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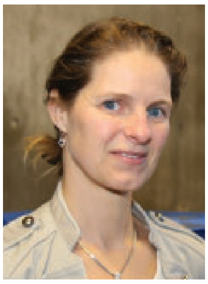

Kære læser

Det er lidt med vemodighed at jeg skriver denne leder. Efter tretten Orbits er tiden kommet til at videregive stafetten og koncentrere mig om andre opgaver. Redaktørposten overtages af Julia Pahl, som til dagligt er lektor ved Department of Technology and Innovation på Syddansk Universitet. Jeg ønsker Julia alt muligt held og lykke og god fornøjelse som ORbit redaktør. Tag godt imod hende.

I mit første ORbit som redaktør: ORbit 19 bragte vi en erindringsskrivelse af Oli Madsen, hvor han, i anledning af DORS's 50-års jubilæum, så tilbage på operationsanalysens fødsel i Danmark. I de seneste udgivelser er dette fulgt op af historiske skildringer af Jakob Krarup, og senest også af Vagn Ro Knudsen.

I en tid, hvor operationsanalysen udfordres med nye spændende begreber som data driven research og business analytics, for blot at nævne nogle få, og med super computere, cloud computing og hvad-det-alt-sammen-hedder, finder jeg det vigtigt at huske, hvor vi kommer fra og at værdsætte det kæmpe arbejde der, i de tidlige år, blev gjort for at skabe sammenhæng og netværk i en tid før internet, e-mails, online fora og sociale medier. Vi bærer et fælles ansvar for på en gang at holde fast i vores rødder, forny os og sigte højere. Lad os i fællesskab løfte operationsanalysen til et niveau hvor vi kan bidrage til at afhjælpe de store problemer i verden: mangel på fødevarer og ressourcer, forurening og katastrofer… Lad os gøre en forskel. Sammen.

Tak for denne gang,

Sanne Wøhlk, afgående redaktør

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Svenska operationsanalysföreningen

Högst på SOAFs agenda under 2018 står att starta en intressegrupp för forskarstuderanden inom OA. Gruppens första aktivitet blir en träff på temat “vad kan man arbeta med efter disputationen?”. För att ge inspiration och insikter på detta tema har tre talare, med lite olika perspektiv, bjudits in:

• Mattias Grönkvist från Jeppesen berättar om hur det är att arbeta som optimeringsexpert på ett företag som utvecklar mjukvara för optimering av flygplansrutter och deras bemanning.

• Kristofer Hallgren från FOI kommer att prata om hur det är att arbeta som analytiker inom försvaret och varför hans forskarutbildning var en bra förberedelse inför ett sådant arbete.

• Christiane Schmidt, biträdande universitetslektor vid Linköpings universitet, delar med sig av sina erfarenheter från att vara postdok, både i Sverige och andra länder.

Styrelsens förhoppning är att en satsning på föreningens forskarstuderande ska stärka svensk OA, både genom att det ska vara givande för individerna och genom att det utökar vårt nätverk. Att gruppens första träff har hela 25 anmälda är mycket glädjande och ger en indikation på att vi möter ett behov bland våra medlemmar. Styrelsen vill rikta ett stort tack till Björn Morén vid Linköpings universitet som verkar som sammanhållande för gruppen. Den som är intresserad av att engagera sig i denna grupp är välkommen att kontakta Björn på bjorn.moren@liu.se.

Hälsningar

Elina Rönnberg, ordförande SOAF

Indhold

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By Kasper Torp Steffensen

Time Considerations in Liner Shipping Network Design

DORS prisen vinder Kasper Torp Steffensen fortæller her om sit speciale.

Bestyrelsen og redaktionen ønsker tillykke med prisen.

Introduction

Tremendous ships, countless numbers of containers and endless fun when you enjoy solving large scale optimization problems. The liner shipping industry is an impressive, interesting and important industry which we all depend on in some way. It has a crucial role in modern world trade and the amounts of goods transported by sea are continuously increasing, both in volume and value. In this development, together with the increasing importance of environmentally friendly solutions, a demand for more efficient planning is the natural consequence. The liner vessel operators must design their network of vessel routes, so that they can meet the shipping demands in the best way possible while at the same time minimizing their costs. What types of vessels to use, which ports to visit and how fast to sail between them are examples of important decisions they face in the search for a profitable liner shipping network. One would assume that a profitable network is a less environment friendly network, but fortunately reduction of cost and co2 emission go very much hand in hand. One of the reasons for this is slow steaming: the concept of lowering the sail speed in order to reduce bunker consumption. Another reason is capacity utilization, as it allows the transportation of more goods over a certain distance, and hence may lower the operational cost and bunker consumption per transported unit.

Liner Shipping Network Design

It all begins with a demand for transportation of goods from one location to another. The ones who make such a demand, the shippers, may have priorities such as proper pricing and travel time requirements. The ones fulfilling the demand, the carriers, will meanwhile aim to optimize profitable networks of shipping routes on which cargo can flow. In this respect, the liner shipping business is quite comparable with public transport, where trains and busses also operate on networks of fixed routes in order to satisfy the demand of the passengers to travel from one location to another. Just like in public transport, it is not always possible to travel directly from the origin to the destination without shifts. In shipping, moving containers from one vessel to another is referred to as transshipment.

The demands in the liner shipping network design problem, LSNDP, are estimated quantities of containers shipped from an origin port to a destination port within a certain time frame. Furthermore, these demands have a revenue value which is an estimation of what the carriers can earn from the associated product. The fleet is clustered into vessel classes with vessels sharing the same features, such as size and speed properties. As mentioned previously, the sail speed has an influence on the bunker consumption and thereby the cost of sailing between ports. The size is a critical factor in regard to how much cargo a vessel can carry, and to whether it can sail through a certain canal or dock in a certain port. When a vessel sails through a canal or docks at a port, a fee must be paid. These costs depend on the type/size of the vessel as well. The ports are the link between transportation by sea and inland distribution. Furthermore, some ports serve as hubs where containers can be transshipped

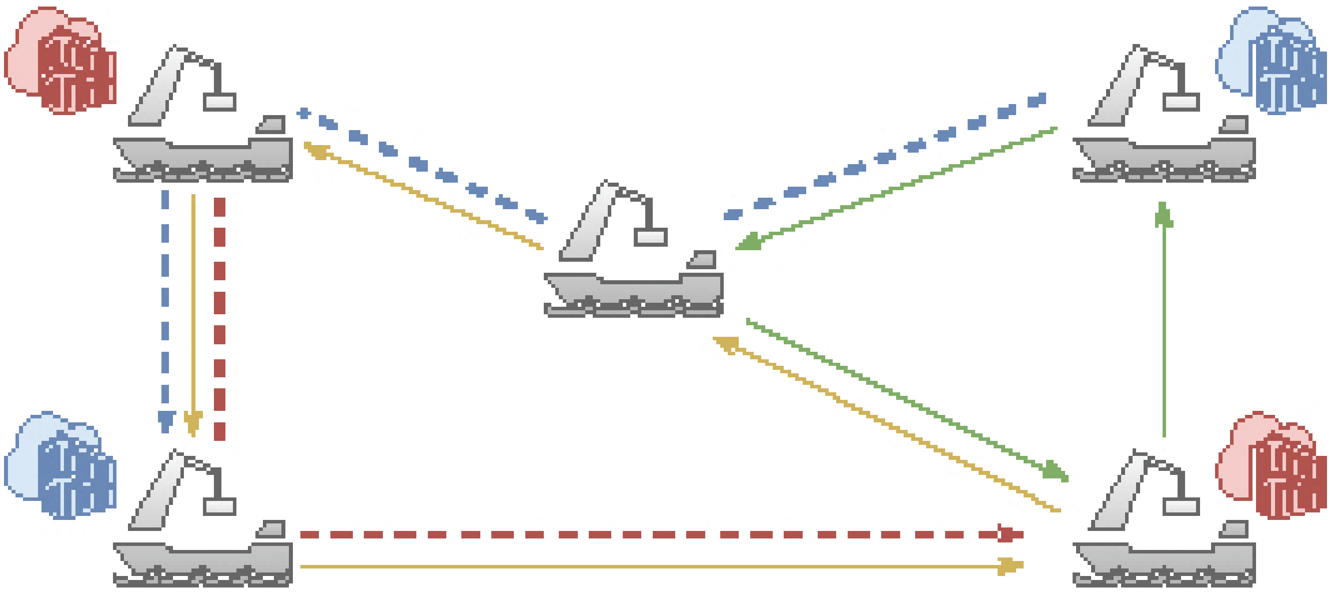

Figure 1. A simple network with two services.

from one vessel to another. If cargo is being loaded or unloaded, either as part of a transshipment or when connecting to inland transportation, an operational cost is paid per unit for the service. Both, the cost for docking at a port and the operational costs vary, which is why decisions regarding which ports to call and use as hubs for transshipment are significant factors in the LSNDP. The aforementioned elements are combined into a service which is offered to the shippers. Such a service is a scheduled sequence of port calls performed in a loop with a certain frequency, which is most often weekly. When a service has a weekly frequency and includes a certain departure time for a certain port, a vessel will leave at that time from that port every week. A port could have multiple departures during a week, but then each of the departure times would be the same every week. For the carriers to be able to offer the weekly departures, they also have to allocate enough vessels to the services so that a weekly frequency may be maintained. Figure 1 illustrates a simple network consisting of two services – the green and yellow cycles. The blue and red arcs correspond to commodity paths from two different demands. The red commodity travels on the yellow service all the way from its origin to its destination. The blue commodity, on the other hand, first travels with the green service and then the yellow after a transshipment at the port in the middle.

Recent Research

In 2014 the benchmark data set LINER-LIB was introduced. This is the first benchmark data set for LSNDP and it consists of multiple instances corresponding to different geographical areas: from a single hub instance in the Baltic region to a multi-hub instance with ports and demands from all over the world. The vessel classes, ports and demands in the data set are different in each instance and differ in both, the quantity and in the characteristics explained above. As several of the instances are quite large compared to previous data sets, there has been a natural switch from using exact methods towards using heuristic methods for solving the LSNDP. Since the introduction of LINER-LIB, improved methods have been suggested and more realistic solutions have been found after adding additional requirements, such as transit time restrictions. The transshipment time in the commodity paths has, however, not been considered. Due to this, the maximum transit time of demands could potentially be violated in reality although the commodity paths were feasible when solving the problem with transit time restrictions. To account for this, a new model was presented in the thesis »Liner Shipping Network Optimization with Exact Modelling of Transshipment Time«. The new time indexed formulation is defined to include transshipment time in the transit time and in the planning of liner shipping services. In addition to this, the time indexed formulation has other beneficial features regarding the solutions and modelling technicalities, which will be looked into in the following.

