Sticking to plans: capacity limitation or decision-making bias?

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1. A theoretical approach to cognitive lockup

The first chapter is an attempt to identify possible explanations for cognitive lockup: the tendency to focus on a subpart of a system while ignoring the rest of it. In order to exemplify this phenomenon we first describe the case of flight 401, an example of an airplane crash which was caused by cognitive lockup. Next, we briefly discuss two studies on cognitive lockup that demonstrated the phenomenon in an experimental setting. Since no theoretical explanation for cognitive lockup has been provided to date, we explore three research paradigms where phenomena similar to cognitive lockup have been found: planning, task-switching and decision-making. For each paradigm we discuss the main results with respect to these similar phenomena and we try to identify the explanations that have been provided. These explanations are summed up at the end of this chapter.

Flight 401 of Eastern Air Lines

In 1972 a dramatic plane crash took place. During the landing, the pilot of flight 401 of Eastern Air Lines is warned about a problem with the landing gear. To win time, the pilot cancels the landing, sets the plane in the autopilot mode and starts solving the problem with the landing gear. This problem fully occupies the pilot and multiple warnings about a decreasing altitude (a low-altitude alarm, a remark of the air-traffic controller) are ignored. As a consequence, the plane crashes, resulting in the death of most people aboard.

The National Safety Transport Board concluded that the accident was due to a "preoccupation with a technical malfunction". However, it is not clear what caused this preoccupation. Why did the pilot hold on to solving the problem with the landing gear in spite of several warnings? Or, to reframe this question in more psychological terms, which mechanisms caused the pilot to be captured in a problem-solving task?

A fashionable concept in this respect is that of Situation Awareness. Situation Awareness (SA) is a stage in information processing immediately
preceding the stage of decision making. Endsley (1988, 1995) used the following definition of SA: “SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (Endsley, 1988, p. 97). And, because control actions are taken automatically, operators are less aware of the actual situation, which becomes problematic when critical situations occur. In such non-normal, and mostly time-critical, events human intervention is required. But because operators lack knowledge of the details of the system, they are not able to cope with these critical situations.

The concept of SA is fairly broad however. It doesn’t tell us which element of the SA – perception, comprehension or projection – contributes to people being captured in a task. So, it remains a question which psychological mechanism caused the pilot of flight 401 to stick to the landing gear problem.

One possible reason why the pilot did not attend to the descending altitude is that he just did not notice the warnings. Maybe he was so caught up in the problem with the landing gear that signals like alarms simply did not reach his attention.

Another reason for sticking to the relative less urgent problem with the landing gear is that the pilot did notice the alarms but was incapable to provide attention to it. The task of solving the landing gear problem may have required so much of his attention that there was nothing left for (switching to) the problem with the altitude.

A final reason for the pilot to stick to the problem with the landing gear could be that he actually made a decision to do so. He decided to continue working on the malfunctioning of the landing gear and to postpone solving the problem with the altitude.
The example of the air crash of flight 401 is not an isolated case; there are multiple examples, especially in aviation and shipping, where accidents happened because operators solely concentrated on a particular subtask, thereby ignoring the rest of the system. Though the consequences of focusing on a subpart of the system can be disastrous, experimental research on this phenomenon has been confined to mere demonstrations of the existence of it.

In the next section we will briefly discuss two experimental studies where being locked up was manifested in the data.

**Experimental studies of cognitive lockup**

Moray and Rotenberg (1989)

Moray and Rotenberg (1989) were the first to use the term “cognitive lockup” for operators’ tendency to deal with disturbances sequentially. As this term reflects the problem adequately, we will use this term throughout this thesis.

Moray and Rotenberg (1998) asked participants to supervise a simulated thermal hydraulic system that consisted of four subsystems. There were two critical conditions: in one condition a single fault appeared in a subsystem and in the other condition a fault in one subsystem was followed by a fault in another subsystem. Eye-movement recordings showed that for the first (and in half of the cases only) fault, attention was given to the corresponding subsystem within 30 seconds, but for the second fault, attention started to shift only 45 seconds after occurrence. According to the authors a first fault absorbs the operators’ attention to such a degree that they cannot spend time on the rest of the system.
Kerstholt, Passenier, Houttuin and Schuffel (1996)

Another demonstration of cognitive lockup comes from a study by Kerstholt, Passenier, Houttuin and Schuffel (1996). Participants in their study were required to supervise four dynamic subsystems (navigation, electricity, propulsion and cargo) and to deal with disturbances whenever they occurred. The system included an option to stabilise a subsystem in which an additional fault occurred. Some participants used this option, thereby acknowledging their understanding of the development of a disturbance over time. Most participants, however, handled the disturbances sequentially: full attention was given to the first disturbance(s) and subsequent disturbances were ignored.

These experimental studies are clear demonstrations of operators being locked up in a subpart of the system. However, as we mentioned earlier, none of these studies have produced a theoretical explanation for this phenomenon. Why do operators hold on to solving a minor problem in a subpart of the system while a major problem is evolving somewhere else in system?

In generating possible explanations for cognitive lockup it is useful to review some related phenomena. Cognitive lockup seems a relatively new phenomenon coinciding with the rise of automation but the tendency to stick to a course of action is far from new. It has been identified in a number of adjacent fields, namely planning, task-switching and decision making. In the following sections we will discuss results from these lines of research.

Planning

Planning is a complex process that has been defined in different ways by different investigators. Nevertheless most definitions comprise the following two features: (1) scheduling a series of actions in order to (2) achieve a
certain goal. Read (1987), for example, defined planning as the selection and organization of actions to attain certain goals. In the same line, McDermott (1978) conceives planning as the identification and organization of subtasks to execute a problem solution.

These definitions do not recognize the need to revise a plan during execution when environmental changes occur. More recent articles on planning use definitions that do take into account the notion of a changing environment. In their article, Mumford, Schultz, Van Doorn and Judy (2001) provide an elaborate review of the scarce literature on planning. They argue that the early conception of planning provides little room for the adaptive flexibility that seems to characterize most high-level performance. For that reason they define planning as “the mental simulations of actions in a dynamic environment” (p. 214).

