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Why designers can't understand their users

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10. Cognitive quantity

10.1 What is ‘cognitive quantity’

The cognitive quantity of an interface reflects the number of differences a human faculty can distinguish in a cognitive field. This includes the quantity of cognitive elements. For *motor quantity* this can be the number of keys to press, for *visual quantity* this can be the number of visual objects and for cognitive quantity this can be the number of elements in a list. Quantity also includes the number of values of properties that are functional in the cognitive field. In a visual field these are the number of forms, sizes, luminance differences, colours and flashing rates for the element properties. In a cognitive field cognitive quantity includes the number of values of the cognitive field properties distance and structure.

10.2 Why ‘cognitive quantity’

Cognitive quantity is the focus of several types of psychology. Information processing psychology tries to understand human cognition by analysing human processing framed in terms of the number of bits of information. (Sanders and McCormick (1992), for instance, recall that early investigators held out great promise that theories on human information processing would help unravel the mysteries of how people think. Information is measured in bits and a bit is the amount of information required to decide between two equally likely alternatives. This ‘quantum psychology’ and the associated link unit of measurement have often been used to describe the stimuli and responses making up an information-processing task. Students of perceptual psychology have tried to establish channel capacity of human perception (Carterette & Friedman 1978) and students of human memory have focused on the capacity limitations of human short-term memory (Baddely 1987).

In applied psychology cognitive quantity is typically studied under the topic of mental load (Kantowitz, 1987; Seeber et al., 1981; Williams, 1982). When cognitive quantity is too high, there is too much mental load and the individual will become stressed. Mental load is an effect, whereas a high value of cognitive quantity is a cause. Therefore the term cognitive quantity is preferred in a design context because we want to reduce the unnecessary load on individuals by getting at the root causes, and designing them out, rather than by trying to teach people to cope with what they have been given by poor design ergonomics (Wagenaar, Hudson & Reason, 1992). Another way of studying cognitive quantity in applied areas is by reducing quantity by careful design. An example of this approach is the 'data-ink ratio' of graphical designer Tufte (1986). The 'data-ink ratio' is 'the proportion of a graphic's ink devoted to the non-redundant display of data'. Gillan and Richman (1994) showed that the effect of using little ink to present a large amount of information is a reduction in reaction time and making fewer errors.

10.3 Which 'cognitive quantities'

Counting is easy, but deciding how to determine *what* to count is difficult. For counting the group at least has to be nominal, i.e. it must be possible to sort the elements objectively into classes (De Groot, 1961) and those classes must be mutually exclusive (Brink and Koele, 1985). For a data entry task the relevant motor elements are the keys of a keyboard and not the written text on the keyboard. For a text reading task the relevant visual elements are the written words and not the colours of the pages. Relevant cognitive elements for train passengers are, in most cases, at least departure time and platform number. Irrelevant, for instance, might be train number. What is a relevant element in a field is determined by the task. Elements that are presented on an interface but are irrelevant for the task in hand (they might well be relevant for a different task) can generate poorer performance because individuals might assume that information presented *is* relevant for their task. Grice's maxims for good communication are equally relevant in the area of display design (in: Strawsom, 1971).

Determining human performance by counting cognitive quantities is difficult because of human flexibility and resilience. When the number of actions required to perform a task using a human faculty is too high, a

human being might change to a process that is able to perform the task using fewer elements. When there is much memory load, human reasoning might take over by trying to find a structure in the information, thereby reducing memory load and effective quantity of the problem by chunking. A structured list might be more easily to recall than a random list of elements. Another solution is to perform some motor actions and to write down the information to be recalled. When this flexibility is not identified the user escapes from the control of the psychologist and the designer.

Finally, the definition of a unit can change when the task is changed. The dot on the character 'i' is a unit for a graphical letter designer but it is not a unit when the same designer is reading a book. Yet again this distinction is a truly psychological one as the notion of a significant item is determined by the task to be performed, not the objects in the environment as such. Empty elements, such as white space in, or gaps between movements in a symphony, can be equally meaningful. The way in which elements are combined is considered under *cognitive structure*, here the point is that 'empty' elements are also elements that can or even should be counted *in the context of a specific task*.

The next section describes an observational experiment in which it is suggested that wrongly chosen cognitive field properties resulted in poor user performance. The second experiment reported in this section focuses on the effect of the field property: cognitive quantity.

