Intuitive Mission Planning on a Digital Map Table

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ABSTRACT

Although there exist highly sophisticated computer-based mission planning tools, episodic evidence and observations during mission planning reveal that crew members do not use the full capacity of these planning tools. Instead planning tasks are preferably executed in an old-fashioned way with the user relying heavily on paper-map and pencil methods.

We have developed a prototype mission planning front end with the aim to utilize the advantages of both planning methods: the paper map concept providing general overview and intuitive handling, combined with the existing sophisticated algorithms of computer-based mission planning tools.

Our planning front end is based on a user-centered multi-modal operating concept that uses an interactive workbench, i.e. the digital map table, to provide the user with efficient and intuitive tools for planning and managing the pre-flight mission task. The core of the system is the digital map table, which uses projection technology to generate a high quality map image onto a tabletop. Interactive route planning is supported through an electronic pen, which allows direct pointing and drawing functions on that digital map. The functionality of the system is enhanced through symbol and voice recognition.

Work on the mission planning system started with the analysis of a conventional paper and pencil route planning task performed by regular crew members. This task analysis served as the basis for an operating concept, which basically consists of two possibilities to interact with the digital map table:

- pointing and drawing functions, including symbol recognition with the electronic pen and
- speech input

The operating concept has been implemented on the map table, tested, and adapted in a series of iterative usability tests. Results of the usability evaluation will be presented as well as approaches to further system improvements, with respect to

- the suitability of the implemented electronic pen,
- the use of speech input during route planning, and
- the overall efficiency of the system.

1 INTRODUCTION

The mission planning stations which are currently in use in the German Air Force offer to the flight crew all functions and algorithms necessary for mission planning, including the possibility to store the planning data on a digital storage medium. The complexity of these systems, coupled with their complicated handling, however leads to usability problems. As a consequence, the mission planning stations are not used to their full capacity, but are only utilized for specific parts of the mission planning task. Episodic evidence and observations during actual mission planning revealed that crew members still rely on the use of paper map and pencil methods.

Based on these observations EADS has developed a prototype mission planning front end with the aim to utilize the advantages of both planning methods:

- the paper map concept providing general overview and intuitive handling;
- combined with the existing sophisticated algorithms of computer based mission planning tools.

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The digital map table, as the mission planning front end is called, is described in chapter 3 of this paper. Several steps were necessary before we were able to define the functionality of the system. First we had to perform a task analysis for the basic mission planning tasks. From that we derived a prototypical route planning task (detailed in chapter 2), which defines the functionality which was implemented on the digital map table. The moding concept (see chapter 4) was also based on the functionality given by the prototypical planning task. The system then was subjected to extensive usability tests, the procedure and the results of which are presented in chapters 5 and 6.

2 MISSION PLANNING

2.1 Task Analysis

Out of the four main types of tactical air operation missions, i.e., offensive air, air defense, tactical reconnaissance, and combat air support (see Agard, 1991), the task analysis concentrated exclusively on the offensive air mission, where a target on the ground is being attacked.
The typical attack order provides the aircrew with information about the target (e.g. type of target, type of attack, time on target), the electronic order of battle and other mission relevant information (e.g. appropriate communication frequencies, position of friendly troops, position of hostile surface-to-air missiles - see Agard, 1991). The planning task then is divided into route planning and target planning.
The task analysis was performed with three Tornado crew members. With each crew member mission planning was conducted individually, concentrating on the route planning task, whereas target planning was not further looked at. Analyzing route planning should lead to a prototypical route planning process which served as the main input for the moding concept of the digital map table and for the determination of the functionality which was to be implemented.

2.2 Prototypical route planning process

Route planning is typically performed on a 1:500,000 scale map, with the route being planned as a series of waypoints. At the beginning of the planning process, the target is drawn as a triangle onto the map. With the determination of two specific waypoints, a waypoint in front of the target, called initial point (IP, symbolized as a square) and a waypoint behind the target, called rejoin point (RP, symbolized as a circle), the mission planning is split-up into route planning and target planning (see Fig. 2.1)

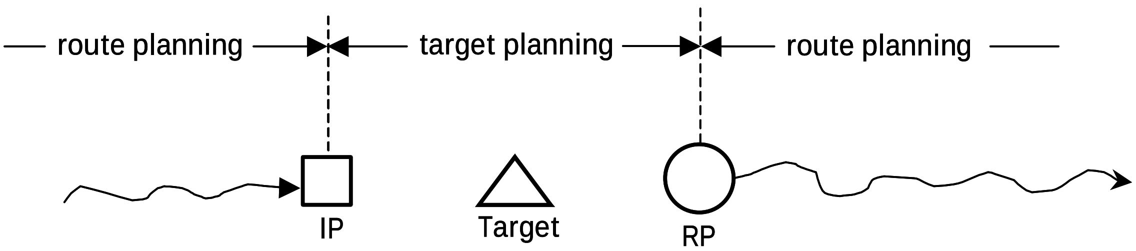

Fig. 2.1: The planning task is split into route planning and target planning.

