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Trends in Infrastructure Modeling and Policy

Procurement and Auctions of Transport Services

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1 Introduction

Due to deregulation, unbundling and decentralization of infrastructure networks, the importance of auctions is rapidly increasing in the whole transport and logistics sector. Public entities use procurement auctions in order to award contracts to public transport firms. Truckload transportation often is allocated using combined auctions. Auctions could also be used to allocate airport slots. Furthermore, there is a discussion whether they could be used to allocate trackage rights in the railway sector.

The buyer can adopt auction mechanisms in order to acquire goods or services if there are several potential suppliers. The use of auctions seems to be appealing because it forces the bidders to reveal information about their valuation for the good. Otherwise this information would be difficult or even impossible to detect.

The aim of this paper is to provide some insights into the use of auctions in the railway sector. It is structured as follows: The next chapter gives a basic introduction into auction theory explaining the properties of this allocation mechanism. The questions addressed are: Do auctions induce bidders to report their valuation truthfully? Are they efficient in the sense that they maximize the total surplus? Do different types of auctions yield different types of revenues?

Chapter three provides a review of optimization methods that are used in practice to resolve auction problems. The fourth chapter presents a case study examining the application of auctions to railways. In a first step the problem of tendering railway services is addressed. Afterwards that section turns towards auctioning of trackage rights. The final chapter concludes by summarizing the main issues.

2 Auction theory

Bidding games (namely auctions) belong to the class of trading mechanisms, as opposed to bargaining mechanisms by which privately informed parties attempt to achieve mutually profitable transactions.

Bidding game designers let potential acquirers compete for some given prize while pursuing the maximization of their own payoffs. They attempt to benefit from bidders' rivalry by proposing rare and valuable object(s) that all of them would like to obtain. The outcomes of the games that are induced by the mechanisms crucially depend on the players' information as well as on the way it is revealed and distributed through the contract structure and execution.

2.1 The Vickrey-Clarke-Groves (VCG) Auction

In a seminal paper tracing back to 1961, Vickrey considered an auction where a seller offers a single indivisible good for sale to a finite number of bidders. Each bidder privately knows her own valuation for the good and submits her own bid without being informed about the competitors' valuations. Valuations are drawn independently from a commonly known prior distribution. Vickrey shows that, within this environment, if the item is allocated at a price that equals the second highest bid, then bidders have an incentive to bid precisely their true valuations for the good and the winner is the participant exhibiting the highest valuation.

Therefore, under rather general circumstances, Vickrey auctions display the following major properties:

- *Incentive-compatibility*. In a Vickrey auction, each of the bidders fares best when she truthfully reveals her private information (namely, her individual valuation for the good that is sold). As this is so whatever the expectations about the competitors' valuations, truthful bidding is a *dominant strategy* for each of the auction participants.
- *Ex-post efficiency.* In a Vickrey auction, the winner is the bidder with the highest valuation. Hence, the resulting allocation maximizes social welfare.

An immediate generalization of the Vickrey auction to situations where multiple identical units (or, equivalently, a divisible good) are sold is given by the uniform-price auction where all bidders pay the highest non-winning offer. However, the uniform-price auction induces participants to propose their real valuations only in the event that each of them bids on a single unit of the good for sale.

This does not mean that the incentive to truthful bidding cannot survive in a multi-good context. For it to be preserved as a dominant strategy for all participants, the more general Vickrey-Clarke-Groves (hereafter, VCG) mechanism should be relied upon. The latter does make truthful bids incentive-compatible by requiring bidders to offer a separate bid for each additional unit of the good and each winner to pay the opportunity cost she imposes to the other bidders for the allocation of the concerned unit. As this opportunity cost is given by the reduction in the declared welfare of the other agents, the winner internalises the externality she causes on the other participants.

In fact, the VCG scheme constitutes the *sole* mechanism for which everybody bidding truthfully is a dominant-strategy equilibrium even in the rather general (and, possibly, more realistic) environments where multiple items are auctioned off, either one by one or in packages (or both). This means that quite a powerful tool is available for inducing efficiency through bidders' rivalry.

Nevertheless, together with the desirable aspects so far illustrated, the VCG mechanism does display a bunch of shortcomings, which should not be neglected. We hereafter list these problems. Many of them arise whenever the goods for sale are (more or less perfect) *complements* from the bidders' perspective.