10.4 Experiment 1: observation of performance¹

10.4.1 Introduction

In the early days ergonomics focused on anthropometrics and psychophysiological aspects of stimuli like character size and contrast. Rookmaaker (1985), for instance, investigated how many passengers were able to read a trains indicator board positioned in the main station hall of Amsterdam Central Station (see Figure 1). Nowadays, however, train schedules are becoming increasingly complex. The front of a train could have a different destination from the rear of the train. Trains

¹ Some of the results were reported in Verhoef (1993).

leaving later could arrive earlier at a station than a train that left some minutes earlier. An earlier arrival could be due to an earlier departure, higher speed, a shorter route, or fewer intermediate stops. Passengers might have to pay extra for the privilege, but not always. To assure that the passengers understood this, setting anthropometric and psychophysiological requirements for an indicator board only covers issues that may be necessary but are not necessarily sufficient. Therefore a systematic observation study was performed on passengers who used the Amsterdam Central Station trains indicator board to select a train going to their destination.

Figure 1. The current dynamic trains indicator, Amsterdam CS, upper left hand part of the left indicator only



tijd	naar	spoor	treinsoort	via
13 43	Enkhuizen	13a	Stoptrein	Zaandam-Hoorn
13 51	Beverwijk - Uitgeest	2a	Stoptrein	Haarlem
13 52	Den Helder	8a	Intercity	Castricum-Alkmaar
14 00	Vlissingen	14a	Intercity	Schiphol - Den Haag
14 03	Haarlem	4a/b	Stoptrein	
14 05	Alkmaar	8a	Stoptrein	Zaandam
14 07	Den Haag CS	11a	Sneltrain	Schiphol - Den Haag
14 11	Rotterdam CS	1	Sneltrain	Haarlem - Den Haag
14 19	Paris Nord	14b		Rotterdam
14 19	Enkhuizen	13a	Stoptrein	Zaandam-Hoorn
14 21	Beverwijk - Uitgeest	2a	Stoptrein	Haarlem
14 22	Den Helder	7a	Intercity	Heiloo-Alkmaar
14 30	Brussel Zuid	14a/b	Intercity	Schiphol

10.4.2 Method

In the main hall of Amsterdam Central Station, under the indicator board the experimenter asked 105 passengers: "Please, can you tell me at what time the train for x leaves?" X was the next station from a random list,

including all stations on the trains indicator (See Annex 2). The experimenter did not introduce himself as an experimenter but pretended to be a passenger. After having received the answer the experimenter wrote down the answer of the passenger. The answers of the passengers were evaluated and classified as follows.

a) Correct

The answer was scored as 'correct' when the train mentioned arrived at the destination requested, even when less travel time was possible by a change to another train.

b) 'Sub-optimised'

The answer was scored as 'correct' but 'sub-optimised' when the train did arrive at the destination named but when another train would arrive sooner because it departed sooner, stopped at fewer stations or had a shorter route. For the sub-optimally correct answers the delays were calculated. The total of these delays were divided by all passengers. This figure was the mean delay across the sample.

c) Incorrect and don't know

An answer was scored as 'incorrect' when the train mentioned did not lead reasonably to the destination, even by changing trains somewhere. As most destinations can be reached with changes, this was also scored in terms of the travel time.

The time it took the passenger to give their reaction was also noted.

10.4.3 Results

Of all passengers interviewed, 62% could find the departure time of the first train to arrive on the destination named by the experimenter. 'Sub-optimal' answers were given by 18% of the respondents. These sub-optimal answers, however, increased the mean travel time for all respondents by 6 minutes. Five percent mentioned a train that did not go to the named destination, even if one changed trains somewhere. The remaining 15% could not give any destination. The mean search time was 20 seconds.

10.4.4 Discussion

Poorly applied anthropometrics was not expected to be the cause of these 20 seconds reading time, nor was legibility. Character sizes were appro-

priate and none of the passengers commented that they could not read the information. In addition, they mentioned a train that was present on the indicator, making it very likely that they were able to read the text on the indicator. No problems were found regarding the visual field properties.

