

The Impact of Visualizing Uncertainty on Train Trip Selection

Annex

M. Wunderlich, K. Ballweg, and T. von Landesberger

Part I

Study Data and Visualizations

1 Description of the Train Trips

Attribute	TO1	TO2	TO3
Departure	\approx	$b \prec a$	$a \prec_S b$
Arrival	$a \prec_S b, b \prec_D a$	$b \prec a$	$b \prec_S a, a \prec_D b$
Travel duration	$a \prec_S b, b \prec_D a$	$b \prec a$	$a \prec_S b, \approx_D$
Transfers	no transfers	2 in a and b, longer in a	1 in b
Delays	a's delay meets deadline (C2)	never critical	critical transfer
Alternatives	none	none	1 for b's transfer

Table 1: Attribute-wise comparison of the two train trips TO1–TO5 per decision situation. (a denotes the first, b the second trip; \approx similar for a and b; shorter/earlier with a: $a \prec b$; according to schedule: $_S$; according to (maximum) expected delays: $_D$)

Attribute	TO4	TO5
Departure	$a \prec b$	\approx
Arrival	\approx	$a \prec_S b, b \prec_D a$
Travel duration	$b \prec a$	$\approx_S, b \prec_D a$
Transfers	2 in b	1 in a and b
Delays	never critical	critical transfers
Alternatives	none	1 for each transfer

Table 2: Attribute-wise comparison of the two train trips TO1–TO5 per decision situation. (a denotes the first, b the second trip; \approx similar for a and b; shorter/earlier with a: $a \prec b$; according to schedule: $_S$; according to (maximum) expected delays: $_D$)

TO1 *Direct influence of train delay on the arrival time:* Both train trips depart at the same time and have no transfers. The travel duration with the first connection is shorter according to the schedule while the travel time with the second connection is shorter according to the (maximum) expected delays.

TO2 *Influence of delay on transfer time:* Departure and arrival times of the two trips are similar whereas the travel duration with the second trip is slightly shorter. Each trip has two transfers. The transfer durations of the first connection are longer according to the schedule but shorter according to the expected delays at the transfer stations.

TO3 *Influence of a critical delay on arrival time via potential miss of a connecting train:* The travel duration of the first trip is longer but the trip contains no transfers. The second trip contains one transfer that is also critical, i.e., the connecting train of the second connection might be missed due to the expected delays. If the connecting train is missed, the arrival time of the second trip is before the arrival time of the first trip. If the connecting train is reached, the order of the arrival times is vice versa.

TO4 *Trade off between travel duration and transfers:* The arrival time of both trips is similar. The first trip contains no transfers but departs earlier, i.e., its travel duration is longer. The second trip contains two transfers but none of them is critical (i.e., the connecting trains will most probably will be reached).

TO5 *Influence of arrival time due to critical delay:* Each of the trips contains one transfer of equal duration. The connecting trains in both trips might be missed due to the delay of the preceding trains. The arrival time of the first connection is earlier if the connecting train is reached and later otherwise.

