying have to be investigated closer and be regarded within the concept.

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