Passengers not selecting the optimised train trip, probably did not notice that elsewhere on the trains indicator, there was another train arriving sooner than the train mentioned. So, it seems that passengers often did not know what information was being presented and how it was presented. They had no control over the cognitive field because they did not know what the relevant unit was. As discussed in Chapter 4 there are three cognitive field properties of the indicator that could be changed to improve performance. Changing cognitive distance was not expected to lead to any improvement, as the passengers are familiar with all the concepts used. They know what trains are, that an Intercity is a train and they know the meaning of 'via', for instance. Changing cognitive structure was expected to lead to improvement as passengers apparently had navigational problems. This field property is discussed in Chapter 11. This chapter focuses on cognitive quantity. Cognitive quantity of the indicator could be reduced without reducing functionality too much. The next sections describe the results of an experiment comparing indicators having different values of cognitive quantity.

10.5 Experiment 2: the effect of cognitive quantity

10.5.1 Introduction

When analysing the cognitive property quantity it became clear that on the board double trains were listed Double trains are trains having the same route and stops but a different departure time. Mostly the difference in departure time is 15, 30 or 60 minutes. As a consequence of this strategy the indicator sometimes shows 14 trains to Utrecht Central Station and none to Leiden². This strategy is inspired by a marketing department that wants to present as many trains as possible (van 't Wout, 1988). The goals of the marketing department - to impress passengers with the number of trains that the NS offers - are quite different from those of the

² This has been changed. Today the indicator shows Leiden as well.

passengers, who want to know where to go for a train arriving as soon as possible at their destinations. It can be argued that passengers only want the train that will arrive first in their destination. In addition, passengers who do not necessarily want to take the first train to depart might have sufficient time left to use other sources of information. Another strategy for these passengers would be to analyse the pattern on the indicator. For several decades the schedule of Netherlands Railways has had a very regular time pattern. Many Dutch train passengers know that when there is a train leaving at 14:10 hours, it is very likely there is a train leaving at 15:10 hours too.

When double trains are deleted, cognitive quantity is reduced. One might expect passenger search performance improves in that case. To test this prediction and, if so to establish the effect of a reduction, the next experiment was carried out.

10.5.2 Method

304 train passengers who had left Amsterdam Central Station participated in this experiment, in which they were confronted with printed ‘indicator boards’ during their trip. The independent variable was the type of indicator. For large cognitive quantity there was a trains indicator and a destinations indicator, both with double trains information. For small cognitive quantity there was a trains indicator and a destinations indicator, both with single trains information. Randomly the passengers were assigned to the large quantity group or to the small quantity group. All passengers got two indicators, a trains indicator and a destinations indicator. The order of presentations was random. Details on the subjects, the procedure and the destinations asked can be found in Annex 1 and Annex 2.

10.5.2.1 The indicator used

The basis for the experimental indicators was the trains indicator of Amsterdam Central Station and the information presented on a working day between 13:00 and 14:00 hours. Only those destinations mentioned on the indicator were asked. There were the following differences between the Amsterdam Central Station indicator and an experimental indicator. The real indicator was a large hardware indicator mounted on the wall in the main hall of Amsterdam Central Station. The experimental indicators presented the information on paper.

Some destinations were abbreviated.

Real indicator: *Experimental indicators:*

Brussel zuid Brussel
Naarden-Bussum Naarden
Zandvoort aan Zee Zandvoort

Abbreviation was necessary to be able to design a portable indicator that could rest on the lap of the passenger.

10.5.2.2 Condition little information; single indicator

The material used for the little information condition was a 'single indicator'; i.e. an indicator that includes every train or destination only once. When the 10:20 train to Maastricht is indicated the 11:20 train to Maastricht is not indicated. See Figure 2 and 3.