Time Indexed Formulation

In the graph describing the LSNDP it is common to let the vertices correspond to the ports, while the arcs correspond to sailing from one port to another. If, however, the graph is extended in a way that vertices describe port and departure time combinations instead, it is possible to draw arcs from a certain port to the same port later in time, which indeed can be used to express transshipment at the port. Furthermore, it is possible to draw arcs between vertices with different ports, which then corresponds to sailing between ports at different speeds. This can be seen in Figure 2 which shows an illustration of the time indexed graph above the horizontal line. Vertices above each other correspond to the same port, and hence arcs between these would be transshipment arcs. The arcs which are shown in the figure are however sailing arcs, as they go from one port to another. Changing the end position of any arc in the figure from a vertex to another without changing the port would correspond to changing the speed, as the travel distance would be unchanged but the travel time would be different.

Of course, adding an extra dimension to the problem will add to the complexity of the model. However, there are definitely also benefits in introducing time indices to the model. In addition to being able to express transshipment time, the inclusion of time indices

• allows more complex service structures than previous models

• makes it possible to describe such complex services with just a single cycle while maintaining a requirement for weekly services

• makes it possible to have varying speeds on a service

In figure 2, the same service is shown in a standard graph below the horizontal line and in the time indexed graph above it. This way it is clear to see how the non-simple cycle is expressed as a simple cycle in the time indexed graph. Any cycle is necessarily a multiple of a week as long as the time indices together represent a full week.

The problem can be decomposed into two problems: a subproblem for determining commodity paths, and a master problem which takes these paths as input and determines the overall network design. In a column generation setting,

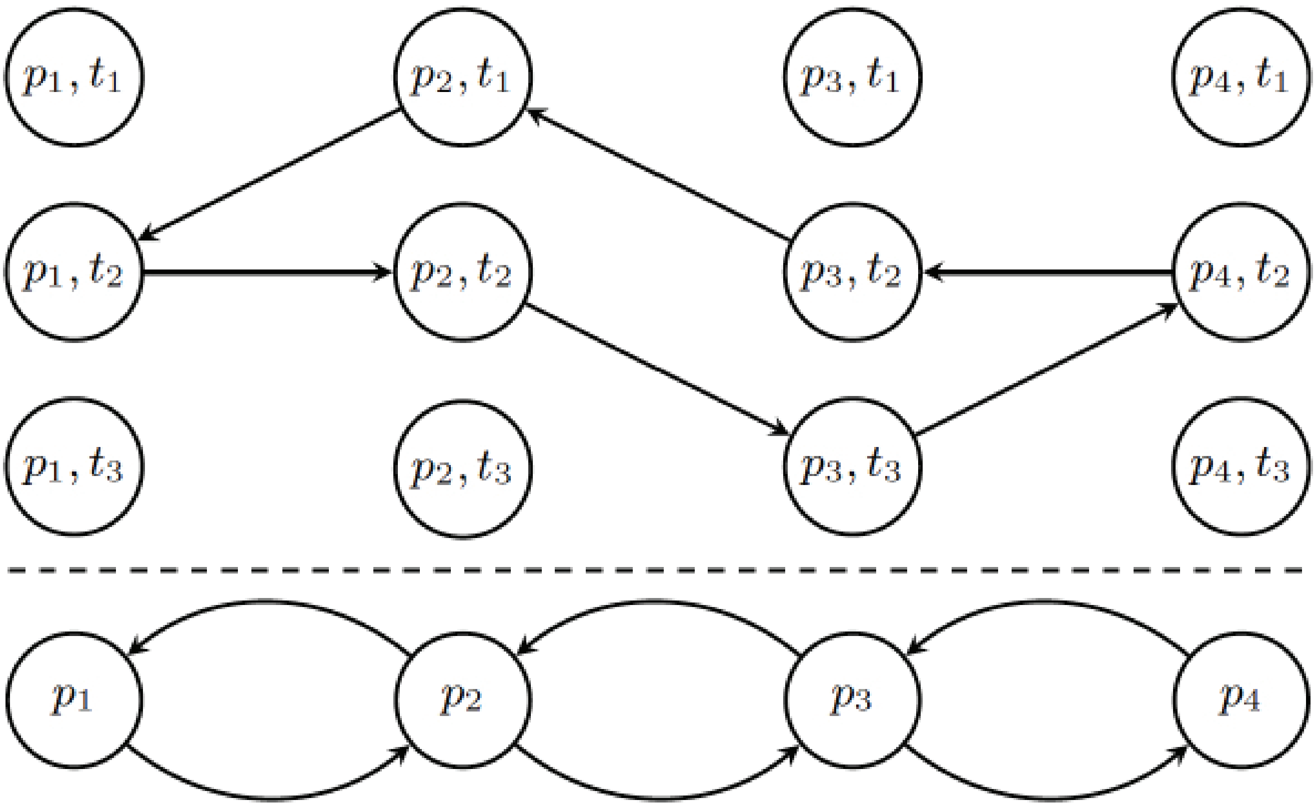

Figure 2. A service illustrated in the time indexed graph with three time indices and in the traditional graph for the LSNDP.

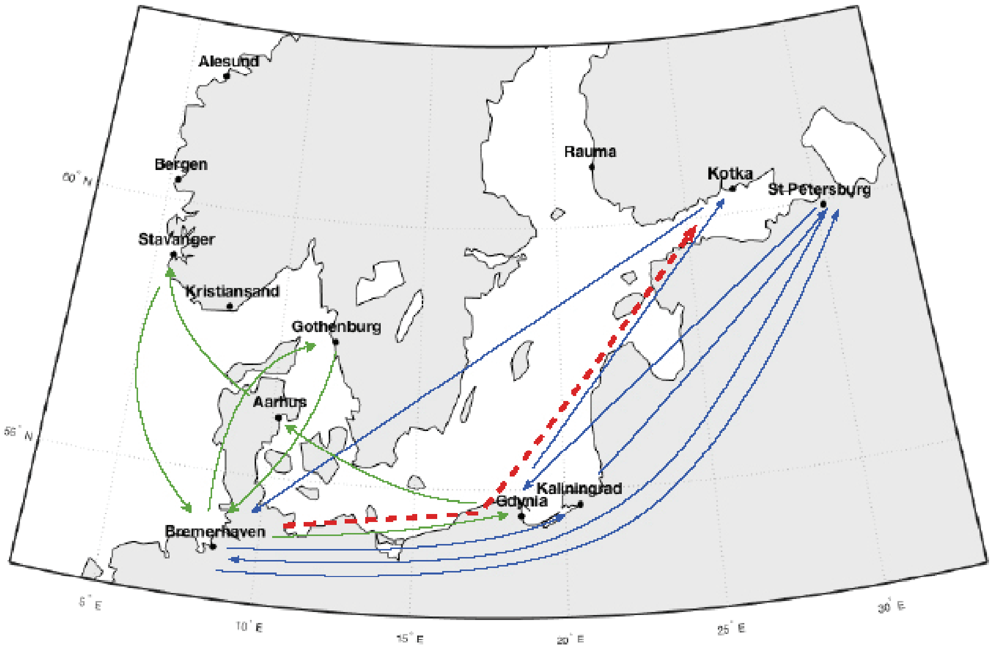

Figure 3. A part of the optimal solution for the Baltic instance with seven time indices.

commodity paths are determined in the subproblem by minimizing the reduced cost while respecting the transit time for each demand. The objective of the master problem is to minimize costs subtracted with revenue. This must be done while ensuring sufficient capacity along any commodity path. Also, the number of vessels within each vessel class as well as the quantity for each estimated demand are restricted. Lastly, flow must be conserved and it must be ensured that only one vessel leaves a port at a certain time. These last two modelling technical constraints are necessary in order to construct realistic networks without disappearing ships and time travelling containers.

Computational Tests

The foundation of the implemented solution methods has been column generation where the subproblem was solved as resource constrained shortest path problem using a label setting algorithm. Preprocessing techniques together with cutting and branching techniques have been used with the goal of improving solve times and bounds and obtaining integer solution. As data, the instances from the aforementioned LINER-LIB have been used.

The Baltic instance is the smallest instance in LINER-LIB, and the LP-relaxed version of this is solved by using column generation in less than a second when using seven time steps. Unfortunately the solve time for the LP-relaxed problem increases exponentially with the size of the instances. As examples, the Mediterranean instance takes close to half an hour to solve, while the Pacific instance takes more than three hours to solve. The main reason for this is to be found in the solve time of the restricted master problem, not the solve time of the subproblem. The solve time of the subproblem is only a few seconds, even for the World Small instance, when using some of the following techniques.

Clustering Demands

When the subproblem is solved for a certain demand using a label setting algorithm, labels are initially extended from the origin of the demand to other vertices corresponding to port and time combinations. The process of extending labels continues, and thereby potential routes from the demand's origin to the other ports are generated. This information may be used to calculate the shortest path, not just for that one demand, but for all demands sharing the same origin. The exact same thing counts for demands sharing the same destination, as long as the label setting algorithm is implemented using a backward procedure. This means that for determining the shortest path for all demands, it is sufficient to solve the subproblem for each cluster of demands as long as these share the same origin or destination when the algorithm runs with a forward or backward procedure, respectively. Using this approach instead of solving a shortest path problem for demands individually improved the performance significantly in all instances. As an example the average solve time of the subproblem for the World Small instance was reduced from approximately 42 seconds to approximately 2 seconds.

Tightening Time Limits

The constrained resource in the subproblem is the time as all commodity paths must respect their associated maximum transit time. One way to ensure that is to limit all labels regardless of which port they are associated with. It is however desirable to limit the number of labels as this may improve the performance of the label setting algorithm - of course without removing any feasible solution. It will never be possible to reach a demand's destination from any port faster than by sailing directly at the maximum speed in an instance. Hence, limiting the number of labels may be achieved by setting a maximum time at each port as the demand's maximum transit time subtracted with the product of the maximum speed and the direct distance to the destination. Note that the same can be achieved with a backward procedure by using the distance to the demand's origin in a similar manner. When this approach was used, the aforementioned World Small subproblem solve time of approximately 42 seconds was reduced to approximately 29 seconds, and generally improved the performance with separated demands. The method had some but little effect when demands were clustered as time limits at any port must respect all transit times in a cluster.

