Capacity Allocation Modelling by Auction

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joint work with

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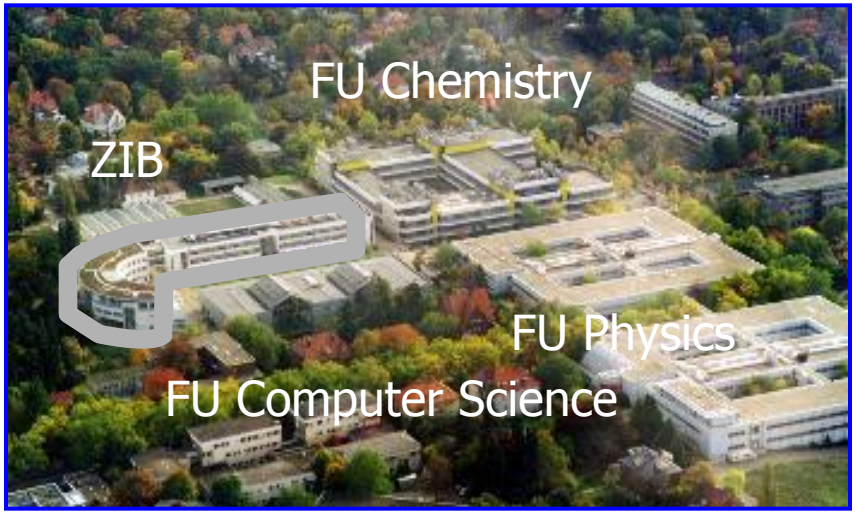
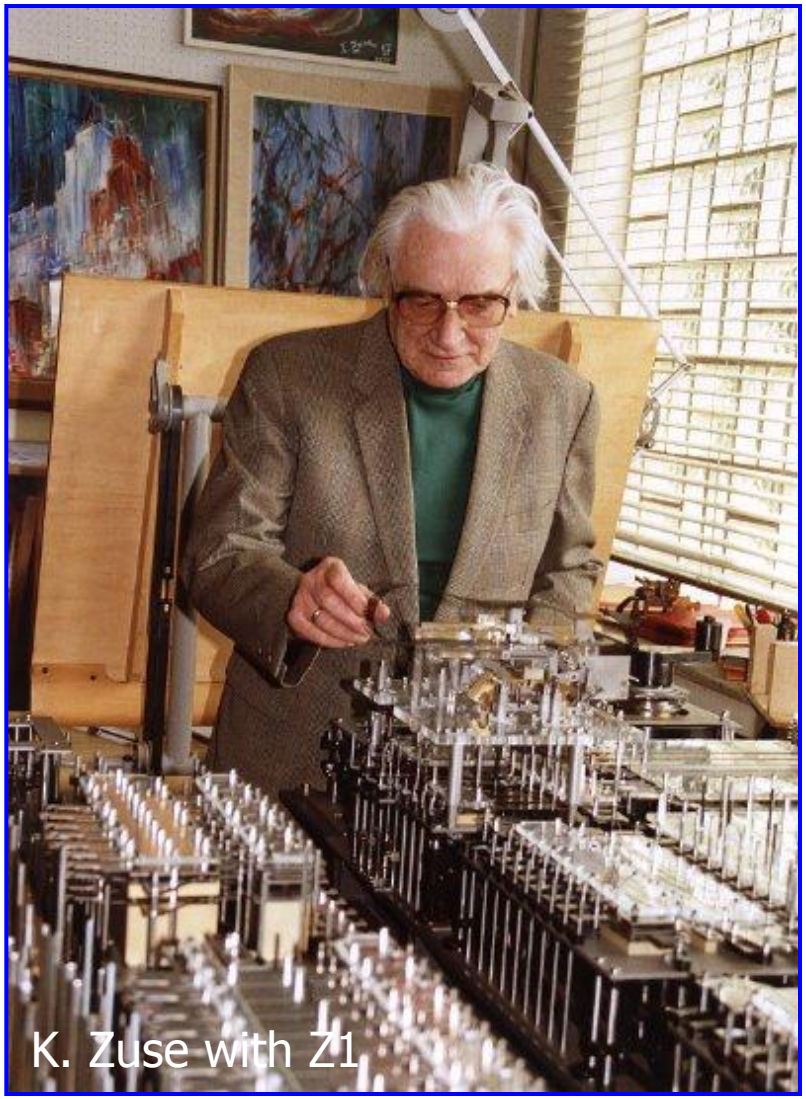
Konrad Zuse


HAMBURG-AMERIKA LINIE


FU Chemistry
ZIB
FU Physics
FU Computer Science


K. Zuse with Z1

Zuse Institute Berlin (ZIB)

Agenda

- Motivation
- Auction Theory
- Railway Slot Allocation

Project „Trassenbörse“

- Goal:

  „Introduce a competitive and fair marketing of railway capacity“

- Duration: 12/2002-04/2010
  - funded by

    Bundesministerium für Bildung und Forschung

    Bundesministerium für Wirtschaft und Technologie

    TÜVRheinland® Genau. Richtig.

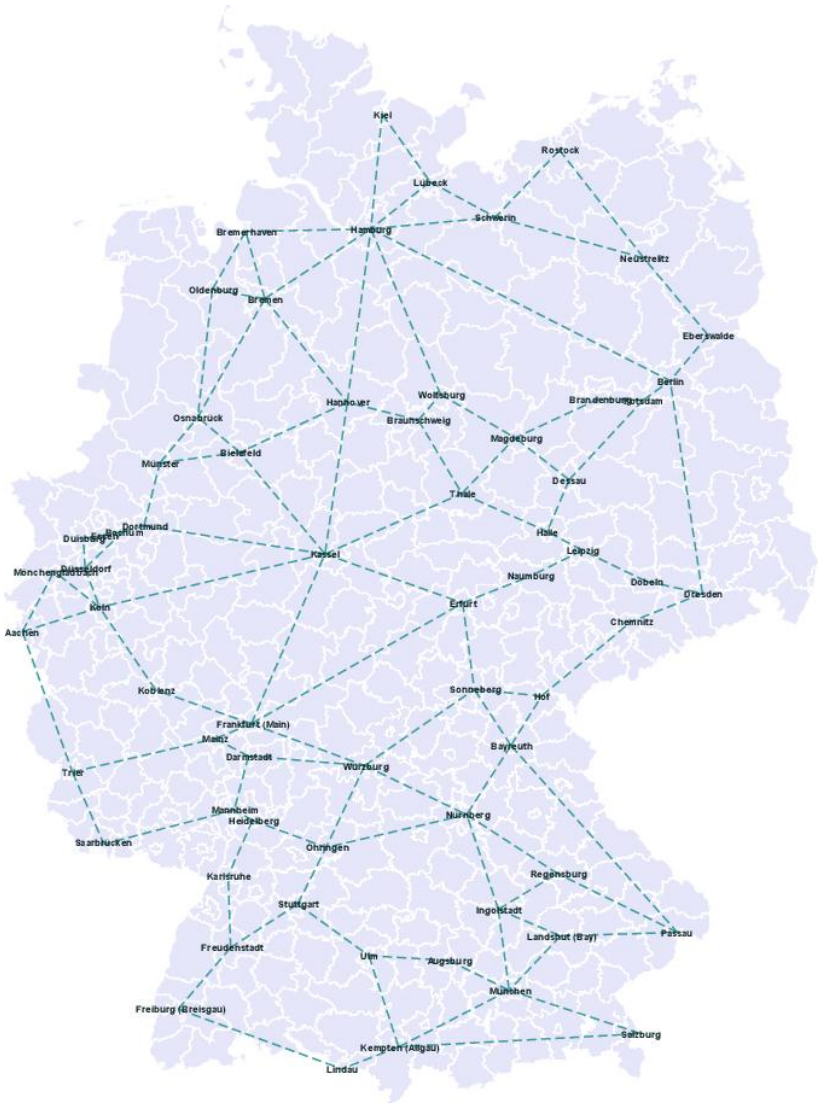
  - Partners:

    WIP, ermcon Rail Management Consultants, IMP, IVE, SFWBB

  - Cooperation:

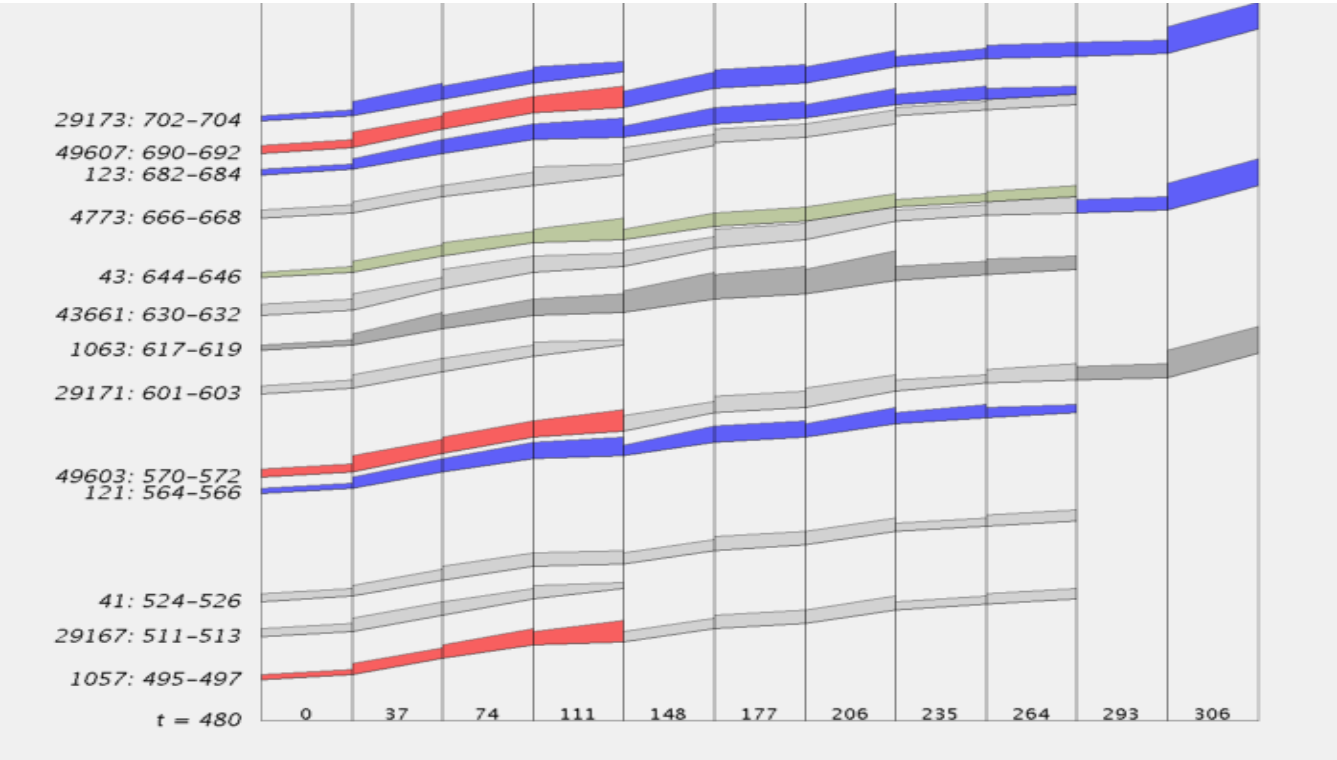
    SBB CFF FFS, OPEN TRACK, ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