- *No budget balance*. There is no guarantee that budget balance will be entailed in a VCG auction and deficits may well be generated.
- *Suboptimality*. VCG auctions do not need to maximize sellers' revenues, which can be very low or even equal to zero.
- *Non-monotonicity of revenues.* The auctioneer's revenues are non-monotonic in the number of bidders, hence increasing competition does not need to yield larger benefits to the seller. This outcome, which is rather counter-intuitive, follows from the circumstance that the amount the winning bidders pay equals the opportunity cost that is generated for the losing bidders, not for the auctioneer.
- *No incentive-compatibility with iterations.* Truthful revelation of privately known valuations is no longer bidders' dominant strategy in the event that the VCG auctions are run iteratively.

- *Collusive incentives.* The losing bidders may have incentives to collude and so affect the outcome of the auction in their favour. Collusive agreements may well be stable, *i.e*. admitting no profitable deviation for any participating bidder.
- *Undesirable merger prevention.* In VCG mechanisms, mergers among bidders are prevented, which would be otherwise profitable, whenever winning mergers end up with paying a total amount that exceeds the payments autonomous participation would involve.
- *Reliance on "shill" bidders.* VCG mechanisms can provide incentives to use bidders in strategic ways. Indeed, the auctioneer may introduce "false" bidders at the aim of inducing the true participants to more aggressive behaviour.

The difficulties so far described are susceptible to discourage the implementation of VCG auctions in real-world situations. The existence of such shortcomings might help explain, at least to some extent, why VCG mechanisms are quite rarely used in reality.

2.2 The Green-Laffont Theorem

A natural question that can be raised after such an analysis of the VCG mechanism is to know whether there are other auction mechanisms that have the same properties (truthful, efficient). Green and Laffont (1976) show that the VCG mechanism is the unique one only when there is typespace connectivity. In fact, for instance, when there is no typespace connectivity, the reservation price mechanism may be more efficient than the VCG mechanism.

The question that can be raised now is if we can replace *truthful* by *Bayesian incentive compatible*. The answer is negative, the VCG mechanism is not the only one to be Bayesian incentive compatible, as it is highlighted in the following part through the revenue equivalence theorem.

2.3 The revenue equivalence theorem

The revenue equivalence theorem is a classical result in the theory of auctions about the division of expected social surplus among risk-neutral bidders and a risk-neutral bid-taker. Whenever the bidders have independent private valuations for the resource in sale, all auction formats lead to the same expected revenue to the bid-taker, and to the same expected profits of the bidders, which award the object to the bidder that submits the highest bid - regardless of the specific payment rule of the auction. In particular, the equilibrium expected payments in the first price sealed bid auction or the Dutch auction are the same as in the second price sealed bid auction, in the English auction, or in any all pay auction.

Roughly simultaneously, Myerson (1981) and Riley and Samuelson (1981) showed that Vickrey's results about the equivalence in expected revenue of different auctions apply very generally "Assume each of a given number of risk-neutral potential buyers of an object has a privately known signal independently drawn from a common, strictly increasing, atomless distribution. Then any auction mechanism in which (i) the object always goes to the buyer with the highest signal, and (ii) any bidder with the lowest-feasible signal expects zero surplus, yields the same expected revenue (and results in each bidder making the same expected payment as a function of her signal)".

Note that the result applies both to private-value models (in which a bidder's value depends only on her own signal), and to more general common-value models provided bidders' signals are independent. Thus all the ''standard'' auctions, the ascending, the descending, the first price, sealed-bid, and the second-price sealed-bid, yield the same expected revenue under the stated conditions, as do many non-standard auctions such as an ''all-pay'' auction (in which every competitor pays her bid but only the highest bidder wins the object, as in a lobbying competition).This Revenue Equivalence Theorem result is so fundamental, so much of auction theory can be understood in terms of it.

Although this work was a remarkable achievement, there seemed to be little relationship to traditional price theory, which made the subject a difficult one for many economists. Bulow and Roberts (1989) greatly simplified the analysis of optimal auctions by showing that the problem is, in their own words, ‘‘essentially equivalent to the analysis of standard monopoly third-degree price discrimination. The auctions problem can therefore be understood by applying the usual logic of marginal revenue versus marginal cost.’’