Cutting & Branching

Several different branching decisions and search strategies have been tested in a Branch and Price setting. The branching decisions regarded the arc flow, the port flow and the total number of vessels, which all have to be expressed by integers in a valid solution. As search strategies, Depth First and Best First search were used. The quantity of the demands can be used to add valid inequalities, which was implemented when the solution method was extended to a Branch Cut and Price method. Unfortunately, the inequalities were not effective in regard to reducing the fractionality, which could be explained by the unbalanced cost-benefit relation between using a commodity arc for a certain demand and operating vessels on the same connection. The inequalities were however quite efficient for increasing the lower bound. The effect of branching on port, vertex and arc flow were tested separately. Branching on port flow yielded fast improvement of the lower bound, especially when this was done including all vessel arcs connected to the port. When vessel arcs for a specific vessel class were used, the improvement of the lower bound was less fast, but still considerably faster than branching on vertex and arc flow. The Best First search strategy generally outperformed the Depth First search strategy in regard to improving the lower bound. On the other hand, the Depth First search had the advantage of finding upper bounds faster.

There is room for improvement when it comes to solving the larger instances of LINER-LIB. In particular, the performance of the methods were limited by the solve time of the restricted master problem in all cases. For future work, this is definitely something interesting to focus on, together with implementing heuristic methods for the time indexed formulation. By using the Branch and Price algorithm, it was however possible to determine an optimal solution for the Baltic instance with seven time steps. A part of this solution is shown in Figure 3. The blue and green arcs correspond to two different services, both departing twice per week from Bremerhaven; the hub of this instance. The red arc corresponds to a commodity path which goes from Bremerhaven to Kotka and includes a transshipment in Gdynia. This commodity leaves Bremerhaven on a Wednesday and arrives in Gdynia Saturday. It is then being transshipped and leaves with the new container ship on the next Wednesday. This container ship transports the commodity to its end destination Kotka, which it arrives at on the following Friday.

Kasper Torp Steffensen has specialized in Operations Research at the Technical University of Denmark. He holds a B.Sc. in Mathematics & Technology together with an M.Sc. in Mathematical Modelling and Computation. Currently, he is working as a software developer at Schilling A/S.

Source: www.unsplash.com

By Daniele Lubrano

Shift design and meal breaks: a practical application

Virtually every company faces the challenge of planning its workforce in both an efficient and effective manner. Given the considerable number of employees necessary in most sectors to run a business, non-optimized schedules often lead to significant opportunity costs.

Here we will focus on the security staff necessary to running airports operations. Moreover, this article will tackle the workforce-planning problem from a shift design perspective, meaning how to best design shifts with respect to the expected demand.

An important fact to consider while building a model to reflect operational tasks of an airport (or, in general, of a company) is that the number of possible shifts should be limited, because they would otherwise become too challenging to manage. This transitions the problem from the broad category of Shift Design Problems (SDP) to a Cardinality Constrained Shift Design Problem (CCSDP) [1].

Problem definition

The objective for a shift design problem can be measured in different ways, based on the company strategy. A common option that considers both the service level offered to the customers, and the operational costs, is to use a penalized weighted sum for the staff undercoverage and overcoverage. Undercoverage is a term that reflects how many employees a shift plan is missing compared to the desired target. For example, a business might have forecasted or calculated that Monday at 3 p.m. there is a need for ten employees in order to satisfy the demand at that time. Now, let us assume that a shift plan only assigns nine employees in that timeslot; this would result in an undercoverage of one unit. Similarly, the overcoverage measures how many employees, at any given point in time, are not strictly necessary to cover the customer demand. Finally, one can add a penalization weight for each of the two coverage components and balance these two values to reflect the company's strategy. In our case, the undercoverage penalization weight was set to be ten times higher than its counterpart because not serving customers is seen as much less desirable than to have a higher salary cost.

The European Airport used as case study has several constraints regarding the shift design for their security personnel, among which:

• The number of employees used throughout the week should never exceed the total workforce availability. I.e. There is a limited number of employees and we should not rely on external workforce

• The number of shifts proposed by the model should not be higher than the limit of shifts imposed by the management.

At this point, the problem can be extended to include meal breaks, usually manually allocated by the respective managers. Meal breaks can be modelled in a large variety of ways and an optimization model is unlikely to satisfy the preference of every individual. Some people like to have lunch every day at the same time, some others prefer uncommon hours to avoid long queues in the canteen, some do not have a strong preference etc.

Our implementation assigns meal breaks close to the center of a shift duration, in order to avoid situations where a worker starts or ends with a meal break, while still having long uninterrupted hours of work.

Data and Methods

We have used a dataset containing the average demand of security staff during high season, where each day of the week has an independent curve. It is acceptable to consider a weekly cyclicality within the same season but this does not hold for different times of the year. For example, the last Monday of July will probably require a similar level of security staff compared to the second Monday of August since they

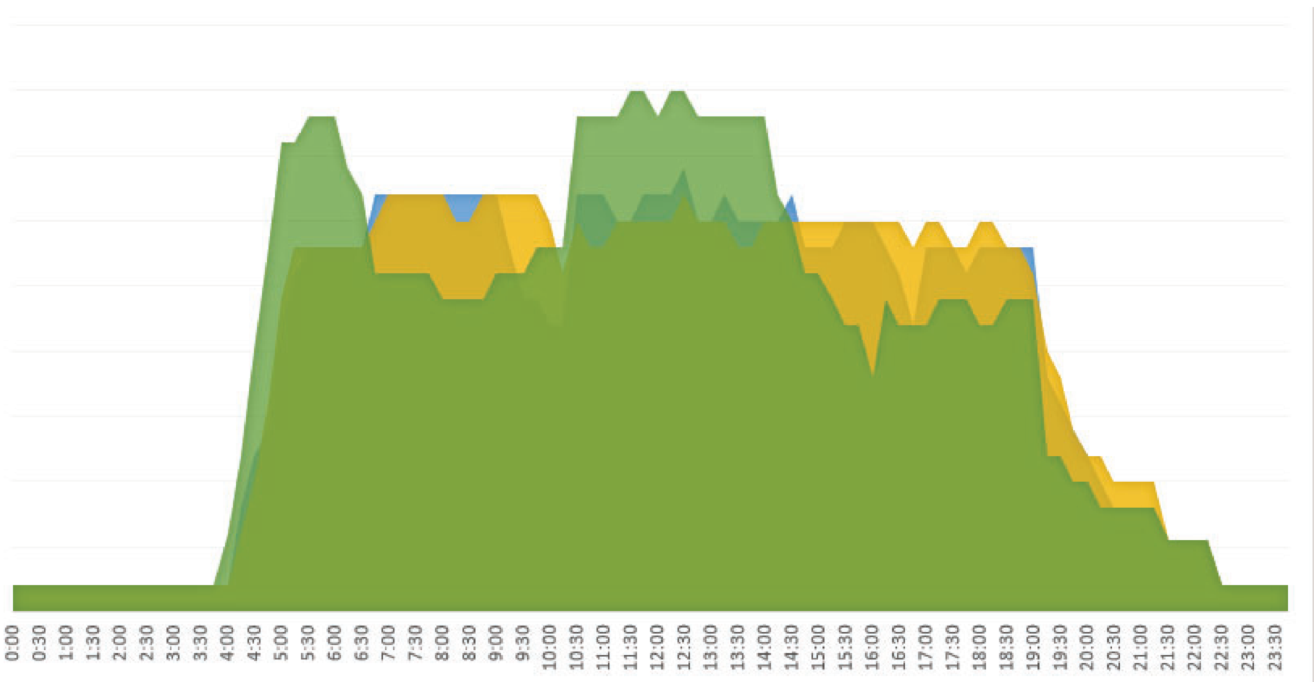

Figure 1. Example of demand curve.

are both in high season and with akin flight schedules. In contrast, a weekday in low season may have a very different demand than the same weekday in summer because the first one is mainly chosen by business customers, while the second one by leisure customers.

Every demand curve is expressed as number of employees required, with intervals of 15 minutes. An example of demand curves for three different days is shown in Figure 1.

The standard problem was solved both via a Hill Climber algorithm and a variation of the Large Neighborhood Search consisting of seven destroy and two repair methods. Furthermore, the meal break problem was solved with two different approaches. The idea behind the first method was to resemble a common human approach where, after the shifts are designed, a manager tries to place meal breaks in the best possible way. In contrast, the second approach takes the problem from a different angle and considers meal break allocation already from an early stage; meaning that every shift is designed together with its own pre-allocated break.

At first, this may seem as a small difference. However, it will play an important role in the final results.

Results and conclusion

If benchmarked against the best results available in the literature, both metaheuristics used to solve the CCSDP have excellent performance, with the LNS variation as the best one between the two solution methods. When it comes to analyzing the meal break extension of the CCSDP problem, it becomes more difficult to find other studies to compare the results with. Yet, one of the two methods used in our study was superior to the other one in every aspect – at least for this specific application of the meal break shift design problem.

When meal breaks are to be assigned on pre-defined shifts there is often a low level of flexibility, ending up in solutions that are far away from the optimum. In contrast, we notice that considering shifts and meal breaks allocation simultaneously widens the searchable solution space, allowing for many more options that would be otherwise disregarded. Unfortunately, this comes at the cost of a more complex problem to solve, making the method selection not always as trivial as it was for our instances.

One important takeaway from this study is that meal break placement is often overlook and considered as just a duty. Here we have shown that, with proper planning and by designing shifts that take employees breaks into consideration it is possible to reach a higher efficiency and to offer a better customer service. This application was restricted to the security personnel of an airport and it would be interesting to investigate how the same concepts may apply to different operational tasks and to other industry sectors.

References

[1] R. Lusby, T. Range, and J. Larsen, "A benders decomposition-based matheuristic for the cardinality constrained shift design problem," European Journal of Operational Research, vol. 254, pp. 385–397, 2016.

Daniele Lubrano holds a MSc degree in Industrial Engineering and Management from Danmarks Tekniske Universitet (DTU). Currently, he works as a Data Analyst for Danske Bank. He has several areas of interest, including operations research and deep reinforcement learning.

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Figure 1. One of the rolling stock depot of Chinese high-speed railway.

By Jesper Larsen, Qingwei Zhong, and Richard Lusby

Rolling stock scheduling with maintenance requirements at the Chinese high-speed railway

In China, the railway network, as in many other countries, forms an integral part of the transportation network. The Chinese High Speed Railway (CHSR) network in particular is an attractive service that provides fast, direct connections to many of the country's large cities. High-speed trains in China reach speeds of up to 350 km/h. In 2016 alone, there were some 1.4 billion passengers who used the service. By September of the same year the CHSR network had reached 22,000 km in length, and connected 295 stations. The network of CHSR at that time accounted for more than 60 percent of the world's HSR network. The CHSR has had tremendous success with growth rates above 20% in passenger numbers for a number of years and in 2015 the network for the first time serviced more than a billion passengers in one year. By 2025 the network will have a total track length of 38,000 km.