Railway Infrastructure

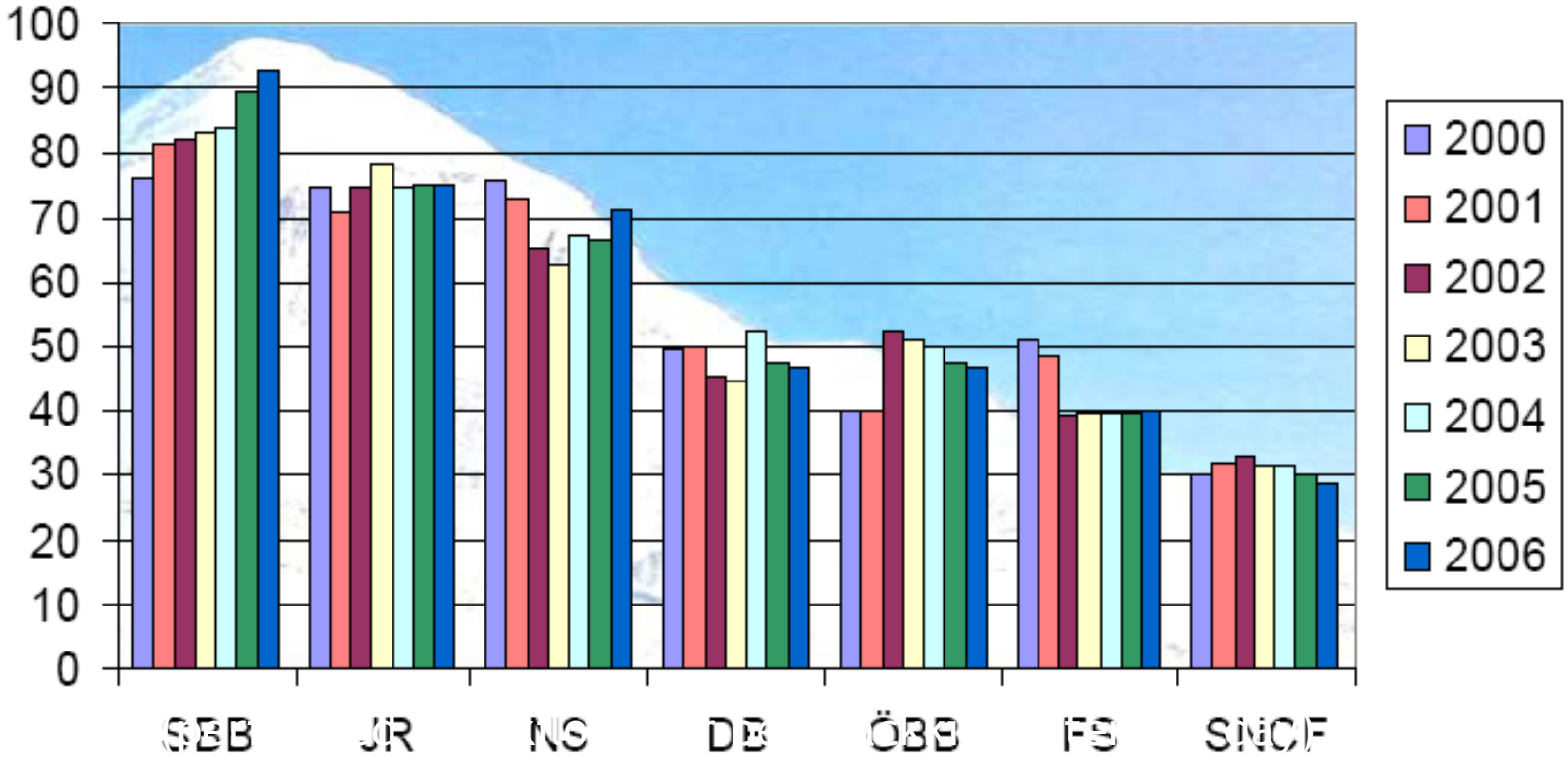


UIC 406 – Capacity

- Standardization of railway infrastructure capacity
  - Resources with space and time dimension
  - UIC Leaflet 406: „*Capacity*“, International Union of Railways, [2004]

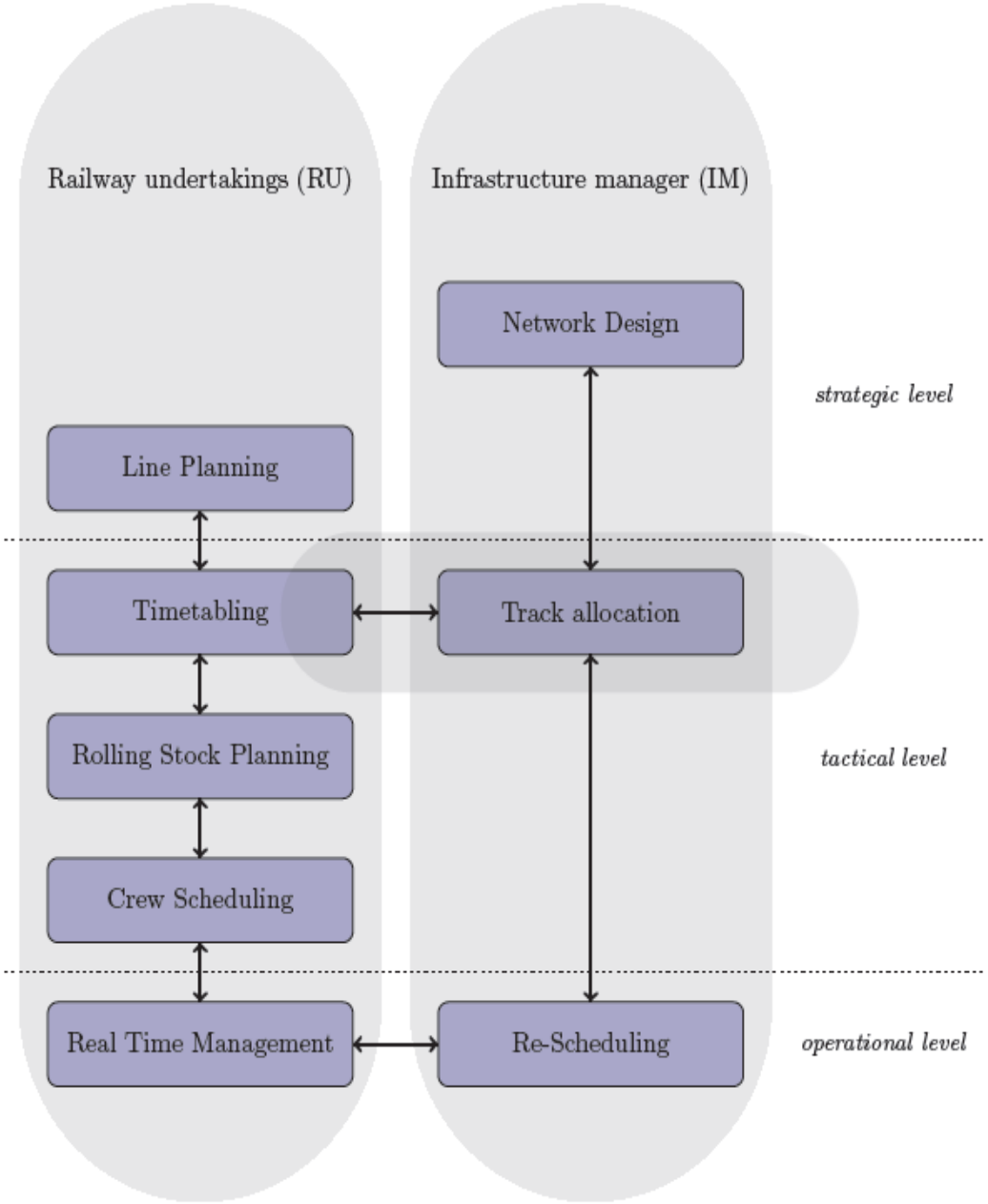


Increase efficieny (by fair access and optimization)



Official UIC Statistic

„idealized“ Planning in Railway Transportation



DB AG, Competition Report 2009

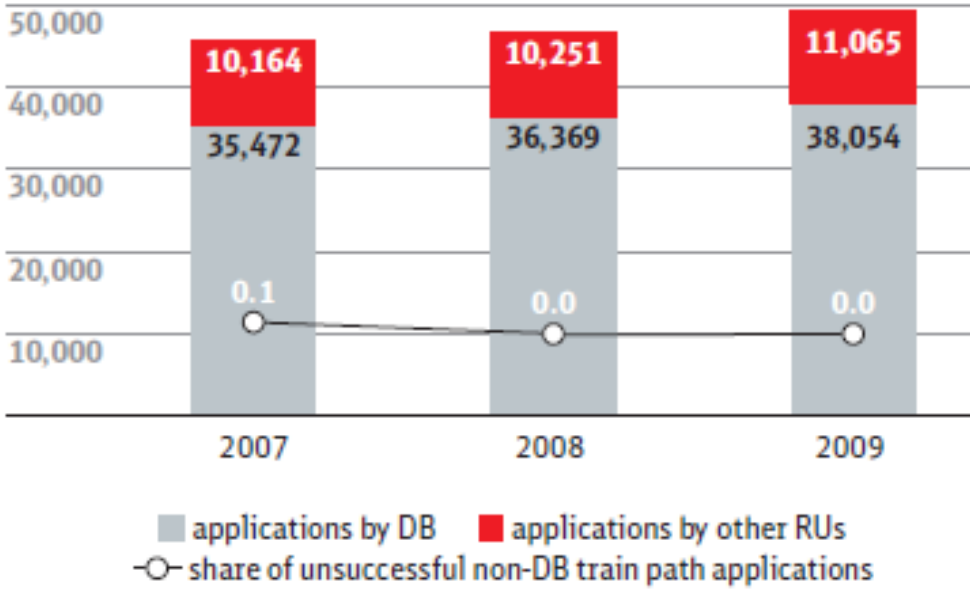
- **prescribed statutory criteria** is to select conflict-free slots such that the total income (w.r.t. the German track price system) is maximized
- **optimization is required by law**

Successful coordination procedures

The increasing number of train path applications also made train path compilation and operational implementation of the working timetable **increasingly complicated**.
The rise in demand for the current timetable (in force since 14 December 2008) meant that approx. **12,000 train paths** had to be coordinated. Conflicts of interest arose between customers who had applied for the same time slot or with overlapping requirements.
In such cases, **alternative solutions** are sought in consultation with the affected RUs in the form of coordination procedures: the opposing positions are first compared, their feasibility examined and a solution which is acceptable to all the parties involved is then sought. If no agreement can be reached in the coordination procedure, DB Netz AG is entitled to rule on the train path application dispute, **subject to prescribed statutory criteria** for reaching its decision. To ensure that these criteria are correctly applied, the legislator has granted the regulatory authority the right to examine any rejected train path applications.**The Federal Network Agency did not object to the three rejected train paths for the 2009 working timetable.**

2009 timetable compiled without problems

The number of train path applications by competitors rose by 7.9 per cent year-on-year. Only three train paths could not be included in the working timetable and had to be rejected (absolute figures)



Source: DB data

Trasse Schweiz AG, Geschäftsbericht 2009

„Die Trasse Schweiz AG (trasse.ch) blickt auf ein bewegtes Jahr zurück. Die Regelung der Trassenbestellkonflikte für den Jahresfahrplan 2010 war trotz, oder gerade wegen der Wirtschaftskrise im Vergleich zu den letzten Jahren **aufwändiger und zeitintensiver**. Zwar nahm die Anzahl eingereichter Trassenanträge des Güterverkehrs für den Jahresfahrplan 2010 im Vergleich zum Vorjahr um rund 10 Prozent ab. Die Eisenbahnverkehrsunternehmen (EVU) konzentrierten aber ihre Bestellungen angesichts des verschärften Kosten- und Konkurrenzdrucks auf die attraktivsten Zeitfenster und hielten in den **Konfliktlösungsverhandlungen** länger an ihren ursprünglichen Anträgen fest. Dennoch gelang es uns zusammen mit den Infrastrukturbetreibern, **für alle Konflikte Alternativtrassen zu finden**, welche von den EVU gutgeheissen wurden. Es mussten keine Trassenanträge abgelehnt werden.“