2 Visualizations of the Train Trips

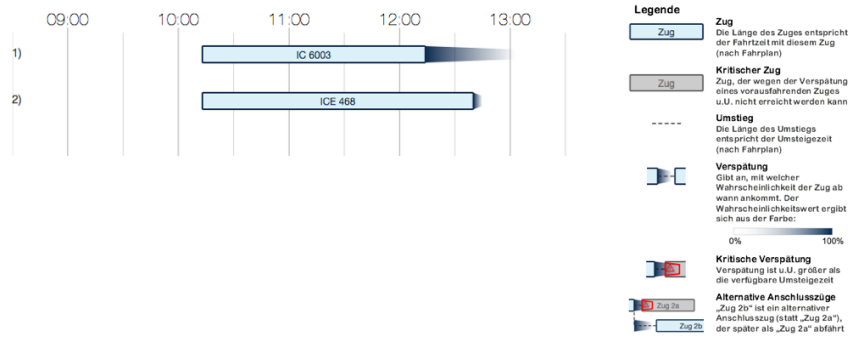


Figure 1: Train Trips TO1 displayed with design D_{cum}

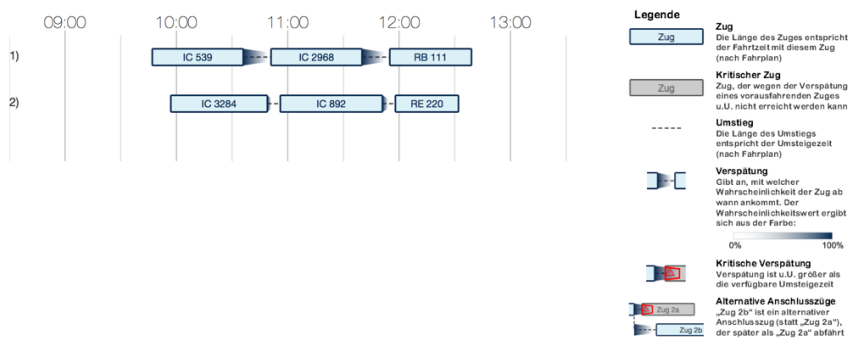


Figure 2: Train Trips TO2 displayed with design D_{cum}

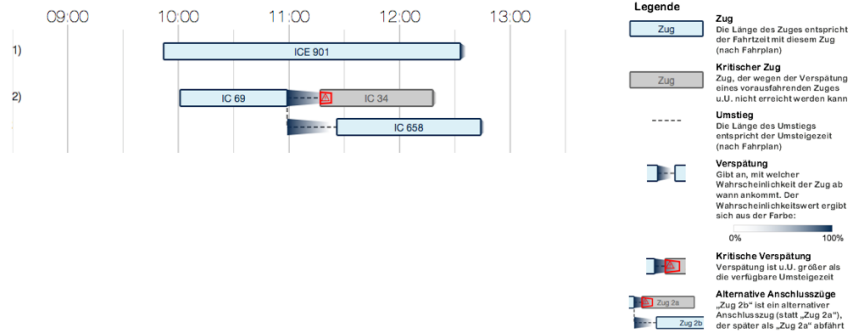


Figure 3: Train Trips TO3 displayed with design D_{cum}

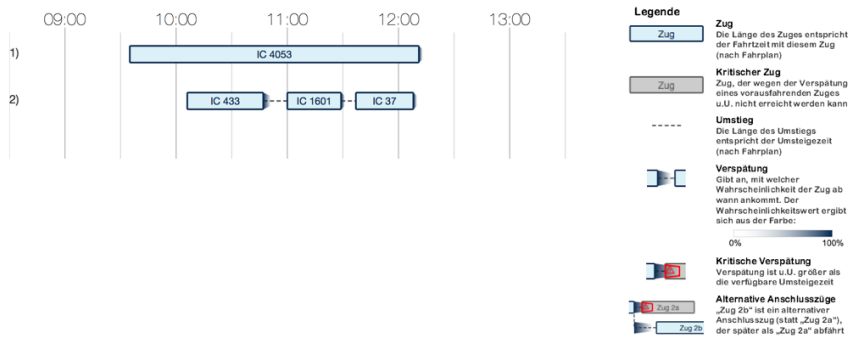


Figure 4: Train Trips TO4 displayed with design D_{cum}

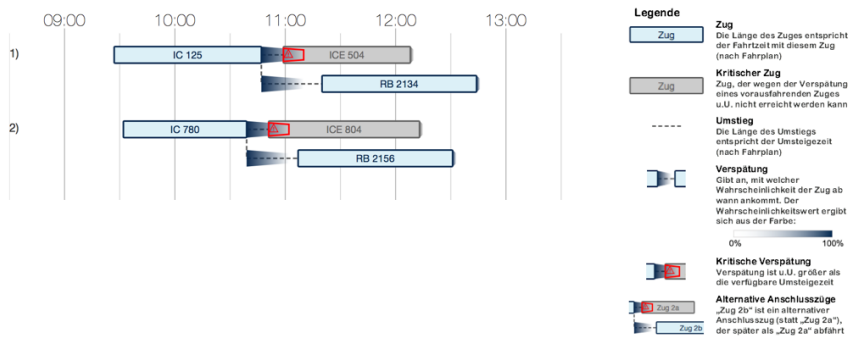


Figure 5: Train Trips TO5 displayed with design D_{cum}

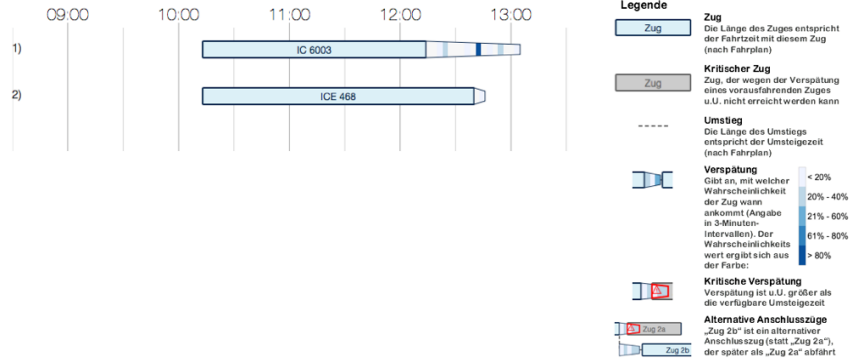


Figure 6: Train Trips TO1 displayed with design D_{noncum}

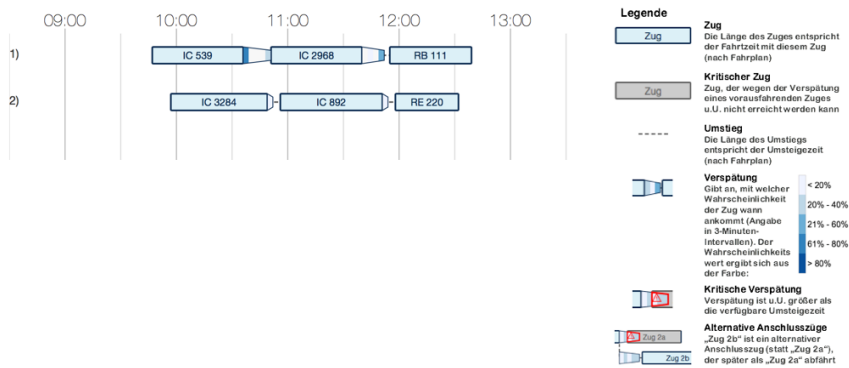


Figure 7: Train Trips TO2 displayed with design D_{noncum}

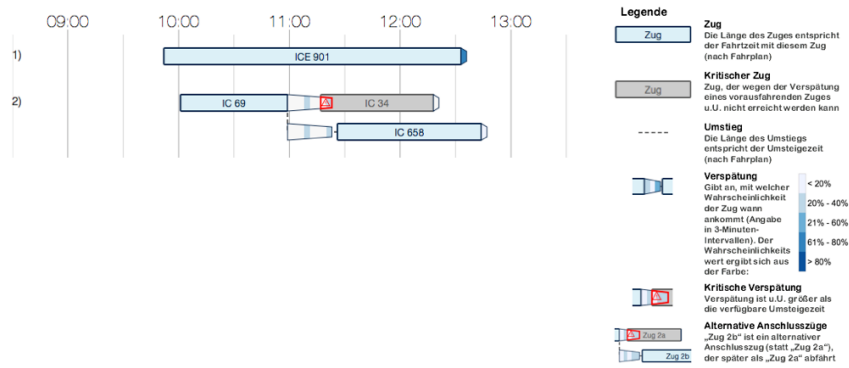