Each route or route section consists of a starting waypoint and an ending waypoint, both of which can be associated with specific times. These times are called nominated timing points (NTPs) and the aircraft has to arrive at the associated waypoints at the specified times. Although there can be various waypoints with NTPs along a planned route (e.g. a corridor waypoint or a waypoint for air-to-air refueling), this prototypical route planning includes NTPs only with two specific waypoints, the take-off point and the initial point (IP).
Keeping in mind the provisions above, the process of a prototypical route planning can be broken down into the following subtasks:

1. specification of the take-off point (airfield), the destination point (airfield), and the waypoints IP and RP,
2. specification of NTPs for take-off point and IP;

3. determination of the planning goal, i.e. that planning will be done between take-off point and IP;
4. route planning by specification of additional waypoints along the chosen route (by way of backward-planning from IP to take-off point).

The main steps of the prototypical route planning are summarized in Fig. 2.2.

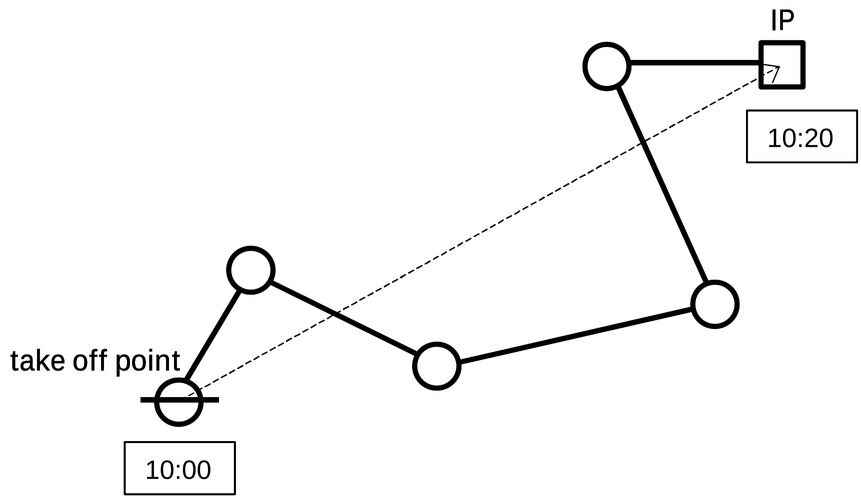

Fig. 2.2: Main steps of a prototypical route planning task from take-off point to IP. The dashed line symbolizes the planning goal. Additional waypoints are depicted as circles. NTPs are shown below the take-off point symbol and the IP symbol.

The aim of the route planning process is to add waypoints between take-off point and IP in such a way that IP can be reached at a given speed within the time difference determined by the two specified NTPs (20 minutes in the example of Figure 2.2). The route planning is still predominately carried out using a paper map, pencil and a ruler with distance templates.

3 DIGITAL MAP TABLE

Major problems identified with available mission planning systems are the missing overview or the missing detail of the digital map material and the missing possibility to directly interact with the digital map. The digital map table developed by EADS addresses exactly these problem areas. Our digital map table has a visible map area of 1024 x 1280 mm, which provides the necessary overview. Furthermore it allows the direct interaction with the digital map material by use of an electronic pen system. Routes can be drawn directly onto the digital map and the planning process is supported by computer algorithms which interactively survey and control the planning task.

3.1 Hardware

The hardware of the digital map table consists of a cabinet with a large projection surface, onto which the digital map material is projected. This projection is realized through four LCD-projectors, a mirror system, and four control computers. The projectors together with the mirror system are placed inside the cabinet underneath the map table. With this setup we have realized a large display area with high resolution, allowing to perform the planning task on large and highly detailed map material. The main input device consists of an electronic pen system. An additional notebook is responsible for the mission planning algorithms and for database maintenance and internal communication. The components of the digital map table are shown in Figure 3.1.