Kennzahlen

Trassenvergabe für Jahresfahrplan des nachfolgenden Jahres	2009	2008
Anzahl Besteller	**18**	19
formell zurückgewiesene Trassenanträge	**0**	0
Total zugeteilte Trassen	**12 818**	12 685
davon Personenverkehr	79%	77%
davon Güterverkehr	21%	23%
Anzahl bearbeitete Trassenkonflikte	**103**	127
davon in Konfliktbereinigungsgesprächen einvernehmlich gelöst	89	88
davon Doppelbestellungen	5	11
davon bei Grenzabstimmung hinfällig geworden	9	26
davon abgelehnte Trassenanträge	0	2
für überlastet erklärte Strecken	**0**	0

Agenda

- Motivation
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- Railway Slot Allocation

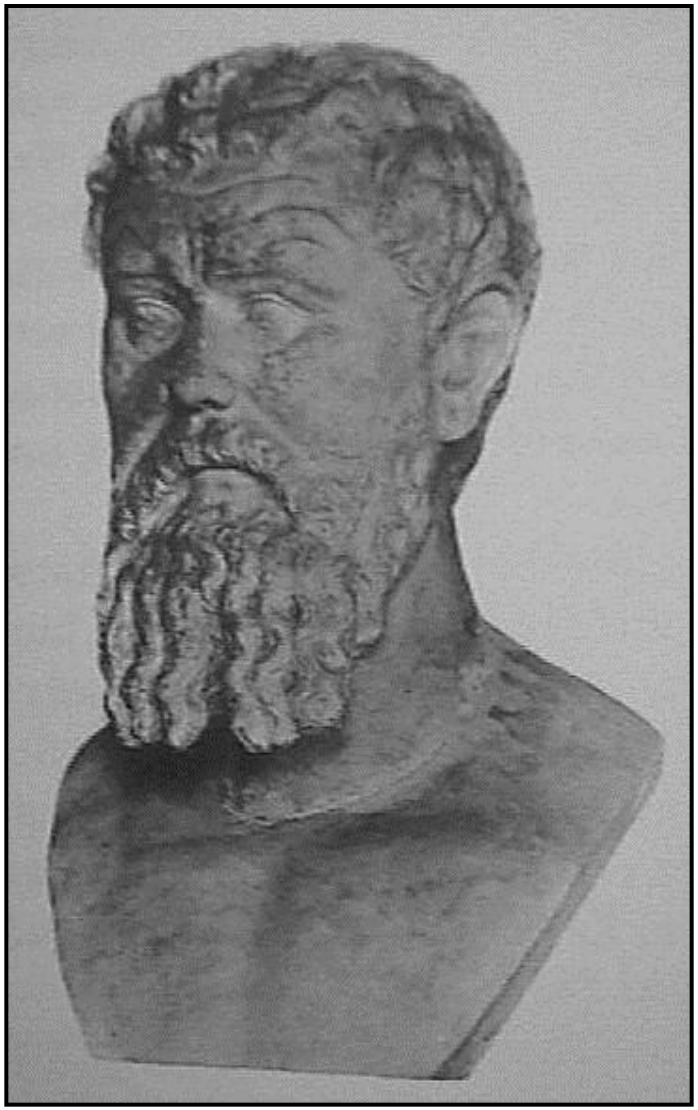
In ancient times …

- 500 b.c. in Babylon auctioining of marriageable women

- March 28, 193 a.d.: The pretorians auction the Roman Emperor's throne to Marcus Didius Severus Iulianus, who ruled as Iulianus I. for 66 days

The Story of Didius Iulianus

[193 A.D., March 28] When the emperor **Pertinax** was killed trying to quell a mutiny, no accepted successor was at hand. **Pertinax's** father-in-law and urban prefect, Flavius Sulpicianus, entered the praetorian camp and tried to get the troops to proclaim him emperor, but he met with little enthusiasm. Other soldiers scoured the city seeking an alternative, but most senators shut themselves in their homes to wait out the crisis. **Didius Julianus**, however, allowed himself to be taken to the camp, where one of the most notorious events in Roman history was about to take place. **Didius Julianus** was prevented from entering the camp, but he began to make promises to the soldiers from outside the wall. Soon the scene became that of an auction, with Flavius Sulpicianus and **Didius Julianus** outbidding each other in the size of their donatives to the troops. The Roman empire was for sale to the highest bidder. When Flavius Sulpicianus reached the figure of 20,000 sesterces per soldier, **Didius Julianus** upped the bid by a whopping 5,000 sesterces, displaying his outstretched hand to indicate the amount. The empire was sold, **Didius Julianus** was allowed into the camp and proclaimed emperor. ***(http://www.roman-emperors.org/didjul.htm)***



English Auction – Sotheby's & Christie's

Arguments for Auctions

Auctions can …

- resolve user conflicts in such a way that the bidder with the highest willigness to pay receives the commodity (efficient allocation, wellfare maximization)
- maximize the auctioneer's earnings
- reveal the bidders' willigness to pay
- reveal bottlenecks and the added value if they are removed

Economists argue …

- that a "working auctioning system" is usually superior to alternative methods such as bargaining, fixed prices, etc.

Sears, Roebuck & Co.

3-year contracts for transports on dedicated routes

First auction in 1994 with 854 contracts

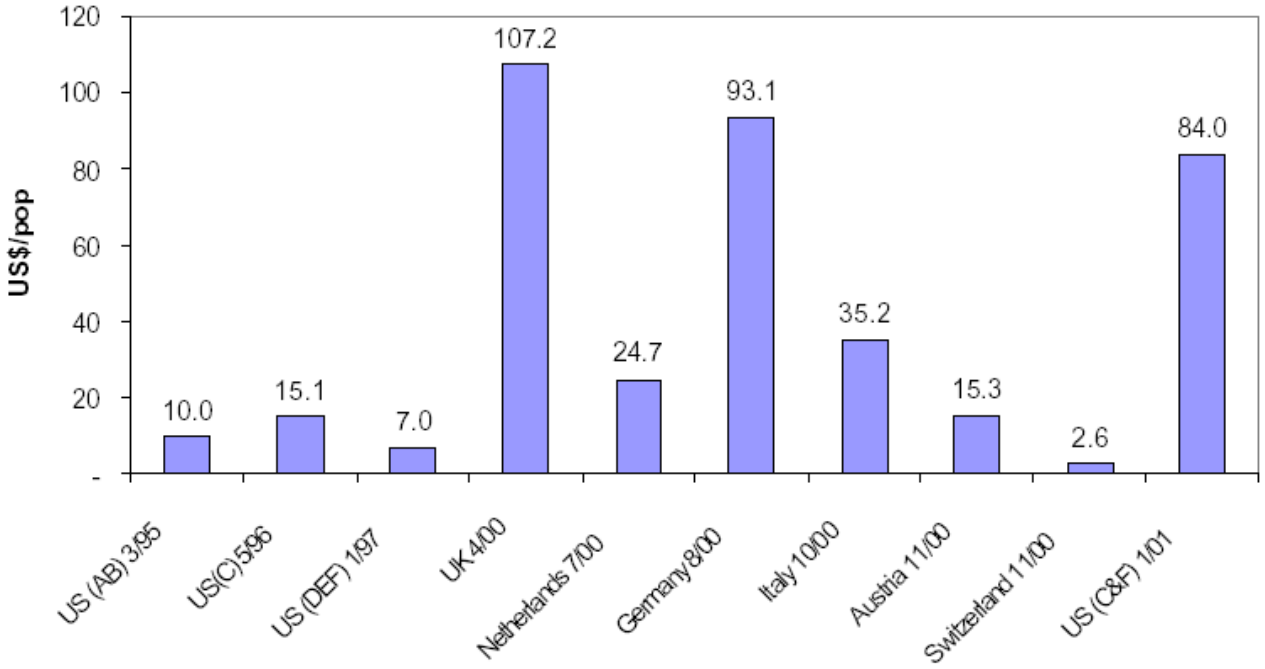
Combinatorial auction

- „And-“ and „or-“ bids allowed
- 2^{854} ($\approx 10^{257}$) theoretically possible combinations
- Sequential auction (5 rounds, 1 month between rounds)

Results

- 13% cost reduction
- Extension to 1.400 contracts (14% cost reduction)

Frequency Auctions



- Prices for mobile telecommunication frequencies (2x10 MHz+5MHz)
- Low earnings are not per se inefficient
- Only min. prices => insufficient cost recovery

Cramton [2001], Spectrum Auctions,
Handbook of Telecommunications Economics

Game Theory

Game (N,S,a)

- N={1,…,n} player
- S={$(s_1,\ldots,s_n)$} strategies
- a:S$\rightarrow R^n$ payoff

Non-cooperative games

- Dominance
- (Nash-)Equilibrium $\hat{s}$

  $a_i(\hat{s}_1,..,s_i,..,\hat{s}_n) \leq a_i(\hat{s}_1,..,\hat{s}_n)\ \forall i$

  (i.g. no existence/uniqueness)
- Matrix games: saddle point, minimax

Theorem (Nash): Every finite non-cooperative n-person game has at least one equilibrium of mixed strategies.

Theorem (Nikaido, Isoda): Generalization to auction frameworks.

Cooperative games

- Imputation (payoff to members of a coalition)
- Concepts such as core, stable set, bargaining set, kernel, nucleolus, etc.

AND-Bids:
"One for all,
and all for one"

XOR-Bids:
"There can be only one"

Combinatorial Auction Problem (CAP)

- M objects, N bidders, $b^j(S)$ bid by j for $S \subseteq M$
- y(S,j) 0/1-variable for giving S to j

$$\max \sum_{S \subseteq M} \sum_{j \in N} b^j(S) y(S,j)$$

$$\sum_{S \ni i} \sum_{j \in N} y(S,j) \leq 1 \qquad \forall i \in M$$

$$y(S,j) \in \{0,1\} \qquad \forall S \subseteq M, j \in N$$

- Set Packing Problem

Auction framework

Vickrey Auction (Nobel price in Economics 1996)

Combinatorial auction

$$E(N,b) := \max \sum_{S \subseteq M} \sum_{j \in N} b^j(S)\, y(S,j)$$

$$\sum_{S \ni i} \sum_{j \in N} y(S,j) \leq 1 \quad \forall i \in M$$

$$y(S,j) \in \{0,1\} \quad \forall S \subseteq M,\ j \in N$$

Private values v_j

Mechanism

- Bids $b_j = v_j$
- Payments
  $z_j = E(N\backslash j, v) - E(N,v) | N\backslash j$

Some Defintions from Auction Theory

Definition 1:

A *bidding strategy* is called *dominant*, if it maximizes the utility function of the bidder no matter what any other participants submits.