When bidders have independent private values, a bidder’s ‘‘marginal revenue’’ is defined as the marginal revenue of this firm at the price that equals the bidder’s actual value. Bulow and Roberts follow Myerson to show that under the assumptions of the revenue equivalence theorem the expected revenue from an auction equals the expected marginal revenue of the winning bidder(s).

So in an optimal auction the objects are allocated to the bidders with the highest marginal revenues, just as a price-discriminating monopolist sells to the buyers with the highest marginal revenues (by equalizing the lowest marginal revenues sold to across different markets). And just as a monopolist should not sell below the price where marginal revenue equals marginal cost, so an auctioneer should not sell below a reserve price set equal to the value of the bidder whose marginal revenue equals the value to the auctioneer of retaining the unit. If bidders with higher signals have higher marginal revenues, then the winning bidder has the highest marginal revenue. So under the assumptions of the revenue equivalence theorem, and if bidders with higher signals have higher marginal revenues, all the standard auctions are optimal if the seller imposes the optimal reserve price.

2.4 Combinatorial auctions

Most theoretical developments of auction theory focus on the sale of a single indivisible unit. There is, however, a growing literature on the combinatorial auctions, in which agents can place bids on every subset of the object put to tender and/or on combinations of items, called “package bids”.

The advantage of combinatorial auctions is that they allow bidder to express their preferences more fully. In other words, the sale of multiple units and the resulting opportunity for bidders to construct “package bids” is expected to allow them benefiting from coordination synergies and economies of scale. Within some industries, like public transport sector (Cantillon and Pesendorfer, 2006), the introduction of combinatorial auctions coupled with the unbundling of the network is expected to foster competition and, thus, leads to improved economic efficiency.

Most of the basic types of single-item auction described above may be generalized to combinatorial auctions. In the standard first-price combinatorial auction, bidders can submit bids on any number of items or package item. The seller then determines the allocation that provides the best economic value and the winner pays the amount he bids for the items he won. In particular, a “package bid” will be considered as a winning bid if it exceeds the sum of the individual bids for the single items.

In the combinatorial generalization of the Vickrey-Clarke-Groves mechanism, bidders simultaneously submit sealed bids giving their value for single items and/or package item. The seller determines the best allocation and each winner pays the opportunity cost of his winnings (i.e. the value that would be obtained by assigning the items according to the second best bids)

However, the following example highlights the fact that the use of combinatorial auction must rely on a careful analysis of the mechanism design (see the first part of the paper on the VCG mechanism limits), mainly because the theoretical properties of the basic types of auction in the single-unit case do not systematically extent to combinatorial auctions.

Consider for example a two-item auction in which three agents are bidding: bidder 1 is only interested in submitting a package bid; bidder 2 submits a bid of 6 on item A and 6 for the package; bidder 3 submits a bid of 5 on item B and 5 for the package. The following table summarizes the situation:

	A	***B***	***AB***
Bidder 1	0	0	12
Bidder 2	6	0	6
Bidder 3	0	5	5

According to Vickrey-Clarke-Groves mechanism, bidder 1 should get item A and B and pay 11 (i.e. the sum of the second highest bids), seller A and B should respectively get 7 and 6. The result of this auction rule is that the total amount received by the sellers exceeds the sum paid by bidder 1 and, as a consequence, budget is unbalanced.

3 Combinatorial Optimization

3.1 Introduction

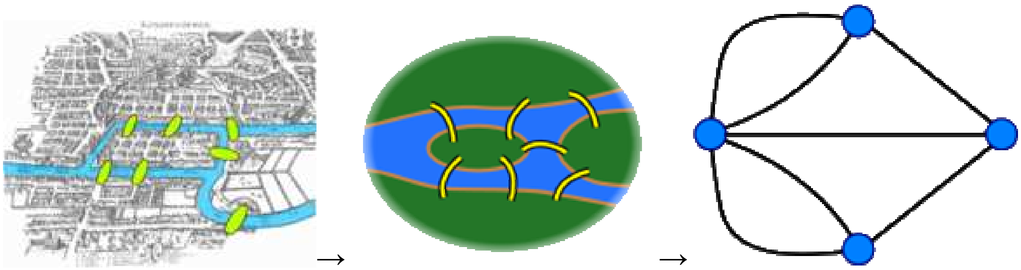
The domain of combinatorial optimization is optimization problems where the set of feasible solutions is discrete or can be reduced to a discrete one, and the goal is to find the best possible solution. Combinatorial optimization is the study of packing, covering, and partitioning, which are applications of integer programs. They are the principle mathematical topics in the interface between combinatorics and optimization. These problems deal with the classification of integer programming problems according to the complexity of known algorithms, and the design of good algorithms for solving special subclasses. In particular, problems of network flows, matching, and their matroid generalizations are studied. This subject is one of the unifying elements of combinatorics, optimization, operations research, and computer science.