In their route planning experiment, Hayes-Roth and Hayes-Roth (1979) acknowledged the importance of simulating the execution of a plan mentally and indicated how simulations can be used to guide subsequent planning. In fact, most recent definitions of planning follow the Hayes-Roth and Hayes-Roth (1979) idea, that planning involves a mental simulation of future action sequences, intended to direct action and optimise the attainment of certain goals (e.g. Berger, Karol and Jordan, 1989; Patalano and Seifert, 1997). Plans are generated and adjusted in interaction with the environment, though the environment in the Hayes-Roth and Hayes-Roth study (a map) remains static throughout the task.
The notion of a dynamic environment in the process of planning is taken into account only recently (Bainbridge, 1997; Brichin and Rachadzo, 1995, and Hine and Gifford, 1997). Hine and Gifford (1997) for example inspected how participants' strategy changed over the course of a simulated common dilemma involving harvest decisions. During the simulation, harvesters had to make a choice at several points in time. After each choice they were provided with feedback of other, fictitious harvesters participating in the simulation. As a result of this repeating interaction with fellow harvesters, the environment is under constant change.

How can cognitive lockup be related to research in the planning paradigm? First of all, people possibly make their initial planning in too much detail. Secondly, people may not be sufficiently susceptible to emerging environmental changes. And, third, people may go through the process of mental simulation too restrictively, leaving individuals unprepared for contingencies.

In the next section we will elaborate on how these three planning errors can result in cognitive lockup.

*Detailed planning*

Simon and Galotti (1992) suggested that successful planners not only organize their activities but also maintain flexibility in their activity organizations. They appeared to be more sensitive to goal priority than poor planners. Goldin and Hayes-Roth (1980) provided further empirical support for the importance of flexibility. They found that successful planners tended to avoid early commitments to detailed action plans and specific goals. In contrast to unsuccessful planners they first explored the task environment. Also Berg, Strough, Calderone, Sansone and Weir (1998) attribute successful planning to a flexible and adaptive use of models.
Kleinmutz and Thomas (1987) and Kerstholt (1994, 1995) also showed that people do not always exercise flexibility in the selection of strategy. They found that in general participants use a judgement-oriented strategy - a strategy to reduce uncertainty by requesting information - even in situations where an action-oriented strategy - a strategy where people apply actions and react on the observed effects - would have resulted in better performance.

Mumford et al. (2001) argued in this respect for the use of midrange models. Midrange models “provide some general direction, albeit direction appropriate to the situation at hand” (p.233). Plan models should neither be highly abstract or overly detailed. Successful planners refrain from committing themselves to detailed action planning and specific goals. They rather explore the context of the task and set up a global initial plan. During its evolvement, the plan can be filled up and adjusted on the basis of environmental cues. This type of planning is also known as “opportunisti c planning”.

In the planning task of setting out a route to run a set of errands, Hayes-Roth and Hayes-Roth (1979) found that participants, while planning a route according to an initial strategy, noticed opportunities to achieve other goals. For example, a participant planning to proceed toward the bank to satisfy a high-priority goal noticed that her planned route passed by the dry cleaning shop where she needed to pick up a cleaning order. Her initial strategy to satisfy high-priority goals first, was altered into satisfying proximate goals. People, they conclude, modify current planning to take advantage of unforeseen opportunities.

Patalano and Seifert (1997) elaborated on the recognition of opportunities. In their experimental task, participants were presented with a set of goals. They had to imagine being left alone in a friend’s dormitory room for a short
period of time, during which these goals should be reached. An example of one of the goals is the following:

**You go to put your hair in a ponytail with Chris’s favourite elastic ponytail holder. The ponytail holder snaps out of your hand and flies across the room. It lands atop her bookshelf, too high for you to reach. You cannot stand on the furniture to reach it because dorm furniture is very unstable. But you need to retrieve the elastic band before Chris returns.**

The presented goals were accompanied by a plan. For the example above, this plan was to use a set of encyclopaedias. In a later stage of the experiment, participants were presented with cue objects available in the dormitory room. Participants were asked to record next to each cue any of the goals from the earlier phase that came to mind.

Cues that were identical to objects studied in the goal study phase (e.g. a set of encyclopaedias) resulted in a greater number of reminding than cues that were based on the same abstract plan as the cues in the goal study phase (e.g. a trash can). Apparently, the authors conclude, “participants did not always encode plans at an abstract level” (p.20), which is suboptimal since the retrieval of goals did not always occur when later opportunities to achieve them arose. However, instructions to encode a plan at a more abstract level resulted in recognition of a wider range of opportunities.

To conclude, studies on planning and flexibility show that people are rather inflexible in selecting an accurate strategy or model. In a very early stage they select a model that is too concrete, which hinders them in recognizing opportunities in the environment.
Neglecting to monitor the environment

Good planning requires a general rather than a detailed approach, leaving open the opportunity to adjust or fill out the original plan. This implies that good planners must have the ability for scan the environment on emerging opportunities. Eisenhardt (1989) did an exploratory study on how executives in a rapidly changing environment (the computer industry in the eighties) made decisions. She found that effective decision makers made more use of real-time information (e.g. a sudden profit drop) than less effective decision makers who, on the contrary, based their decisions on long term information (forecasts and trends).

Another observation in Eisenhardt’s study was that decision making was more effective when more alternative plans were considered. That there may be an interaction between the availability of plans and monitoring behavior may be inferred from the work by Oswald, Mossholder and Harris (1997). They examined how the availability of plans influenced managers’ perception and reaction to their environment and found that the disposal of multiple plans made them more aware of their relative strengths and weaknesses. This way the environment was monitored more analytically and individuals were more prone to identify relevant information. In the same vein, Thomas and McDaniel (1990) found that plan availability influenced the range and relevance of the environmental information being considered.