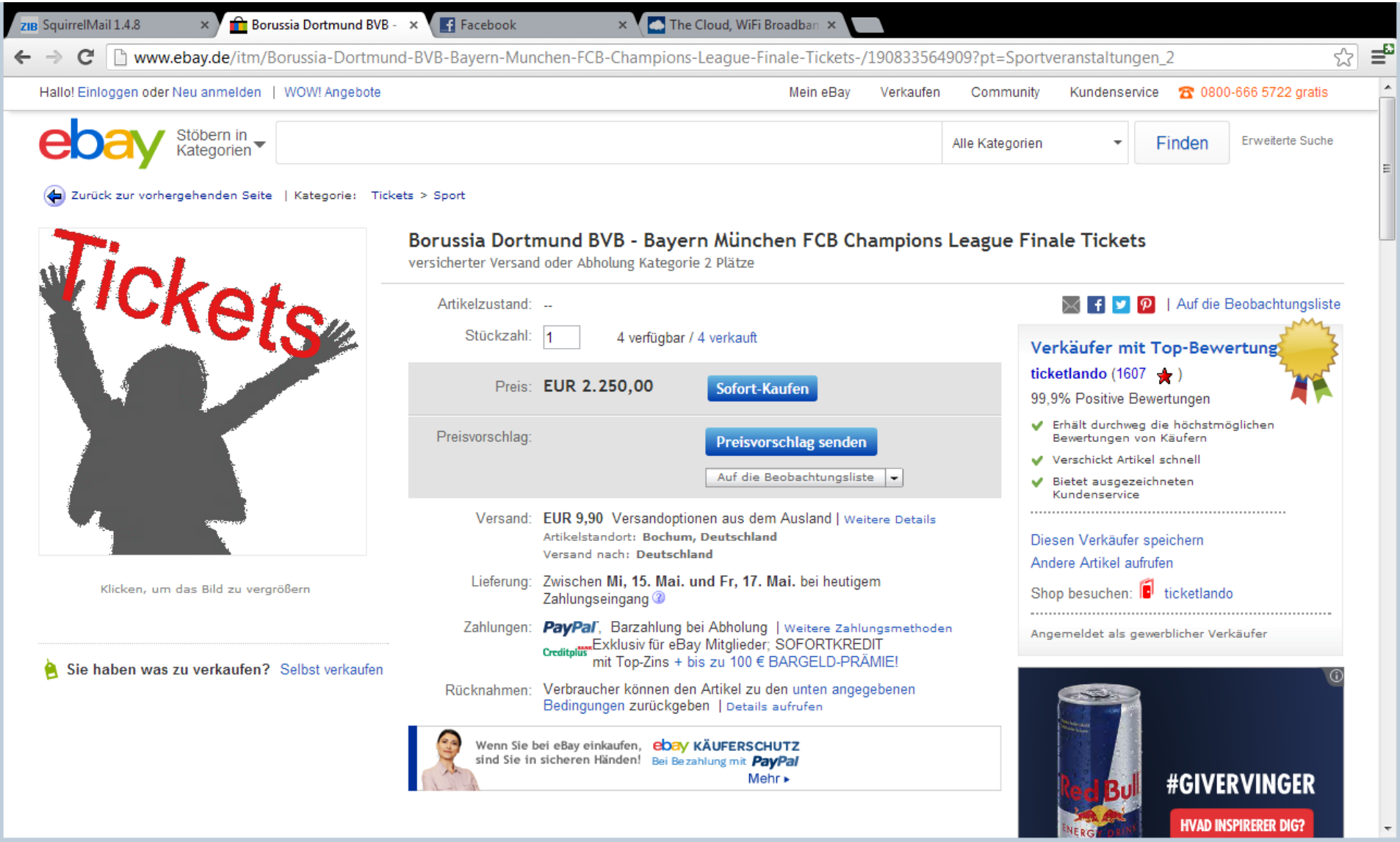
Definition 2:

An *auction* mechanism is called *incentive compatible*, if truthful bidding (b=v) is a dominant strategy.

Definition 3:

An *auction* mechanism is called *(allocative) efficient,* if the winner allocation is maximizing the willingness to pay (v).