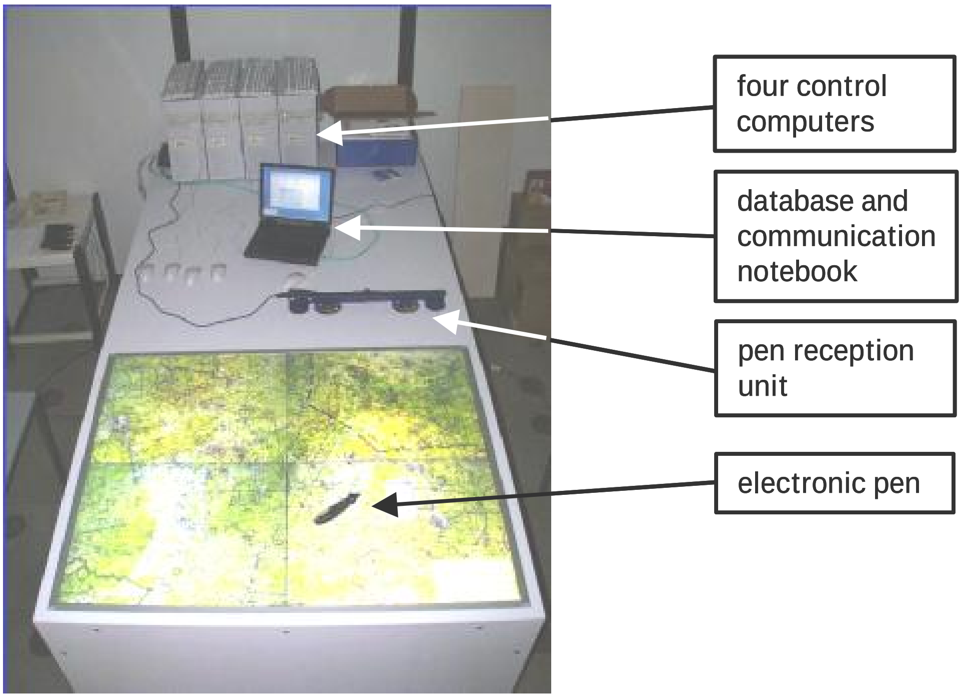

Fig. 3.1: The digital map table and its components

The electronic pen is an ultrasonic/infrared positioning device. Its tip is pressure sensitive, i.e. when being pressed firmly onto a surface the pen starts sending a signal to the reception unit which calculates the position of the pen. This is implemented by a small microswitch inside the pen which also provides tactile feedback to the user.
The software driver of the pen is used to simulate a computer mouse with a left button. When the pen is not pressed no positioning information is available, so only a press of the pen generates a position on the map. This position is maintained even when the pen is released (pressing and releasing the pen is analogous to a left mouse button click). When the pen is pressed again onto a different map position, a new position is generated and the old one deleted. While the pen stays pressed (analogous to holding the left mouse button depressed), its position is instantly updated, – this functionality is used for dragging and drawing operations. The release of the pen is interpreted as a release of the left mouse button, which drops an object or stops drawing. More information on the working principle of the pen is given in chapter 4.

The digital map table was realized as a prototype mission planning front end to demonstrate the usage of advanced human machine interfaces for mission planning.

3.2 Human-Machine–Interface

Figure 3.2 schematically shows the digital map table within the human machine system. The main focus will be on the human machine interfaces (HMI) which defines the interaction between the air crew member and the digital map table.

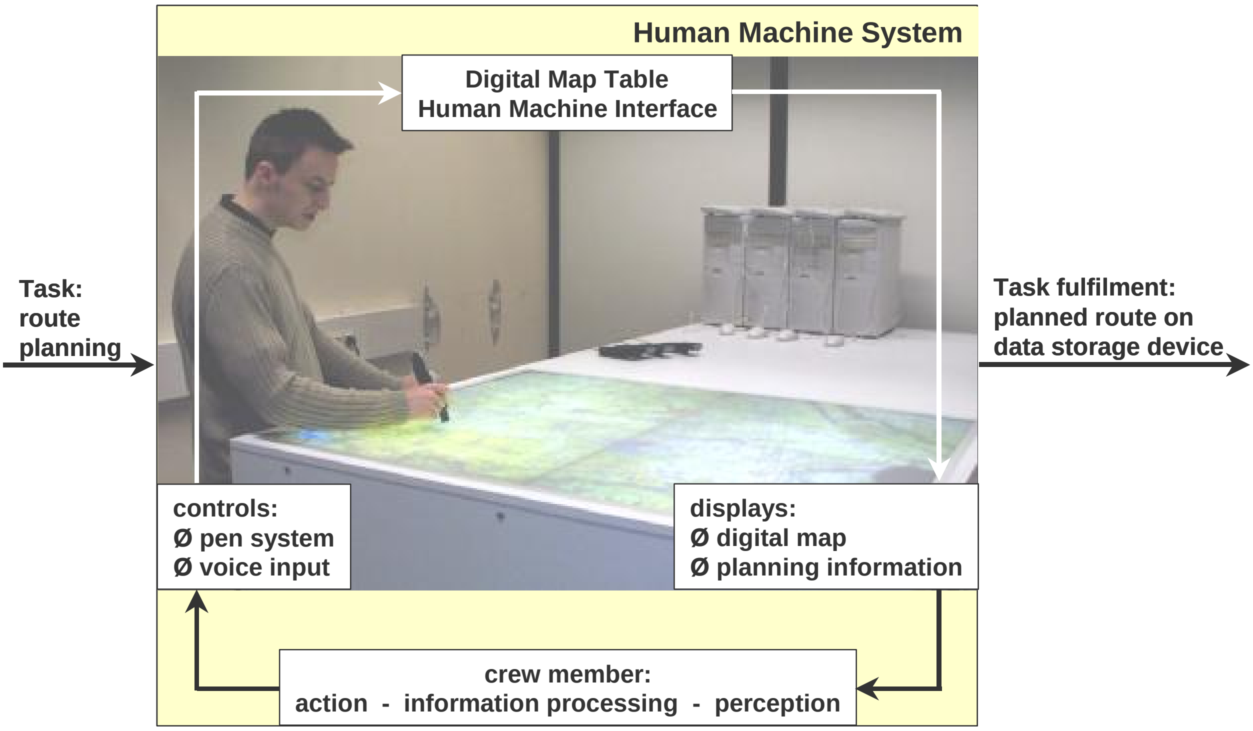

Fig. 3.2: Schematic human machine system illustration for the digital map table.

In order to establish the digital map table as a functional human machine system, a series of design options had to be accomplished (see Frieling & Sonntag, 1999):

1. adequate allocation of functions between the operator and the digital map table;
2. implementation of user friendly human machine interfaces;
3. development of a generic moding concept for the interaction with the implemented interfaces.