Xiao, Milgram and Doyle (1997) also stressed the importance of monitoring the environment. They found that an active and direct scanning of the environment stimulated the development of contingency plans. Data from a field study with anaesthesiologists revealed that options changed during examination of a patient’s anatomy. For example, the placement of a particular transducer during open-heart surgery places anaesthetists for different potential problems and solutions than during brain surgery. In open-heart surgery the transducer can be placed from inside the patient’s
chest and reviewing potential problems in this particular case engendered the option of asking the surgeon for assistance. This option does not exist in the case of brain surgery.

In sum, there seems to be an interaction between monitoring the environment and the availability of plans. Direct monitoring of the environment can draw one’s attention to emerging opportunities and stimulates the development of contingency plans. The availability of multiple plans, on the other hand, seems to affect the way the environment is scanned.

Lack of mental simulation
As noted earlier, Hayes-Roth and Hayes-Roth (1979) were the first ones who acknowledged the importance of mental simulation. They argued that people mentally simulate the execution of a plan and use the results of this simulation to guide subsequent planning. Mental simulation can be either time-driven or event-driven. In other words, one can simulate walking through a sequence of time units, or one can simulate a plan by mentally moving from one situation to another.

Support for the use of mental simulation in planning was provided by, amongst others, Xiao, Milgram and Doyle (1997). They asked anaesthetists to think aloud during surgical problems. It was found that anaesthetists anticipated potential problems by preparing both physically (assembling and arranging materials needed) and mentally (“if blood pressure rises quickly then...”). In their study, McLenan and Omodei (1996) also found evidence for the use of mental simulation and how this process could be beneficial for planning performance. Fire officers were asked to report all kinds of things that occurred between receipt of a fire call and the beginning of the fire fighting operation. Analyses of their reports revealed that information prior to an operation (e.g. type of structure involved) is used to mentally simulate
possible situations and actions. For example, a fire officer who has attended a fire at a particular site will review this experience while travelling to the next similar fire. During this process of mental simulation potential pre-existing situations are activated so that when an actual incident is encountered those preprimed situations are inspected first.

During mental simulation, one generally imagines doing a sequence of actions in a period of time. A finding in the study by Hayes-Roth (1981) and Hayes-Roth and Hayes-Roth (1979) is that participants typically overestimate how much they can accomplish in a given time period. Kahneman and Tversky (1979) termed this finding the "planning fallacy" referring to the tendency to hold a confident belief that one's own project will proceed as planned, even while knowing that the vast majority of similar projects have run late.

Cognitive lockup may be regarded as a result of the underestimation of predicted time. People may structurally underestimate the time needed to solve problems. At the time a second disturbance occurs, people may think they have more time to solve the subsequent disturbance than they actually have, even in the worst case when there is only limited time for handling the second disturbance. They may think they have enough time to complete the first disturbance first and then to solve the second one.

Following the line of Hayes-Roth and Hayes-Roth (1979), Buehler, Griffin and Ross (1994) drew the conclusion that people anticipate that they will finish their own project earlier than they actually do. In their study, university students were asked to estimate the time needed for academic tasks (e.g. completing a thesis) and non-academic tasks (e.g. cleaning one's department). The overall finding was that when they actually performed these tasks, a majority of students did not finish the task within the predicted time.
What psychological mechanism underlies this bias? In the aforementioned study by Buehler et al. (1994), it was stated that the planning fallacy results from an internal focus on predictions of success. When asked to predict time necessary for the completion of a task, people are focussed on the future rather than the past. This future orientation may prevent them from looking backward in time. When they do consider the past, the authors argued, they are usually focussed on previous occasions that justify their optimism. They rarely mention past experiences involving difficulties or delays.

An ‘internal’ approach on the predictions implies that forecasters apply data from the specific data at hand rather than the distributions of outcomes in similar cases (Kahneman and Tversky, 1979). By neglecting distributional information, people might underestimate the time to complete tasks, even when they have considerable experience.

The planning fallacy appears to be a persistent phenomenon. Several techniques to debias the planning fallacy failed (Byram, 1997; Newby-Clark, Ross, Koehler, Buehler and Griffin, 2000). In a series of experiments, Byram (1997) asked participants to predict how long they thought it would take to assemble a computer stand. He tried to break through people’s tendency to underestimate completion times by testing several debiasing techniques.

One such technique is decomposition. An explanation for time underestimation is that people tend to look at the task holistically, thereby ignoring task components. By subdividing a task and predicting the time to complete each component, the net prediction should be based on more information than a single prediction. Decomposing the computer stand into three components (a computer table, a key-board tray and a monitor stand) to predict the time for each component did not result in a more accurate net prediction of completion time.
Both Byram (1997) and Newby-Clark (2000) tested another debiasing technique: multiple scenarios. This technique takes advantage of the outcome of the study by Buehler et al. (1994) that when considering past experiences, people focused on previous occasions that justify their optimistic view of completing a task within time. In the multiple scenarios technique participants were asked to elicit predictions for alternative scenarios (optimistic, best guess, pessimistic). Each scenario contained different information and forced consideration of events that might otherwise be ignored. However, neither of the studies found that generation of alternative scenarios reduced the bias to underestimate completion times.

According to Newby-Clark et al. (2000) participants are motivated to disregard pessimistic scenarios of the future. They very much want to believe that they will successfully achieve their goals. Evidence for this notion was provided by an experiment in which this motivational aspect was excluded by letting participants predict someone else's completion times. In that case participants were able to take into account pessimistic scenarios.

Byram (1997) provided additional support for a motivational explanation. In his series of studies on debiasing techniques he found evidence for only one of them: financial incentives. A group of participants who were given explicit incentives for speed before making their prediction- the faster they finished, the more money they would receive- gave shorter predictions for an origami folding task than a group of participants that were not given those incentives. The actual performance time was the same for both groups.

