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December • 2019

Smart Fleet Size and Mix Decision Making • Optimization in Nurse Rostering • Opportunities in Autonomous Shuttle Services • DORS Master Thesis Article • A Review of Selected Research Papers

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Leder

Kære Læsere,

Lidt forsinket, men nu er dette nummer Af ORbit ude og vi håber, at I vil tage godt i mod vores nyhedsafsnit, som informerer om de seneste begivenheder samt det nyligt introducerede afsnit "Who is Who".
Afsnittet præsenterer kollegaer, deres forskningsområder og deres aktuelle projektarbejder inden for Operations Research. Sidstnævnte skal gerne gradvist give en oversigt over de personer, der er aktive indenfor Operations Research i Danmark.
Vi håber, at det vil give mulighed for at lære hinanden at kende og at der opstår udbytterige samarbejdsinitiativer.
Vi har samlet en række interessante artikler om blandt andet "smart fleet size", blandet beslutningstagning til indsamling af blodprøver, optimeringsmetoder for sygeplejepersonalets vagtskemaer, muligheder for selvstyrende shuttle services, lineær forsendelse som emne for DORS Master Thesis Price samt en gennemgang af udvalgte forskningsartikler af Jakob Krarup.

God læsning

Julia Pahl, redaktør

Aktuelt om DORS
juli 2010

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Svenska operationsanalysföreningen

För SOAF är udda år de bästa – det är nämligen då vår konferens går av stapeln och vi får en chans att samlas för att höra om de senaste projekten i OA-Sverige och utbyta idéer för framtida projekt. Uppslutningen har varit god, vilket gav styrelsen den trivsamma utmaningen att lyckas få plats med 36 bidrag under konferensens två dagar. Som vanligt var det en inspirerande bredd på bidragen, både med avseende på vetenskapsområde och i spännvidden från att vara direkt tillämpbara i praktiken till att vara inomvetenskapliga. Vi samlade drygt 50 deltagare och årets inbjudna talare var Thomas Schön, Uppsala University and Arne Andersson, Coupa Software.

Vår intressegrupp för forskarstuderanden börjar bli väl etablerad nu. Årets aktivitet var att förlänga konferensen med en extra dag som dels innehöll sociala aktiviteter, dels innehöll en Gurobi-workshop. Det var glädjande att se dryga 20-talet deltagare på denna aktivitet!

När detta nummer kommer från tryck så är det hög tid att nominera en examensarbetare till årets exjobbspris. Har du handlett en student som du tycker skrivit en bra uppsats, passa på att uppmärksamma detta genom att se till att denne nomineras! Mer information återfinns på vår hemsida.

Hälsningar

Elina Rönnberg, ordförande SOAF

Indhold

Aktuellt om SOAF
juli 2010

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By Satya S. Malladi and Jonas M. Christensen, project done in collaboration with David Ramirez, Allan Larsen, and Dario Pacino

Smart Fleet Size and Mix Decision-Making For Collection of Blood Samples in Region Hovedstaden

Introduction and Context

Region Hovedstaden is a municipal authority that performs various functions for ensuring that health and growth thrive in the Greater Copenhagen area. Running the healthcare system is one of its primary responsibilities. This system is organized in the following manner: there are a number of private physicians and a few major hospitals. While the physicians carry out non-emergent consultation, hospitals cater to emergencies, surgeries, and diagnostic services such as biomedical sample testing, X-rays, etc. As part of diagnostic services, private physicians conduct blood tests on patients in their clinics. The Region must collect these blood samples from all the clinics to a specific testing laboratory in a hospital in a timely manner. This is exactly the focus of this study. Looking at this planning problem from a strategic view, we aim to decide the fleet the Region should invest in to minimize the Total Cost of Ownership (TCO) for the blood collection fleet.