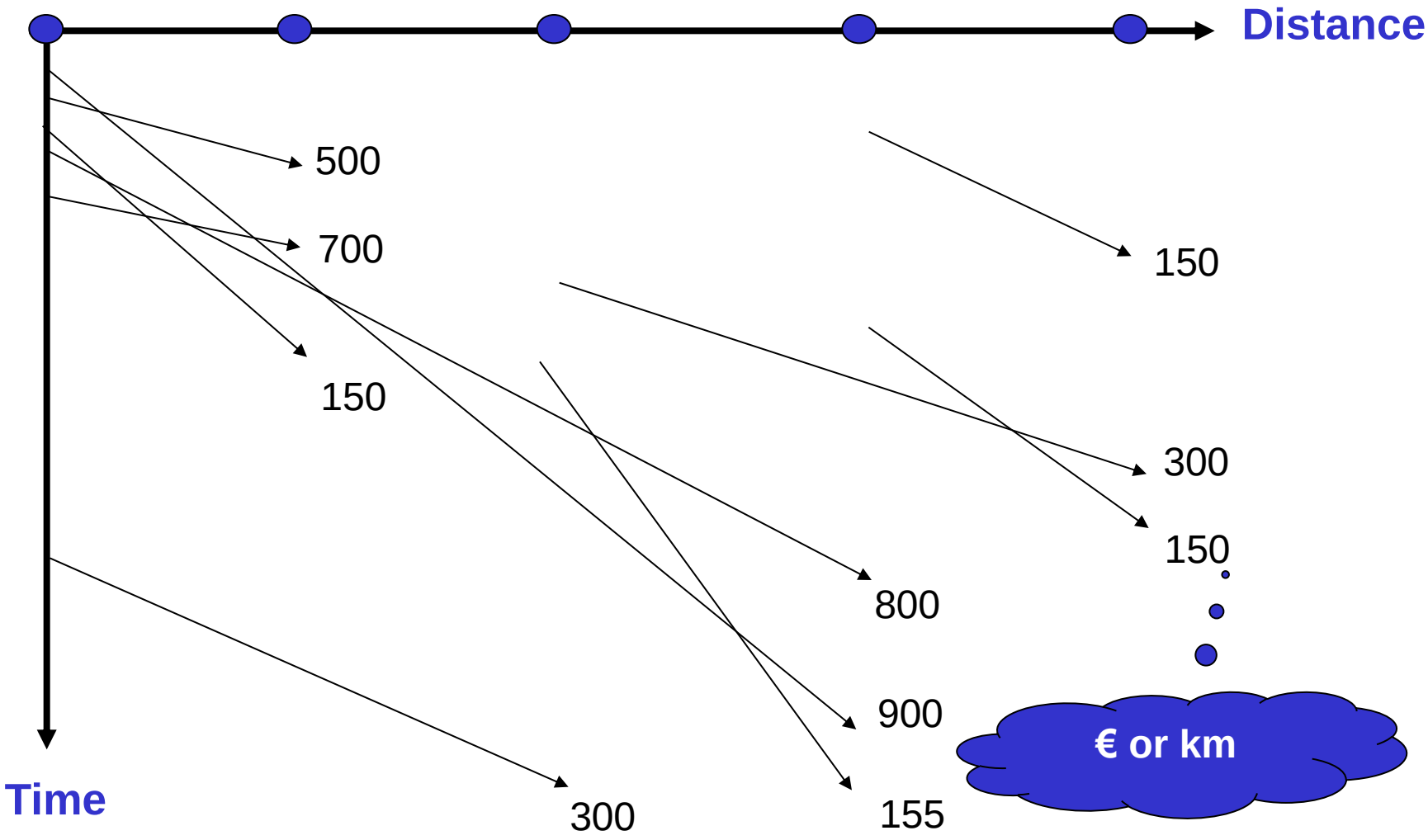
Ebay – 2nd price auction



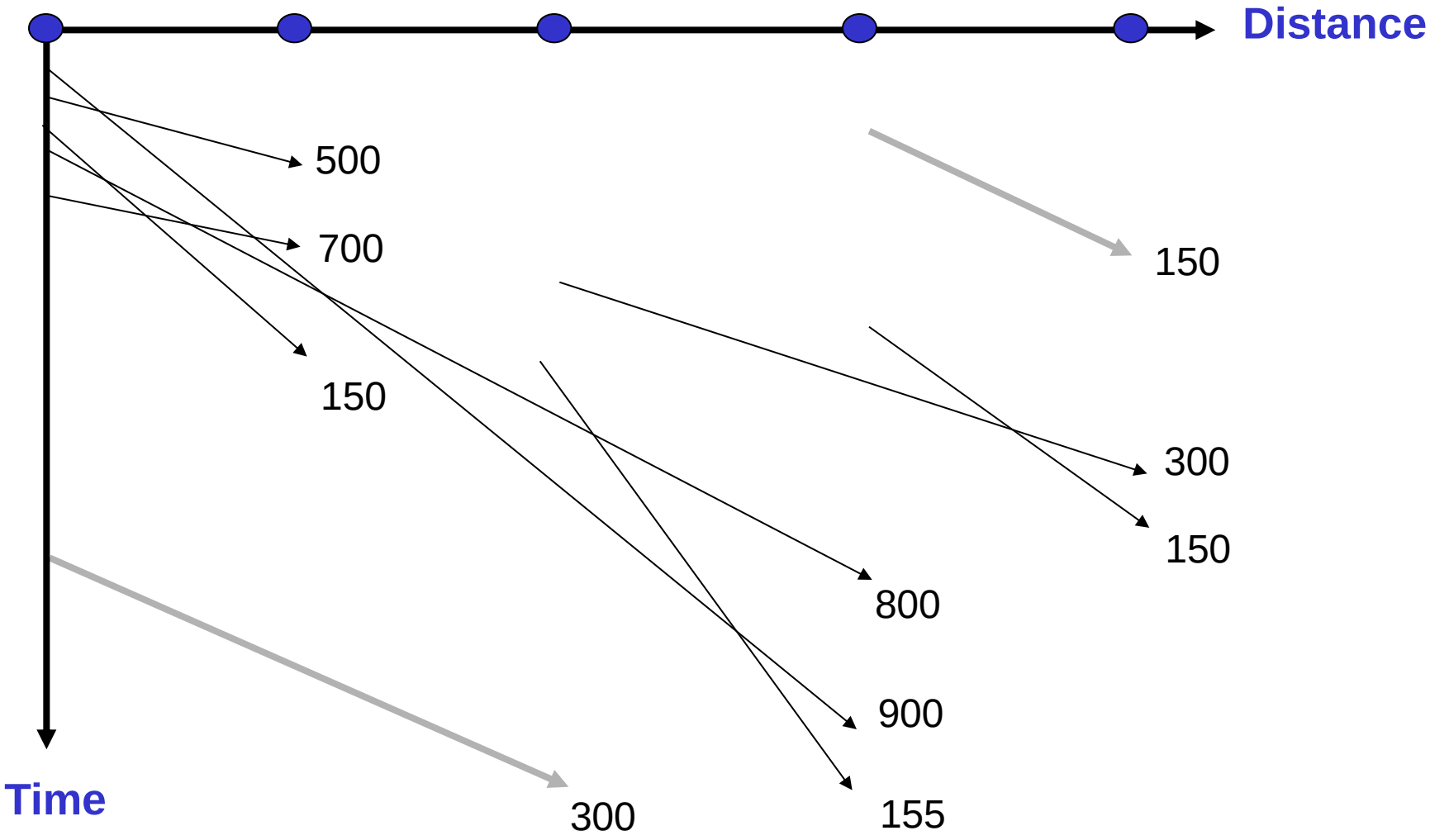
Agenda

- Motivation
- Auction Theory
- Railway Slot Allocation
  - An Easy Idea

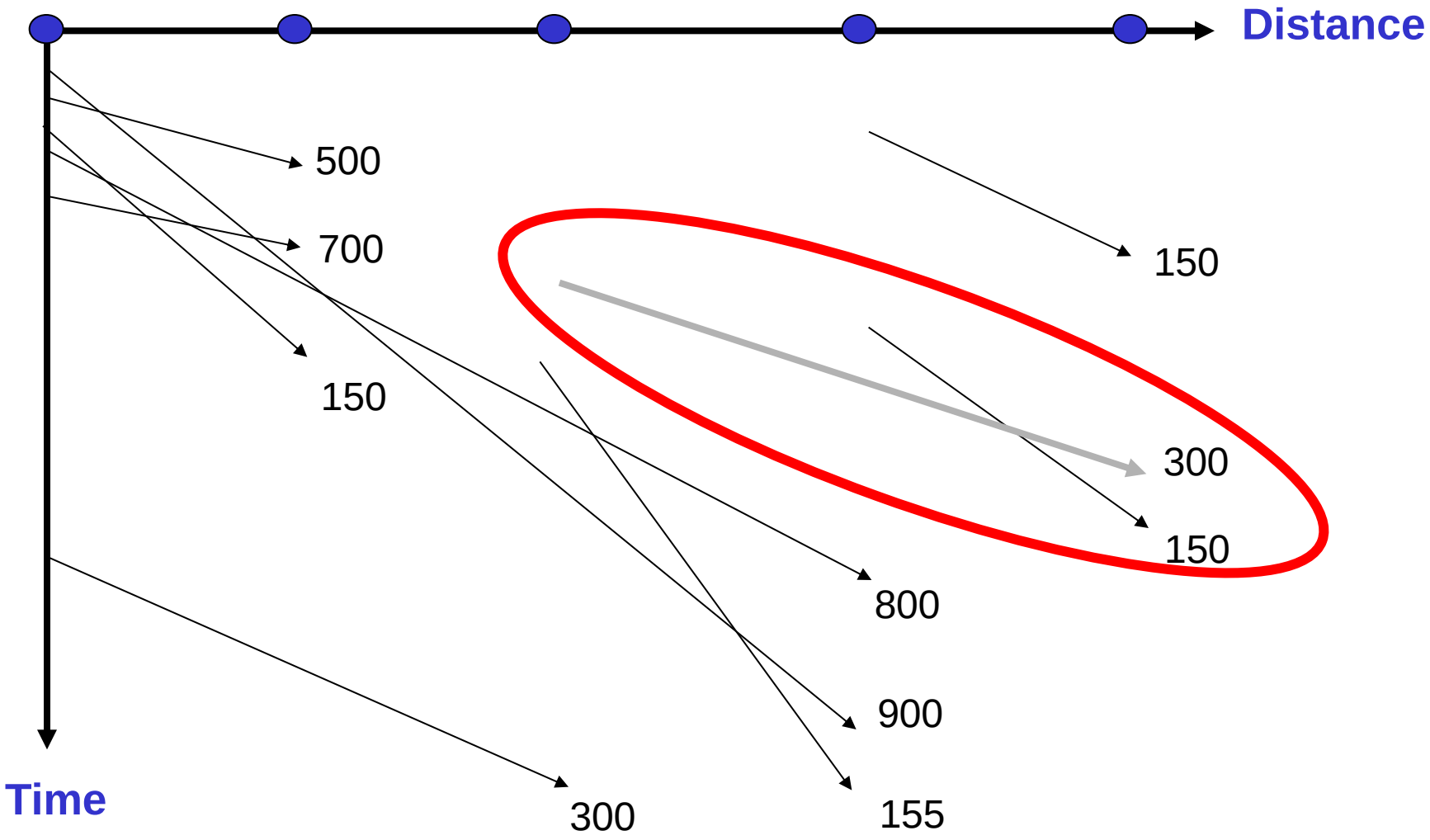
Time-Distance-Diagram



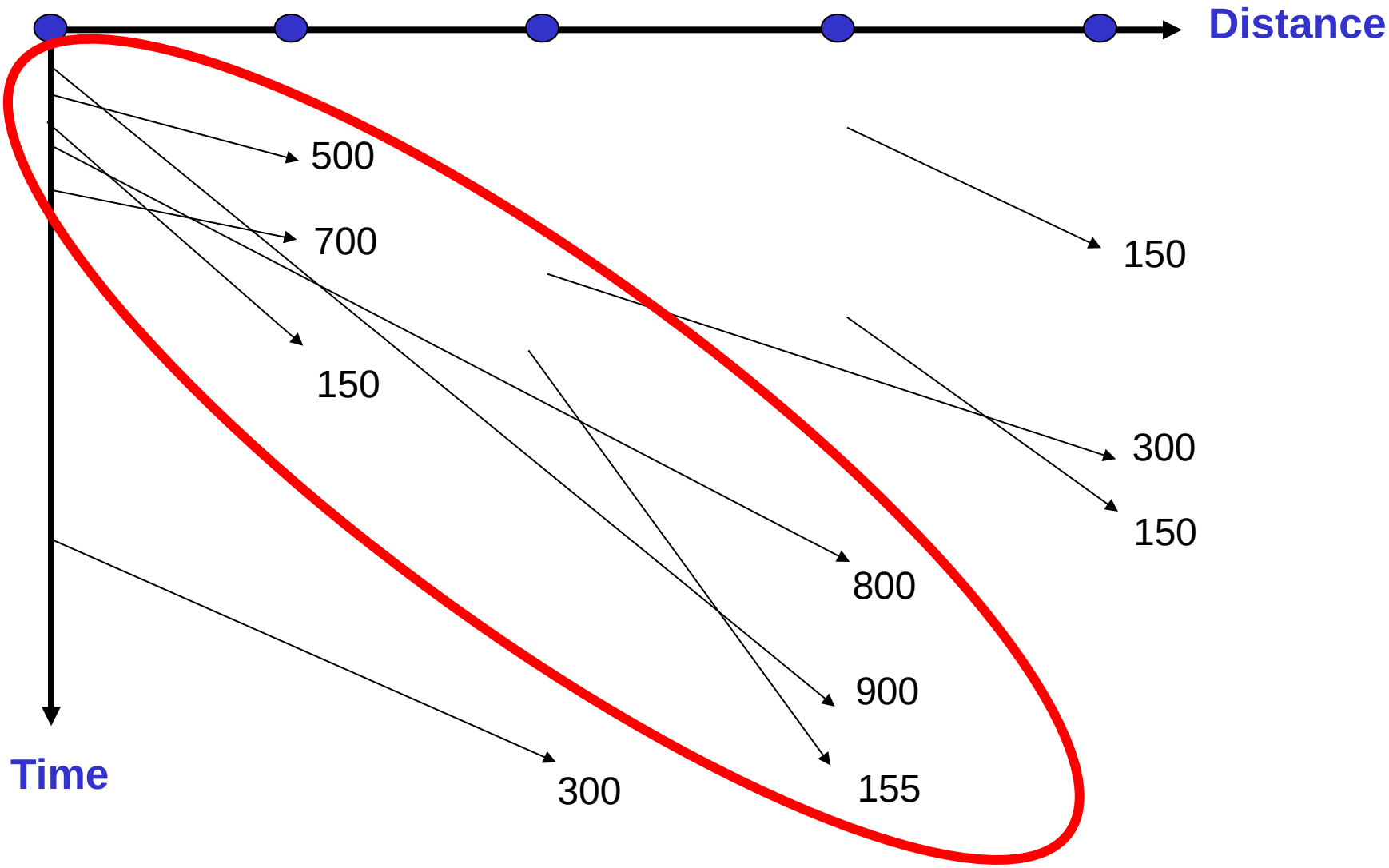
Slots with conflict (Intersections)



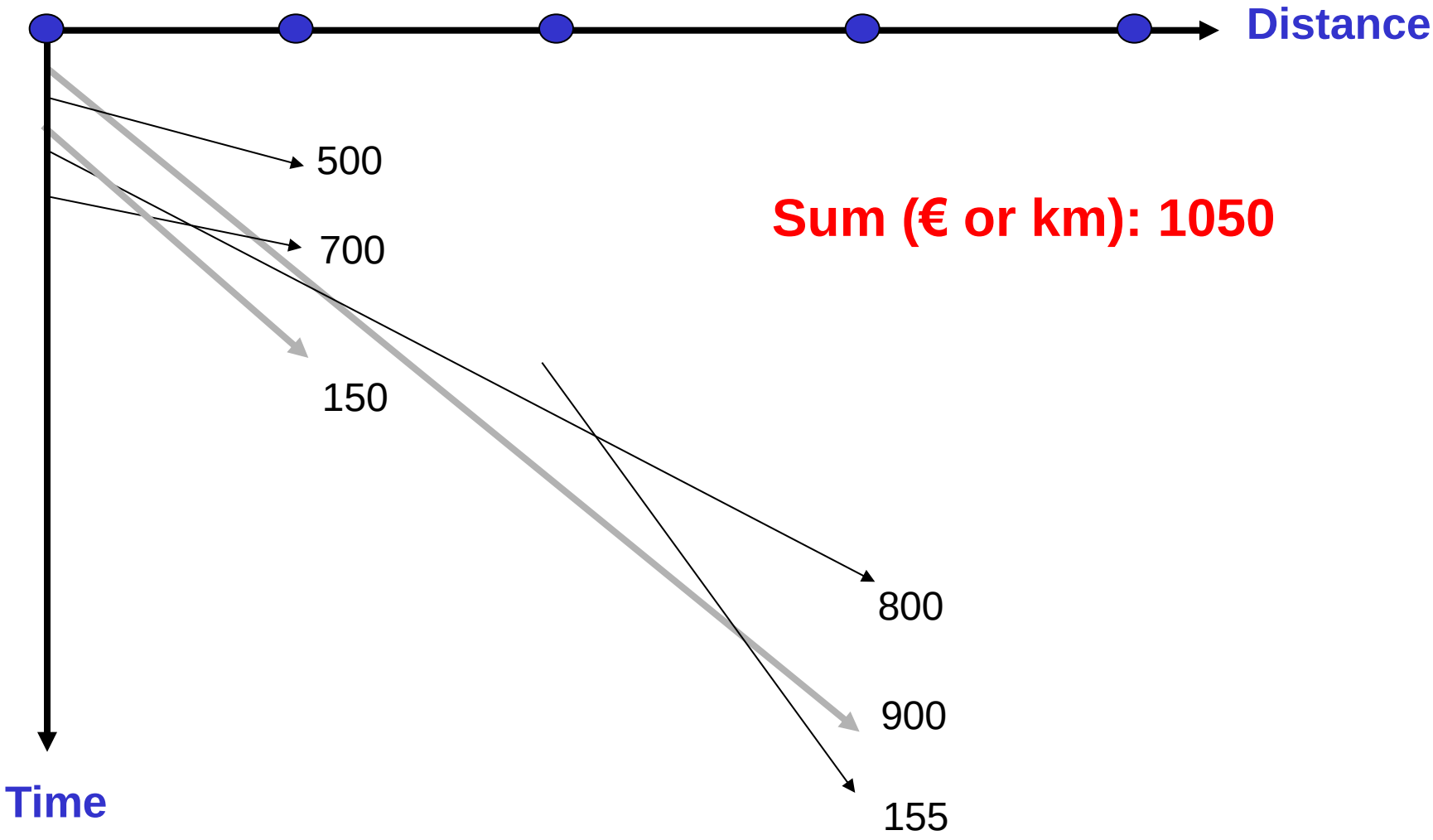
Bilaterale conflicts



Multilaterale conflict – 8 or one ?