The allocation of functions between the operator and the digital map table mainly concerns computer support functions for the planning task, e.g. the correct timing of route planning. This will be detailed in the moding concept below.
Relevant HMI elements are the pen system as the main control device and the digital map table serving as display device, showing relevant interaction information on top of the map, e.g. popup-menus. Details will also be presented in the moding concept.
The moding concept as described below concentrates on the interaction possibilities of the operator with the pen system and the digital map table.

4 MODING CONCEPT

The moding concept of the digital map table is primarily based on pen input. Direct voice input (DVI) has also been implemented, but was only used as a secondary control option for a limited number of tasks (see Figure 4.1).

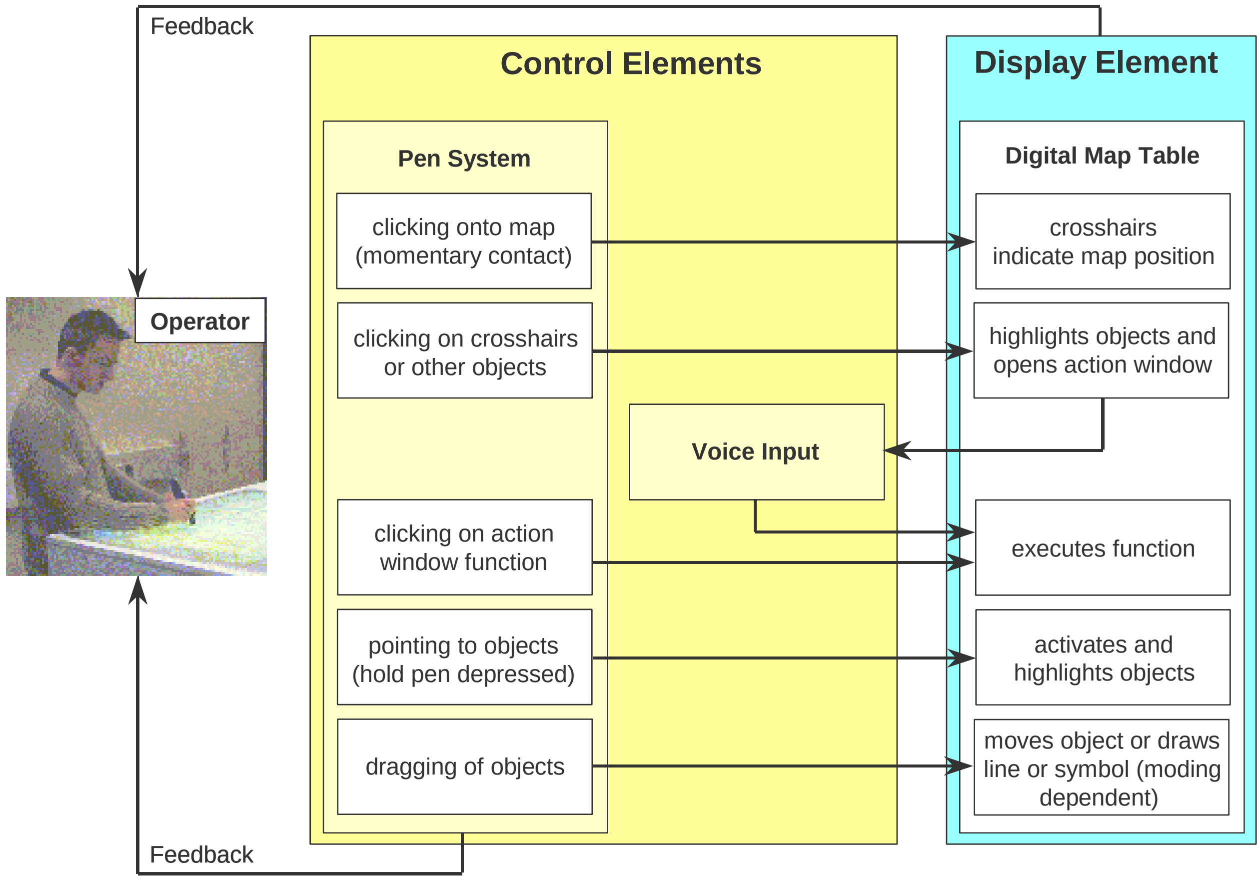

Fig. 4.1: Moding concept for the digital map table

4.1 Pen Control

The electronic pen has two basic states:

1. contact between the pen and the map table - the user presses the pen onto the map table, which closes the switch inside the pen
2. no contact between the pen and the map table - the switch inside the pen is open.

These two states correspond to the function of a left mouse button. They provide the user with the following operating options:

1. **clicking** (i.e. momentary contact) with the pen on an empty space on the map generates an object (a crosshair symbol) on the map at that point where the pen was pointing to
2. **clicking** on an already available object on the map (e.g. the crosshair symbol or a waypoint) makes the functions available which have been specified for that particular object by opening an action window
3. **dragging** of objects is possible by **pointing** on the object (i.e. closing the switch inside the pen – this picks up and highlights the object), holding the pen depressed and moving it over the map surface; the object is coupled to the pen; dropping of the object at a new position is done by releasing the pen from the map surface, thus opening the switch. The same pen functionality can be used to draw objects directly onto the map table surface; in that case a line is drawn onto the map as long as the pen is held depressed and is moved over the table.