Figure 2. The experimental single destinations indicator

Figure 2. The experimental single destination indicator

1301																								
bestemming	tijd	trein soort	spoor	opmerkingen	bestemming	tijd	trein soort	spoor	opmerkingen	bestemming	tijd	trein soort	spoor	opmerkingen	bestemming	tijd	trein soort	spoor	opmerkingen	bestemming	tijd	trein soort	spoor	opmerkingen
Alkmaar	13 06	Stoptrein	15a		Heerlen	13 02	Intercity	2a		Meesp	13 05	Stoptrein	10b											
Alkmaar	13 22	Intercity	11a		Heiloo	13 22	Intercity	11a		Noerden	13 24	Stoptrein	2a											
Almere	13 05	Stoptrein	10b		Hengelo	13 02	Intercity	11b		Zaandam	13 06	Stoptrein	15a											
Amersfoort	13 02	Intercity	11b		Hilversum	13 02	Intercity	11b		Zandvoort	13 04	Stoptrein	7a											
Amersfoort	13 13	Stoptrein	13b		Hilversum	13 13	Stoptrein	13b		Zwolle	13 32	Intercity	11b											
Arnhem	13 19	Intercity	4a		Hoofddorp	13 08	Stoptrein	14a																
Beverwijk	13 23	Stoptrein	2a		Hoorn	13 19	Stoptrein	13a																
Breukelen	13 05	Stoptrein	5b		Leeuwarden	13 32	Intercity	11b																
Brussel	13 26	Intercity	4a		Maastricht	13 32	Intercity	2a/b																
Castricum	13 52	Intercity	11a		Maarsse	13 05	Stoptrein	5b																
Den Haag	13 10	Sneltrain	5a		Naarden	13 26	Stoptrein	13b																
Den Haag	13 26	Intercity	4a		Nijmegen	13 19	Intercity	4a																
Den Helder	13 22	Intercity	14a		Roosendaal	13 26	Intercity	4a																
Den Helder	13 52	Intercity	11a		Rotterdam	13 10	Sneltrain	5a																
Dordrecht	13 10	Sneltrain	5a		Rotterdam	13 24	Stoptrein	2a	via Breukelen															
Enkhuizen	13 19	Stoptrein	13a		Schiphol	13 08	Stoptrein	14a																
Eindhoven	13 02	Intercity	2a		Schiphol	13 26	Intercity	4a																
Enschede	13 02	Intercity	11b		Utrecht	13 02	Intercity	2a																
Groningen	13 32	Intercity	11b		Utrecht	13 05	Stoptrein	5b																
Gouda	13 24	Stoptrein	2a		Utrecht	13 26	Stoptrein	13b	via Hilversum															
Haarlem	13 04	Stoptrein	7a		Uitgeest	13 23	Stoptrein	2a	via Beverwijk															
Haarlem	13 10	Sneltrain	5a		Viissingen	13 56	Intercity	4a																

Figure 3. The experimental single trains indicator

1301 Richting Zaandam, Alkmaar, Hoorn, Haarlem, Schiphol, Leiden, Den Haag, Rotterdam, België				
tijd	naar	spoor	treinsoort via	opmerkingen
13 04	Zandvoort aan Zee	7a	Stoptrein Haarlem	
13 06	Alkmaar	15a	Stoptrein Zaandam	
13 08	Hoofddorp	14a	Stoptrein Schiphol	
13 10	Norddrecht	5a	Sneltrain Haarlem-Den Haag-Rotterdam	
13 19	Cokhuizen	13a	Stoptrein Zaandam-Hoorn	
13 22	Den Helder	14a	Intercity Hellaar-Alkmaar	
13 23	Beverwijk-Digst	2a	Stoptrein Haarlem	
13 26	Brussel	4a	Intercity Schiphol-Den Haag-Rotterdam	
13 52	Den Helder	11a	Intercity Castricum Alkmaar	
13 56	Vlissingen	4a	Intercity Schiphol-Den Haag-Rotterdam	

1301 Richting Hilversum, Amersfoort, Zwolle, Gouda, Almere, Hengelo, Utrecht, Arnhem, Nijmegen, Duitsland				
tijd	naar	spoor	treinsoort via	opmerkingen
13 02	Heerlen	2b	Intercity Utrecht-Eindhoven	
13 02	Enschede	11b	Intercity Hilversum-Amersfoort-Hengelo	
13 05	Utrecht CS	5b	Stoptrein Breukelen-Haarlem	
13 05	Almere	10b	Stoptrein Weesp	
13 13	Amersfoort	13b	Stoptrein Weesp-Hilversum	
13 19	Nijmegen	4b	Intercity Utrecht-Arnhem	
13 24	Rotterdam CS	2b	Stoptrein Breukelen-Haarlem-Gouda	
13 26	Hilversum-Utrecht CS	13b	Stoptrein Haarlem	
13 32	Maastricht	2b	Intercity Utrecht-Eindhoven	
13 32	Groningen-Leeuwarden	11b	Intercity Hilversum-Amersfoort-Zwolle	
13 49	Arnhem	5b	Intercity Utrecht	

10.5.2.3 Condition large amount of information; double indicator

The material used for the large amount of information condition was a double indicator; i.e. an indicator that included as large amount of information about trains and destinations as the indicator can possibly present. When sufficient space is available the 10:20 and the 11:20 train are both on the indicator. A trains indicator can be a single or a double indicator (See Figure 4). A destinations indicator can be a single or a double (See Figure 5) indicator too.