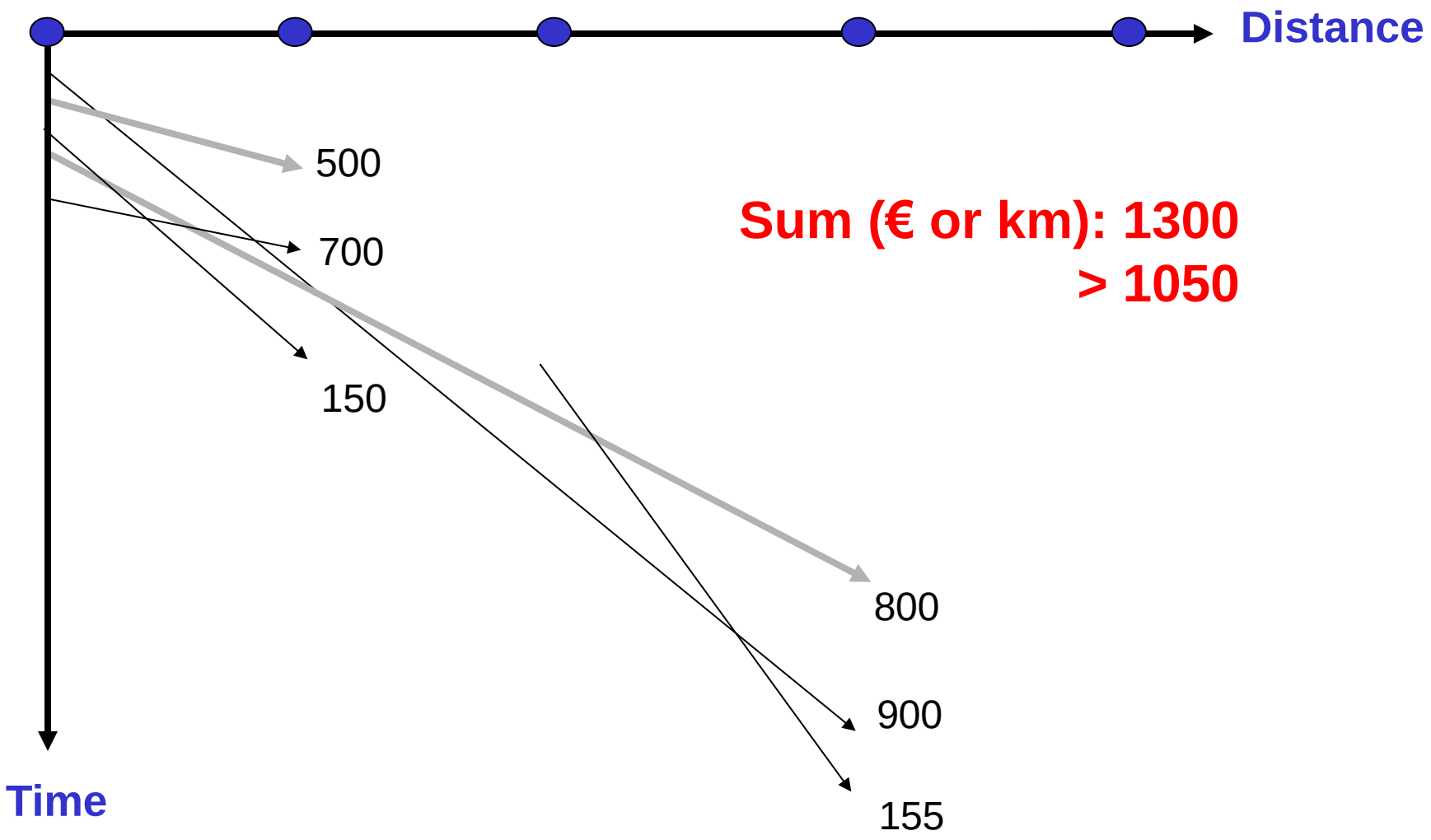


„bilaterale“ & greedy solution



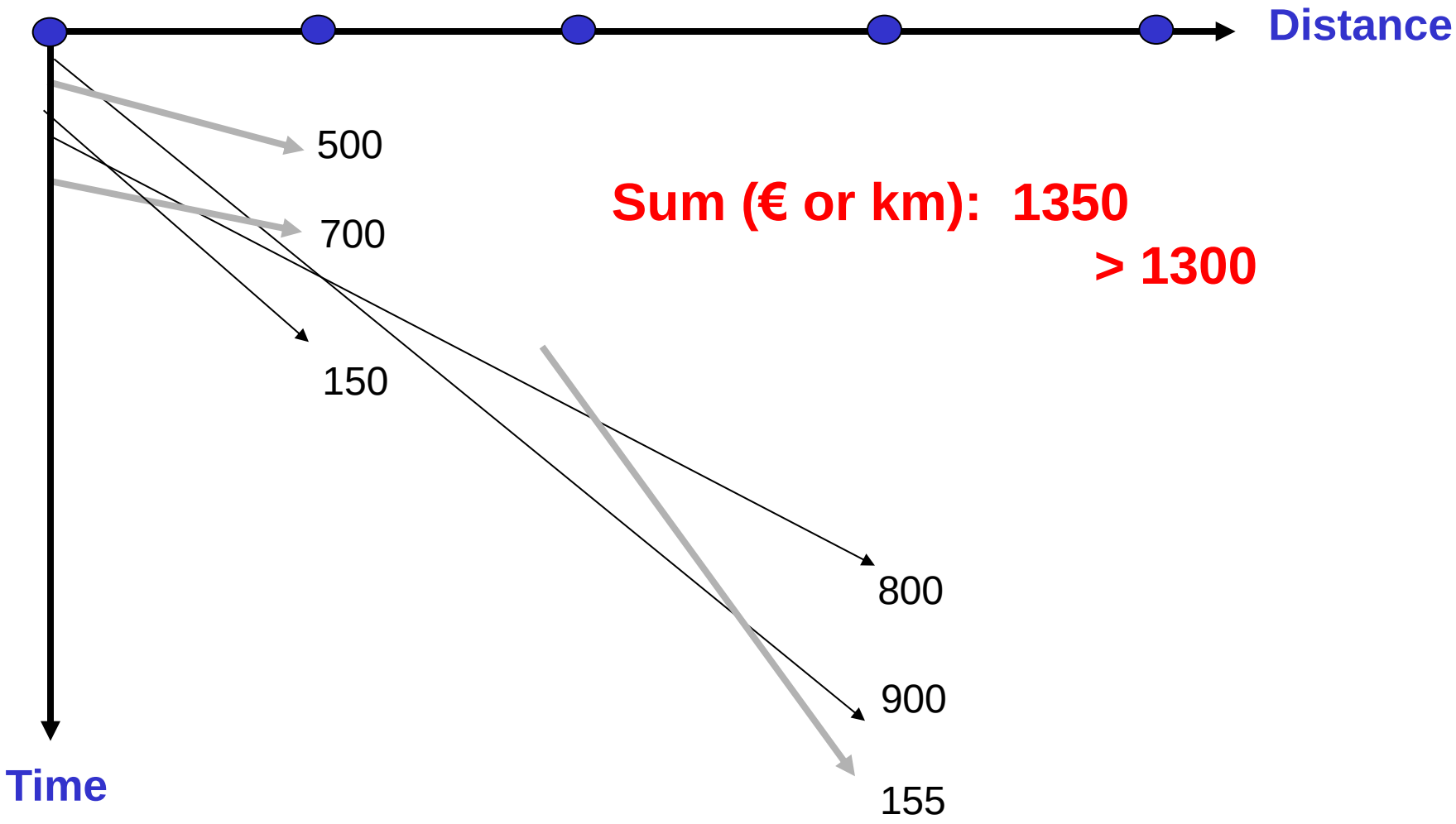
Sum (€ or km): 1050

Improved solution



Sum (€ or km): 1300
> 1050

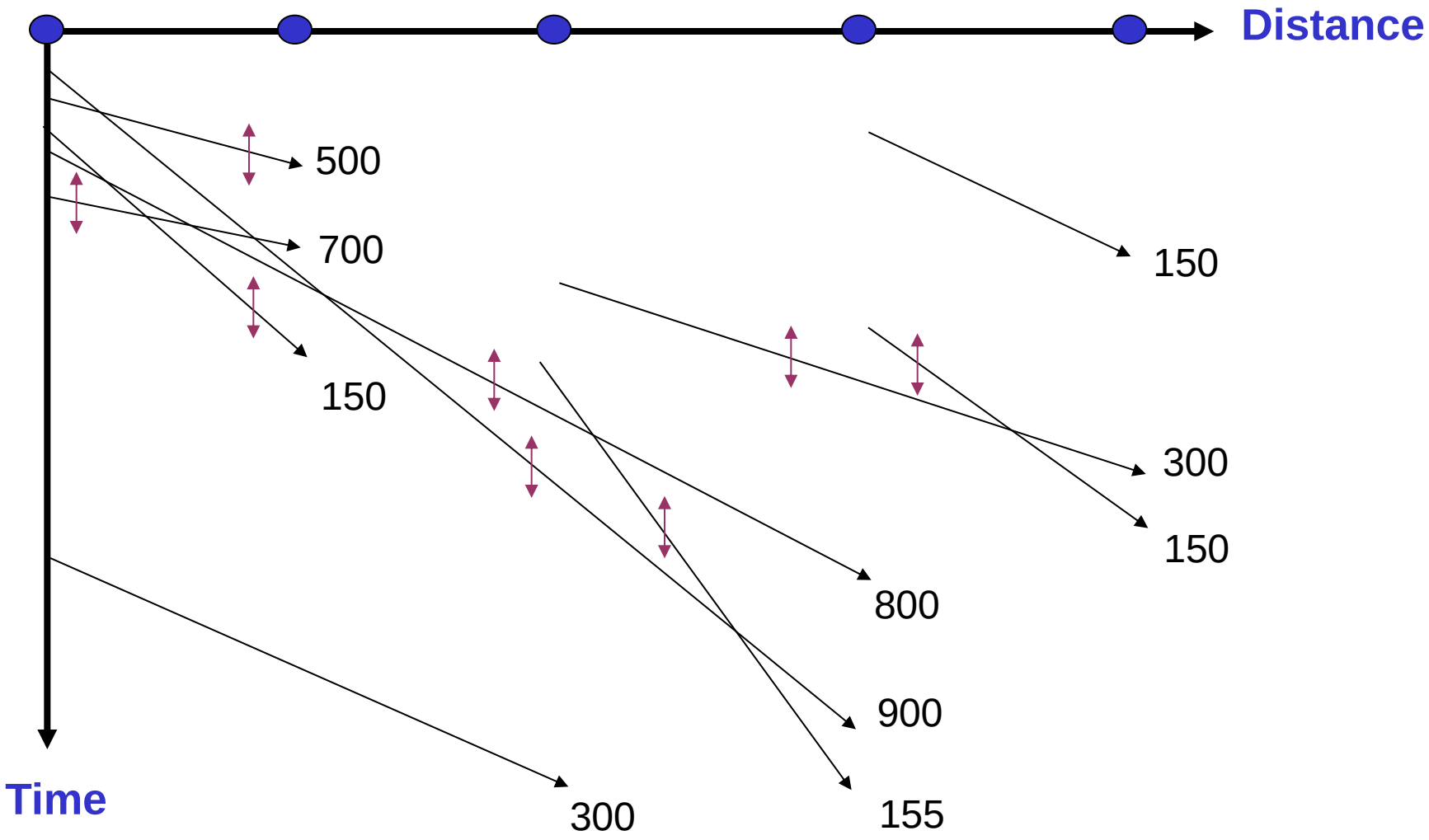
„optimal“ solution



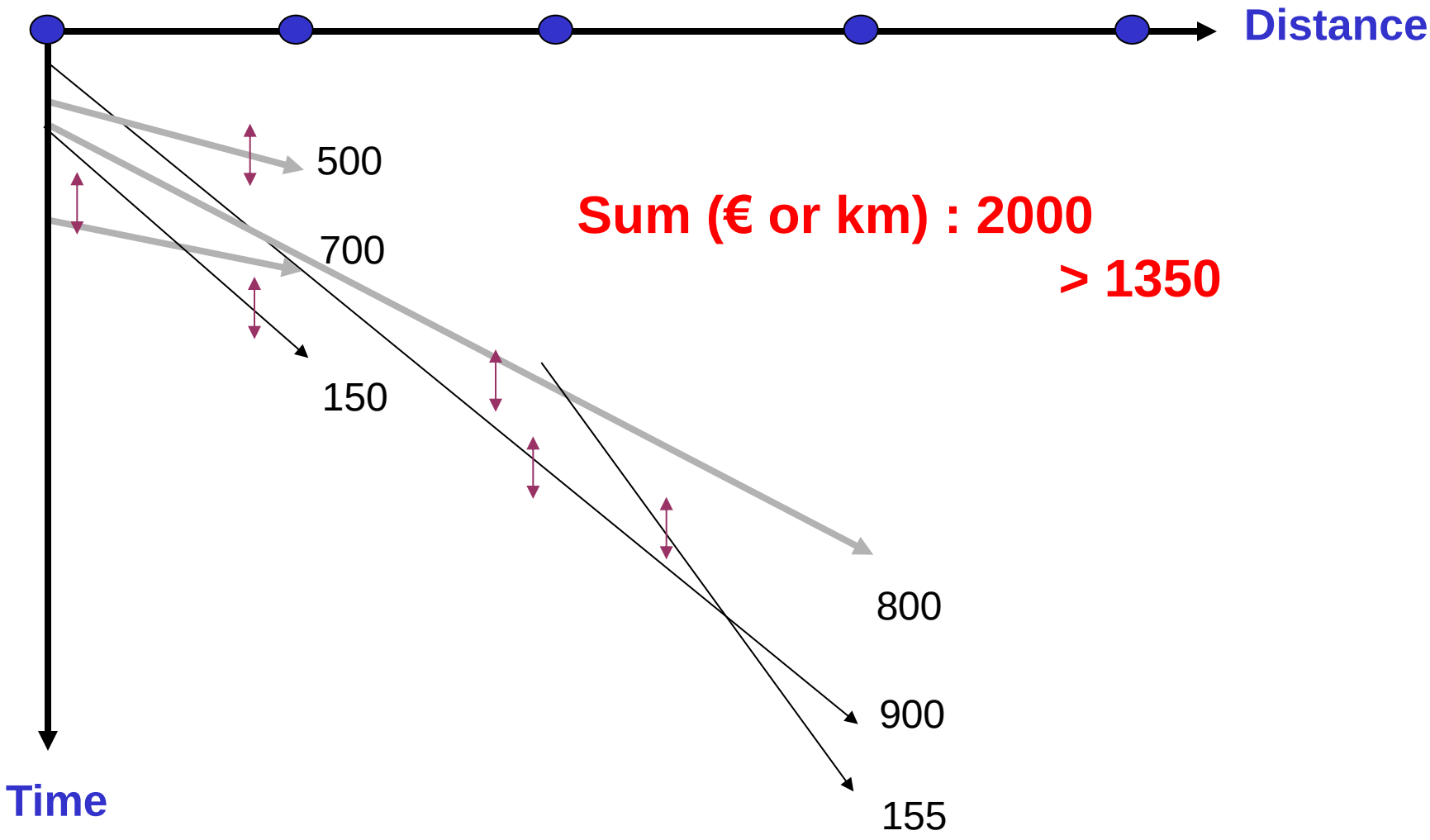
Sum (€ or km): 1350

> 1300

Flexibility of request times



„Optimum“ with time shifting



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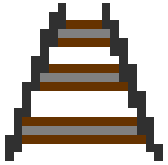
- Railway Slot Allocation
  - A Vickrey Approach