A study of computational complexity theory helps to motivate combinatorial optimization. A complexity class is the set of all of the computational problems which can be solved using a certain amount of a certain computational resource. The complexity class *P* is the set of decision problems that can be solved by a deterministic machine in polynomial time. This class corresponds to an intuitive idea of the problems which can be effectively solved in the worst cases. The complexity class *NP* is the set of decision problems that can be solved by a *non*-deterministic machine in polynomial time. This class contains many problems that people would like to be able to solve effectively, including the Boolean satisfiability problem, the Hamiltonian path problem and the Vertex cover problem. All the problems in this class have the property that their solutions can be checked effectively. Many complexity classes can be characterized in terms of the mathematical logic needed to express them - this field is called descriptive complexity.

An useful classification is between decision and optimization problems. A decision problem asks, *is there a solution with a certain characteristic?* An optimization problem asks, *what is the best solution?* For instance, the traveling salesman problem is an optimization problem, while the corresponding decision problem asks if there is a Hamiltonian cycle with a cost less than some fixed amount k.

One of the first results in graph theory appeared in Leonhard Euler's paper on *Seven Bridges of Königsberg*, published in 1736. It is also regarded as one of the first topological results in geometry; that is, it does not depend on any measurements. This illustrates the deep connection between graph theory and topology. The *Seven Bridges of Königsberg* is a famous solved mathematics problem inspired by an actual place and situation. The city of Königsberg, Prussia (now Kaliningrad, Russia) is set on the Pregel River, and included two large islands which were connected to each other and the mainland by seven bridges. The question is whether it is possible to walk with a route that crosses each bridge exactly once, and return to the starting point. In 1736, Leonhard Euler proved that it was not possible.

In proving the result, Euler formulated the problem in terms of graph theory, by abstracting the case of Königsberg — first, by eliminating all features except the landmasses and the bridges connecting them; second, by replacing each landmass with a dot, called a vertex or node, and each bridge with a line, called an edge or link. The resulting mathematical structure is called a graph.

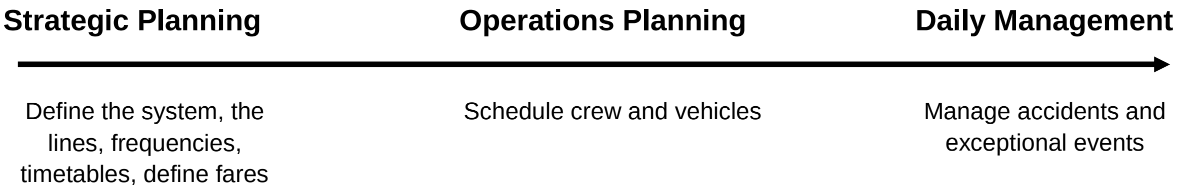


The shape of a graph may be distorted in any way without changing the graph itself, so long as the links between nodes are unchanged. It does not matter whether the links are straight or curved, or whether one node is to the left or right of another.

Euler realized that the problem could be solved in terms of the degrees of the nodes. The degree of a node is the number of edges touching it; in the Königsberg bridge graph, three nodes have degree 3 and one has degree 5. Euler proved that a circuit of the desired form is possible if and only if there are no nodes of odd degree. Such a walk is called an *Eulerian circuit* or an *Euler tour*. Since the graph corresponding to Königsberg has four nodes of odd degree, it cannot have an Eulerian circuit.

The problem can be modified to ask for a path that traverses all bridges but does not have the same starting and ending point. Such a walk is called an *Eulerian path* or *Euler walk*. Such a path exists if and only if the graph has exactly two nodes (or none) of odd degree, those nodes being the starting and ending points. (So this too was impossible for the seven bridges of Königsberg.)