Figure 8: Train Trips TO3 displayed with design D_{noncum}

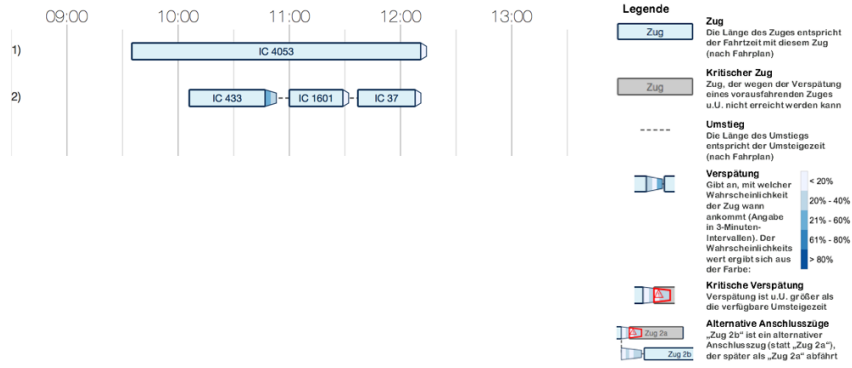


Figure 9: Train Trips TO4 displayed with design D_{noncum}

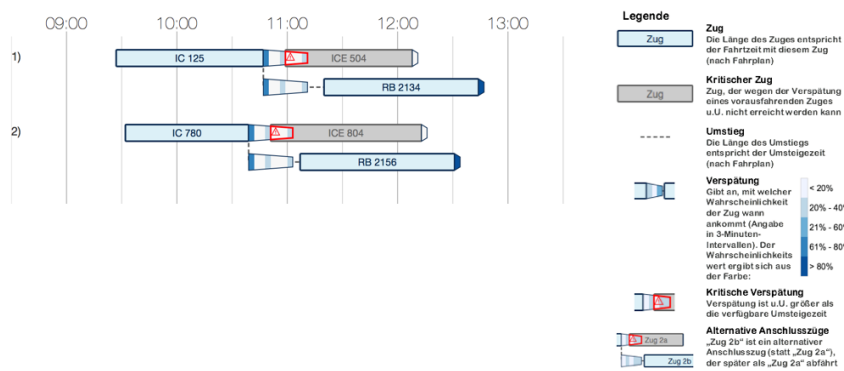


Figure 10: Train Trips TO5 displayed with design D_{noncum}

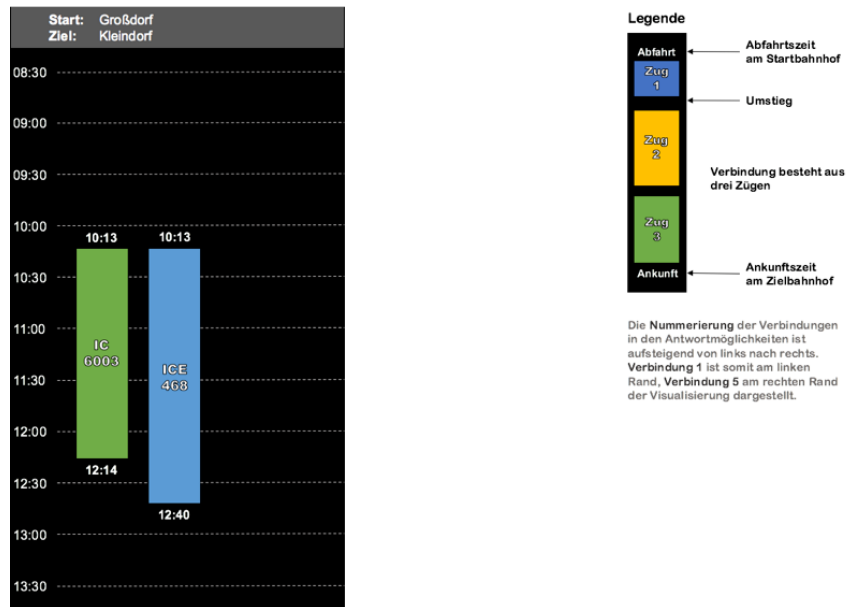
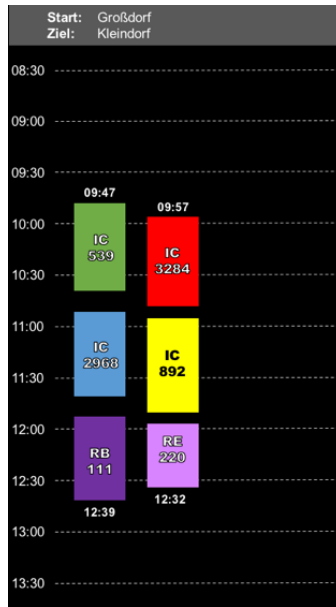
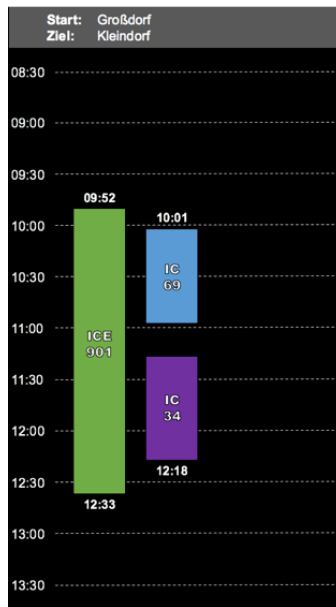


Figure 11: Train Trips TO1 displayed with design D_{vis}



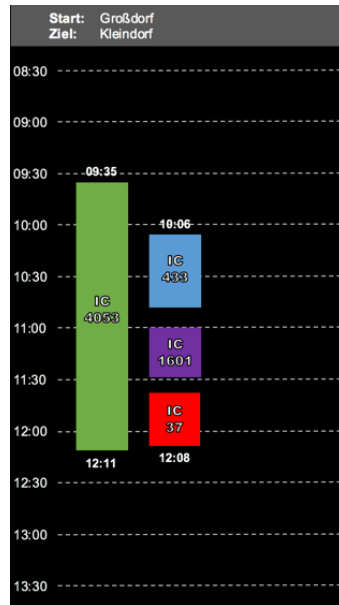
Die Nummerierung der Verbindungen in den Antwortmöglichkeiten ist aufsteigend von links nach rechts. Verbindung 1 ist somit am linken Rand, Verbindung 5 am rechten Rand der Visualisierung dargestellt.

Figure 12: Train Trips TO2 displayed with design D_{vis}