From a freight logistics planning perspective, on the demand side of this supply chain, the clinics must be specified by the quantity of demand, the time window, and the duration of service. The time window and service duration are given by the Region from previous data. The quantity of demand is given by the number of vials of blood samples that must be collected from the clinic. The demand quantity clearly depends on the number of patients visiting the clinic on each day, which is not usually known with certainty beforehand. However, based on interactions with physicians, we found that the variability of the estimate of demand is very low given the day of the week and the time of the year – summer or non-summer. Since these estimates are not readily available, we conducted a survey targeting all the physicians in the region of interest and obtained reasonable estimates for all days of the week and both periods of the year.

On the supply side of the supply chain, we should specify the types of vehicles. The Region plans to use only electric vehicles in the inner city in accordance with its green initiatives. Electric vehicles are effective in reducing particulate emissions and noise pollution in urban areas and are amenable to the relatively short inner-city driving distances. The Region selected two types of electric vehicles for the collection of blood samples in the city area: the cargo bike TRIPL and the mid-sized pickup van Renault Kangoo ZE.

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Figure 1: The TRIPL Cargo Bike

Figure 2 Renault Kangoo ZE

tives. Electric vehicles are effective in reducing particulate emissions and noise pollution in urban areas and are amenable to the relatively short inner-city driving distances. The Region selected two types of electric vehicles for the collection of blood samples in the city area: the cargo bike TRIPL and the mid-sized pickup van Renault Kangoo ZE.

So far, the Region has been using fixed routes based on the full set of clinics. However, this gave rise to a variety of operational issues including running out of driving range, not serving many clinics, and missing time windows. Two main reasons for these operational hiccups are:

1. The previous fleet mix and the fixed routes were not optimized for serving subsets of customers and a spectrum of requests. The previous fleet mix decision used by the Region did not consider uncertainty and variability in operational request profiles at the strategic planning stage.

2. The energy consumed for climate control (which depends on temperature that cannot be known with certainty at the strategic planning stage) and powering auxiliary external devices has not been accounted for so far in the literature and thus in the planning methods. This results in an overestimation of the energy available to execute routes, leading to missed service at some clinics.

We are thus investigating a stochastic fleet size and mix problem aiming to minimize TCO, considering uncertainty in the requests and temperature in every operational period at the strategic planning stage.

Methodology

We extend the model for power consumption from Goeke and Schneider 2015 to include the power consumed for cabin climate control and auxiliary usage (by climate control boxes for transporting blood, for example) using the heat balance method (see Fayazbakhsh 2013). Cabin climate control accounts for ventilation, convection, radiation, and human metabolic loads.

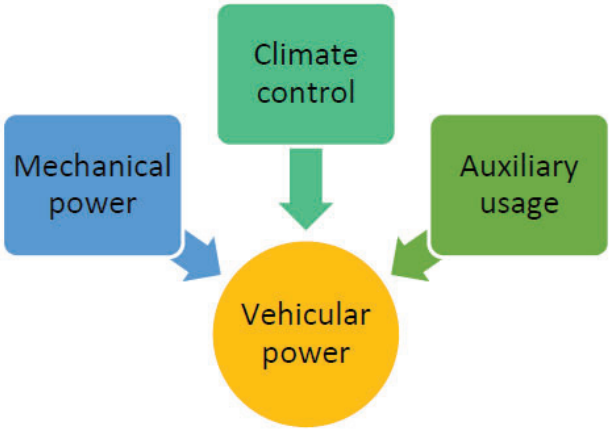


Figure 3:Illustration of the power consumption model

The objective of the strategic problem is to determine a fleet size and mix that minimizes the TCO (sum of the cost of acquisition of the selected fleet and the total operational cost). Since there is uncertainty at the strategic stage, this problem is modeled as a two-stage stochastic program. Solving this problem exactly is NP-Hard and becomes intractable quickly. We solve this problem using Sample Average Approximation (SAA) in which, a number of operational instances are sampled and solved to obtain an estimate of the average operational cost, for all fleet mixes of interest.

Figure 4: Illustration of the operators of the ALNS. SISR refers to 'Slack Induction by String Removals' as introduced in Christiaens

The operational problem is a vehicle routing problem with time windows and compatibility constraints. We solve it using a state-of-the-art metaheuristic, an Adaptive Large Neighborhood Search (ALNS) algorithm (introduced in Ropke and Pisinger 2007) created for this problem. Starting from an initial solution, iteratively, one of five randomly chosen destroy operators is used to remove customers and one of two randomly chosen repair operators is used to insert the removed customers. In the figure on the left, the green circles show the destroy operators while the blue circles show the repair operators.

