5. Conclusions

In the fifth chapter we discuss the explanations of the three research paradigm – planning, task-switching and decision making – in the light of the results of the present thesis. Next, we return to the example of flight 401 and try to apply the findings of this thesis to this example. Finally, we give some recommendations for future system support.

In the introduction we discussed three paradigms that described phenomena that are similar to cognitive lockup: planning, task switching and decision making. Each paradigm provided us with a number of possible explanations for cognitive lockup. Table 5.1 presents an overview of these explanations.

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<th>Table 5.1 An overview of possible explanations for cognitive lockup.</th>
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<td>1. People commit themselves too early to a detailed plan</td>
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In the following section we will discuss each explanation in the light of the findings of the present thesis.

1. People commit themselves too early to a detailed plan

The experimental task that was used throughout the thesis was not designed with the intention to examine planning activities. In the present task, there was only one plan available that in some scenarios had to be substituted by another plan. Nevertheless, we did manipulate commitment in the present thesis. All experiments in the present thesis contained conditions in which
participants were committed to a fire when a second fire occurred, the so-called sequential condition. In the first three experiments this condition was compared to the simultaneous condition in which fires started at the same time and participants were not committed to a fire. Overall, participants in the sequential condition tended to hold on to their initial plan and as a consequence fires where not always dealt with in the correct order. In the simultaneous condition participants did not need to revise plans and fires were generally handled in the correct order. So, it seems that once people have committed themselves to a course of action, they are inclined to continue with it. We therefore found the results in favor of the explanation that a commitment to a plan prevents participants from adopting an alternative plan.

2. People refrain from monitoring the environment

According to the monitoring explanation for cognitive lockup would occur because people do not actively scan environment on changes. In our fire control task this would imply that during the process of diagnosis, operators neglect their monitoring function. The fourth experiment of this thesis provided data that do not comply with this explanation. Overall, during the diagnosis of the first fire, participants detected a second fire before the first fire was dealt with but often solved it after the first fire was dealt with. So, operators did scan the environment and notice any changes, but nevertheless decided to continue with the first problem. In other words, cognitive lockup in our experiment could not be explained by a neglect of the environment.
3. People generate future scenarios that are too optimistic

Another explanation for cognitive lockup that originates from planning research is that people generate scenarios that are too optimistic. As a consequence, they overestimate the available time necessary to complete a task (Hayes-Roth, 1981; Hayes-Roth and Hayes-Roth, 1979). So a possible explanation for cognitive lockup in our fire control task was that participants overestimated the remaining time to deal with two fires. And, because operators overestimate the available time, they could have assumed they had sufficient time to take care of the first fire and then the second fire.

This explanation may hold for the first four experiments of the present thesis but not for the fifth experiment. In this experiment we provided participants with a time index, which indicated how much time was left before the fire caused a total burn down. Making this time explicit would rule out the possibility that operators make incorrect estimations of the remaining time. The fact that participants still continued with the first fire, makes it implausible that cognitive lockup can be ascribed to a too optimistic view of the time that is left. We therefore did not find support for the explanation that cognitive lockup is due to people generating future scenarios that are too optimistic.

4. People lack sufficient resources to switch to a second disturbance

This explanation was examined in the second experiment of this thesis. In this experiment we varied the complexity of the diagnosis process of the first fire. We reasoned that if cognitive lockup is due to a lack of resources, there would be more cognitive lockup as the diagnosis process of the first fire was more complex and consequently required more resources. However, manipulations of complexity did not affect the degree of cognitive lockup.
So, no support was provided for the notion that cognitive lockup is due to limited information processing capacity.

5. The costs of switching are (perceived as) too high

This explanation was examined in the third experiment of the thesis. In this experiment we manipulated the costs of reassessment when a second fire was introduced. We found that cognitive lockup was reduced when it was obvious that the benefits of a reassessment were higher than the costs. On the basis of these results we concluded that individuals decide whether to reassess the situation by trading off the costs and benefits of such a reassessment and that the benefits clearly have to outweigh the costs before participants decide to switch. The fact that the costs of making a reassessment have to be disproportionately low before participants decide to abandon the current task suggests that they are biased in their decision-making process.

6. Sunk costs: prior investments are taken into account
7. Task completion: people have a desire to fulfil a task

Since the sunk-cost bias and task completion were examined in the same experiments we discuss these explanations together.

The sunk-cost effect is the overall finding in decision-making studies that people are inclined to continue with an ongoing task once they have invested time, money or effort in it. However, the fourth experiment of this thesis showed a reversed sunk-cost effect: participants were less inclined to continue with the first fire when more investments were done. We ascribed this effect to a higher perception of time pressure in scenarios with high investments. Although the actual time pressure is equal for both conditions of investment, the experience of time pressure may have been stronger in
scenarios were more investments were done. The results further indicated that participants generally detected a second fire before but solved it after the first fire was dealt with. As we could not distinguish a problem-solving phase in this experiment we conducted a fifth experiment in which there was no need to detect a fire explicitly and participants were only required to solve the second fire. We also included a static condition that comprised snapshots of the dynamic condition. To examine the attribution of a real time component we compared this static condition to the dynamic condition.