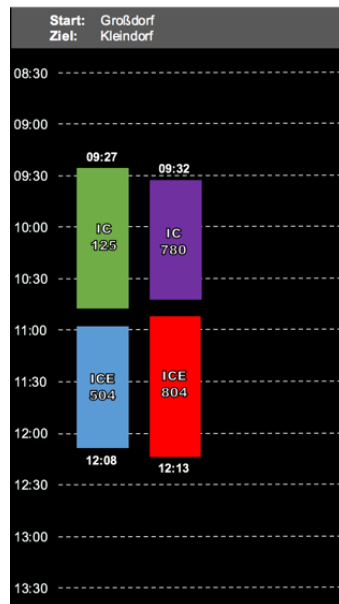
Die Nummerierung der Verbindungen in den Antwortmöglichkeiten ist aufsteigend von links nach rechts. Verbindung 1 ist somit am linken Rand, Verbindung 5 am rechten Rand der Visualisierung dargestellt.

Figure 13: Train Trips TO3 displayed with design D_{vis}



Die Nummerierung der Verbindungen in den Antwortmöglichkeiten ist aufsteigend von links nach rechts. Verbindung 1 ist somit am linken Rand, Verbindung 5 am rechten Rand der Visualisierung dargestellt.

Figure 14: Train Trips TO4 displayed with design D_{vis}



Die Nummerierung der Verbindungen in den Antwortmöglichkeiten ist aufsteigend von links nach rechts. Verbindung 1 ist somit am linken Rand, Verbindung 5 am rechten Rand der Visualisierung dargestellt.