In the next section, we present our findings obtained using SAA to solve the stochastic fleet size and mix problem defined above in the context of managing Region Hovedstaden's operations.

Results

The main result is shown in Figure 5, which shows the composition of the ten best fleet mixes, their associated TCO and average fill rate. The results show the best fleet mix consists of one pickup van and four cargo bikes. Comparing the best fleet mix with the second best fleet mix, we see that the single pickup van from the best fleet mix is substituted with two cargo bikes. This results in a lower average fill rate, but a higher TCO. The difference, in TCO, between the best and the tenth best solution is 40,000 US dollars (equivalent to 25% of the best solution's TCO). This justifies the need to consider the uncertainty.

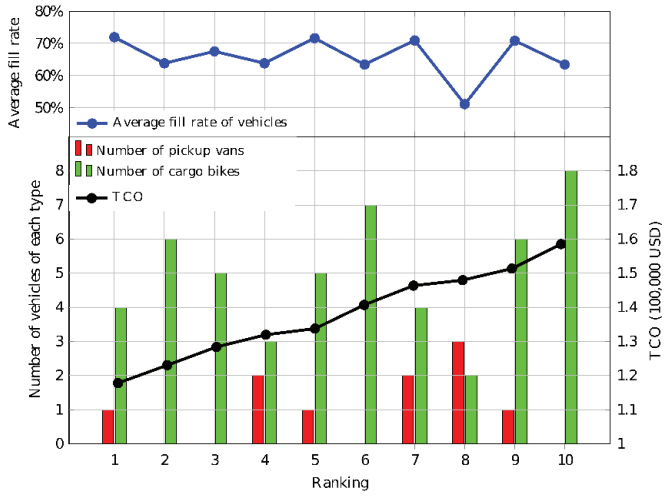


Figure 5: The ten best fleet mix solutions their TCO and average fill rates

Figure 5 is based on the current demand characterization, but as we are considering an operational period of 10 years, we must take into consideration what might happen in the future as well. Evaluating different scenarios, decisions makers often prefer a slightly costlier solution if it means it is more robust, and has a built-in resilience against future changes in the logistic systems. In Figure 6, we present such an analysis. Figure 6, shows the TCO for the top eight fleet mixes, when varying the demand factor. Varying the demand factor means all doctors have their demand scaled by a multiplier. The previous best fleet mix ([1,4]), still remains the preferred solution for the demand scaling interval 0.95 to 1.15. If the demand were to increase by more than 20%, the best fleet mixes would be [2,3] and [1,5], as they have an increased capacity to cope with the increased demand. However, the demand in blood samples is expected to be relatively stable over a 10 year period, but for another firm such an analysis could be vital, if they are preparing an expansion.

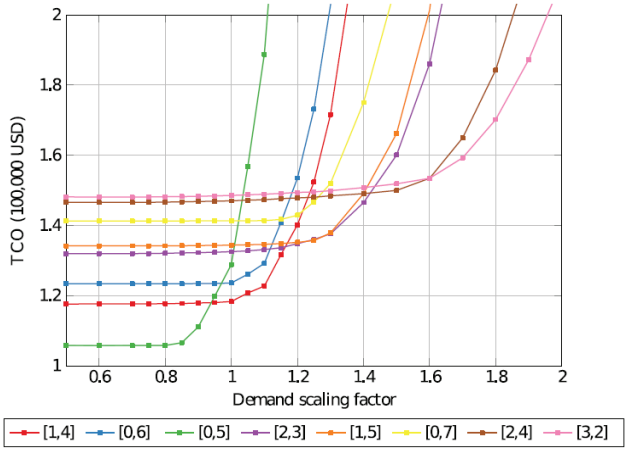


Figure 6: Sensitivity analysis on the top eight fleet mix solutions to variation of scaling demand at all doctors. A legend entry [a,b] refers to a fleet mix with a vans and be cargo bikes