To conclude, mental simulation seems to be a beneficial process for planning. However, people appear to be biased in their simulations of future events; they generally underestimate the time they need to fulfil a sequence of tasks.
In sum, from a planning point of view, cognitive lockup can be explained in three different ways: (1) people commit themselves in an early stage to a detailed plan, which prevents them from recognizing opportunities in the environment, (2) people refrain from a direct and active monitoring of the environment which hinders them in contingency planning, and (3) during the process of mental simulation people generate scenarios that are too optimistic with respect to completion time.

Task Switching

Hitherto, cognitive lockup has been formulated in terms of holding on to a task or sticking to a problem. In terms of the task-switching paradigm, cognitive lockup can be considered as a reluctance to switch to an alternative task or problem. In this respect, a review of task-switching studies can provide insight into why people refrain from switching.

Most studies on task switching are simple reaction-time experiments where the level of control is low. Typical tasks in this branch of studies require participants to respond as quickly as possible - mostly in a manual way - to a simple (visual) stimulus, such as a letter or a symbol. Studies that describe task switching on a higher level of control are quite scarce (Gillie and Broadbent, 1989; Schiffman and Greist-Bousquest, 1992 and Zijlstra, Roe, Leonara and Krediet, 1999). Tasks in these studies are more complex and instead of task-switching people have to deal with interruptions.

For simple reaction time studies, Rubenstein, Meyer and Evans (2001) distinguished two kinds of task switching: task switching in successive tasks and task switching in concurrent tasks. In successive tasks a response to the current task stimulus is typically made before the stimulus for the next task is presented. In concurrent tasks the stimulus for the next task is presented
before a response to the current task stimulus is made. So, in concurrent task studies there is an overlap between the tasks.

**Successive task switching studies**

Jersild (1927) was the first one to report results on task-switching experiments. In his experiments there were always two conditions: an "alternating" condition in which participants had to alternate between performing two tasks (ABABAB...) and a "pure" condition in which participants had to perform just one task (AAAAAA..., or BBBBBB...). In one experiment Jersild displayed a column of 25 two-digit numbers. In the Alternating condition, participants had to subtract 3 from the first number, add 6 to the second, subtract 3 from the third and so on. In the Pure condition participants had to subtract 3 from every number for the first half of the list and add 6 to every number for the second half of the list. The average time for the Pure lists was subtracted from the average time for the Alternating lists, resulting in switch costs of 1.2 sec per item.

Spector and Biederman (1976) used the same task procedure as Jersild and replicated this result. In an additional experiment each stimulus was accompanied by task-relevant cues (i.e. 34 + 3, 56 - 3, 12 + 3). Switch costs were reduced, supporting the notion that the principal determinant of switch costs is the extent to which the stimulus provides a readily discriminable retrieval cue for the currently appropriate mental operation when the participant switches between the two tasks in the alternating blocks. Experiments by Allport, Styles and Hsieh (1994) support this notion. Two stimulus task sets were used: one task set was an ensemble of incongruent Stroop colour words (e.g. RED printed in green colour). Participants could be asked to name either the colour or the word itself. The other set was an ensemble of displays each containing between 1 and 9 tokens of the same digit. Participants were asked to name either the number of digits or the value of the digit itself. Switch costs were higher when
participants had to switch within the same task set (e.g. between colour naming and word naming) than when they had to switch between task sets (e.g. between colour naming and value naming). In line with Spector and Biederman (1976) the stimulus in the different task set condition discriminated better which of the tasks had to be performed than the stimulus in the same task set condition.

Rogers and Monsell (1995) mentioned two disadvantages of the way Jersild estimated switch costs. First, in the alternating conditions there is an extra demand besides the activity of switching, namely two task-sets rather than one has to be kept available. As a consequence, the source of switch costs is not clear. Second, the alternating blocks condition is very likely to be perceived as more difficult than the pure blocks condition. Therefore, Rogers and Monsell (1995) devised an alternative paradigm: the alternating runs paradigm. Instead of comparing alternating (ABABAB) and pure (AAAA, BBBB) blocks of trials they had participants alternating between runs of trials on the two tasks (AABBAABB). To help the participant keep track, the stimulus was accompanied by a cue indicating its position in the current run. Switch costs were estimated by comparing performance on trials in which participants had to switch (AB, BA) with performance on trials in which no switch was required (BB, AA).

In this paradigm switch costs were substantial as well. The authors explained these switch costs in terms of task-set reconfiguration (TSR): there is an executive controller that initiates the appropriate task-set. Initiating the appropriate task-set takes time and when the interval between tasks is short, it is reasonable to suppose that switch costs occur only because there is not enough time to complete the TSR process before the next stimulus arrives. So processing the next stimulus has to be postponed until the TSR process is completed. However, when the interval between tasks was set so large that the TSR process could be completed, switch costs were still present. Rogers
and Monsell (1995) suggested that besides an endogenous component there
is an exogenous component: "stimuli can of themselves activate or evoke in
a person a tendency to perform actions (or tasks) habitually associated with
them, irrespective of prior intention, and sometimes in conflict with prior
intention" (p. 208).

Evidence that the residual switch costs are exogenous comes from a series of
experiments by Rogers and Monsell (1995) who used two tasks: classifying a
letter as a consonant or a vowel and classifying a digit as odd or even. An
irrelevant character accompanied the stimulus (letter or digit). In one
condition the irrelevant character was always drawn from a “neutral” non-
alphanumeric set (e.g. an @ or a #). This character was neither related to a
response in the ‘letter’ task, nor to a response in the ‘digit’ task. This
condition forms the No-Crosstalk condition. In the Crosstalk condition, the
irrelevant character was, in two-third of the trials, a digit in letter-
classification trials, and a letter in digit-classification trials – and, in the
remaining third of the trials, a neutral character.