Figure 4. The experimental double trains indicator

Richting 13:01 Zaandam, Alkmaar, Hoorn, Haarlem, Schiphol, Leiden, Den Haag, Rotterdam, België						Richting 13:01 Hilversum, Amersfoort, Zwolle, Gouda, Almere, Hengelo, Utrecht, Arnhem, Nijmegen, Duitsland					
tijd	naar	spoor	treinsoort	via	opmerkingen	tijd	naar	spoor	treinsoort	via	opmerkingen
13 04	Zandvoort	7a	Stoptrein	Haarlem		13 02	Heerlen	2b	Intercity	Utrecht-Eindhoven	
13 06	Alkmaar	15a	Stoptrein	Zaandam		13 02	Enschede	11b	Intercity	Hilversum-Amersfoort-Hengelo	
13 08	Hoofddorp	14a	Stoptrein	Schiphol		13 05	Utrecht CS	5b	Stoptrein	Breukelen-Haarzen	
13 10	Dordrecht	5a	Sneltrain	Haarlem-Den Haag-Rotterdam		13 05	Almere	10b	Stoptrein	Meesp	
13 19	Enkhuizen	13a	Stoptrein	Zaandam-Hoorn		13 13	Amersfoort	13b	Stoptrein	Meesp-Hilversum	
13 22	Den Helder	14a	Intercity	Heiloo-Alkmaar		13 19	Nijmegen	4b	Intercity	Utrecht-Arnhem	
13 23	Beverwijk-Wegest	2a	Stoptrein	Haarlem		13 24	Rotterdam CS	2b	Stoptrein	Breukelen-Hoorden-Gouda	
13 26	Brussel	4a	Intercity	Schiphol-Den Haag-Roosendaal		13 26	Hilversum-Utrecht CS	13b	Stoptrein	Naarden	
13 34	Zandvoort	8a	Stoptrein	Haarlem		13 32	Maastricht	2a/b	Intercity	Utrecht-Eindhoven	
13 36	Alkmaar	15a	Stoptrein	Zaandam		13 32	Groningen-Leeuwarden	11b	Intercity	Hilversum-Amersfoort-Zwolle	
13 38	Hoofddorp	14a	Stoptrein	Schiphol		13 35	Utrecht CS	4b	Stoptrein	Breukelen-Haarzen	
13 40	Dordrecht	5a	Sneltrain	Haarlem-Den Haag-Rotterdam		13 35	Almere	10b	Stoptrein	Meesp	
13 49	Enkhuizen	10a	Stoptrein	Zaandam-Hoorn		13 43	Amersfoort	13b	Stoptrein	Meesp-Hilversum	
13 52	Den Helder	11a	Intercity	Castricum-Alkmaar		13 49	Arnhem	5b	Intercity	Utrecht	
13 53	Beverwijk-Wegest	2a	Stoptrein	Haarlem		13 56	Hilversum-Utrecht CS	13b	Stoptrein	Naarden	
13 56	Vlissingen	4a	Intercity	Schiphol-Den Haag-Roosendaal							