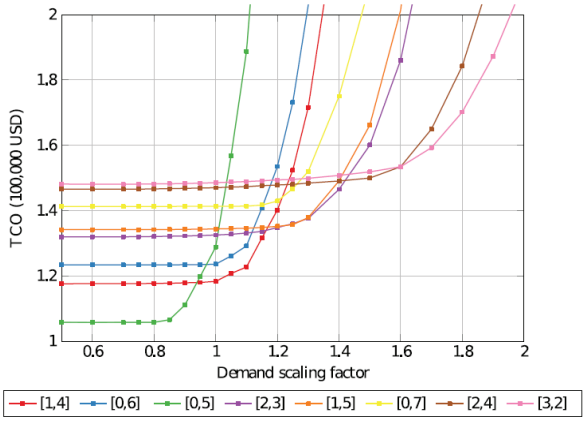


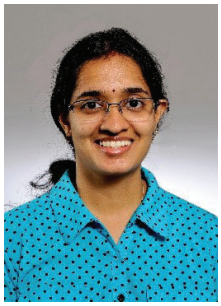
Figure 7: Average operational cost per shift in USD (left axis) and percentage cost difference over the case of no cabin climate control (right axis) with varying ambient temperature for the best fleet mix solution with 1 van and 4 cargo bikes.

Figure 7 shows the importance of including the climate control power in the vehicle energy consumption model for the best fleet mix [1,4]. The data for this plot comes from varying the temperature, and for each temperature setting, executing the ALNS on the same operational instances. The left axis shows the average cost of energy for different temperatures with (green line) and without the climate control (red line). The right axis shows the cost difference in percentage (blue line). It is assumed that 20 degree Celsius is the desired cabin temperature, and thus the cost with and without inclusion of climate control is equal here. The average cost without climate control stays constant, whereas it varies a lot for the case with climate control.

Conclusions

We have presented here a versatile general framework in the context of urban service logistics to optimize and evaluate the total cost of ownership of a mixed fleet that may include electric vehicles. The framework has been applied to a Danish case study and the results show the importance of 1) considering uncertainty at the strategic level, and 2) including cabin climate control and auxiliary power in the energy consumption model. The framework is versatile and can handle a variety of cases. Specifically we are working on another case study together with MT Højgaard, and providing inputs to colleagues in Turkey.

Satya S. Malladi is currently working as a postdoc in the Department of Technology, Management and Economics at the Technical University of Denmark. She holds a PhD from Georgia Institute of Technology, specializing in Operations Research and Industrial Engineering.



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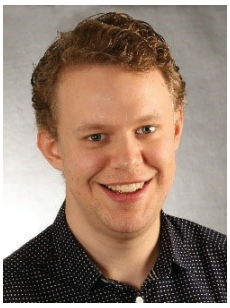

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ELECTRIC URBAN FREIGHT AND LOGISTICS
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By David Pisinger

Glover-Klingsman Prisen 2018

Martina Fischetti (DTU Management/Vattenfall Wind) og **David Pisinger** (DTU Management) har modtaget Glover-Klingman Prisen 2018 for deres artikel "Optimal wind farm cable routing: Modeling branches and offshore transformer modules", som blev publiceret i det anerkendte tidsskrift, Networks i 2018. Glover-Klingman Prisen tildeles for enestående arbejde indenfor netværks modellering, analyse og implementering.

Arbejdet er udført i samarbejde med Vattenfall BA Wind, der er en af de førende producenter af grøn energi, og som arbejder mod at gøre energiproduktion klimaneutralt indenfor een generation. I det studerede projekt bruger Martina Fischetti og David Pisinger matematisk programmering til at optimere kabling af hav-vindfarme. Kabling mellem vindmøllerne, og fra vindmøllerne til forsyningsnettet på land udgør en betydelig del af udgifterne til etablering af en farm.