Switch costs in the Crosstalk condition were much greater than in the No-
Crosstalk condition. Moreover, in the Crosstalk condition the response
associated with the irrelevant character could be congruent with the
response associated with the stimulus (e.g. the stimulus letter is a vowel for
which the right index finger has to be used and the irrelevant character is an
odd digit which requires a response with the left index finger) incongruent
with the response associated to the stimulus (e.g. the stimulus letter is a
vowel for which the right index finger has to be used and the irrelevant
character is an even digit which would have required a response with the
left index finger) or neutral. The switch costs for congruent trials were
slightly smaller than for incongruent trials. The more striking effect however,
was that switching was much faster with a neutral irrelevant letter, than with
either a congruent or incongruent one.
Apparently, the irrelevant character evokes a concurrent task from which participants are supposed to be switching away. The interfering effect of this task makes it more difficult to switch. The authors argue that this effect, and the overall effect of less switch costs for the No-Crosstalk condition, are symptoms of exogenous control. Or, as Monsell (1996) framed it: "the presence of stimulus attributes associated with a task tends to evoke that task-set and makes it harder to suppress when another task is required" (p.139).

An alternative explanation for switch costs is provided by Allport et al. (1994). They assumed that time costs associated with task switching stem from task-set inertia (TSI). By analogy with memory research they attribute switch costs to proactive interference from competing S-R mappings with the same stimuli, persisting from the instruction on previous trials. Switching from task X to task Y is harder if task X comprises the same type of stimuli as task Y. In one experiment, participants switched between the task of ‘vocally reading colour words printed in various ink colours’ and the task of ‘vocally reporting the numerical value of digits for which multiple copies were displayed in spatial arrays’. In the first phase of the experiment these tasks were performed in alternating-task and repetitive-task blocks. After a few blocks of each kind no switch costs remained. In the second phase of the experiment participants were presented with the same stimuli but with different tasks: ‘naming the ink colours of colour words’ and ‘vocally reporting the numerosity of digits in spatial arrays’. The responses to the stimuli of the second phase of the experiment conflicted with responses to exactly the same stimuli of the first phase, resulting in larger switch costs in the second phase. It is concluded that proactive interference from prior S-R mappings makes task switching during the second phase more difficult.
Concurrent task switching
A paradigm that is very often employed in overlapping tasks is that of the psychological refractory period (PRP). In this paradigm two stimuli are presented in rapid succession. Responses to these stimuli are discrete and usually simple (e.g. pressing a key). The second stimulus (S2) is presented after the first stimulus is presented but before a response (R1) is given. The typical finding in these studies is that the response to the second stimulus (R2) is considerably slowed as compared to when S2 is presented in isolation. De Jong (1995) states that the PRP-effect “appears to reflect a fundamental limitation in people’s ability to engage in the performance of more than one task at a time” (p. 2). He assumes that there is a central channel that can deal with only one task or stimulus at a time. He investigated whether there is a control mechanism that allocates the central channel to the tasks and, if there is such a mechanism, how it would work.

In typical PRP-tasks the order of tasks is held constant. De Jong altered the standard paradigm by using a variable order of tasks. The task was either an auditory task or a visual task. Participants were cued about the actual order in every trial. Cues could be either informative or neutral. When informative, cues could be either valid - for example the cue predicted that the auditory stimulus was presented first followed by the visual stimulus which happened accordingly - or invalid - for example the cue predicted that the auditory stimulus was presented first followed by the visual stimulus while in fact the presented order was reversed. Results showed that when the cue was invalid and the time between S1 and S2 was short (100 msec), participants had the tendency to respond to the second stimulus first and then to the first stimulus. This tendency was much weaker when the time between the two stimuli was longer (350 msec). When the cue was valid the tendency to respond to the second stimulus first was also very weak. So, it seems that participants possess a controller that initially allocates the central channel to the task to be performed first and re-allocates it to the other task
after the first one is finished. These results contradict the theory that holds that the central channel is not explicitly allocated but is instead simply recruited by the order in which stimuli arrive at the channel. For, according to this ‘recruitment theory’, participants should always process two stimuli in the order in which they are presented while De Jong’s data show that participants in some cases are inclined to process the second task first.

Furthermore, De Jong found that participants not only prepared for the first task but also for the subsequent switch to the second task. In an additional experiment a fixed-order condition - that is a condition in which the order of the auditory and visual task was fixed - was compared with an alternating order condition - that is a condition in which task order regularly alternated between trials. This implies that in the fixed order condition the switch to the second task was the same throughout the block (for example there was always a switch from an auditory to a visual task) whereas in the alternating-order condition the switch alternated (for example, a switch from an auditory to a visual task was followed by a switch from a visual to an auditory task). Since it was assumed that preparation requires time it was predicted that for short intervals between trials, responses to the second stimulus would be substantially delayed in the alternating order condition. In the fixed-order condition this preparation time would not be necessary because one can use the same control structure for each switch. The outcome of the experiment was that responses to the second stimulus in the alternation-order condition were indeed much slower than in the fixed-order condition, especially for short interval between trials. These findings support the idea that participants not only prepare for the first task but also for the subsequent switch to the second task.

Recent studies on multiple task performance lend support to the existence of a controller for simple reaction time tasks (Meyer and Kieras, 1997; Meyer, Kieras, Lauber, Schumacher, Glass, Zurbriggen, Gmeindl and Apfelblat,
1995 and Schumacher, Lauber, Glass, Zurbriggen, Gmeindl, Kieras and Meyer, 1999). All these studies adhere to a model that assumes that people have flexible control over processing a second task. According to this model a so-called lockout point is set for the second task. Processing the second task is suspended temporarily until the first task is judged to be completed. For the first task there is an unlocking event. When this stage is reached, the first task is judged to be completed and the executive process permits processing of the second task. So at that point executive processes unlock the second task so that processing that task continues from the point at which it was previously suspended. The specific location of lockout points and unlocking events are presumed to be optional and are contingent on factors like relative task priority, participants' strategic biases and the amount of practice.

The main observation from the traditional task-switching studies is that switching between tasks always results in switch costs in terms of time. Concurrent task-switching studies demonstrated that extra time is needed for the second task because people are unable to deal with more than one task at a time. Processing the second task is postponed until the first task is completed. Also in studies where simple reaction time tasks follow in close succession there appear to be switch costs which are either explained in terms of task-set reconfiguration or in terms of task-inertia.