All control actions on the map table can be realized through these operating options. They are described in detail below.

The digital map surface is the display of the map table. All relevant route planning symbols are depicted directly on top of the digital map.
The activation of a route planning object opens an additional action window on the digital map next to the corresponding route planning object. This action window is a popup window which includes all possible selections for the activated route planning object and serves to the user as a command display (see Stokes, Wickens & Kite, 1990). An action can be chosen by clicking with the pen on the corresponding menu line - the action is executed and the action window is closed[1].
The first click action on the map generates a crosshair symbol at the point where the pen got contact to the map table. The crosshairs symbol indicates the position the map table system has recognised, giving feedback to the operator. The crosshairs symbol is activated by clicking on it. This opens the corresponding action window on the digital map next to the crosshairs symbol. Figure 4.2 shows the action window for the crosshairs marker.

Fig. 4.2: Typical action window on the digital map table. The example shows the action window for the crosshairs marker.

The user can select for example the “Target” option in the menu by clicking on it. The action window is then closed and the target symbol appears on the digital map at the corresponding crosshairs marker position.
Additionally, information windows have been implemented, which display specific information with respect to map objects. They are used in particular for the indication of times (NTPs) which correspond to waypoints.
For route planning, the timing between two waypoints with corresponding NTPs is crucial. The crew must be aware whether the actual plan allows the arrival at a particular point at the specified NTP-time or whether they will arrive too early or too late. Route planning on our map table therefore is supported by automatically calculating and displaying to the user the state of the time planning for a specific route section. This is done by colour- and linestyle-coding of the flight leg indications, following the specifications below[2]:

- a planning time Delta (PT Δ) is defined as the difference between two NTP times and the already planned flight leg times of the route, so PT Δ is the time which remains open for planning: PT Δ = (NTP (waypoint 2) – NTP (waypoint 1)) – Σ already planned flight leg times
- if PT $\Delta = 0$ ($\pm$ x seconds), then all lines indicating the flight legs of the route are displayed bold in black colour;
- if PT $\Delta \neq 0$ ($\pm$ x seconds), then all lines indicating the flight legs of the route are displayed dashed in either green or red colour, depending on PT Δ (see Fig. 4.3 below).

[1] The popup/closing of the action window activates/deactivates also the DVI. The action window includes all possible DVI-commands.
[2] Possible color- and form-codings are described in the guidelines VDI/VDE 3850 (2000).

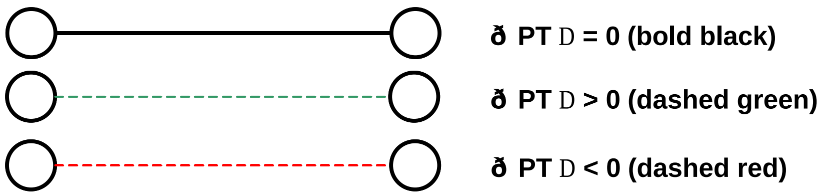

Fig. 4.3: Indication of a flight leg depending on the planning time PT Δ.

The task analysis identified a series of subtasks for the route planning process. It revealed that the first step of the route planning process is the definition of a planning goal (see chapter 2.2) and that additional waypoints are only added to the route afterwards. Therefore, it was decided that waypoints can only be inserted into a route by splitting the flight leg where the waypoint is intended to be inserted. This procedure, comparable to the so-called rubber band function in normal paper-and-pencil route planning, is shown in Figure 4.4.

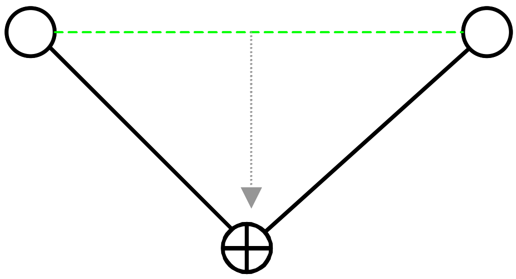

Fig. 4.4: Procedure to insert a waypoint into a route

In the implemented moding concept, the flight leg where a waypoint is intended to be inserted has to be activated (i.e. pointed at) with the pen somewhere in the middle of the line. Successful activation highlights the line and dragging splits the line into two new lines. A new waypoint is generated at the map position where the pen is released. The corresponding PT Δ is indicated in real-time while dragging the pen to the new position, which means that the colour and linestyle of the two new flight leg lines will immediately show whether the new plan allows an arrival on time.
The moding concept also allows to move or to delete existing waypoints. These changes have an effect on the appearance of the route's flight leg lines with respect to the planning time PT Δ.

Table 4.1 shows the complete HMI processes for the prototypical route planning task (see Figure 2.2) at the digital map table based on the implemented moding concept.