I de seneste år har vindmølle-producenterne gjort det muligt at tilpasse møllerne individuelt til det givne projekt. F.eks. kan en vindmølle fås med nød-strøm anlæg, så man slipper for at have redundante kabler der sikrer strømforsyning i tilfælde af kabelbrud. Man kan installere mindre transformer-stationer på nogle af vindmøllerne, så man slipper for en central basis station med transformer. Og man kan forsyne vindmøllen med flere kabel-stik, så en given vindmølle kan forbindes til et større antal andre møller således at man får en mere forgrenet og kompakt kabling.

Denne fleksibilitet fra producenternes side gør det nærmest uoverskueligt at designe en vindfarm. Martina Fischetti og David Pisinger har derfor udviklet beslutningsstøtte-værktøjer som kan optimere kablingen for hvert "what-if" scenarie, og dermed præcis vurdere hvilken økonomisk konsekvens det vil have. Resultaterne er meget lovende, idet man for nogle hav-vindparker kan se besparelser på flere millioner euro.

Artiklen har, sammen med andre resultater fra Martina Fischetti's PhD afhandling, gjort det muligt for Vattenfall at bygge vindfarme helt uden statsstøtte. Dette åbner op for et enormt potentiale i den grønne omstilling, idet man ikke længere behøver at poste skattekroner i projekter. samtidig åbner det op for at det ikke kun er de velhavende lande som kan få grøn energi fra vindkraft, men den grønne omstilling drives fremad af markedskræfter.

Glover-Klingman Prize

The Glover-Klingman Prize is awarded each year to an individual or a group for the best paper published in Networks. Each co-author of the winning paper receives a certificate and a cash award.

Fred Glover and Darwin Klingman (1944-1989) published more than 100 articles on the innovative implementation of network optimization algorithms. Their goal was to reduce computation time and memory requirements, thereby enabling solution of the larger, more realistic problems that confronted and continue to confront practitioners. In their joint work, they developed special list structures, labeling techniques, and clever hybrid algorithms and they successfully applied these ideas to a variety of network optimization problems.

The Glover-Klingman Prize pays tribute to the high quality of their work at the interface of operations research and computer science. The prize, however, is for outstanding work in the general area of network modeling, analysis, and implementation, and is not limited to papers at the OR/CS interface.

The Editors-in-Chief, with assistance from members of the Editorial Board of Networks, select the winners of this annual award.

For more information, see: https://onlinelibrary.wiley.com/page/journal/10970037/homepage/glover-klingman_prize.htm

By Line Reinhardt

Applications of Optimization (AOO) 2019

On Monday the 6th of May 2019, academic and professional members of the Danish society for operations research were once again assembled for the yearly one-day conference in Applications of optimization (AOO) for professionals in the area of operations research. The conference was possible due to the sponsors Mozek, Ørsted and The Association of European Operational Research Societies.

This year we had two academic speakers Magrét Vilborg Bjarnadóttir from Robert H. School of Business in Maryland USA and Professor Dolores Romero Morales from Copenhagen Business School. Magrét Vilborg Bjarnadóttir gave a very interesting and entertaining presentation on Operations Research and People Analytics showing results on achieving gender equality according to the metrics applied today and the maybe unintentional consequences of optimizing gender equality with the metric.

Figure 1: Magrét Vilborg Bjarnadóttir

Professor Dolores Romero Morales from Copenhagen Business School gave a presentation of a large set of methods for how mathematical optimization can enhance the Interpretability of Data Science.

Figure 2: Professor Dolores Romero Morales

Figure 3: Fernando Alvarez

From the industry Fernando Alvarez from the company Bunker Metric, Norway represented a small research based startup presenting the optimization of marine fuel procurement with an enlightening discussion afterwards on the maritime data and quality. The other industrial presenter was Torben Barth from Frankfurt Airport, FRAPORT, which is one of the busiest airports in Europe with a presentation on how applied analytics was used at the airport and especially which projects the analytics group had success with and how these project had evolved with time.

Figure 4: Torben Barth

A networking session with several topics to discuss was part of the networking session in order to get the participant to socialize and get to know each other better.

The conference venue was Industriens hus in the center of Copenhagen and after the conference a several of the participants continued the networking with the organizers and some of the presenters at a nearby bar.