As mentioned earlier, tasks in the task-switching paradigm are simple reaction time tasks. Switching between tasks at a higher level of complexity is found in studies on interruptions. Therefore, in the next paragraph we will look more closely at the literature on interruption tasks.
*Interruption studies*

Already in the 1920s Zeignarik (1927) found that interrupted tasks that could not be completed were better recalled than tasks that were not interrupted. She administered a series of 20 brief simple tasks (e.g. making words from letters or writing names of cities beginning with the letter L). Half of the tasks could be finished whereas the other half were interrupted and could not be finished. Immediately following the completion of the series, the participants were required to recall as many of the tasks as possible. The percentage of interrupted tasks recalled appeared to be significantly higher than the percentage of completed tasks (68% versus 43%). Oviankina (1928) demonstrated that, when interrupted, participants have a tendency to complete the interrupted task. Later studies confirmed this effect (Brown, 1948; Krech, Crutchfield and Livson, 1967).

In a recent study, Zijlstra, Roe and Krediet (1999) tried to identify which cognitive processes underlie the Zeignarik effect. Two groups of secretaries - one from a Dutch university and one from a Russian university - worked on standardized text editing tasks for two days. During the main task the secretaries were interrupted by telephone calls from the experimenter.

The interrupting task could differ in complexity (a ‘simple’ interruption consisted of a request for some irrelevant information, a ‘complex’ interruption consisted of a more elaborate task with a greater similarity to the main task). Besides complexity, interruptions could vary in frequency: in the Dutch part of the experiment participants were not interrupted at all, or one or three times during a session, and in the Russian part participants could not be interrupted or two times during a session.

Several dependent variables were measured: performance measures (e.g. the time required for the interruptions and the number of errors in the text editing task), psychological state indicators (scales that indicated
participants’ well-being) and psycho-physiological state indicators (the cff technique - which stands for Critical Flicker/Fusion Frequency - which reflects the level of activation of the central nervous system). Contrary to expectation, interruptions did not have a detrimental effect on performance of the main task. Participants even spent less time on the main task. Dutch and Russian participants differed in the way they handled interruptions. Russian secretaries executed the interrupting task immediately, whereas Dutch secretaries, being more used to interruptions during work, postponed execution of the interrupting event. Interesting in the performance data is the finding of an after-effect of interruptions: after a complex interruption participants needed more time to disengage from the interrupting task and to reorient themselves on the main task than after a simple interruption.

There was a difference in the emotional and psychological state between Dutch and Russian secretaries as complexity of interruptions increased. While Dutch participants experienced a decrease in negative emotional feelings, Russian participants showed a reduced subjective well being. This divergence was also explained by the difference in professional background: Dutch secretaries may be accustomed to frequent and demanding types of interruptions thereby perceiving complex interruptions as welcome distractions whereas secretaries in the Russian study may be less used to interruptions and consequently perceived these interruptions as stressors.

Gillie and Broadbent (1989) wondered why some interruptions are more disruptive than others. During a computer-based adventure game where participants needed to issue commands to the computer in order to achieve certain goals, they were interrupted by mental arithmetic tasks. The interrupting task varied in length, similarity to the main task and complexity of processing. Results suggested that similarity to the main task and
complexity of interruptions were determinants of the disruptive effects of interruptions. The length of the interruption did not seem to be a critical factor.

Like simple reaction time tasks, switching between complex (interrupting) tasks is accompanied by costs. The studies discussed above show that interruptions have disruptive effects on the main task. These costs are generally explained in terms of task-set inertia.

In sum, task-switching studies provide two reasons for cognitive lockup. (1) People may refrain from switching and stick to their initial plan of action because of the costs that accompany task switching. (2) People may not be able to deal with two tasks simultaneously. This second reason for not switching to the second problem is derived from PRP (Psychological Refractory Period) studies. The general explanation for the slower response to a second stimulus presented during processing of the first stimulus than to the same stimulus in isolation is a bottleneck in people's information processing capacities. One simply lacks executing capacity to deal with a second task before the first task is completed.

**Decision Making**

People have the tendency to stick to an initial plan, even in situations in which it is rational to switch to an alternative plan. In the literature on behavioral decision making this tendency is reflected in a number of biases, four of which - the sunk-cost effect, task completion, the omission bias and the endowment effect - will be discussed shortly.

**Sunk cost effect**

The sunk-cost effect is the finding that an endeavour is continued once an investment in money, effort or time has been made. An example of the sunk-
cost effect comes from a study by Arkes and Blumer (1985). They offered one group of participants the following scenario:

As the president of an airline company, you have invested 10 million dollars of the company’s money into a research project. The purpose was to build a plane that would not be detected by conventional radar, in other words, a radar blank plane. When the project is 90% completed, another firm begins marketing a plane that can not be detected by radar. Also, it is apparent that their plane is much faster and far more economical than the plane your company is building. The question is: should you invest the last 10% of the research funds to finish your radar-blank plane?

Another group of participants received the following scenario:

As the president of an airline company, you have received a suggestion from one of your employees. The suggestion is to use the last 1 million dollars of your research funds to develop a plane that would not be detected by conventional radar, in other words, a radar blank plane. However, another firm has just begun marketing a plane that can not be detected by radar. Also, it is apparent that their plane is much faster and far more economical than the plane your company could build. The question is: should you invest the last million of your research funds to build the radar-blank plane proposed by your employee?

On the question whether they would invest the last one million dollars to finish their radar-blank plane a majority of the participants in the first group answered “yes”, whereas a majority of the participants in the second group
answered negatively. The difference between the scenarios is that for the first group 9 million dollars have already been invested while for the second group nothing has been invested yet. The fact that so much money has been spent on the research project motivates participants in the first group to keep investing money in it.