Vickrey Track Auction



BEGIN

NIP declares infrastructure

TOCs decide on bids for single timetabled train paths

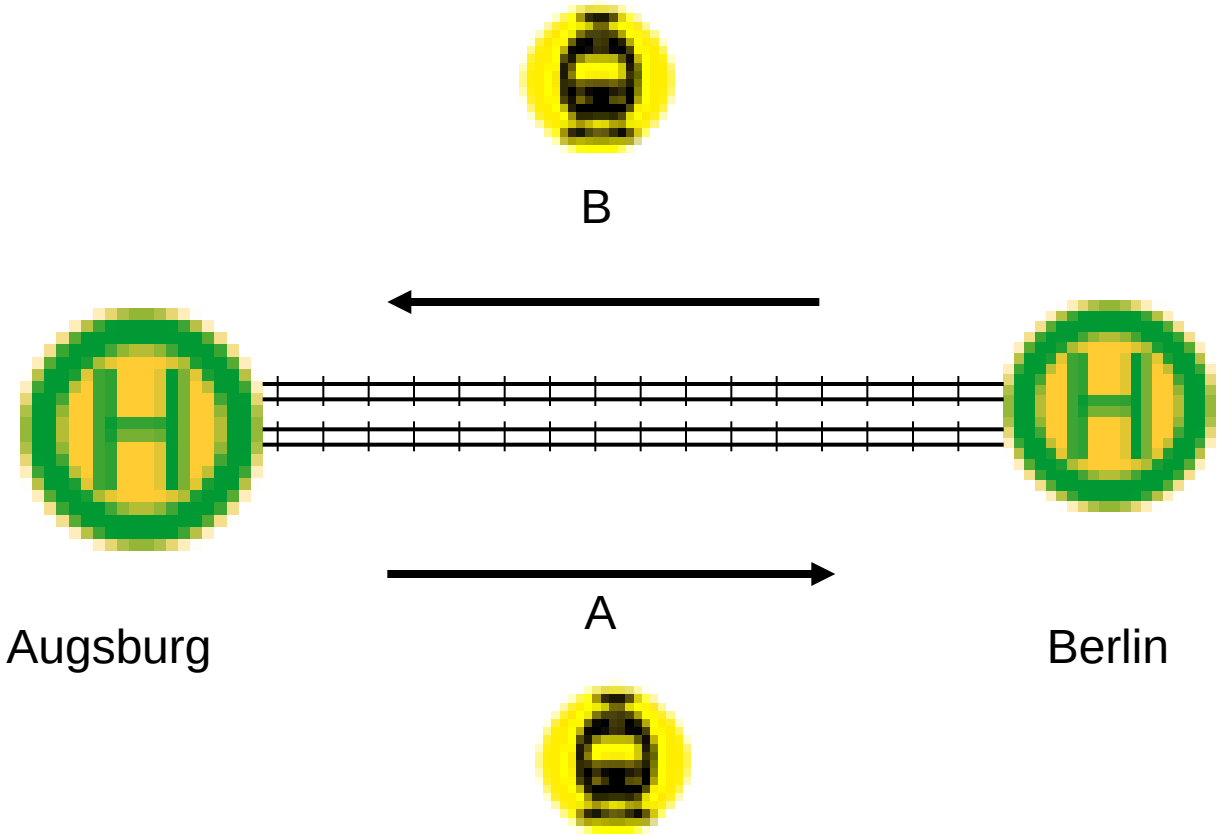
Winner Determination
Solve Track Allocation Problem :
Find optimal track allocation
with maximum earnings

Vickrey Price Determination

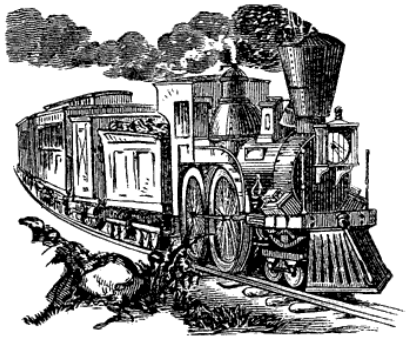
END

IP inside!!!

Railway Example :



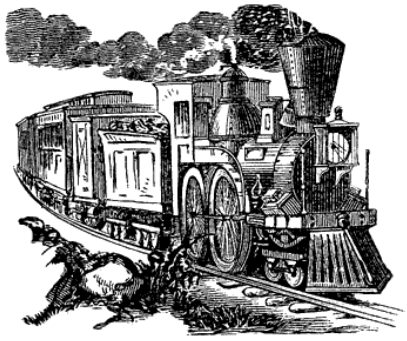
Track Auction



Track / Bidder	A	B	A and B
CityConnex	10	10	10
DB Regi	20	20	20
DB Longi	0	0	24

Track Auction

Winner



Track / Bidder	A	B	A and B
CityConnex	10	10	10
DB Regi	20	20	20
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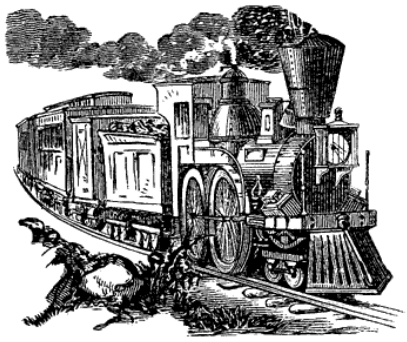
Track Auction

Winner

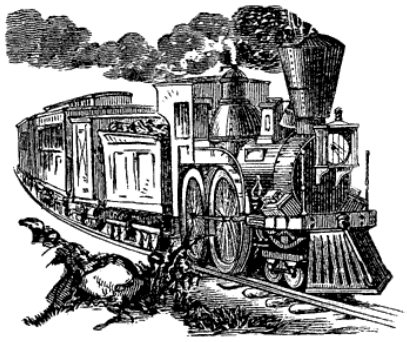


Track / Bidder	A	B	A and B
~~CityConnex~~	~~10~~	~~10~~	~~10~~
DB Regi	20	20	20
DB Longi	0	0	24

Vickrey-Price for CityConnex is 24 - (30 – 10) = 4

Track Auction

Winner

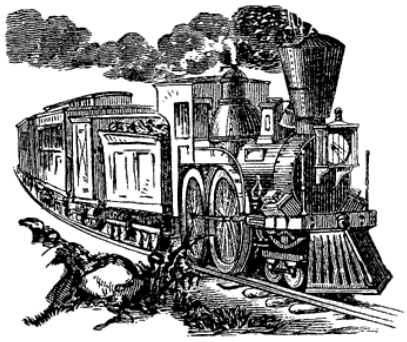


Track / Bidder	A	B	A and B
CityConnex	10	10	10
~~DB Regi~~	~~20~~	~~20~~	~~20~~
DB Longi	0	0	24

Vickrey-Price for DB Regi is 24 – (30 – 20) = 14

„Pokern“ makes no sense!

Winner



Track / Bidder	A	B	A and B
CityConnex	10	10	10
DB Regi	18/20	18/20	18/20
DB Longi	0	0	24

Vickrey-Price for DB Regi is 24 – (28 – 18) = 14

VCG Auctions are

- incentive compatible (truthful bidding is a dominant strategy)
- efficient (the winner is the bidder with the highest valuation)

A. Mura: *„Trassenauktionen im Schienenverkehr“*, Master Thesis, TU Berlin, 2006.

R.Borndörfer, A.Mura & T.S.: „Vickrey Auctions for Railway Tracks“, OR-Proceedings, 2008.

„Collusion“

Track / Bidder	A	B	A and B
CityConnex	10	10	10
DB Regi	20	20	20
DB Longi	0	0	24

„Collusion“

Track / Bidder	A	B	A and B
CityConnex	0	24	0
DB Regi	24	0	0
DB Longi	0	0	24

„Collusion“

Track / Bidder	A	B	A and B
CityConnex	0	24	0
DB Regi	24	0	0
DB Longi	0	0	24

All Vickrey-Prices are 0

(= 24 – (48 -24)) !

„Shill-Bidding“

Track / Bidder	A	B	A and B
CityConnex	10	10	10
DB Regi	20	20	20
DB Longi	0	0	24

„Shill-Bidding“

Track / Bidder	A	B	A and B
CityConnex	10	10	10
DB Regi	20	20	20
DB Longi	0	0	30

„Shill-Bidding“

Track / Bidder	A	B	A and B
CityConnex	10	10	10
DB Regi	20	20	20
DB Longi	0	0	30

Vickrey-Prices are maximal

(CityConnex 10 and DB Regi 20) !

Some Pros and Cons

VCG Auctions are

- incentive compatible (truthful bidding is a dominant strategy)
- efficient (the winner is the bidder with the highest valuation)

But unfortunately,

- vulnerable to collusion
- vulnerable to shill bidding
- not necessarily maximizing seller revenues
- seller‘s revenues are non-monotonic with regard to the bids
- ...
- rarely accepted by the participants and sellers
- hard to solve ((WDP) is $\mathcal{NP}$-*hard*)

Summary to Auctioning (Theory)

Combinatorial Vickrey (Track) Auction is incentive compatible, but not with rules for

- minimum bid value
- limits on submitted bids
- ...

P. Milgrom: *„Putting Auction Theory to Work“*, Cambridge University Press, 2004.

A. Mura: *„Trassenauktionen im Schienenverkehr“*, Master Thesis, TU Berlin, 2006.

P. Cramton, Shoham & Steinberg, *„Combinatorial Auctions“*, The MIT Press, 2006.

R.Borndörfer, A.Mura & T.S.: „Vickrey Auctions for Railway Tracks“, OR-Proceedings, 2008.