Figure 15: Train Trips TO5 displayed with design D_{vis}

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte
Großdorf Kleindorf	10:13 12:14	2:01	0	IC
Bahnhof/Haltestelle	Zeit	Gleis	Produkte	Weitere Informationen
Großdorf	ab 10:13	4	IC 6003	Intercity Bordbistro
Kleindorf	an 12:14	11		

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte
Großdorf Kleindorf	10:13 12:40	2:27	0	ICE
Bahnhof/Haltestelle	Zeit	Gleis	Produkte	Weitere Informationen
Großdorf	ab 10:13	12	ICE 468	Intercity-Express Bordrestaurant
Kleindorf	an 12:40	1		

Figure 16: Train Trips TO1 displayed with design D_{text}

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte
Großdorf Kleindorf	09:47 12:39	2:52	2	IC, RB
Bahnhof/Haltestelle	Zeit	Gleis	Produkte	Weitere Informationen
Großdorf	ab 09:47	4	IC 539	Intercity Bordbistro
Mittendorf	an 10:36			
↪ Umsteigezeit 15 Min.				
Mittendorf	ab 10:51		IC 2968	Intercity Bordbistro
Nebenstadt	an 11:40			
↪ Umsteigezeit 15 Min.				
Nebenstadt	ab 11:55		RB 111	Regionalbahn
Kleindorf	an 12:39	3		

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte
Großdorf Kleindorf	09:57 12:32	2:35	2	IC, RE
Bahnhof/Haltestelle	Zeit	Gleis	Produkte	Weitere Informationen
Großdorf	ab 09:57	10	IC 3284	Intercity Bordbistro
Städtchen	an 10:49			
↪ Umsteigezeit 7 Min.				
Städtchen	ab 10:56		IC 892	Intercity Bordbistro
Dörfchen	an 11:51			
↪ Umsteigezeit 7 Min.				
Dörfchen	ab 11:58		RE 220	Regional-Express Fahrradmitnahme begrenzt möglich
Kleindorf	an 12:32	12		

Figure 17: Train Trips TO2 displayed with design D_{text}

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte
Großdorf Kleindorf	09:52 12:33	2:41	0	ICE
Bahnhof/Haltestelle	Zeit	Gleis	Produkte	Weitere Informationen
Großdorf	ab 09:52	6	ICE 901	Intercity-Express Bordrestaurant
Kleindorf	an 12:33	6		

2)

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte
Großdorf Kleindorf	10:01 12:18	2:17	1	IC
Bahnhof/Haltestelle	Zeit	Gleis	Produkte	Weitere Informationen
Großdorf	ab 10:01	3	IC 69	Intercity
Mittendorf	an 10:59			
☞ Umsteigezeit 18 Min.				
Mittendorf	ab 11:17		IC 34	Intercity Bordbistro
Kleindorf	an 12:18	13		

Figure 18: Train Trips TO3 displayed with design D_{text}

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte
Großdorf Kleindorf	09:35 12:11	2:36	0	IC
Bahnhof/Haltestelle	Zeit	Gleis	Produkte	Weitere Informationen
Großdorf	ab 09:35	2	IC 4053	Intercity Bordbistro
Kleindorf	an 12:11	10		

2)

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte
Großdorf Kleindorf	10:06 12:08	2:02	2	IC
Bahnhof/Haltestelle	Zeit	Gleis	Produkte	Weitere Informationen
Großdorf	ab 10:06	3	IC 433	Intercity Bordbistro
Dorfen	an 10:47			
☞ Umsteigezeit 13 Min.				
Dorfen	ab 11:00		IC 1601	Intercity Bordbistro
Stadten	an 11:29			
☞ Umsteigezeit 8 Min.				
Stadten	ab 11:37		IC 37	Intercity Bordbistro
Kleindorf	an 12:08	4		

Figure 19: Train Trips TO4 displayed with design D_{text}

1)

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte
Großdorf Kleindorf	09:27 12:08	2:41	1	IC, ICE
Bahnhof/Haltestelle	Zeit	Gleis	Produkte	Weitere Informationen
Großdorf Stadorf	ab 09:27 an 10:47	7	IC 125	Intercity Bordbistro
↪ Umsteigezeit 12 Min.				
Stadorf Kleindorf	ab 10:59 an 12:08	7	ICE 504	Intercity-Express Bordrestaurant

2)

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte
Großdorf Kleindorf	09:32 12:13	2:41	1	IC, ICE
Bahnhof/Haltestelle	Zeit	Gleis	Produkte	Weitere Informationen
Großdorf Dorsadt	ab 09:32 an 10:39	3	IC 780	Intercity Bordbistro
↪ Umsteigezeit 12 Min.				
Dorsadt Kleindorf	ab 10:51 an 12:13	4	ICE 804	Intercity-Express Bordrestaurant