The example described above is a clear example of the so-called sunk-cost effect. Arkes and Blumer (1985) explain this effect in terms of wastefulness. Discontinuing an endeavour for which money (or time) has been spent may give the impression that one is spending money like water. And one does not want to appear wasteful.

However, there are also alternative explanations for the sunk-cost effect (Brockner, 1992; Garland, 1990; Staw, 1981, Thaler, 1980). Staw (1981) for instance, supports the idea that the sunk-cost bias results from a process of self-justification. People have a strong desire to be correct and accurate and also to prove this to themselves and to others. A continuation of investments can be regarded as a justification for prior investments.
Thaler (1980) tried to explain the sunk-cost effect in terms of prospect theory (Kahneman and Tversky, 1979). A crucial feature of prospect theory is that choices are not evaluated in terms of final assets but in relation to a reference point (see figure 1.1). An outcome is considered a gain when it is above the reference point and it is considered a loss when it is below the reference point. The value function that is depicted in figure 1 shows that the function is concave for gains and convex for losses. This implies that people are generally risk averse in gain situations and risk seeking in loss situations. Another characteristic of the value function is that it is steeper for losses than for gains, implying that losses loom larger than gains. This means that the pleasure associated with a gain of $100 is less intense than the pain associated with a loss of $100.

According to a prospect theory account, prior investments are not totally discounted. When evaluating subsequent prospects, prior investments are
regarded as losses. Still being at the loss side of the value function, which is concave, losses do not cause large decreases in value. However, gains do cause large increases in value. From this point of view, risky behavior – like investing even more – is more likely than total withdrawal that would imply a sure loss.

To conclude, the sunk-cost effect is a robust phenomenon in decision-making literature that has been explained from several theoretical perspectives.

Task completion
Recently, a growing body of literature emphasizes the importance of completion effects (Boehne and Paese, 2000; Conlon and Garland, 1993; Garland and Conlon, 1998 and Moon, 2001). Garland and Conlon (1998) pointed out that many sunk-cost explanations may be confounded with “project completion”, the degree to which the project at hand is near completion. In all studies on sunk-cost effects, large sunk costs go together with high project completion and small sunk costs go together with low project completion.

Consider for example the scenario of the airplane company discussed above (Arkes and Blumer, 1985). The overall finding was that participants who were told that already 9 million dollars had been invested show a greater tendency to keep investing in the project than participants who lacked this information. It is true that the degree of investment is higher in the first version of the airplane company than in the second version, but the degree of completion varies as well. In the first version only 10% of the company’s own project has to be completed whereas in the second version the project has not been initiated yet. In other words, the full 100% of the project has to be completed. Investment and completion in this example are clearly confounded.
A number of studies have been conducted that manipulated sunk costs and project completion independently. An example of such a scenario is “The Bank Manager” (Garland and Conlon, 1998, study 1). The scenario reads as follows:
You are a loan officer at a large commercial bank. Custom Molds Inc., a manufacturer of plastic injection molds for high tech and precision parts, is one of your clients of long and good standing.

About 1 year ago, the CEO of Custom Molds approached you with a request for funds in order to revamp his manufacturing capabilities in a manner that would allow the firm to gear up for new competition. After long discussion and detailed scrutiny of the project plans, you recommended that the bank approve a $10 million loan for this project. The bank did approve up to $10 million for the project, with an agreed schedule of disbursement. The covenants provide for bank monitoring of project progress.

To date, $2 ($8) million has been disbursed to the company.

Over the past few months, industry data and market information have suggested that the firm’s competitive position has been negatively affected by the new entrants into this increasingly global market. In fact, just last week, a principal client of Custom Molds dropped the company from its approved vendor list.

The CEO of Custom Molds has now asked you to authorize the next instalment of $2 in order to continue with his revamping project. In his letter to you, he indicated that the revamping project is about 20% (80%) completed.

Failure to authorize the requested funds would place Custom Molds in a very precarious position, with a high probability of default on their outstanding loan.
Sunk costs were manipulated by the amount of money that had been disbursed. Sunk costs were considered low when the amount was $2 million and sunk costs were considered high when the amount was set on $8 million. Project completion was manipulated by a percentage provided by the CEO. This percentage was either 20% (low project completion) or 80% (high project completion).

Participants were asked to indicate the probability that they would authorize the expenditure of the project. Results showed only an effect of project completion: when 80% of the project was completed, the willingness to allocate the next $2 million was stronger than when only 20% of the project was completed.

Boehne and Paese (2000) subjected the project completion hypothesis to a stronger test. Garland and Conlon (1998) stated that “as progress moves forward on a project, completion of the project itself takes increasing precedence over other goals (e.g. economic profit) that may have been salient at the time the decision was made to begin the project” (p.2042). However, as Boehne and Paese argued, Garland et al. (1998) provided no evidence for this explanation. Goals such as economic profit could not even have played a role in their studies because the information how much the project would generate once it would be terminated, was missing.

In their study, Boehne and Paese (2000) included this piece of information in the scenario of a real estate development project. Besides an independent manipulation of sunk costs and task completion, they varied the sales price of the real estate. The sales price information allowed participants to calculate the economic value. According to the authors the information may induce participants to engage in an economically rational decision process.
Contrary to their expectations the authors still found a very strong effect of task completion. In fact, when the project was close to being finished, they often recommended completing the project even when it was economically unwise to do so. The sunk-cost manipulation virtually had no effect.

In a recent study, Moon (2001) found evidence for both sunk costs and task completion. Most interesting, he also found an interaction between the two effects: the sunk-cost effect appeared to be present under conditions of high completion, but appeared to be absent under conditions of low completion. The author explains this interaction in terms of psychological pressure. This pressure is much higher in case of high completion and much lower in case of low completion. This explanation agrees with entrapment studies (Brocker, Rubin and Lang, 1981; Teger, 1980) in which it is assumed that the decision-maker must be psychologically triggered to invest further. In the study of Moon, sunk-cost effects were found when participants were psychologically compelled by a nearly finished project.