In the static condition we found an effect of task completion: participants decided to continue with an ongoing task when it was closer to completion. Furthermore, we found more cognitive lockup in the static condition than in the dynamic condition, probably because the absence of feedback in the static condition made it impossible to adjust an initial strategy. As in the previous experiment there was a reversed sunk cost effect but only for the case the task was not near completion. In that case the assumed high perception of time pressure in the high investment scenarios urged participants to withdraw. We reasoned that in case the task was near completion, the subjective time pressure had an opposite effect: participants tend to complete the ongoing task.

To conclude, sunk costs and task completion do explain cognitive lockup but not entirely in the way as expected.

Conclusion
The main purpose of the present thesis was to find a plausible explanation for cognitive lockup. In all, a main conclusion from the present work is that cognitive lockup is a matter of commitment. The findings support the planning explanation that once people are committed to a fault they are inclined to stick to it. No support could be found for the other planning
explanations, that is, that people neglect to monitor the environment or that people generate too optimistic scenarios of the future.

Neither could cognitive lockup be explained by limited information processing capacity. An explanation that does seem to hold is that operators make a trade-off between the costs and benefits of making a reassessment of the situation when a second fault starts. This trade-off seems to be biased because the costs or a reassessment have to be considerably lower relative to the benefits in order to reduce cognitive lockup. And even then cognitive lockup is still present. Only in the condition in which participants were detached from the diagnosis process they were always capable of revising their initial plan and cognitive lockup was no longer present.

Nevertheless, as long as operators are working on a fault they are biased in their decision to continue with this fault. Sunk costs and task completion affect this decision to continue. In our real time fire control task we found that as more prior investments were done, participants were less inclined to continue. We also found this effect when we looked at problem solving rather than detection, but this effect was mediated by the degree of task completion. There was a reversed sunk cost effect but only for the case the ongoing task was not near completion. In case the task was near completion participants tended to complete the task.

**Flight 401 of Eastern Air Lines**

We started the present thesis with the example of flight 401 of Eastern Air Lines, where cognitive lockup was the cause of a dramatic plane crash. We asked ourselves the question which psychological mechanism was responsible for the pilot being locked up in the problem of the landing gear. Now, at the end of the thesis, we return to this example and - although we
have to be cautious in extrapolating the present findings - apply the knowledge we acquired to explain the pilot's behavior.

An important conclusion from the present work is that cognitive lockup cannot be exclusively ascribed to a bottleneck in human information-processing capacities. For the case of flight 401 this would imply that the preoccupation with the landing gear problem couldn't be entirely explained by a shortage of resources.

The pilot's decision to continue with the landing gear problem and to refrain from dealing with the problem of the descending altitude could be caused by a combination of high time pressure and the expectation that the problem was nearly solved. Because the pilot experienced a high level of time pressure and because he considered the problem of the landing gear to be nearly solved, he decided to continue with that problem.

Which decision support tools might have prevented the pilot from holding on the malfunctioning landing gear? To date, most support systems are designed with the purpose to relieve operators from a high workload. Since the findings from the present thesis suggest that cognitive lockup is mainly due to a combination of subjective time pressure and task completion, we recommend a change of focus.

First of all, the findings of the present thesis imply that support in the form of an auditory alarm is not likely to prevent cognitive lockup. Our data suggest that operators are aware of the occurrence of additional faults (and are able to detect them) but decide not to deal with them until after the ongoing task is dealt with. The report on the accident showed that the low-altitude alarm did not urge the pilot to abandon the current task and since the present findings demonstrated that participants do seem to notice subsequent faults,
we do not expect that a more salient alarm will result in less cognitive lockup.

Our findings showed that cognitive lockup can be reduced by lowering the costs of making a reassessment. To stimulate that operators reassess the situation we therefore recommend that system information is presented in such a way that it is not difficult to determine task priorities. Information about task priorities should be easily accessible for the operator.

However, although our results showed that the tendency for cognitive lockup was considerably reduced in case the costs of a reassessment were low, the tendency was still present. The question then is “how can we entirely break through this tendency?”

The only condition in the present series of experiments where cognitive lockup was no longer present, was in the condition in which priority information was presented on a separate window and participants needed to interrupt their ongoing activities to close that window. Since we found that operators are biased in their decision whether to continue with an ongoing task we consider that detaching operators from this task is an efficient way to debias them. Apparently, irrelevant factors like sunk costs or task completion are eliminated when operators are detached from their ongoing task and are placed in the position to make a new choice between continuing on the ongoing task and start working on an additional task. We therefore suggest that future system support should focus on how operators can be detached from their ongoing activities so that they can make an unbiased decision which fault to deal with first.