Figure 20: Train Trips TO5 displayed with design D_{text}

Part II

Study Results

3 Decisions

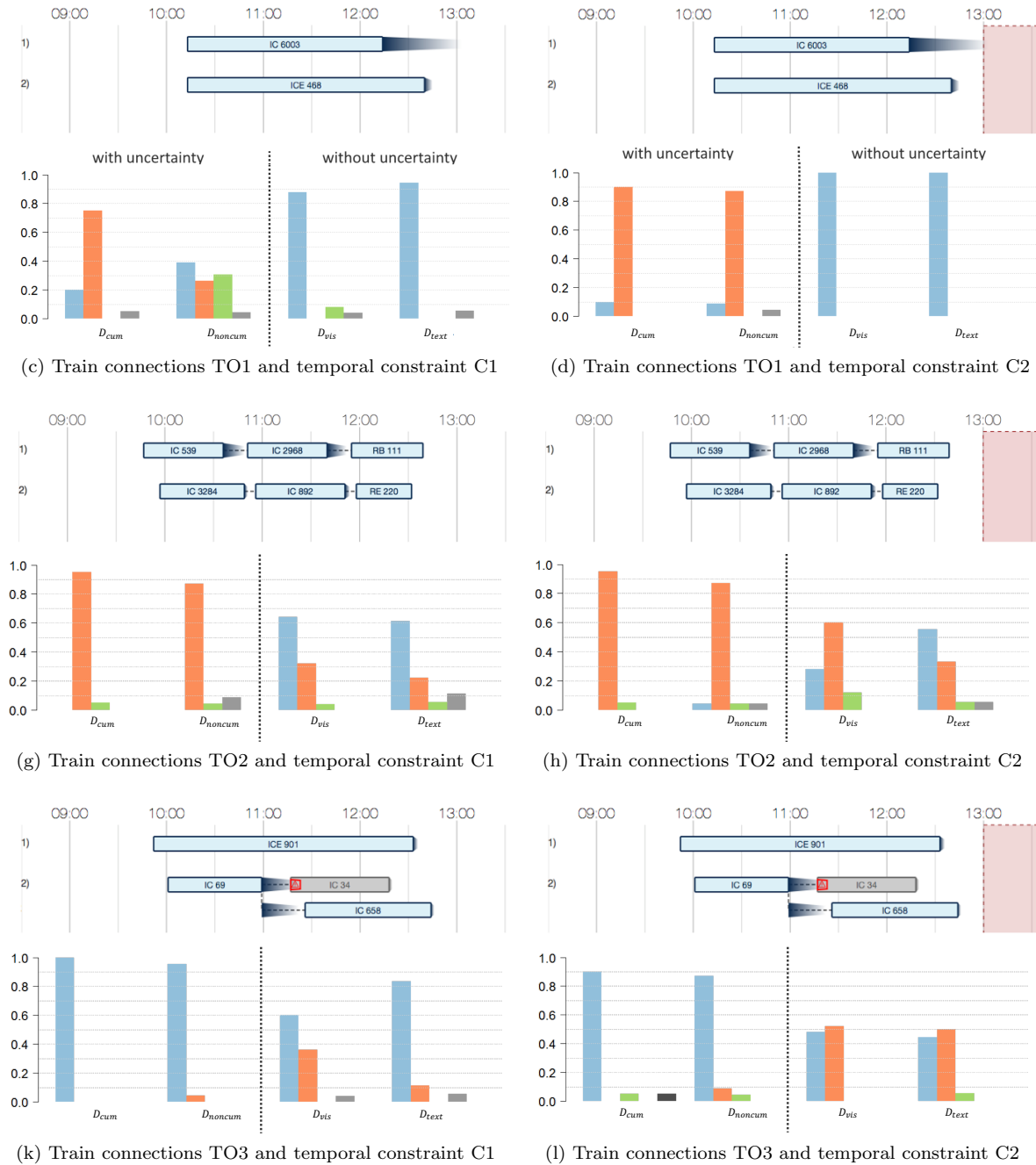


Figure 21: Distribution of the decisions for each situation composed of a set of train connections TO1–TO5 and a temporal constraint C1/C2. The values are relative to the number of answers for each design. *Option 1*, *Option 2*, *For me, both trips are of equal value*, *I can not decide based on this depiction, because: [text input]*, and *I don't know* Above each bar chart the decision situation is displayed with D_{cum} .