Figure 5. The experimental double destinations indicator

1301																			
bestemming	tijd	trein	spoor	opmerkingen	bestemming	tijd	trein	spoor	opmerkingen	bestemming	tijd	trein	spoor	opmerkingen	bestemming	tijd	trein	spoor	opmerkingen
Alkmaar	13 06	Stoptrein	15a		Den Helder	13 22	Intercity	14a		Hilversum	13 32	Stoptrein	11b		Utrecht	13 02	Intercity	2b	
Alkmaar	13 22	Intercity	11a		Den Helder	13 52	Intercity	11a		Hilversum	13 43	Stoptrein	13b		Utrecht	13 05	Stoptrein	5b	
Alkmaar	13 36	Stoptrein	15		Dordrecht	13 10	Sneltrain	5a		Hilversum	13 56	Stoptrein	13b		Utrecht	13 19	Intercity	4b	
Alkmaar	13 52	Intercity	11a		Dordrecht	13 40	Sneltrain	5a		Hoofddorp	13 08	Stoptrein	14a		Utrecht	13 26	Stoptrein	13b	via Hilversum
Almere	13 05	Stoptrein	10b		Enkhuizen	13 19	Stoptrein	13a		Hoofddorp	13 38	Stoptrein	14a		Utrecht	13 32	Intercity	2a/b	
Almere	13 35	Stoptrein	10b		Enkhuizen	13 49	Stoptrein	13a		Hoorn	13 19	Stoptrein	13a		Utrecht	13 35	Stoptrein	4b	
Amersfoort	13 02	Intercity	11b		Eindhoven	13 02	Intercity	2b		Hoorn	13 49	Stoptrein	10a		Utrecht	13 49	Intercity	5b	
Amersfoort	13 13	Stoptrein	13b		Eindhoven	13 32	Intercity	2a/b		Leeuwarden	13 32	Intercity	11b		Utrecht	13 56	Stoptrein	13b	via Hilversum
Amersfoort	13 32	Intercity	11b		Enschede	13 02	Intercity	11b		Maastricht	13 32	Intercity	2a/b		Uitgeest	13 23	Stoptrein	2a	via Haarlem
Amersfoort	13 43	Stoptrein	13b		Groningen	13 32	Intercity	11b		Maarsse	13 05	Stoptrein	5b		Uitgeest	13 53	Stoptrein	2a	via Haarlem
Arnhem	13 19	Intercity	4b		Gouda	13 24	Stoptrein	2b		Maarsse	13 35	Stoptrein	4b		Vlissingen	13 56	Intercity	4a	
Arnhem	13 49	Intercity	5b		Haarlem	13 04	Stoptrein	7a		Naarden	13 26	Stoptrein	13b		Meesp	13 05	Stoptrein	10b	
Beverswijk	13 23	Stoptrein	2a		Haarlem	13 10	Sneltrain	5a		Naarden	13 56	Stoptrein	13b		Meesp	13 13	Stoptrein	13b	
Beverswijk	13 53	Stoptrein	2a		Haarlem	13 23	Stoptrein	2a		Nijmegen	13 19	Intercity	4b		Meesp	13 35	Stoptrein	10b	
Breukelen	13 05	Stoptrein	5b		Haarlem	13 34	Stoptrein	8a		Rosendaal	13 26	Intercity	4a		Meesp	13 43	Stoptrein	13b	
Breukelen	13 24	Stoptrein	2b		Haarlem	13 40	Sneltrain	5a		Rosendaal	13 56	Intercity	4a		Meerden	13 24	Stoptrein	2b	
Breukelen	13 35	Stoptrein	4b		Haarlem	13 53	Stoptrein	2a		Rotterdam	13 10	Sneltrain	5a		Zaandam	13 06	Stoptrein	15a	
Brussel	13 26	Intercity	4a		Heerlen	13 02	Intercity	2b		Rotterdam	13 24	Stoptrein	2b	via Breukelen	Zaandam	13 15	Stoptrein	13a	
Castricum	13 52	Intercity	11a		Heiloo	13 22	Intercity	11a		Rotterdam	13 40	Sneltrain	5a		Zaandam	13 36	Stoptrein	15	
Den Haag	13 10	Sneltrain	5a		Hengelo	13 02	Intercity	11b		Schiphol	13 08	Stoptrein	14a		Zaandam	13 49	Stoptrein	12a	
Den Haag	13 26	Intercity	4a		Hilversum	13 02	Intercity	11b		Schiphol	13 26	Intercity	4a		Zandvoort	13 04	Stoptrein	7a	
Den Haag	13 40	Sneltrain	5a		Hilversum	13 13	Stoptrein	13b		Schiphol	13 38	Stoptrein	14a		Zandvoort	13 34	Stoptrein	8a	
Den Haag	13 56	Intercity	4a		Hilversum	13 26	Stoptrein	13b		Schiphol	13 56		4a		Zwolle	13 32	Intercity	11b	

10.5.2.4 Scoring

The scoring was the same as in the previous experiment (see section 10.4.2).

10.5.3 Results

The means score for the double indicators was 93% accurate and 96% for the single indicators ($F(3.1446)=5.136$; $p=0.024$). The mean search time for the double indicators was 11 seconds and for the single indicators 7 seconds per train ($F(3.1446)=5.043$; $p=0.025$). The mean delay that the passengers would have if they had really taken the train they mentioned was, when using the double indicators, 3.5 minutes and using the single indicators 2.2 minutes.

It is concluded that passengers perform better with single indicators (low cognitive quantity) than with double indicators (high cognitive quantity).