Subtask	**Pen control actions**	**Display events**
Specification of take-off point and IP:		
1. choose map point	click to map point	displays crosshairs marker
2. activate crosshair marker	click to marker	highlights crosshairs marker, opens action window
3. select take-off option	click to "take-off"	closes action window, crosshairs change to take-off point symbol
IP accordingly		

Specification of NTPs:		
1. activate take-off point	click to take-off point	highlights take-off point, opens action window
2. select NTP	click to "NTP"	opens time input window
3. input time	click to digits	displays time, closes action window, NTP window is displayed associated to take-off point
IP accordingly		
Definition of the planning goal:		
1. activate take-off	point onto take-off point (hold pen depressed)	highlights take-off point
2. draw line from take-off point to IP	drag to IP and release pen	inserts line between take-off point and IP (coded)
Route planning, insertion of additional waypoints:		
1. activate flight leg	point to flight leg	highlights flight leg
2. split flight leg	dragging of the pen inserts a new waypoint at the position where the pen is released	old flight leg is split into two new flight legs (coded), which are connected by the new waypoint
repeat until PT D = 0		
relocate waypoint:		
1. activate waypoint	point to waypoint	highlights waypoint
2. move waypoint	drag to new position	moves waypoint and flight legs (coded)
delete waypoint:		
1. activate waypoint	click on waypoint	highlights waypoint, opens action window
2. select delete option	click on "delete"	closes window, deletes waypoint symbol, fits flight legs (coded)

Tab. 4.1: HMI process for the prototypical route planning task

All control actions with the electronic pen on the digital map table can be described either as pointing, clicking, or dragging actions. Pen dragging actions on the map are only possible with activated objects:

- activated crosshairs marker:dragging the pen on the map surface draws a symbol onto the map (on the basis of implemented symbol recognition algorithms),[3]
- activated flight leg: dragging splits the activated flight leg line and inserts a new waypoint,
- activated waypoint without flight leg: dragging draws a flight leg to a second waypoint (only possible for the definition of a planning goal),
- activated waypoint with connected flight leg: dragging moves the waypoint.

The implemented moding concept emphasizes on the intuitive and interactive use of the electronic pen system directly with the electronic map material. This moding concept for the pen control actions closely follows the control actions of a computer mouse.

[3] Symbol recognition algorithms have been implemented with the prototype, but their functionality is only briefly presented in chapter 6.2.

4.2 Voice Control

The moding concept for the implemented direct voice input (DVI) was created exclusively as a control alternative to pen control. Therefore, DVI was controlled through the opening of action windows, whose commands could either be executed through pen control or through DVI. For instance, DVI was implemented to facilitate specific control tasks, e.g., the input of digits for NTP-times in the corresponding action window.

5 USABILITY TESTS

The usability tests described below concentrated on the pen use with the digital map table. DVI and symbol recognition functions were not assessed specifically. However, comments which were made on DVI and symbol recognition were recorded and have been considered for the recommendations presented in chapter 6.

The usability tests were designed to get insight especially into the moding, of which they were intended to revise two main aspects (see DIN EN ISO 9241-11, 1998; Krömker, 1999):

1. the effectiveness of the concept, i.e., the accuracy and the completeness that the crew member achieves the planning goal; and
2. the efficiency of the concept, i.e., the effort of the crew member with respect to accuracy and completeness to achieve the planning goal.

The usability test were performed with five Tornado air crew members.

5.1 Experimental setup and procedure

Testing of the implemented moding concept was conducted while a crew member performed the prototypical route planning task (see Fig. 2.2). The complete experiment lasted approximately one hour. It was divided into several subtasks:

- route planning from take-off to IP,
- relocation of waypoints at the previously planned route,
- insertion of additional waypoints into the previously planned route,
- deletion of waypoints of the previously planned route.

After finishing each subtask, comments of the crew member were recorded following the “critical incident technique” (CIT; see Flanagan, 1954). With this interview technique the crew member is asked to report critical aspects of the control task, separated into efficient and inefficient control actions.
Finally, each crew member was asked to evaluate the usability of the implemented pen moding concept using the system usability scale (SUS; Brooke, 1996). The SUS is described as a reliable, low-cost usability scale that can be used for global assessment of systems usability. It is composed of 10 usability statements covering effectiveness, efficiency and satisfaction, and it yields a single number representing a composite measure of the overall usability of the system being studied. The scale for the individual usability statements ranges from 1 (strongly disagree) to 5 (strongly agree) and the final score is standardized such that the overall SUS scores have a range of 0 to 100 (perfect).

5.2 Results and discussion

Main goal of the usability tests was the evaluation of the implemented moding concept (see chapter 4). However, an evaluation cannot be done independently from the implemented hardware. Therefore, an attempt was made to interpret the results by separating the contribution of the moding concept from the contribution of the implemented digital map table hardware.

In general the crew members agreed to the moding concept for the prototypical route planning task (see fig. 5.1), but they also stressed the necessity for simple, robust and quick interaction with the digital map table.