Many practical problems can be formulated as graphs. Some examples are route problems (Hamiltonian path, shortest path), route problems and network flow. One field of application is in the public transport where many optimization problems arise, from strategic planning to day-by-day operation, and most of them can be formulated as combinatorial optimization problems. Some examples are:



3.2 Mathematical models

3.2.1 Timetabling model

The model of the timetabling was drawn from Peeters (1999). First we have to point out, that all constraint we using have the form $v_i - v_j + Tp_{ij} \in [l_{ij},u_{ij}]$, where T is planning period. That form of constraint allow us to model modulus function. The objective function f_{ij}, could be modeled as quadratic or linear function and it is defined for penalizing certain values of the variables δ_{ij} that are to be avoided.

The variable p_{ij} is binary variable, which indicates us if the certain event takes place in the defined time window. The variable δ_{ij} is an auxiliary variable.

$$\min \sum f_{ij}\left(\delta_{ij}\right)$$

Subject to:

$$\delta_{ij} = v_j - v_i + Tp_{ij}$$

$$\delta_{ij} \in \begin{cases} \left[l_{ij}, u_{ij}\right] & \text{if a constraint is associated with i and j} \\ \left[0, T-1\right] & \text{otherwise} \end{cases}$$

$$v_i \in \left[0, T-1\right]$$

$$p_{ij} \in \left\{0,1\right\}$$

The first and second constraint states that event v_j should take place between l_{ij} and u_{ij} minutes after event v_i takes place. The third constraint assumes that events v_i proceeds only between time 0 and T–1.

3.2.2 Track allocation model

The model of track allocation by using auction mechanism was drawn from Borndörfer et.al. 2005. Let us consider a bid *i* which specifies the train y^i, that departures from station v^i_1 at the time t^i_1, and arrives on the destination station v^i_2 at time t^i_2. The bid has some monetary value b^i. To simplify, let us denote $d^i = (v^i_1, t^i_1)$, and $a^i = (v^i_2, t^i_2)$ as respectivly the time nodes associated with departure and arrival of a slot associated with bid *i*. Assigantion of specific bid *i* is connected with neccesity of assurance that there will be no conflict with another trains. Variable x^i_a is a binary variable, which takes 1 value if bid *i* passes through arc *a*. Parameter p^i_a has the value b^i when arc *a* is on the begining of the track in the slot associated with bid *i*. Finnaly, let us denote by $\delta^i_{in}(v,t)$ the set of all arcs entering a time-node *(v, t)* that are compatible with train type y^i. Similarly, let $\delta^i_{out}(v,t)$ be the respective set of arcs leaving time-node *(v, t)*. With above assumption, we can write a MIP model of track allocation problem:

$$\max \sum_{i \in I} \sum_{a \in A_H} p^i_a x^{\mathrm{i}}_{\mathrm{a}}$$

Subject to:

$$\sum_{a \in \delta^i_{out}(d^i)} x^i_a \le 1, \quad \forall i \in I$$

$$\sum_{a \in \delta^i_{in}(a^i)} x^i_a \le 1, \quad \forall i \in I$$

$$\sum_{a \in \delta^i_{out}(v)} x^i_a - \sum_{a \in \delta^i_{in}(v)} x^i_a = 0, \quad \forall i \in I, v \in V_H \setminus \left\{d^i, a^i\right\}$$

$$\sum_{i \in I} \sum_{a \in A_C} x^i_a \le \kappa_C, \quad \forall c \in C$$

$$x^i_a \in \left\{0,1\right\}, \quad \forall i \in I, a \in A_H$$

Objective maximizes the total profit reached by operator from an accepted bids. First constraint assumes that only one track can finish by an arc *a*. Similarly, second constraint assumes that only one track can start by an arc *a*. The third constraint describes the train flow over all the arcs in the track. The fourth constraint describes maximal capacity κ_C for every conflict free slots.