To serve this network, the CHSR operates a fleet of more than 2,600 high speed trains (also termed rolling stock units), of which approximately 2,300 are in operation on any given day and collectively cover 4,500 timetabled services. Every single rolling stock unit within the fleet must comply with certain maintenance requirement (e.g., time and distance checks) to ensure the safety of the system. High speed rolling stock units require advanced, technical equipment which is extremely expensive to purchase and maintain. Rolling stock associated costs account for a significant part of the railway investment in China. How to efficiently utilize the available rolling stock is therefore a question of paramount importance and motivates this research project. The lack of maintenance consideration in existing rolling stock decision support tools further motivates the research from a theoretical perspective.

When a new timetable is put into service at the CHSR, all dispatchers typically meet in person to devise a new rolling stock schedule. Depending on the complexity of the changes required, not to mention the experience of the dispatchers, a complete rolling stock schedule can take several days to produce. Manually constructed schedules not only consume significant amounts of manpower and time but may also not even satisfy all of the maintenance requirements.

Problem description

Rolling stock scheduling is a classical and an important optimization problem in the operational planning and execution of railway operations (for a general overview of planning rail operations see e.g., Lusby et al. 2011). This problem involves assigning so-called *compositions* to a set of timetabled *trips*. A trip specifies the movement of a train between two stations at a certain time. Associated with each trip is a forecast number of passengers who must be transported. To better match the demand in the network, it is possible to adjust the capacity of a train by (de)coupling rolling stock units at the delimiting stations of a trip. A composition simply refers to a specific set of rolling stock *types* coupled together in a specific order. At the CHSR, several different types of rolling stock are available. Some of the older types cannot be coupled to or decoupled from other units upon leaving a depot. Figure 3 provides an overview of all compositions available. A single unit of each type consists of eight rail cars.

Any composition must have at least eight rail cars, but not more than 16 rail cars. Coupling or decoupling can occur at the front or the rear of one rolling stock unit. The entire set of trips defines the timetable. In this process the forecast demand on a trip can be used to reduce the number of feasible compositions. A sufficient number of seats must be provided and it is therefore not possible to assign a composition that does not provide such capacity. Preventive maintenance is routinely applied to all rolling stock units. The necessary maintenance operations of an individual unit depend on the unit's running time and its accumulated mileage since its last maintenance check. In general, rolling stock units are subject to five levels of maintenance; however, in this work we only focus on level one maintenance, also termed daily maintenance. Daily maintenance is performed so that all rolling stock units must undergo a maintenance check every two days, or when the accumulated mileage exceeds 5,500km. The rolling stock scheduling problem we address therefore not only involves determining the most suitable composition for each trip to minimize operating cost, but also requires identifying a maintenance feasible trip sequences for every individual rolling stock unit.

Solution approach

We propose a solution approach that is built around the idea of decomposing the problem into two distinct components, which are then solved separately.

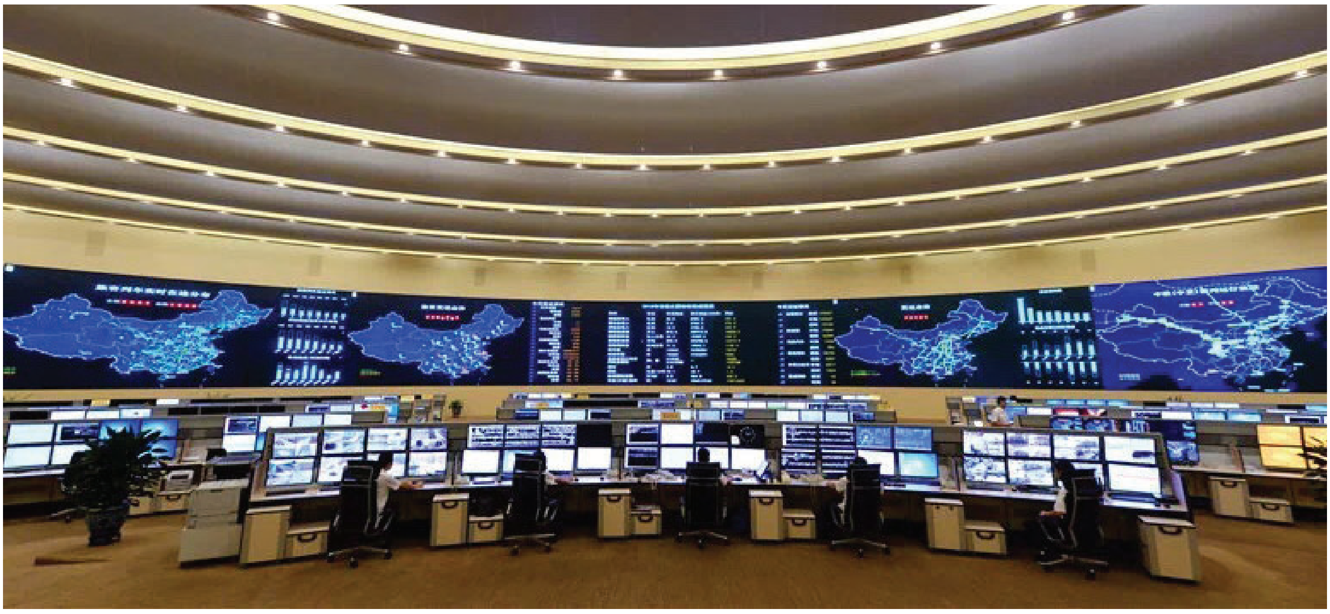

Figure 2 One of the dispatcher hall of Chinese High-speed railway.

Figure 3. Examples of train compositions.

• In the first step we solve the rolling stock scheduling problem ignoring all maintenance requirements to obtain many good rolling stock schedules. Efficient methodologies are available for solving this, and here we make use of the arc- flow model described in Fioole et al. (2006).

• In the second stage we then attempt to obtain a maintenance feasible rolling stock schedule by solving a series of assignment problems, using the rolling stock schedules found in the first stage.

The approach iterates between solving an extension of the conventional rolling stock scheduling problem and a maintenance feasibility assessment problem that attempts to assign maintenance feasible trip sequences to the rolling stock units. The maintenance feasibility assessment phase considers the accumulated mileage and running time of the individual units and tries to assign trip sequences that are compatible in terms of duration and total distance to each of the units. Both problems are solved as Mixed Integer Programming problems, and an iterative procedure is adopted since enumeration of the rolling stock scheduling problem is unnecessary. We stop as soon as the second stage returns a maintenance feasible schedule. The structured way in which the rolling stock schedules are considered ensures that we return a high quality maintenance feasible schedule. A full description of the approach can be found in Zhong et al. (2018).

The experiments

We test and compare the performance of the proposed approach on actual instances from the CHSR. An overview of this network is provided in Fig. 4. Two different timetables are obtained from the Zhengzhou Railway Company, the first is the timetable from 2017 (termed Data-1), while the other is the timetable currently in operation (termed Data-2). Our algorithm is programmed in C# and CPLEX 12.8.0 is used to solve the MIPs generated throughout our approach.

We perform several computational tests to assess the algorithm's performance. We consider a non-maintenance case (NM), a case when maintenance is enforced with our algorithm (M), and a case when our algorithm is forced to use the same simplifications as a manual dispatcher (M-D). These schedules are all compared to a manual schedule (MA). In addition, we also report the results for a day two planning horizon with our algorithm (M-2) and compare this with a two day manual solution (MA-2). The two day horizon is run as two separate days, where the input to the second day uses the planning of the first day as input. The key statistics of these cases can be found in Table 1.

In Table 1, the columns each refer to a key performance indicator a the CHSR. More specifically, 'RS', 'ARL', 'SRL', 'BRL', 'TREL' and 'AREL' refer to the number of used rolling stock units, the average running length (km) of each unit, the minimal running length (km) of a unit, the maximal running length (km) of a unit, the total empty running length (dead head mileage, km), the average empty running length (km), respectively. Column 'OP' and 'TC' indicate the number of units overnighting at stations and total the operating cost, respectively.

From Table 1, we can see that the M is not significantly different to NM in terms of the performance measures. Case M has slightly more deadhead mileage for both of the two datasets. Additional dead heading must be incurred when enforcing the maintenance requirements. However, it is possible to obtain a maintenance feasible rolling stock schedule with a marginal increase in operating cost.

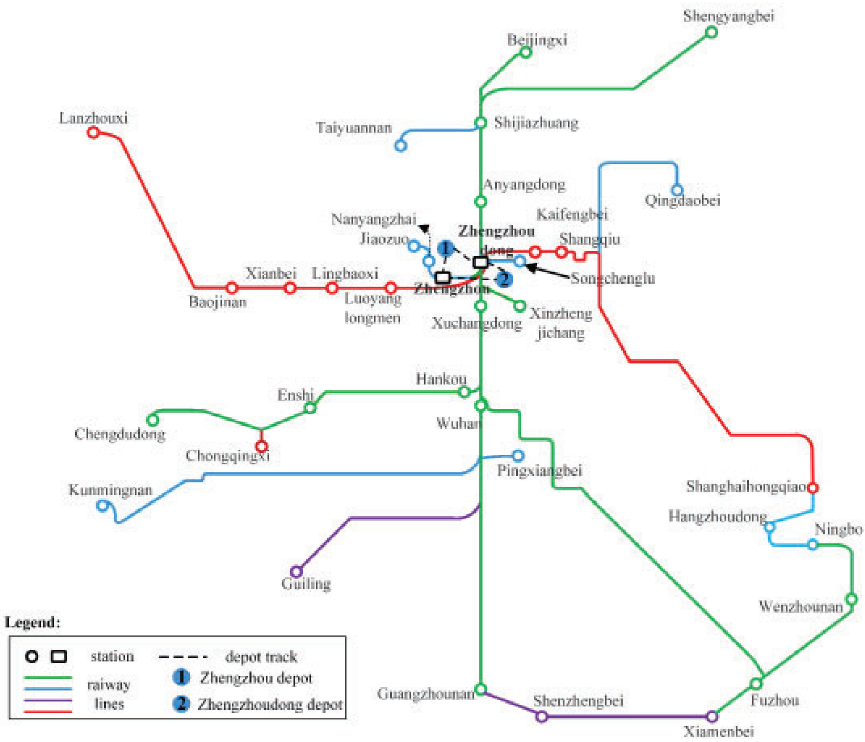

Figure 4. Sketch of China Zhengzhou Railway.

Looking at all cases with a one day planning horizon, it is clear from Table 1 that our approach can significantly reduce the deadhead mileage. Total deadhead mileage gradually increases across the instances NM to MA. The average rolling stock mileage in the optimized schedule is also higher than that of the manual schedule. Both the reduction in dead head mileage and the increase in rolling stock mileage help improve the utilization of the rolling stock units. In practice, the dispatchers always try to identify a schedule with long running distance and minimal deadhead mileage to make full use of the available rolling stock units.