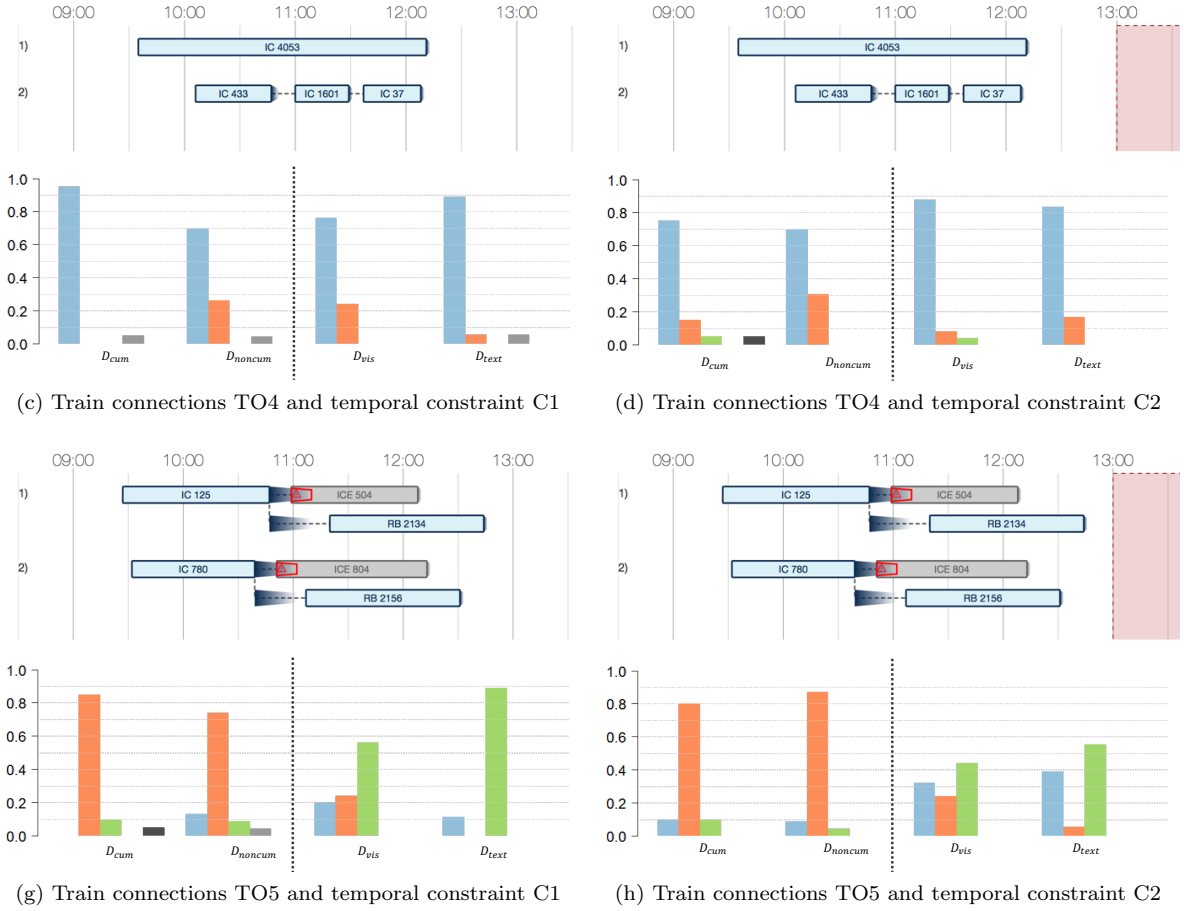


Figure 22: Distribution of the decisions for each situation composed of a set of train connections TO1–TO5 and a temporal constraint C1/C2. The values are relative to the number of answers for each design. *Option 1*, *Option 2*, *For me, both trips are of equal value*, *I can not decide based on this depiction, because: [text input]*, and *I don't know*

4 Statistical Evaluation

4.1 Dependence on the Availability of Delay Uncertainty

The *Fisher's Exact Test* showed that the decisions on train trip selection significantly depend on the availability of delay uncertainty visualization for eight out of ten decision scenarios (cf. Table 3).

	C1	C2
TO1	< 0.001 ***	< 0.001 ***
TO2	< 0.001 ***	< 0.001 ***
TO3	< 0.001 ***	< 0.001 ***
TO4	1	0.281
TO5	< 0.001 ***	< 0.001 ***

Significance levels: p-value < 0.001: ***, < 0.01: **, < 0.05: *

Table 3: P-values according to *Fisher's Exact Test* for decisions depending on the availability of delay uncertainty information in the visualization.

4.2 Dependence on the Design of Connection Display

We tested whether decisions differ depending on the type of display with *Fisher's Exact Test*. We specifically analyzed two cases: with uncertainty (D_{cum} and D_{noncum}) and without uncertainty (D_{vis} and D_{text}).

	C1	C2
TO1	< 0.001 ***	< 0.001 ***
TO2	< 0.001 ***	< 0.001 ***
TO3	0.001 **	< 0.001 ***
TO4	0.047 *	0.336
TO5	< 0.001 ***	< 0.001 ***

Significance levels: p-value < 0.001: ***, < 0.01: **, < 0.05: *

Table 4: P-values according to *Fisher's Exact Test* for decisions depending on the design of train trip display.

		D_{cum} vs. D_{noncum}	D_{vis} vs. D_{text}
TO1	C1	0.002 ** °	0.752
TO2		0.74	0.396
TO3		1	0.116
TO4		0.023 *	0.106
TO5		0.332	0.04 *
TO1	C2	1	1
TO2		1	0.115
TO3		0.593	0.729
TO5		0.839	0.32

Significance levels: p-value < 0.001: ***, < 0.01: **, < 0.05: *

Bonferroni corrected: p-value < 0.0002: °°, < 0.002: °°, < 0.008: °

Table 5: P-values according to *Post-hoc Fisher's Exact Test* for decisions depending on the type of delay display and depending on whether display is visual or text.

4.3 Dependence on the Existence of an Arrival Deadline

	TO1	TO2	TO3	TO4	TO5
†	< 0.001 ***	† 0.096	0.029 *	0.789	† 0.08

† includes the decision that both connections are of equal value

Significance levels: p-value < 0.001: ***, < 0.01: **, < 0.05: *

Table 6: P-values according to *McNemar Test* for decisions depending on the time constraint.

	D_{cum} & D_{noncum}	D_{vis} & D_{text}
TO1	0.004 **	
TO2	1	† 0.039 *
TO3	1	0.034 *
TO4	0.221	0.724
TO5	1	† 0.096

† includes the decision that both connections are of equal value
Significance levels: p-value < 0.001: ***, < 0.01: **, < 0.05: *

Table 7: P-values according to *McNemar Test* for decisions depending on the time constraint for designs with uncertainty (D_{cum} & D_{noncum}) and without uncertainty (D_{vis} & D_{text}).