4 Case study

4.1 Railway Access

Within the railway sector the complexity and organization of time-slots is a challenge for both the providers and the users. Different time-slots have certain advantages based on the structure of the transported items, i.e. passengers and freight. Allocating these time-slots where they maximize value is an important aspect for the individual operator in particular but also for the European railway system in general. By combinatorial auctions each operator are free to bid on different time-slots and can freely make bids correspondent to the perceived value of the operator/bidder. With such an approach operators can analyze the value of different time-slots based on the fit it has in the transportation network of that operator, by means of optimization. The implication of such an application is that the allocation of time-slots can be organized in a value-maximizing manner. As an example: congestion at many major airports is becoming an increasingly difficult problem where auctions can be used to allocate scarce capacity. In the U.S. the Federal Aviation Administration is evaluating a combinatorial auction approach for New York's LaGuardia airport (Cramton, P., Shoham, Y. and Richard Steinberg, 2006). Another example of slot auctioning is the project "Trassenbörse" at the Technische Universität Berlin which focus on the opportunities for allocating time-slots on German railways with the help of auctions. Auctions could be used to allocate time-slots for the larger systems, such as the Trans European Network (TEN) so that international traffic could be organized and cost-efficient in accordance to the current rules of time-slot allocation formulated by the EU. Concerning the current rules of allocating time-slots in EU, auction theory could help to solve the problem of multilateral conflict of slots when using the prioritizing rule of the highest sum of regular access prices by means of mathematical optimization of the "highest sum of bids". It could introduce flexibility in the maximization process by analyzing the effects on access prices by adjusting requested time-slots and departure times. This means that possible discounts could be introduces if bidders accept a certain level of flexibility. The results would be better utilization of railway infrastructure and would be especially valuable for congested links. From a bidder perspective the requested bid could be more flexible since it does not require an exact route. For operators that do not have exact time requirements on time-slots the results could be lower access costs. This could be especially evident for freight transport since small waiting-times and flexible departure time could be acceptable from a business perspective since costs might be of higher priority than small adjustments to the lead-time.

All these opportunities are incorporated into the use of combinatorial bids/auctions. However, if the scope of complexity is too high it challenges the tractability of current mathematical optimization abilities. In sum, auction theory could facilitate a dynamic and value maximization allocation of time-slots by means of willingness to pay by bidders/operators.

The use of combinatorial auctions relies on the supply and availability of time-slots and thus is highly dependent on the level of deregulation for the given sector. Furthermore, the use of auction theory could reform the situation of "grandfather rights" in the different transport sectors by introducing a pricing mechanism (c.f. Rassenti, S., Smith, V. and Bulfin, R., 1982; Parkes, D. and Ungar, L., 2001). This would increase the movement of time-slots and make attractive time-slots more available. The improvement of allocation would benefit both the infrastructure provider who achieves greater value for slots affected by grandfather rights and the users would probably enjoy better service since the highest bidder is probably the operator that can best utilize upon customer satisfaction.

4.2 Railway Services

Many researchers and practitioners call attention to trends in logistics, derived from changes in the business environment like globalisation, production patterns (Das and Handfield 1997; Búrca 1997; O'Donnel 1997) and urbanisation (Scott and Storper 2003). According to Scott and Storper (2003), production and logistics arrives at the consensus of producing every individual product or module in regions where the comparative advantages are greatest. This possibility has been supported by the development of rapid transport of goods over long distance (Nordström 1996). Firms' desire for market expansion and the contemplation of external forces present in geographical areas steadily increases the importance of regions' attractiveness and competitiveness (Trunick 2002; Nordström 1996). Barry (1997) and Kotler, Asplund et al. (1999) state that business activities in peripheral regions can decrease significantly due to these trends. As a consequence, goods flows in peripheral regions may decrease, challenging the transportation system and the logistics effectiveness and competitiveness of firms (McKinnon 1997). This is especially evident for many firms and regions in Europe since many regions are sparsely populated in the periphery of the EU and the world markets.