Perhaps the most impressive statistic is the reduction in operating cost. Maintaining and operating an HSR is not cheap. Here the computation tests show impressive results. The total cost of MA is the highest and the total cost gradually increases from case NM to case

Data	Day	Case	RS	ARL	MRL	MARL	TERL	AERL	OP	TC
Data-1	day 1	NM	51	2679.6	565	4771	3225	63.2	13	812143
		M	51	2678.4	342	4763	3252	63.8	13	817161
		M-D	53	2577.4	130	4753	3257	61.4	13	844097
		MA	57	2435	183	4898	5291	92.8	13	870386
	day 2	M-2	51	2680	338	4986	3334	65.4	13	862711
		MA-2	57	2435	183	4898	5291	92.8	13	939374
Data-2	day 1	NM	65	2760.1	510	5316	4664	71.8	18	1026571
		M	65	2761.2	683	5316	4736	72.9	17	1034611
		M-D	65	2764.5	543	5316	4762	73.3	18	1034973
		MA	70	2575.7	571	5229	5240	74.8	16	1106565
	day 2	M-2	65	2755.4	631	5453	4728	72.7	17	1094765
		MA-2	70	2575.7	571	5229	5240	74.8	16	1173451

Table 1 Key statistics of different cases.

MA. Our approach results in operational cost savings of 6% and 7% when compared to the case MA for Data-1 and Data-2, respectively. Even when we limit the flexibility of our algorithm to mirror the simplifications made by the dispatchers, we still obtain savings of 3% and 6.5% for the two data sets respectively. It is important to state here that our algorithm without the dispatching simplifications still results in operationally feasible schedules. Limiting the flexibility simply limits the number of composition changes that are possible, and this greatly assists the manual dispatchers.

Another significant difference between the manual schedules and our optimized schedules is the decreased number of rolling stock units needed. In Data-1, compared with the case MA, the two cases M and M-D save six and four rolling stock units, respectively. For Data-2, the two cases M and M-D show a savings of five rolling stock units. The average cost of buying a new rolling stock unit in China is nearly €10 million. Using fewer rolling stock units can therefore lead to substantial cost savings. Furthermore, a reduction in the number of rolling stock units also reduces total operating costs, not to mention maintenance costs.

Conclusion

We have developed a two-stage approach for solving the rolling stock scheduling problem with maintenance requirements for a busy part of the CHSR network. Real-world instances provided by the Zhengzhou HSR network have been used to test the performance of the proposed approach. The computation time of our approach is trivial, which typically takes a few minutes in total, and the results demonstrate that our approach is significantly better than the empirical method used in practice in terms of solution quality.

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Qingwei Zhong is a Ph.D. student in Transportation planning and management from Southwest Jiaotong University, China. Now he is doing his visiting Ph.D. in Technical University of Denmark with Richard Martin Lusby and Jesper Larsen as supervisors. His research focused on railway optimization and his Ph.D. research project is the optimization of rolling stock scheduling at Chinese high speed railway.

Richard Lusby is an Associate Professor in operations research at the Technical University of Denmark, Department of Management Engineering. He received his Ph.D. in Engineering Science from the University of Auckland in 2009. His main research interests include large-scale combinatorial optimization problems and, in particular, optimization problems that arise in the Railway industry. Much of his work involves the development of decomposition techniques to solve these.

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By Julia Pahl, Dario Pacino, and Line Reinhardt

Highlights from AOO 2018

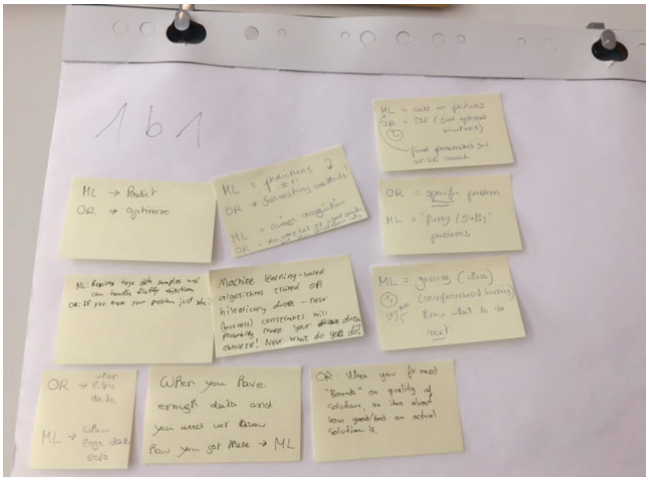
It was a sunny day in Copenhagen when the participants of this year's Applications of Optimization (AOO) event were welcomed at the Industriens Hus. AOO is an inspirational event organized by the Danish Operations Research (OR) Society for its members on a yearly basis. It discusses the latest developments in the field of OR and gives much space for networking and exchange of ideas with talks from national and international speakers.

This year's AOO was held on the 23th of April with four speakers and a newly introduced discussion workshop on current OR questions. We welcomed participants from companies such as Maersk, Optivation, PDC, Macom, Energinet, Novozymes, and Mosek. All technical Danish universities were present and to ensure the interest of the next generation to come in OR, four of the highest motivated students were invited to participate.

Two talks from academia and two from local Danish industries were given, namely Onlaw and AMCS Denmark. Kenneth Sørensen from the Universiteit Antwerpen, Belgium, started the day with his talk about metaphors and metaheuristics introducing the audience to very colorful and entertaining names and principles that can be found in the literature highlighting the problem of this field that lack standards and what it needs to overcome this challenge.

Figure 3. Stefan Voss from the University of Hamburg presenting at AOO 2018.

Simon Spoorendonk from Onlaw introduced the audience to their platform that uses an artificial intelligence toolbox provided to legal professionals to search for legal content. He gave a demonstration that provided a vivid and clear understanding of this field together with a nice discussion on the challenges.



After the lunch break, Stefan Voss from the University of Hamburg talked about the digital transformation in maritime shipping and presented a new conceptual framework based on game theory to foster collaboration of stakeholders. Remaining in logistics, the day concluded with the talk of Jonas Bæklund from AMCS Denmark on commercial waste route planning showing us how complex the problem can become including different possible objectives, side constraints, and problem size.

Besides the space for networking with other DORS members in the coffee breaks and during the gourmet lunch, a new concept was introduced on the AOO-agenda which was a discussion workshop that was organized as a kind of "speed dating." Participants were randomly grouped for short discussions and re-grouped for the next rounds. Questions to be discussed were, e.g., when to use OR and/or machine learning. The results of the discussion were presented to the overall audience in the end and gave food for further thoughts and talks during coffee break. Participants feedback was very positive, so we think of continuing experimenting with such activities on socializing and networking.

The board of DORS and the organizers of AOO 2018 would like to thank all the participants and the speakers that have made AOO a success. Our special thanks go to our sponsors: Mosek and Optivation.

We love to welcome you to the next AOO 2019 in sunny Copenhagen on the 6th of May 2019!

By Michael Lindahl

Artificial Intelligence and optimization in the shipping industry

Artificial Intelligence (AI) is currently a popular topic of discussion in the business community. Though the concept might sound futuristic, AI applications are already shaping parts of our everyday lives. Throughout this post we will cover the general concept of AI, its evolution through the years, and ultimately why AI will grow to become a key growth driver in many industries (including shipping) over the years to come. Operations Research and Artificial Intelligence is two different framings of the same technology. Where A.I has been focused of automating human decision making, O.R has always been driven towards making the best decisions and getting a higher understanding of the problems we are solving.

What is AI?

At this point AI has become mainstream business lingo, but the term AI has been around for many years with varying popularity over the decades. The film community was one of the first to embrace the concept of AI. We can trace examples all the way back to Fritz Lang's iconic 1927 sci-fi film Metropolis which features robots mimicking human behavior. AI-pioneer John McCarthy was the first to coin the term AI.

McCarthy defined AI as »machines that can perform tasks that are characteristic of human intelligence.[1]«

General vs. Narrow AI

When looking at AI, it is helpful to distinguish between what is known as General AI and Narrow AI.

General AI encompasses the more movie-like way to look at AI. Think about a supercomputer which possesses all the capabilities of human intelligence. An example from Hollywood is the Terminator, a robot that can learn, think, and make decisions on its own as a result of its' advanced General AI operating system. At this point, General AI systems like this are still far out in the future. When we see impressive breakthroughs in AI today, they are contained to a single specific task.

We have seen IBM's Watson beat the grandmasters in Jeopardy, but we would not be able to for instance play a game of chess against it [2]. Similarly, Google's AlphaGO beat the world's best Go player, but the computer would not be able to answer even the simplest question. However, as these examples shows, an AI just has to be very good at one thing to be useful, which brings us to Narrow AI.

Narrow AI is when a computer imitates human intelligence in one particular area and performs the task more efficiently than any human can do. One of the first famous examples of this is IBM's Deep Blue computer that beat Garry Kasparov in chess in 1997. More recently, we have seen huge break-throughs in image recognition where computers have surpassed human performance in identifying objects. Faster computers, better algorithms, and more data have sparked a revolution in narrow AI, and we are now seeing an explosion of these systems across industries. The O.R community has been a main-driver in this revolution when it comes to making impact in businesses and organizations. By tackling complex decision problems one at a time and applying advanced mathematics and computer science to drive better decision making.

Computer-aided decision making in industry

Using computers to guide decisions in different industries is nothing new. Most truck drivers rely on a GPS to find the fastest and most energy-efficient route to their destination, and delivery companies use computer systems to find which packages should go into the same truck to minimize delivery costs. Banks rely on fraud detection systems that search through a large amount of data to find suspicious transacti-

Figure 1. Photo by chuttersnap on Unsplash.

ons, and flag them for further investigation by a human. Today we are already benefitting significantly from Narrow AI in our everyday lives.

It is all about collaboration between humans and AI. For AI-driven systems to achieve the highest impact possible, it is crucial that they are operated and monitored closely by humans. For example, after Deep Blue beat Kasparov in chess, a new form of chess took rise called freestyle chess. It allowed teams to combine both humans and machines to compete against each other in a tournament. Chess grandmasters teamed up together, and the most advanced chess computer at that time, Hydra, also competed.

This provided an important new insight. The advanced chess computer performed well as expected, and the team of chess grandmasters also did very well. However, two amateur chess players using a less advanced computer program were able to far outperform both the better chess-players and the computer programs individually. The two players used their strategic skills to control the direction of the game and the computer's abilities to search through millions of moves quickly to ensure that no errors were made.