The task completion effect is a phenomenon that has recently been raised as an alternative explanation for the sunk-cost effect.

The endowment effect
Another example of people's tendency to stick to old plans is the endowment effect. The endowment effect is the phenomenon that people are unwilling to give up an item, with which they have been randomly endowed, for an alternative item. A well-known experiment is that of the coffee mugs (Kahneman, Knetsch and Thaler, 1990). Half of a group of participants were given a coffee mug while the remaining participants received a large Toblerone chocolate bar. After that, participants were given the opportunity to exchange items. Since items were assigned randomly it was expected that half of the participants would be willing to trade their item. However, only a small part was actually willing to do so.
This effect is related to the finding that the lowest selling price for an endowed item is considerably larger than the highest price for which one wants to buy the same item. In a study by Kahneman, Knetsch and Thaler (1990) a group of students were given a coffee mug from their university bookstore and they were asked to indicate for which price they would be willing to sell the mug. Another group of students indicated for which price they would be willing to buy the same mug. The median price was $7.12 for the “sellers” and $2.87 for the “buyers”.

The effect mentioned above could be explained by prospect theory: people are loss averse and they have the tendency to weigh losses more heavily than corresponding gains. So, when participants are endowed with a coffee mug and are asked to exchange the mug for a chocolate bar, the loss of the mug looms larger than the gain of the chocolate bar. Once given an item, that item gets a surplus value. As a consequence, people are reluctant to give up what they have.

The status quo bias
The tendency to cling to an initial course of action is also reflected in the so called status-quo bias, reported by Samuelson and Zeckhauser (1988). Participants tended to choose the current state of affairs, although it was no more attractive than other available alternatives. They presented participants with either one of two different versions of a funds investment decision task. In one version - the neutral version - participants are told to picture they had inherited a large sum of money from an uncle. Furthermore, they were told that they had to imagine considering different portfolios. Participants could choose between four different options.

In the other version – the status quo version – participants were told to imagine they had inherited a portfolio of cash and securities from their great uncle. As in the neutral condition, participants had to choose between four
different portfolios, one of which was the actual portfolio inherited. So, the status quo was equal to one of the alternatives. The general finding in this experiment was that participants in the status quo version demonstrated a much higher preference for the alternative that corresponded to the status quo than participants in the neutral version.

As the endowment effect, the status quo bias is generally explained in terms of loss aversion. The status quo is a reference point. A switch to an alternative course of action entails expected losses on one dimension and expected gains on the other dimension. One gives more weight to potential losses from switching than to potential gains. Hence, people are unlikely to prefer alternatives for which the expected gains are only slightly higher than the expected losses.

According to some researchers (Ritov and Baron, 1992) the exaggerated preference for the status quo is actually the same phenomenon as the omission bias, people’s tendency to prefer omissions over acts. The omission bias is often demonstrated by the following example:

Paul owned shares in Company A. During the last year he considered switching to stock in Company B, but he decided against it. He now finds that he would have been better off by $1,200 if he had switched to stock of Company B.

George owned shares in Company B. During the past year he switched to stock in Company A. He now finds that he would have been better off by $1,200 if he had kept his stock in Company B.
Most participants imagined that George would feel more regret than Paul, even though both are faced with the same final outcome. The only difference is that in George's case the outcome resulted from an action whereas in Paul's case it resulted from inaction. This effect reflects the phenomenon that negative consequences from acts are evaluated as more negative than the same consequences that result from omissions.

Ritov and Baron (1992) argued that sticking to the status quo is actually confounded with a preference for omissions over acts. Presented with scenarios in which the effects of status quo and omission to act were not confounded, evidence was in fact only obtained for an omission bias. However, in a later report, Schweitzer (1994) demonstrated both a status quo and an omission bias.

Several explanations have been proposed for the omission bias. Apart from loss aversion, the omission bias is explained in terms of norm theory and reluctance to choose. According to norm theory (Kahneman and Tversky, 1982) acting is considered as more abnormal because “it is usually easier to imagine abstaining from actions that one has carried out than carrying out actions that were not in fact performed” (p.145). Omission is taken as a reference point and, since acts are considered as more abnormal than non-acts, emotional reactions (e.g. regret) are enhanced.

Another explanation for the occurrence of the omission bias is a reluctance to choose (Ritov and Baron, 1992). Omissions may be perceived as non-acts rather than a deliberate choice “not to act”. When confronted with an awkward dilemma one may find it difficult to make a decision and a way to deal with this difficulty is by making no decision at all. Or, as Janis and Mann (1977) put it: “a decision maker under pressure to make a vital decision will typically find it painful to commit himself, because there are some expected costs and risks no matter which course of action he chooses.
One way of coping with such a painful dilemma is to avoid making a decision" (p. 6).

So, loss aversion seems to be the general psychological mechanism underlying both the endowment effect and the status quo bias. The omission bias implies that people prefer the option of non-acting over options of acting. We think that the status quo bias – referring to a preference for the status quo over alternative state of the world – is better applicable to lockup phenomena than the omission bias. The actual problem with being locked up is that people prefer to continue the ongoing course of action rather than any alternative course of action. Doing nothing is no option.

In sum, a review of decision-making literature renders three different explanations for cognitive lockup: (1) loss aversion, (2) sunk costs and (3) task completion.

Summary

Earlier, we stated that a review of research areas related to cognitive lockup could provide entries to investigate this phenomenon. We elaborated on three adjacent fields, planning, task switching and decision making, each generating a number of hypotheses for cognitive lockup. Summarized, the following explanations were discussed.

Planning
1. People commit themselves too early to a detailed plan;
2. People refrain from monitoring the environment;
3. People generate future scenarios that are too optimistic;
Task-switching
4. People lack spare attention to switch to a second disturbance;
5. The costs of switching are perceived too high;

Decision-making
6. People are loss averse: they weigh losses larger than gains;
7. Sunk costs: prior investments are taken into account;
8. Task completion: people have a desire to fulfil a task.