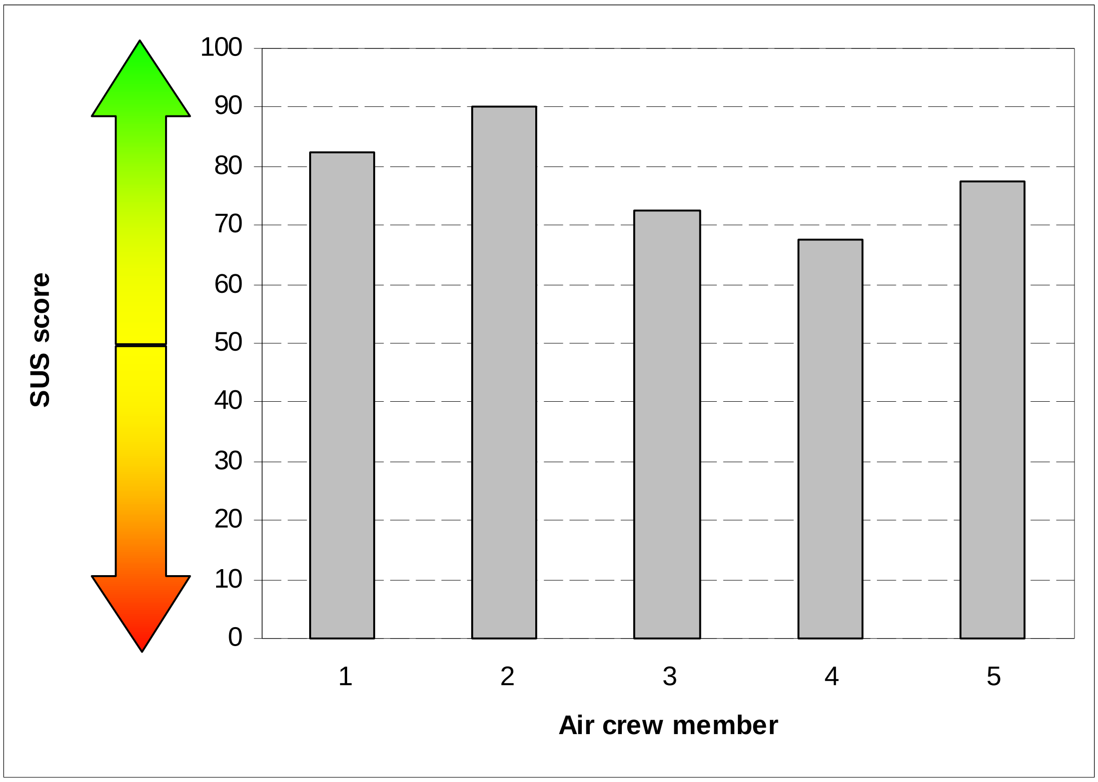

Fig. 5.1: Overall evaluation of the moding concept for the digital map table

Table 5.1 summarizes the main comments of the five crew members elicited through the CIT-interviews. Most criticism was expressed about the implemented electronic pen system hardware, which was not accurate enough to allow efficient interaction.

positive comments		negativ comments	
hardware	moding concept	hardware	moding concept
• free pen system (without cables)	• color coding of timing • rubber-band function to insert waypoints • straightforward operating through popup action-windows	• clumsiness and inaccuracy of the electronic pen system	• display of planning times through interactive information window • laborious highlighting of flight leg to split flight leg • planning goal should also be selectable through an action window command

Tab. 5.1: CIT-comments on the prototype mission planning front end.

Figure 5.2 summarizes the ratings of the five air crew members with respect to the ten individual usability categories of the SUS. In particular the aspects effectivity (represented by the usability categories 2, 5, 6 and 8) and efficiency (represented by categories 3, 4, 7 and 10) are vital for the usability of a system (see Brooke, 1986; Krömker, 1999). The results (see figure 5.2) indicate that the implemented moding concept fulfills especially the efficiency aspect with respect to the learnability to control route planning.

The effectiveness of the map table for the route planning task was also evaluated positively (all categories have higher ratings than 3), but the analysis of the scores of individual usability statements shows that improvements are necessary. The particularly low score of statement 5 for instance is a clear confirmation for the problems the users had with the inaccuracy of the pen system, as was stated in table 5.1. But it is also a hint to other necessary improvements, such as additional interactive digital time read out windows along the flight leg.