Decisions arising in business are vastly more complex than chess. The space of potential solutions to a problem by far exceeds the 64 squares on a chess board. Moreover, in chess there is a clear and unchangeable ruleset that determines how to win, whereas in business you often have many conflicting interests to consider. You want to minimize costs, minimize risk exposure, and maximize customer satisfaction all at the same time, but with different weight in different situations. Because of these factors and dynamic environment, collaboration between humans and AI is the most likely way to win.

Research supports this view, showing that companies that incorporates human and AI collaboration into existing processes achieve higher return of investment than the companies that focus merely on automating manual tasks [3]. At Portchain our philosophy is the same. We believe that the highest impact on operational results can be achieved when humans apply AI-methods for enhanced decision support, rather than merely focusing on task automation.

How AI will transform the shipping industry

AI will transform almost every industry. McKinsey & Company for instance predicts that transport and logistics will be one of the industries that will experience the most value generation from AI support [4].

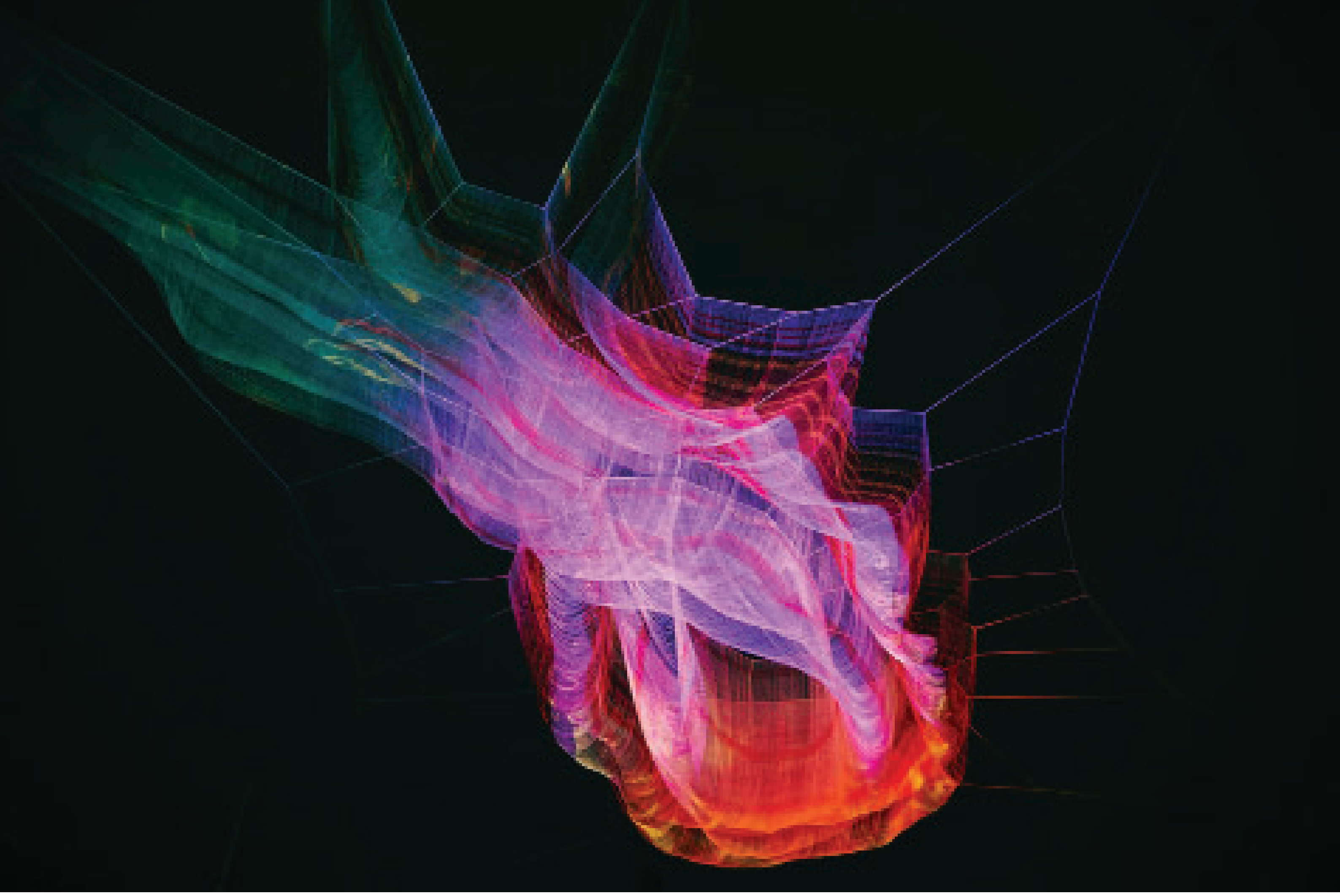


Figure 2. Photo by Arif Wahid on Unsplash.

Transporting 90% of all manufactured goods, container shipping is one of the most complex industries in the world. This is why it is one of the industries that will reap the largest benefits from applying AI technology to its operations. There are millions of combinations in which one can ship containers from A to B, and every single decision needs to take multiple factors into account. For example, to change the ETA of a single port call you need to be aware of berth availability, transhipments, impact on bunker usage, weather conditions, and so on.

At Portchain, we are leveraging what we believe are the two most important AI value drivers in container shipping: **Prediction and Optimization**.

• **Prediction**: A basic condition in shipping is that you always need to be ready for disruptions as they occur constantly. Weather, equipment breakdowns, and other events cause 48 percent of container ships to arrive more than 12 hours behind their original schedule [5]. Using machine learning we can, for example, predict potential berth conflicts sooner, and allow the planner to respond both more quickly and proactively to disruptions.

• **Optimization**: Shipping requires large investments in the form of vessels and terminal equipment. It is therefore crucial that both terminals and carriers utilize their assets as efficiently as possible. For terminals, constructing a berth plan is very complex with an exponentially rising number of possible combinations, each with different pros and cons. Using mathematical optimization, we can include all these factors to make significantly more efficient plans that reduce cost while increasing utilization of network and terminal. This increases the capacity of both terminals and vessels without the need for additional investments.

Putting it all into practice

Given the complexity in shipping, all companies rely heavily on experienced operational planners. When resolving operational conflicts, they draw on their experience to make the right trade-offs to create the operational plans that are most beneficial to themselves and their stakeholders under the given constraints. At Portchain, we have seen how AI enhanced decision support can support planners in these situations, as a GPS giving you different optimal options to choose from. Different solutions may optimize specific KPIs e.g., lowest cost, least impact on the network, or maximum asset utilization. Ultimately the experience of the planner that ensures that the best plan is chosen for a particular situation.

At Portchain, supporting operational planners to make more optimal decisions is our core mission. When a planner needs to make a decision, our algorithms synthesize all crucial information and constraints, calculate and compare millions of potential solutions, and present the optimal solutions to choose from — all in less than 60 seconds. The planners can then in turn tweak and compare options to select the preferred solution, relying on their vast experience, like the chess players mentioned earlier. Our AI enhanced decision support products for terminals and carriers help planners reduce cost and maximize capacity, while always remaining in full control.

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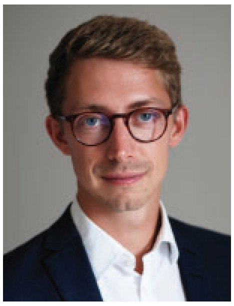
Michael Lindahl is Head of Analytics at Portchain, a digital startup specialized in using advanced analytics to create user-friendly solutions in shipping, both for carriers and terminals. He has a PhD in Operations Research from the Technical University of Denmark. Michael was also president for DORS from 2015 to 2018.



Her kunne din artikel have været!

Send dit bidrag til orbit@dorsnet.dk

By Vagn Ro Knudsen and Jakob Krarup

DAPS Society, European OR Seminars: the first forty years

Who rowed the boat across the stream: the starboard or the port oarsman? A pertinent question for papers having two authors as they, in most cases, cannot be distinguished from one another. Thus, the visible result of their joint efforts normally represents true teamwork.

The present paper, however, is an exception in this respect as the gateways to the subject addressed are entirely different for its two authors. Accordingly, the story to be told is organised into four parts. Initially, Jakob accounts for the background up to 1978. Vagn, by that time being Jakob's M.Sc. student at DIKU (Dept. of Computer Science, University of Copenhagen) reports on the first seminar. The two last sections covering the ensuing period 1978-2018 and the epilogue are true teamwork.

The background

Milestones along the road towards the conception of DAPS Society are the birth of Linear Programming, the establishment of the first OR division in Denmark, the increasing interest in "yes/no" decisions leading up to Combinatorial Optimisation and, finally, the NATO Advanced Study Institute on Combinatorial Programming (Versailles, France, 1974).

There is no Nobel Prize in mathematics. Otherwise, and beyond all doubts, the recipients of this prestigious award would have included George B. Dantzig (1914-2005) who in 1947 devised the Simplex algorithm for solving Linear Programming (LP) problems. All constituent data of an LP are real numbers and the same applies for the decision variables whose values upon termination of an LP-solver represent an optimal solution. Still today, perhaps upon having emphasized that modelling inevitably is an art, an abundance of textbooks on OR embark from LP.

The years up to the early 50s, however, witnessed an increasing interest in models for which a "yes/no" answer was sought. Thus, for example, before the Great Belt bridge eventually materialized in 1998, dozens of reports were written with the overall purpose of answering the question: should the bridge actually be built or not? Essentially, and disregarding other aspects of the problem, we are dealing with a model with but a single decision variable x which can take the values 0 and 1 only: $x=1$ yes, build the bridge, $x=0$ no. Resorting to LP only, the Simplex algorithm may return $x=0.551$. How to interpret this answer: should only about one half of the bridge be built?

Upon having graduated from a Danish upper secondary school in 1954 and endured two years of compulsory military service, time was ripe for making a decision on what to do next. In the mid 50s OR and computer science were still to become academic disciplines and no courses were on the curriculum of any Danish university. To go for pure maths was indeed a possibility though not really appealing viewed against later career prospects.

Considering all pros and cons I enrolled at The Technical University of Denmark (DTU). Upon two years of study I failed in June 1958 to pass an exam in electrical engineering; a great

The first seminar, Zaborów, Poland, 1978.

luck in retrospect. By that time, Richard Petersen, Denmark's first professor of applied mathematics had recently been appointed. Besides being an inspiring teacher at DTU he was also the first Chairman of the Board of *Regnecentralen* (RC), Danish Institute of Computing Machinery, where Denmark's first computer called DASK was built and officially inaugurated in February 1958. Richard Petersen was approached and arranged for me to join the staff at RC subject to the condition that the remaining part of the studies towards the M.Sc. degree should be completed concurrently.