10.5.4 Discussion

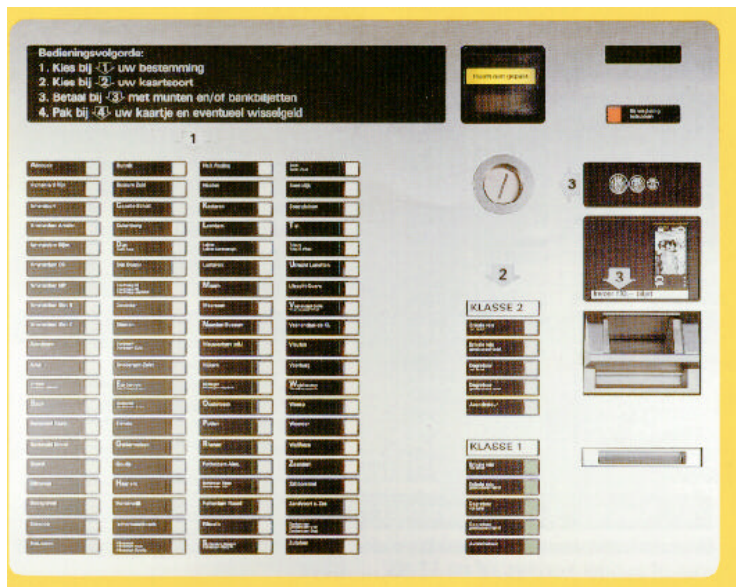
All measurements carried out indicated that single indicators perform better than double indicators (See Table I). These differences were significant and were as expected. The experiment supports the assumption that human search performance is better when cognitive quantity is lower. Deleting excess information is useful. One can argue that the extra information on the double indicators is useful on the grounds that a degree of redundancy benefits users. It is for passengers not knowing that Netherlands Railways train schedules have a regular time pattern. However, this consideration does not affect the conclusion and the argument is of dubious validity, even for foreigners who would be best served by information about their immediate future travel plans than by learning about what is possible two hours away. The next section describes how the knowledge obtained, is used to design other information systems.

Table I. Performance of passengers for using timetables having several types of cognitive quantity

	Quantity	
	large double trains	small single trains
Score	93%	96%
sd	25.3	20.2
n	708	742
Mean delay	3.5 min.	2.2 min.
Mean search time	11 sec.	7 sec.
sd	37	38
n	708	742

10.6 Generalization of knowledge

Figure 6. 80 destinations ticket vending machine



10.6.1 Interface technology generalisation: button train ticket vending machine

The property cognitive quantity was applied in the redesign for the 80 destinations train ticket vending machine shown in Figure 6 and 7 reported in Verhoef (1988). One of the errors observed was selecting wrong ticket type. Figure 7 shows the ticket type selection interface of that interface in detail.

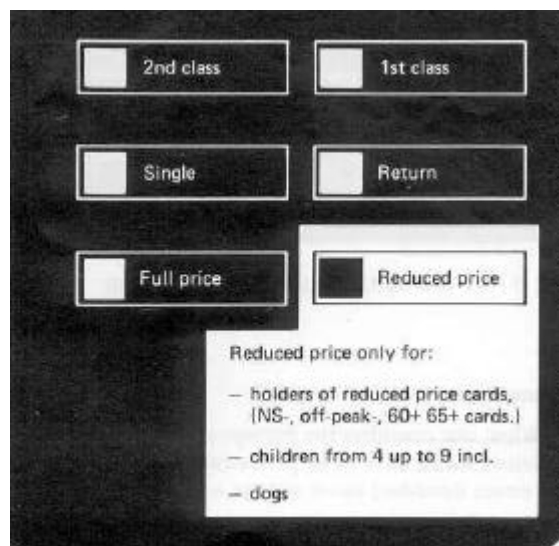
Figure 7. Ticket type interface on the 80 destinations ticket vending machine



In this interface the passenger has to make three decisions when pressing one button: class type, fare (full price, reduced fare), and single/ return/ evening return.

To reduce ticket type selection problems the quantity of cognitive elements to deal with at the same time was reduced by proposing the ticket type interface presented in Figure 8.

Figure 8. Proposed ticket type interface for the 80 destinations ticket vending machine



The solution was applied in the next generation machines, the code destination train ticket vending machines of NS as can be seen in Figure 9.