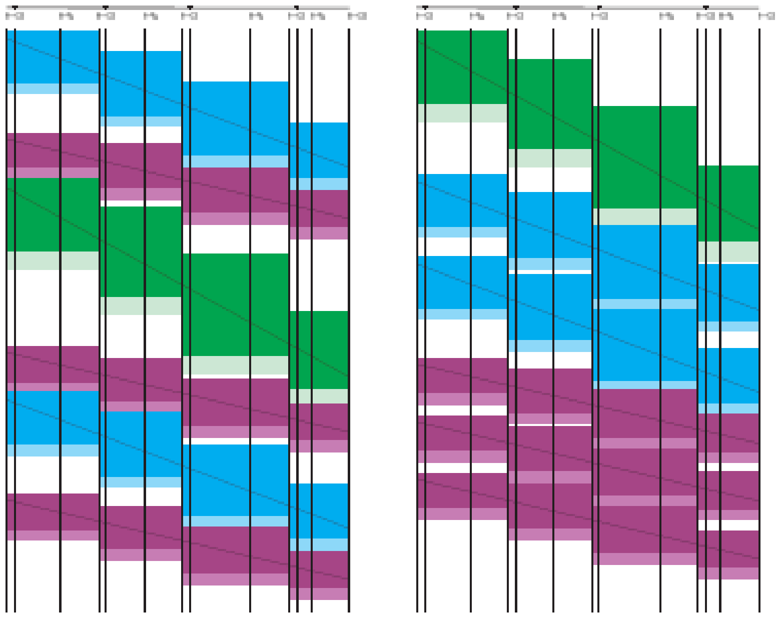
The motives behind studying regional logistics system have its starting points in the observation that geographical closeness between firms has logistics advantages. Because of geographical dependencies and geographical transaction costs (McCann and Shefer 2004), the region is a natural origin for a systemic setting of logistics supply chains. From a logistics perspective the origins of outgoing goods flows and the destinations of incoming goods flows for regional firms are nearby, hence, opportunities for logistics coordination. Carriers actively pursue this logic in their construction of logistics systems. The coordination achieved by carriers is traditionally managed with regard to the structure of the carrier's logistics system. Hypothetical, the system could benefit further if shippers adapted to the system structures and even adapted with regard to other shippers. A possible explanation according to McKinnon (1997) why this opportunity is not commonly exploited is a lack of efficient tools and structures for managing the complex situation of consolidating and coordinating the goods flows of small and medium-sized companies for both carriers and shippers.

Combinatorial auctions may facilitate the coordination of logistics flows by introducing the opportunity to optimise and analyse regional logistics systems. This application enables shippers in peripheral regions to cooperate and coordinate and tender combinations of logistics flows to rail operators that otherwise due to the size of flows would be difficult. Combinatorial auctions could be used for tendering for example geographical regions' outgoing export and import flows for a particular relation. Another possible application could be to tender specific lanes that are important and thus attractive for operators. This analogy relies on the logics of economies of scale. This is especially important from a sustainability perspective of the regional logistics system as it enables the use of more environmentally friendly modes of transports. i.e. rail/road intermodal system.

The same analogy is of course also applicable to more densely populated regions. Here, another interesting field of application is the public transport sector (e.g. Clarke, E. H. 1971). Large public transport systems have a vast level of complexity in its construct and the use of optimisation is a necessity for an efficient system. The introduction of combinatorial auctions in this setting can facilitate the introduction of competition in the sector. Combinatorial auctions enable bidders and potential operators to analyse and make sophisticated package bids based on their most suitable setup of the system (Cramton, P., Shoham, Y. and Richard Steinberg (2006), In the end the quality of service can be the same or even greater for the users at the same time cost-efficiency is enhanced.

4.3 Optimization in railway scheduling

One area where optimization can be used is railway scheduling. Current system of unbundling of train has left the railway network capacity underutilized. Train bundling involves arranging trains into types so that each train type (i.e. trains with blocking time stairways of identical slops) is allocated to a particular line. As can be observed from Figure 2, bundling help reduce the headway between train, hence making it possible to increase network capacity (Bondoerfer, 2005). Because bundling is a combinatorial problem, it makes it possible to use optimization approach to improve railways scheduling and hence increase network capacity.



(a) Before bundling (b) After bundling

Figure 1: A set of trains with blocking times, before and after bundling

5 Conclusions

As the national railway systems in Europe becomes deregulated and integrated in the European setting it is important that there are tools and techniques available that facilitate the entry of new players as well as the efficiency of the incumbents. Combinatorial auction is such a tool. It enables complex bidding where the tender can be highly tailored to fit particular purposes at the same time it enables bidders to construct attractive bids and packages. The tool is especially useful for auctioning specific part of a railway system, e.g. single lanes, routes or combination of lanes. This enables larger parts of the European railway system to be tendered and thus available for new structure of railway operators, hence, introduce elements of increased competition.

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