The staff at RC comprised in 1958 an astronomer, some graduates in engineering, economics or political science, and a gathering of undergraduate students who felt uncomfortable with what they were doing. We were about 20 in total, all curious to find out what DASK – a construction of monstrous size which occupied two floors of a spacious villa – could do. 56,000 basic operations per second. 2,048 words each of 40 bits. 2 magnetic drums. I wonder whether the term *computer science* actually meant anything to anybody at that time. It is tempting to say that the field here was invented 'on location' and achievements, including the development of a full ALGOL-compiler, were indeed made with far reaching impact on other researchers world-wide.

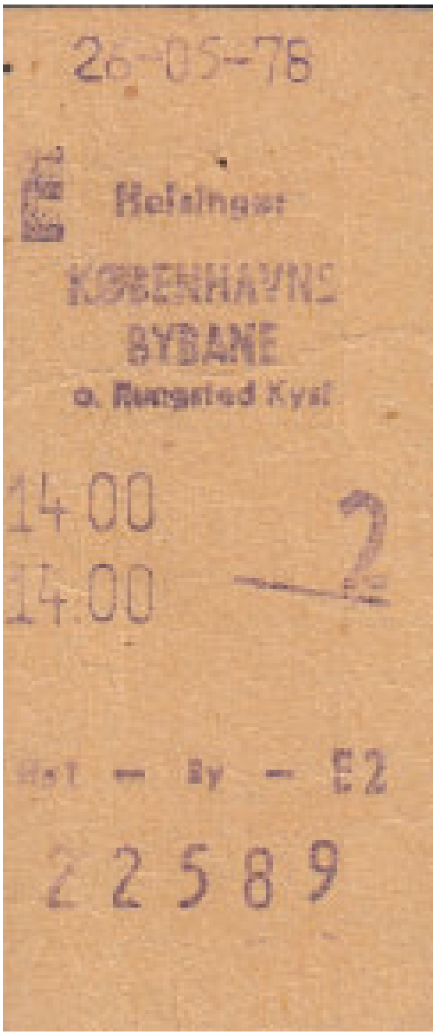
Still with no flair for electrical gadgets and no professional niche in sight, I found the climate around DASK and its users appealing in every conceivable aspect. As the variety of applications further broadened new books had to be purchased for RC's library. Among these was Steven Vajda's 'Mathematical Programming'. A first entry to Operational Research, OR, a magic word! The first OR division in Denmark was established at RC in 1959. Were we two or three? A new world opened itself before us. From conceptually simple scenario analyses we moved on via LP and were soon spellbound by the fascinating computationally 'intractable' integers. Actually, this fascination about zeros and ones – to the exclusion of almost everything between these two extremes – has remained with me ever since and appeared to be crucial to my later career.

Sic transit ... : The period later referred to as 'the Golden Years' terminated in 1964 when RC, due to an appalling incompetence of some individuals in the Danish government, had to surrender to IBM. The staff broke up. Nine full professors at Danish universities or abroad could afterwards be grateful for having been part of a highly esteemed team.

The direction set by the lesson learnt so far at RC was further pursued in my Ph.D. work at IMSOR (Institute of Mathematical Statistics and OR, DTU) established in 1963 and headed by Professor Arne Jensen (1920-2008). I am grateful to Arne, my thesis supervisor at that time, not primarily for his supervision as such since our professional interests hardly intersected, but for his emphasis on the significance of building a personal network and his creativity in finding support for conference participation and the like. The most important event of that period was a two-week NATO Summer School on *Contemporary Methods of Discrete Mathematics* (Varenna, Italy, 1966) directed by leading scholars in the field. Besides an invited speaker was awaited with particular anticipation, a certain Professor S. Vajda ... . This first meeting with Steven in person had a considerable impact on my further Ph.D. work. Feeling unable to follow my supervisor's ideas on statistical equilibrium and the like, much more fruitful ways were pointed out by Steven and brought me eventually out of the wilderness.

The fall term in 1969 was spent at Univ. of California, Berkeley, which, amongst others, offered a possibility for visiting George Dantzig and Dick Cottle at nearby Stanford University. The three of us were shortly after in charge of the NATO Conference, '*Optimization Methods, Large-Scale Resource Allocation*' (Elsinore, Denmark, 1971) which in turn led to membership of NATO's Systems Science Panel (1974-79), the main sponsor of a series of subsequent events, notably the NATO Advanced Study Institute on *Combinatorial Programming* (Versailles, France, 1974) and five years later the NATO Advanced Research Institute on *Discrete Optimization* (Vancouver, 1977). Note that NATO's role in this respect was completely disentangled from its military activities. Thus, participation was not restricted to people from member countries and the resulting proceedings volumes were made accessible to all as part of the open literature. In retrospect one may say that these meetings were crucial in propelling combinatorial optimisation and related areas to prominence. Moreover, several of those who later became the central figures in the further development assembled here for the first time.

The famous ticket which saved our return to Denmark after the Zaborów meeting in 1978.



Among the participants at the Versailles meeting was Professor Stanislaw Walukiewicz, or *Staszek* among friends, by that time Head of a research group at SRI (Systems Research Institute, Polish Academy of Sciences, Warsaw). Imagine the chaotic and indeed dangerous situation that might arise unless air traffic controllers employed at international airports world-wide had not agreed on English as their common language. Less dangerous but still inconvenient is it that significant results within some branch of science are published in the open literature but in different languages, and hence, not accessible to all potential readers. In 1974, English was, and is still, the first foreign language taught at Danish schools as opposed to Poland where Russian was ranked first. This annoying fact was one of several good reasons to initiate cooperation between SRI and DIKU, in the first round in terms of organizing a seminar for staff members at SRI and graduate DIKU-students specializing in OR with the aim of establishing a framework for both parties to address an international audience – not in Russian(!) - but in English. This idea, fostered by two soulmates was in retrospect the real conception of DAPS Society. As a first step ahead I taught a course in the Spring semester 1978 for graduate students preparing their M.Sc. theses under my supervision. The students presented their works in English, criticized each other, and improved their presentations until the ultimate result was deemed acceptable. Partially sponsored by the Polish Academy of Science we departed on 26th May 1978 from Copenhagen for the first Danish-Polish Mathematical Programming Seminar to be held in Zaborów near Warsaw. In addition to the two main target groups, also a handful of senior researchers from Hungary, Sweden, and (West) Germany were invited.

References: Being invited to address a conference organized by EWG-DSS, the EURO Working Group on Decision Support Systems (Graz, Austria, 2012), an interview appeared afterwards in EWG-DSS Newsletter 12. Due to its very limited circulation, I have in Section 1 taken the liberty of reusing minor parts of the text. Another pertinent reference is the ORbit article (Krarup, 2017) providing my personal recollections on OR in Denmark with emphasis on the period up to around 1979.

The first meeting in Zaborów

We prepared all semester for our presentations at the upcoming seminar. Each had to make a half hour presentation "based on the subject of our master thesis" – which most of us had not even begun at that time. Meticulously we presented to each other and received comments and advise on our performance. Yes, we were quite well prepared.

Then in late May we went to Poland, by ferry to Swinoujscie, by train to Warsaw, and, finally, by bus to Zaborów, a magnificent mansion located west of Warsaw, where we were to meet our

DAPS-85, "Rolighed", Denmark.

Polish counterparts for the event named PDMPS (Polish Danish Mathematical Programming Seminar).

Maybe we should have guessed earlier from the invitation letters addressed to "Dr. so-and-so"; but we still expected to meet a group of Polish students. On arrival, we got the final list of participants and were somewhat aghast to see it. This was not a group of Polish students, but rather a group of senior scientists, many real doctors. Some of the names were recognized and a whisper started: "These are the people who wrote our text-books. How are we going to perform here?"

Our professor advised us to remember that on our own specific subject, we were quite likely to be among the very few world experts. Also, that with our careful preparation we could probably perform well. And finally, our command of English was often superior to many East-Europeans of that time. So, over the next 4 days, with trembling hearts and hands we went to the lecture hall, gave our presentations and actually survived. This experience bolstered our self-confidence, and since then going to oral exams has been a walk in the park, because "we have performed for higher brows than these".

Fortunately, besides the strict, scientific programme there was also a rich social programme, which may have been an even more profound experience. We came to see and know these highbrows, not just as stiff academics (well, a few may have been), but as real living human beings, who were really fun to be with.

A group ticket comprising all members of the Danish delegation and valid for the train ride Swinoujscie-Warsaw round trip, was issued by DIS travel agency, Copenhagen. No problems on the out-ward journey. But what happened by our departure from Warsaw? To bid us properly farewell, Staszek joined us all the way to the right platform at Warsaw Central Railway Station. By the time of our departure with the overnight train, however, he realized that the train ticket for some reason was left in his office at SRI. As no other means of transportation were available on that evening, we felt compelled to climb the train and hope

Year	Location	Country	Organizer
1978	Zaborów	Poland	Stanislaw Walukiewicz, SRI
1979	Småland	Sweden	DAPS-DK (preparations for DAPS-79)
1979	Rolighed	Denmark	DAPS-DK
1980	Visegrád	Hungary	András Prékopa, MTA-Sztaki, Budapest
1981	Bad Honnef	(West) Germany	Rainer Burkard, TU Cologne
1981	Bornholm	Denmark	DAPS-DK (discussing the future of DAPS)
1983	Zaborów	Poland	Stanislaw Walukiewicz, SRI
1984	Dijon	France	Christian Michelot 1)
1985	Rolighed	Denmark	DAPS-DK
1986	Leibniz / Graz	Austria	Rainer Burkard, TU-Graz
1988	Frankenau	(West) Germany	DAPS-DK

Table 1.

1) The EURO Working Group on Locational Decisions


May 1986: Vagn presents his finalized M.Sc. thesis to his supervisor.

for the best. Two compartments, each accommodating 6-8 people, were found but locked with a "Reserved" sign posted on the door. Obviously, they were booked by us! Eventually the ticket inspector showed up. As none of us were capable of saying anything meaningful in Polish, fragments of other languages were attempted to explain the situation but of no avail. The matter remained unsolved until Jakob produced a ticket dated 26-05-78 "Helsingør – KØBENHAVNS BYBANE o. Rungsted Kyst". Heureka: the inspector smiled, stamped the ticket, and unlocked the doors. Poor Staszek: in the belief that we might have been deported to Siberia or the like, spent most of the night in his office waiting in vain for a telephone call. Called on the day after upon our safe return to Denmark, however, Staszek was more than just relieved. About a week later the missing ticket was sent to us. Realizing that only one half was used, DIS agreed favourably to refund the difference.