	D_{cum}	D_{noncum}	D_{vis}	D_{text}
TO1	0.023 *	0.248		
TO2	1		† 0.059	0.48
TO3	1		0.505	0.046 *
TO4	1	0.248	0.134	0.617
TO5	1	0.48	1	

† includes the decision that both connections are of equal value
Significance levels: p-value < 0.001: ***, < 0.01: **, < 0.05: *

Table 8: P-values according to *McNemar Test* for decisions depending on the time constraint for each design.

5 Decision Making Durations

Decision Situation		D_{cum}	D_{noncum}	D_{vis}	D_{text}
TO1	C1	33,33	35,40	30,32	41,33
TO2		29,67	19,15	19,29	49,72
TO3		18,38	16,65	16,64	33,50
TO4		13,33	20,55	12,07	24,56
TO5		24,04	29,45	17,43	32,67
TO1	C2	15,00	15,45	14,11	18,28
TO2		17,33	16,15	13,14	34,22
TO3		11,38	14,05	17,00	29,22
TO4		11,54	10,65	11,86	25,78
TO5		17,25	27,15	13,75	25,00

Table 9: Decision Making Durations

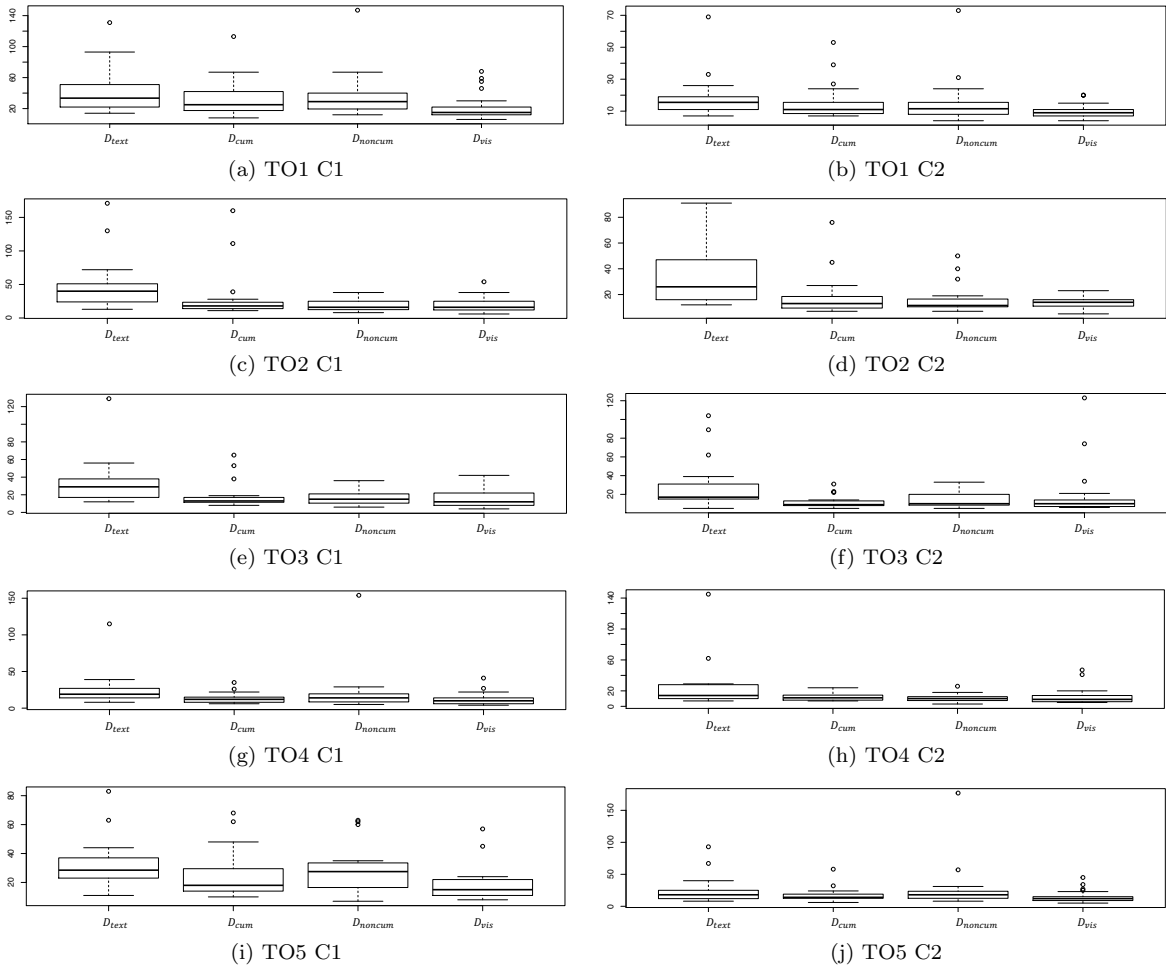


Figure 23: Decision Making Durations