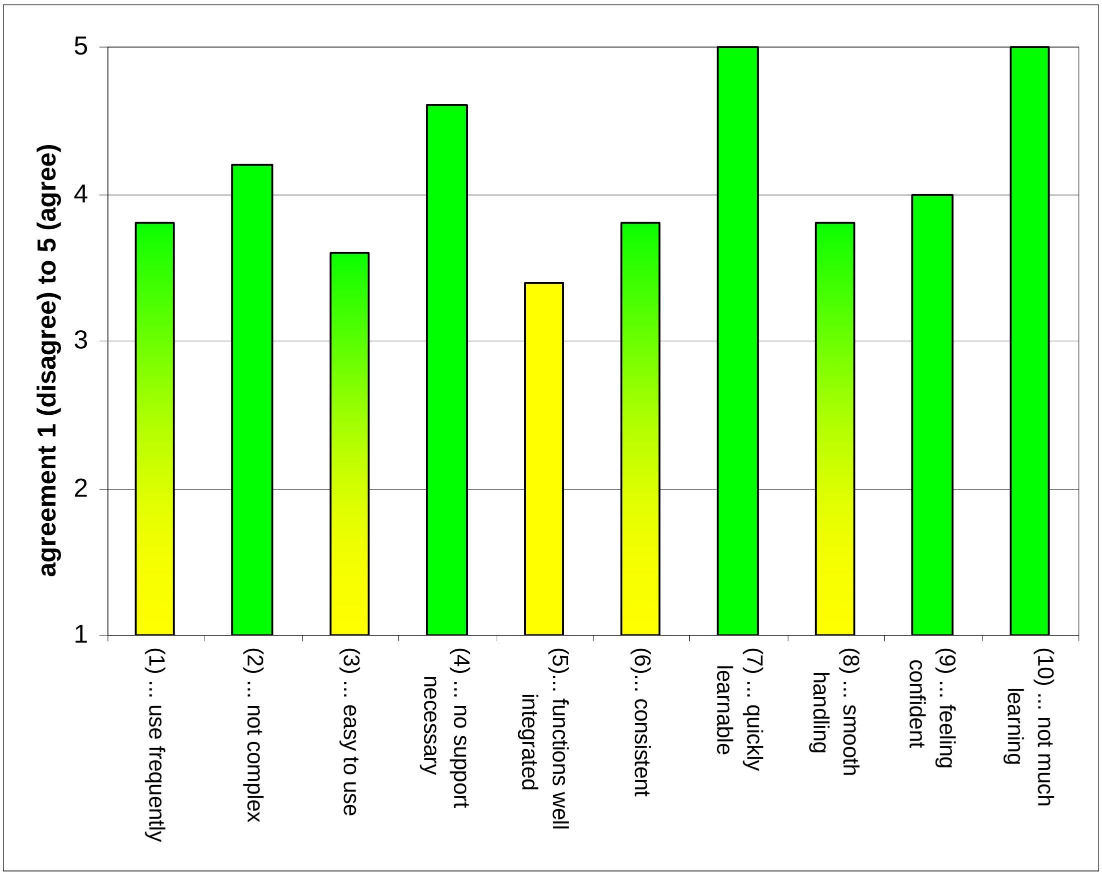

Fig. 5.2: Mean value of five crew members for the 10 usability statements of the SUS

6 RECOMMENDATIONS

The above described usability tests demonstrated the general potential of a digital map table. A digital map table can be an adequate tool for mission planning, since it offers intuitive, easy to use, and direct handling options for the execution of the required planning tasks.

Future activities with mission planning front ends should concentrate on the following issues which have been derived from the results obtained in the reported usability tests:

- the development and integration of efficient control devices and control alternatives,
- the fine tuning of the displayed information on the digital map material and
- the possibility to transfer the moding concept onto a portable mission planning front end (lap top type computer).

6.1 Control devices

An electronic and wireless pen system allows direct interactive handling with the electronic map material. If a pen is used as the main control device, the pen system has to be optimized in its technical handling characteristics. Mostly important, the pen system has to be very exact to facilitate detailed pointing and dragging functions. The installation of additional buttons at the pen might be helpful to allow control actions analogous to the left and right mouse button.

Additionally to the pen, the optional utilization of an alphanumerical keyboard could be helpful for the input of e.g. exact waypoint positions.

Direct voice input (DVI), which was only tested marginally in the usability tests, is considered by the crew members as being critical, since mission planning can take place in a very noisy environment. Therefore, the robustness of speech input commands has to be proved. The activation and deactivation of DVI through the opening of popup menus (like the implemented action windows) could be very supportive. Also, possible speech commands can be fully displayed in the popup menus. In any case, DVI should be optional, i.e. the user should be able to handle the complete planning task with and without the use of DVI.

6.2 Display information

The digital map material upon which the route planning is performed is the primary information source for the crew member. Each piece of information added during the planning process might clutter the map display and therefore the presentation (e.g., location and timing) of additional action or information windows and other symbolic information (e.g., weather data, notes) has to be done cautiously.

The digital map table includes symbol recognition functionality; specific symbols used for route planning can be drawn directly onto the electronic map display (a triangle is used for a target, a circle for a waypoint and a square for the IP). Although this feature was not tested systematically, episodic evidence revealed that such a symbol recognition algorithm was not considered necessary by the crew members. Common opinion was that the corresponding waypoint types can be easier defined using the action window method described in chapter 4. However, symbol recognition may be useful as a simple notes function on the electronic map display, e.g. for:

- additional route planning information, e.g., threats or
- the writing of text notes (e. g. NOTAMS – notices to airmen) directly onto the electronic map display.

6.3 Moding transfer

One goal of the presented moding concept was to allow direct and intuitive route planning on a digital map table prototype. Consequently, this moding concept was developed for the specific use of an electronic pen as major control device for the interaction with the digital map table (see Fig. 3.1). While the high resolution, large area display was chosen to combine the advantages of both the paper map planning method and the data processing capability of digital systems, it is conceivable to develop a mission planning front end which is fully portable, e.g. a laptop version with a high resolution, large-size display.

If future technical developments should materialize cost-efficient portable hardware components, it should be assured that the moding concept of the digital map table is easily transferable to such portable mission planning front ends. Since a portable system will probably rely on standard computer control devices, such as a mouse or a touch screen, this consequently means that the moding of the mission planning system and in particular of the electronic pen system must be compatible with these standard control devices.

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