DAPS Society (1978-2018)

The experiment with the excursion to Poland turned out to become a highly memorable event for all involved, the happy side effect being that the foundations for lasting friendship were laid among many. We wanted to see each other again. It was therefore agreed that this series of seminars deservedly should be continued with the same group of DIKU-students, and Denmark was an obvious choice as site for its successor.

The acronym *DAPS-79* was coined for the less idiomatic 2nd DAnish-Polish Mathematical Programming Seminar held at "Rolighed" in May 1979. "Rolighed" is a marvellous estate located north of Copenhagen with a view across Øresund to

Year	Location	Country	Organizer
1994	Birkerød	Denmark	Maurice F. Shutler [2] et al.
1998	Møn	Denmark	DAPS-DK
2003	Wierzba	Poland	DAPS-PL
2007	Felberg/Warsaw	Poland	DAPS-PL
2008	Prague	Czech Republic	DAPS-PL
2009	Bornholm	Denmark	DAPS-DK
2010	Swinoujscie	Poland	DAPS-PL
2011	Budapest	Hungary	Piroska Turchányi [3] et al.
2012	Berlin	Germany	Marek Trojanowski [4] et al.
2013	Amsterdam	The Netherlands	Barbara Bjørn Olsen [5] et al.
2014	Craców	Poland	DAPS-PL
2015	Bornholm	Denmark	DAPS-DK
2016	Bornholm	Denmark	DAPS-DK
2017	Langeland	Denmark	DAPS-DK
2018	Lund	Sweden	DAPS-DK

Table 2.

2) Monopolies & Mergers, London. Visiting Professor at London School of Economics. President of EURO 1993-1994. Deceased in 2015.
3) Participant at several DAPS-seminars as of 1979. Staff member at MTA-Sztaki, Budapest, now retired.
4) Staff member at SRI and member of DAPS-PL.
5) M.Sc. from DIKU. Staff member at SAS Institute, Copenhagen. Joined DAPS-DK in 1989.

Sweden; an ideal site for smaller meetings and well equipped with everything needed. DORS, the Danish OR Society, was actually founded there on 21 august 1962.

The organization of DAPS-79 was in the hands of, what henceforth is termed *DAPS-DK* which largely comprises the Danish attendees – the students and their supervisor - at the first seminar. Similarly, *DAPS-PL* is the group consisting of Staszek and those of his staff members who still show up at the annual seminars.

DAPS-79 was originally intended to be a vehicle for further cooperation, primarily between SRI and DIKU. Due to generous grants received from Danish research foundations, however, it was possible to invite not only all eight staff members from SRI but a similar number of leading scholars in the field from England, Hungary, The Netherlands, Switzerland, United States, and (West) Germany. Furthermore, virtually all Danish researchers within discrete optimization and combinatorics were here brought together for the first time. In addition to the residing participants, certain parts of DAPS-79 were also attended by the Board of Officers of DORS as well as representatives from various private companies including most of the OR consulting firms in Denmark. To find means for an extensive social programme, a heavy registration fee was charged to those who could afford it – and were willing to pay.

As evidenced by the following list, and disregarding the preparatory meetings in 1979 and 1981, the series of seminars continued. See Table 1.

Upon the last student's graduation in 1986, the scientific content was reduced and likewise for the duration of the seminars. Accordingly, *Annual Meetings* rather than seminars is a more apt term to describe how the series was resumed as of 1994. Note that the word "annual" should be taken with a grain of salt as evidenced by the lacunas in the overview in Table 2.

1982 is the first blank spot in the series of seminars. What happened? *Martial law* in Poland, proclaimed by Prime Minister Wojciech Jaruzelski refers to the period of time from 13 December 1981 to 22 July 1983, when the authoritarian communist government of the Polish People's Republic drastically restricted normal life. Citing purported recordings of Solidarity leaders planning a coup, martial law was introduced in an attempt to crush political opposition. The DAPS file is silent as regards a regular seminar in 1982. Knowing that our Polish friends and colleagues during the stern days were anxious to maintain our usual connections, however, a subset of DAPS-DK paid a visit to Warsaw, armed with medicine and other items believed to be articles in short supply or possibly not within reach at all.

The duration of each seminar was normally five days with attendance limited to about 45-50 people comprising the "hard core" of DAPS veterans plus a larger contingent from the host country. As to the scientific content, emphasis was originally placed on combinatorial optimisation but room was also allowed for other areas of theoretical and applied OR. Thus, several seminars have witnessed an increasing proportion of contributions dealing with stochastic programming,

DAPS-85: Professor Jørgen Tind's presentation of Karmarkar's interior point algorithm.

Staszek and Jakob heading for the banquet along the Rhine at EURO 2009, Bonn.

multicriteria decision-making and case studies of various kinds. Formal proceedings were published after the first two seminars only; later on, authors of selected papers were encouraged to submit them for publication in first-rate journals, notably the *European Journal of Operational Research*.

The members of DAPS-DK joined forces anew when DAPS-85 was on the drawing board. Upon having booked "Rolighed" for the second time and having submitted a bulk of applications for financial support to selected foundations and private companies, we realized the advantages of establishing a society as an official framework for similar activities in the future. While the DAPS acronym for all practical reasons should be preserved, the subtitle "European Operational Research Seminars" was added to stress its wider scope. As the result of these deliberations, DAPS Society materialized on 21st July 1984 when the founding General Assembly Meeting took place. Subsequently, and upon having approved the by-laws, DAPS Society was officially registered with the Danish authorities.

Among all the seminars held on Danish soil, DAPS-85 appeared to be the most ambitious as regards both the scientific and the social programme. Furthermore, in addition to the Danish and Polish delegates, we managed to attract "big OR wheels" from Université Libre de Bruxelles - Vrije Universiteit Brussel – CORE, Louvain-la-Neuve - Imperial College, London - Technion, Israel Institute of Technology - Universität Bonn - Universität Kaiserslautern - TU-Graz, Austria. Heavenly weather throughout prompted us now and then to leave the indoor lecture hall and instead move the overhead projector to a shady corner of the lawn. Thus, amongst others, Jørgen Tind's presentation of Karmarkar's "interior point algorithm" (the shrinking water melon!) under unusual conditions turned out to become a particularly spectacular affair.

Close contact with both EURO, the Association of European OR Societies within IFORS, and IFORS itself has been maintained throughout in one way or another. Cross fertilization is probably an apt term in this context. Thus, the annual, up to week-long, seminars held in various European countries may in hindsight be viewed as a forerunner of the EURO Summer/ Winter Institutes launched at the initiative of J. Pierre Brans in 1984. Concern for the next generation, the best investment in the future! Furthermore, over the years no less than six EURO presidents, two IFORS presidents, eight presidents of national OR socities, four EURO Gold Medal laureates, three winners of the EURO Distinguished Service Medal, and Helle Welling, Secretary of IFORS 1976-1998, have been among the participants at various DAPS events.

Epilogue

Outside the DAPS framework, the close cooperation primarily between SRI and DIKU materialized also in other ways. Thus, Staszek served several times as a Visiting Professor at DIKU, in 1979 for five months. Furthermore, in 1990-1992, Susan Powell (London School of Economics), Maurice Shutler, and Jakob were among the members of a European consortium sponsored by the TEMPUS programme of the European Commission with the purpose of building the entire curriculum for what afterwards became Warsaw Business School having Staszek as its Rector (Krarup et al., 1996).

"Blood, toil, tears, and sweat": between 1979 and 1986 all student members of DAPS-DK managed eventually to complete their M.Sc. theses. Afterwards all the by now full-fledged computer scientists left academia and built a career, few, if any, as operational researchers, but as consultants affiliated with various private companies within the broad area nowadays called Information Technology. Their contact with DIKU, however, was maintained up to 2006 when their supervisor retired. Thus, all have served as external examiners in conjunction with the course "Computer science in practice" taught by Jakob for about 25 years. And all have enjoyed the ensuing dinner (in January, for the most) upon a long day at work. It is in this context noteworthy that six out of eight of the original group of graduate students plus their supervisor actually managed to stay together for forty years, an achievement steeped in devotion to a common task and *friendship* where the latter, as time passed by, developed to encompass our families as well.

Today, almost all the former students are retired and several are nursing their grandchildren. As of 2007, DAPS-X, held in year X, has been reduced to but an extended weekend starting on the first Thursday in September, primarily together with DAPS-PL plus a few DAPS-veterans from other countries. In view of our different interests in professional matters as they have developed over the years, there is no longer a formal, scientific programme whereas presentations spiced with nostalgia still are welcome.

The old emeritus' and second author's closing remark: To me the engagement in DAPS Society has been a true *con amore* activity spanning 40 years so far. Preferably accompanied by Staszek, I look forward each year to the annual January dinner at our *Stammtisch* in an Italian down-town Copenhagen restaurant since the mid 80s offering a true red carpet treatment to "*Il Generale*" (me!) + Co. Then, in this moment of writing, there is the forthcoming DAPS 2019, scheduled to be held in Kolobrzeg, Poland in September 2019.

Overall conclusion. Regardless of their field, university professors and other teachers should feel encouraged to travel with their students, to train them in presenting their work also in English if different from their mother tongue, to confront them with international audiences, and to assist them in meeting with the right people at the right moments in order to build their personal network. These initiatives may prove to be invaluable for the students' later careers. Besides, the most precious side effect should not be ignored: the lasting friendships that may evolve along the way.

Acknowledgments

A host of renowned OR people outside Denmark and Poland has over the forty years contributed to DAPS Society in one way or another. Our debts are gratefully acknowledged to today's *professores emeriti*, J. Pierre Brans (Vrije Universiteit Brussel), István Maros (University of Pannonia, Veszprém), Carl D.T. Watson-Gandy (Imperial College, London), and Dominique de Werra (Ecole Polytechnique Fédérale de Lausanne). A lot is also owed to professors Ulrich Derigs (University of Cologne), and Ulrike Leopold-Wildburger (Karl-Franzens Universität Graz), both still active though presumably approaching their retirement. Sorely missed are László Béla Kovács (1939-2016), Heiner Müller-Merbach (1936-2016), András Prékopa (1929-2016), and Maurice F. Shutler (1931-2015). Like all the other still alive they have enriched our lives. May they rest in peace.

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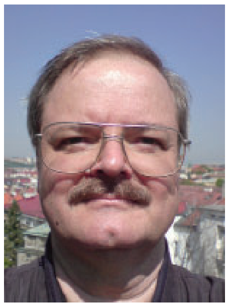

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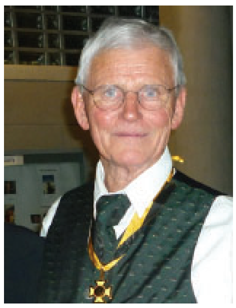

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