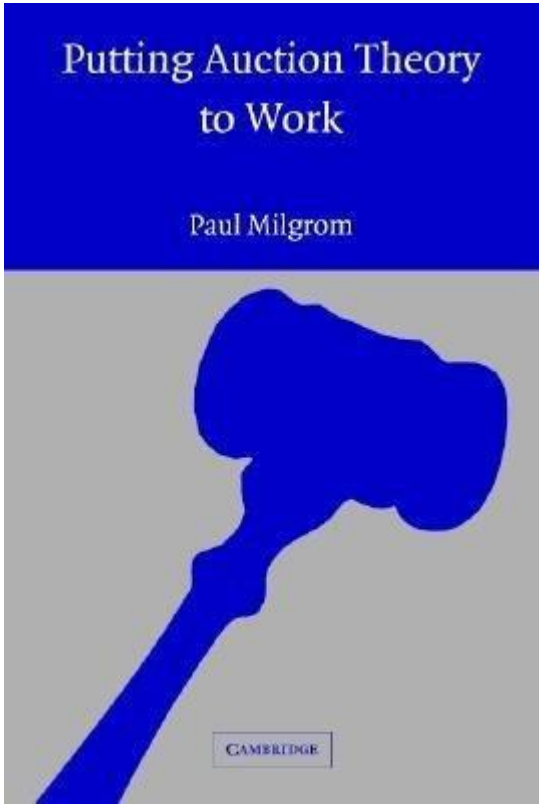
Agenda

- Motivation
- Auction Theory
- Railway Slot Allocation
  - Real World

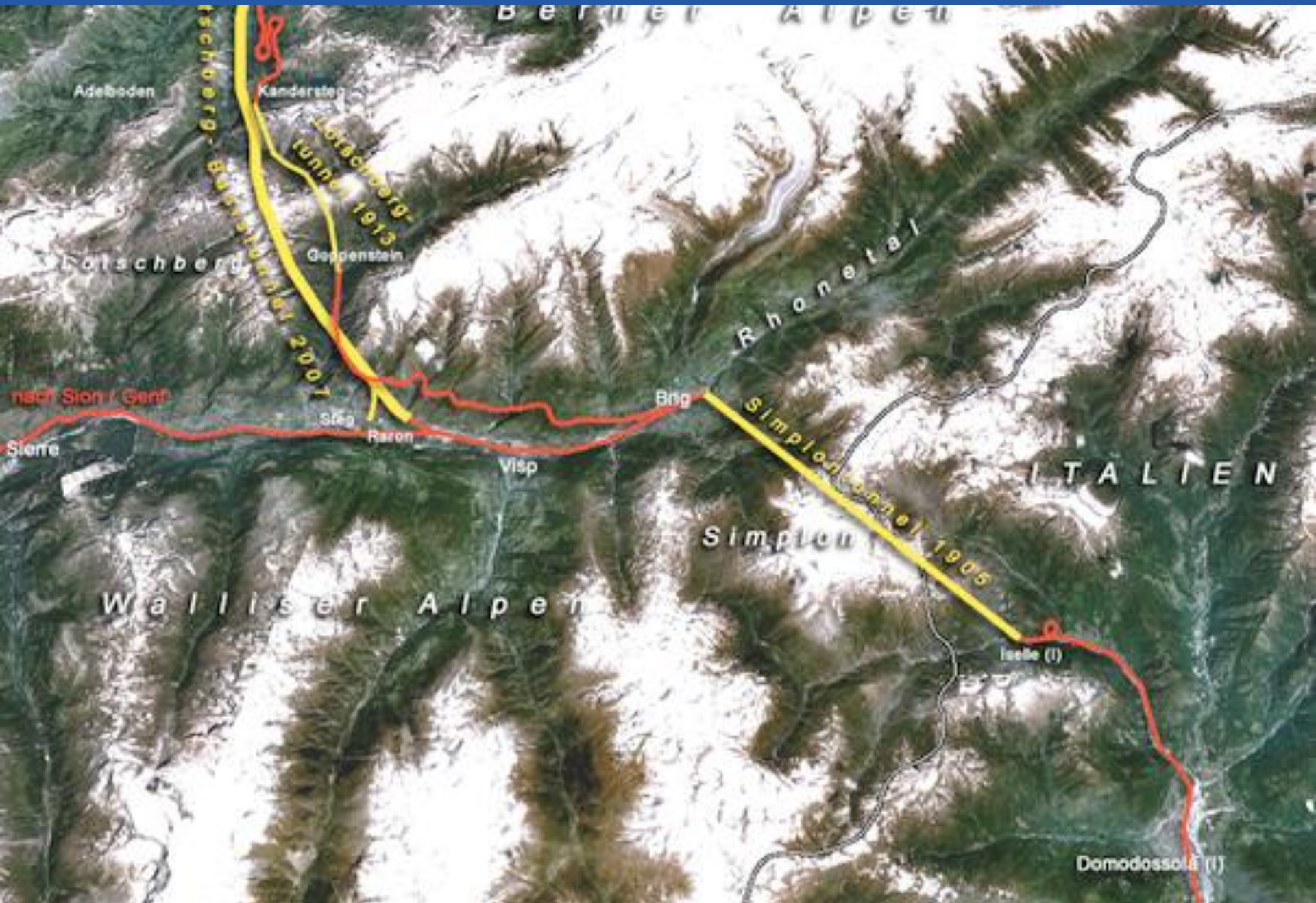
Solutions in practice:

trasse.ch
trasse schweiz ag
sillon suisse sa
traccia svizzera sa
swiss train paths ltd

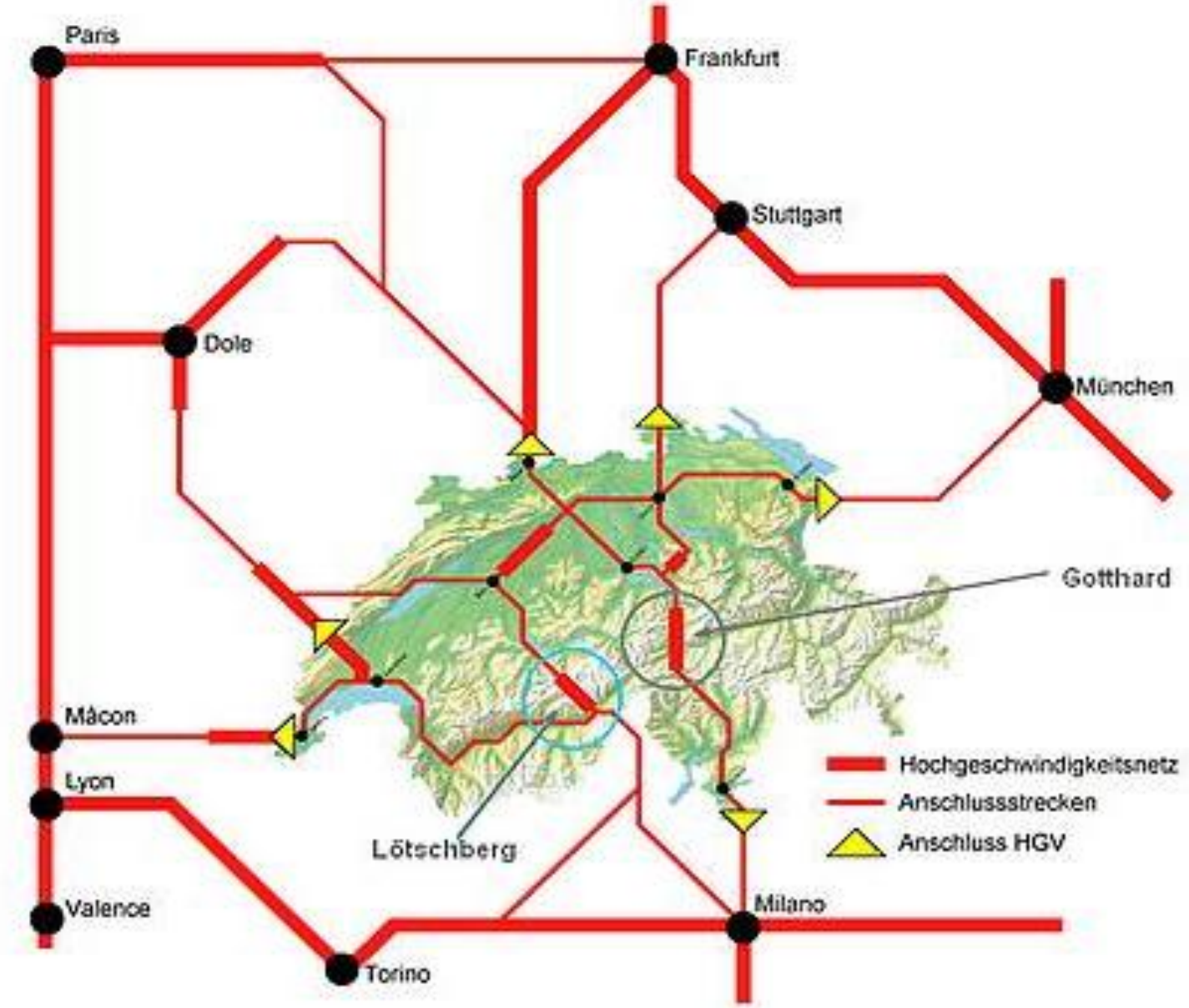
1. Identify bottlenecks
2. Predefined fixed traffic (passenger trains, long term contracts)
3. Optimize residual capacity and define slots for auction
4. Run auction for a small number of slots
5. Easy and solvable WDP



Case Study - Simplontunnel (www.swisstrains.ch)



Transit over the Alps



Highest Bidder Procedure for „Simplon“ – 2012

- Trasse Schweiz AG, News 12.09.2011 Head of Train Path Allocation)

„Die Trassenvergabe für den Jahresfahrplan 2012 gestaltete sich **sehr herausfordernd**. Zwischen Anfang 2012 und Frühjahr 2014 wird der Simplontunnel zwischen Brig und Iselle saniert. Der Simplontunnel besteht aus zwei einspurigen Röhren mit einer Kreuzungsmöglichkeit in der Tunnelmitte. Dies …. und die Kapazität des Güterverkehrs gar um zwei Drittel reduziert.
Diese Kapazitätseinschränkung bewirkte, dass die eingegangenen Trassenanträge insgesamt **240 Bestellkonflikte auslösten; fast dreimal so viele wie im Vorjahr**.
Während den acht Wochen der „Sperre Ein-spur“ werden noch zusätzliche Bestellkonflikte hinzukommen.
Das Ziel von trasse.ch ist es, für alle konfliktbehafteten Trassenanträge Alternativen zu finden, sodass alle Netznutzungswünsche umgesetzt werden können. In einem intensiven Austausch mit den betroffenen EVU und SBB Infrastruktur gelang es, beinahe alle der 240 Konflikte zu lösen. Die EVU können ihre Transporte zu **akzeptablen Bedingungen** durchführen, wenn auch teilweise gegenüber den ursprünglichen Absichten leicht geändert. trasse.ch dankt bei dieser Gelegenheit allen Beteiligten für ihr großes Engagement und die gezeigte Flexibilität.
In vier Konfliktfällen am Simplon zwischen Güterverkehrsunternehmungen konnten keine befriedigenden Alternativen gefunden werden. In diesen Fällen führte trasse.ch erstmals ein Bietverfahren durch. Die Trasse wurde demjenigen EVU zugeteilt, welches ein höheres Gebot einreichte. Die gebotenen Beträge leitet Trasse Schweiz an die beteiligten Infrastrukturbetreiber als Beitrag an den Netzbetreib und -unterhalt weiter.“

Allocation for the annual timetable – 2013

The starting point for the train path allocation process this year remained challenging. The renovation of the Simplon tunnel (which will last at least until the end of 2014) required the closure of one tunnel bore at a time up to the crossing in the middle of the tunnel. This reduced the capacity for freight trains on the Simplon axis by about one third. On the remainder of the network, changes to the …

remedial work in the tunnel, for existing flows as far as possible the railway undertakings would apply for just the same paths as they had done in the previous year. That limited train path conflicts to new flows as well as unavoidable amendments. The number of conflicts was significantly reduced in this way and the effort required to search for alternatives greatly reduced. The whole process of resolving conflicts was speeded up and the railway undertakings had their plans confirmed earlier. Despite these measures, no alternatives could be found for six conflicts on the Simplon axis. **A bidding process had to be used to decide how the paths were to be allocated. The bidding process was improved by comparison with the previous year.** The improvements were welcomed by the railway undertakings.

As a whole the train path allocation process for the 2013 annual timetable can be described as being considerably more efficient.

Thank you for your attention!

- Thomas Schlechte

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