Figure 9. Ticket type interface on the code destinations ticket vending machine

Maak keuze

2e klas 1e klas

Maak keuze

vol tarief korting

Korting geldt voor Voordeel-urenkaarten:

- Rail-Aktief-kaart
- 60+ Seniorenkaart
- Jongerenkaart
- Jaartrajectkaart
- Ketenkaart
- OV-studentenkaart
- Kind 4 t/m 11 jaar
- Hond (maximaal 710,- zie Toeslagen)

Maak keuze

alleen vandaag geldig zonder datum

Stempelen op (eerste) reisdag verplicht

Maak keuze

enkele reis retour

5-retour kaart

5-Retourkaart
stempelen op reisdag verplicht

avond-retour

Avondretour
geldig met Voordeel-urenkaart vanaf 18.00 uur; niet geldig op vrijdag

weekend-retour

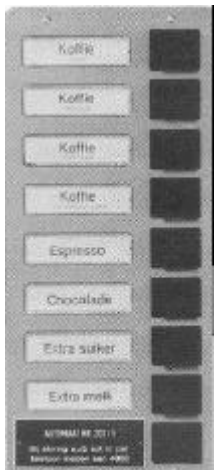
Weekendretour
geldig met Voordeel-urenkaart: heenreis geldig vanaf vrijdag 19.00 uur of op zaterdag

The very same problem and solution existed in the domain of coffee vending machines as can be seen in Figure 10 and 11.

Figure 10. Coffee vending machine, two cognitive elements (decisions) on one button for coffee type



Figure 11. Coffee vending machine, one cognitive element (decision) one button for sugar type



10.6.2 Domain generalisation: the Windows/ Office terminology

The experiment showed that from a practical point of view it is possible to reduce the quantity of cognitive elements and at the same time improve human performance. The experiment was carried out with travel information but the theory is more general and does not impose this restriction. The figures 10 and 11 show application of the same principle to the design of the coffee-machine. This can also be applied to more complex systems than train schedules and coffee machines. An analysis has been made of the concepts used in the vocabulary of the computer program Windows and Office and a so-called 'Commander' vocabulary has been elaborated. The Windows/ Office vocabulary analysed so far, has 89 words. It proved to be possible to reduce this number of words to 61, without reduction of the number of concepts, which leads to a raw score of 69% of the Windows vocabulary. A smaller vocabulary is achieved by not using synonyms. Terms like accessories, control panel, field, function, tool, menu, (menu) option, start and tool are translated using the word 'command' and, if necessary some specification is added. A menu, for instance is a 'word command list' and a toolbar is an 'icon command list'. Also, reducing the quantity of cognitive elements results in having a smaller vocabulary. For instance the following 14 words: attach(ment), bookmark, cell reference, clone, cross reference, dial-up connections, favourite (websites), hot link, hyperlink, link, network connections, reference, short cut and wireless link all have in common that they are (1) a link, to (2) a whole file or a part of a file, that (3) exists a computer; the current one, one within a private network or some computer somewhere connected to the Internet. Probably more computer interface words than the 14 mentioned refer to the same basic concepts and can be added to this list. A bookmark referring to another section of this chapter, for instance, is a 'link of a file element within this file' and an Internet hyper link is a 'link to a file within an other computer'. Of course, in some cases the words refer to concepts, not fully described by the three cognitive elements and an adjective is required. 'Hot', 'short', and 'bookmark' in an Internet program, for instance, refer to frequency of use. However, as this example also shows, the quantity of cognitive elements for these adjectives can also be reduced.

10.7 Conclusion

A theoretical analysis including several researches for areas of psychology and ergonomics suggested that cognitive quantity is a fundamental property of a field with cognitive elements.

An experiment reported in this chapter supports this suggestion. The experiment showed that changing cognitive quantity of an interface affects human performance. When the number of elements in a cognitive field increases, human performance decreases.

An experiment reported elsewhere (Verhoef, 1988) provides information on the interface independence of the conclusion. An analysis of decision making of vending machines users concluded that taking more decisions at the same time caused passengers to buy tickets of the wrong ticket type. Technically, a design forcing passengers to take one decision at a time is possible too and was subsequently implemented by NS.

Cognitive quantity can also be applied to the domain of computer interfacing. It became clear that it is possible to reduce the number of concepts (and consequently, the number of words) substantially. Although no experimental data are available the hypothesis that user will perform better using a computer interface having substantially less words and concepts, without having less functions, seems defensible.