By Elín Björk Böðvarsdóttir, Anders Reenberg Andersen

This project has been funded and supported by the Department of Data and Development Support at Region Sjælland

Can optimization methods reduce expenditures in nurse rostering?

Nurse rostering is the task of generating work schedules for nurses. When generating a schedule, one needs to balance three aspects: The nurses' working hours and conditions, sufficient staffing levels to ensure patient safety, and lastly budgetary restrictions.

As the Danish population is gradually aging, pressure on hospital budgets is growing. Thus, it is vital that hospitals ensure high-quality treatments, while keeping the length-of-stay of patients as low as possible. Achieving this is costly, and therefore an efficient resource utilization is of the utmost importance in hospitals today. With cost-efficient planning, the hospitals are given the choice to either: Do the same with less, or do more with the same. In this article, we investigate the potential of employing mixed integer programming to create cost-efficient rosters under Danish legislation. Thus, we have assessed the potential for Danish hospitals to do the same, but with lower expenses for their personnel resources. Manually generating rosters results in a poor utilization of the resources, as criticized by The National Audit Office of Denmark [4]. They concluded that the work schedules were not cost-effective, and emphasized that most of the investigated wards did not assign all of the working hours corresponding to a fixed monthly salary.

In 2013, the expenditures related to human resources in Danish hospitals amounted to 45 billion DKK, or a total of 60% of the hospital expenditure [4]. In 2017, the hospitals in Denmark had over 35 thousand full-time equivalent nurses, or close to half of the full-time equivalent health care personnel in the hospitals [5]. Therefore, the expenditures related to nurses in Danish hospitals are substantial.

The salary expenditures for nurses can generally be divided into several categories as seen on Figure 1. The spendings within some of these categories depend on the allocation of the resources, for example the cost of substitute staff or time-related supplements (for working evenings, nights and weekends).

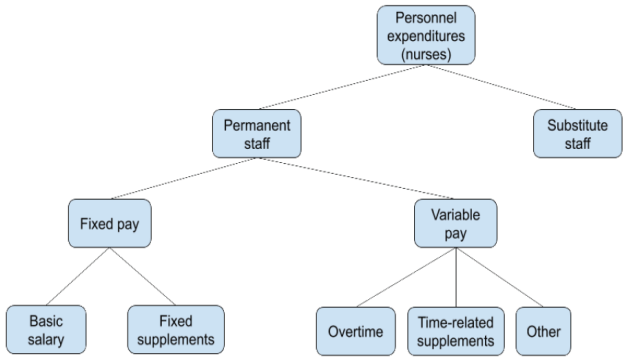

Figure 1: A hierarchical categorisation of salary expenditures

Figure 2 shows an example of a one-week work schedule for nine nurses. The nurses have been assigned to shifts to satisfy a pre-defined staffing requirement for day, evening and night shifts. All nurses get two consecutive days off, and work between three to five shifts each. Although creating a small schedule like this one is not the most challenging task, managers will quickly loose oversight when creating longer schedules for 50-100 nurses. Nurse rostering is a complex combinatorial problem, but it is solved manually in most hospitals in Denmark.

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
n1		D	D	D	D		
n2		E	E	E	E		
n3	N	N	N	N			
n4	D	D			N	N	N
n5	E		D			D	D
n6	E	E			E	E	E
n7	D			D	D	D	D
n8	D	D	E	E			
n9			D	D	D		

Figure 2: An example of a roster with nine nurses working 3-5 shifts a week to meet a predetermined staffing requirement

Problem description

We analyzed the potential for reducing time-related supplements (cf. Figure 1), by a better allocation of the personnel. Table 1 shows the rate for different times. All these supplements are paid by the hour and calculated for every 30 minutes begun. Furthermore, the supplements are additive, e.g., during Saturday evening the nurses obtain the combined supplement for evening and weekends, corresponding to 69% of the nurse's hourly rate.

As the supplements are calculated based on the salary of individual nurses, the allocation of nurses to shifts can have a huge impact on the spendings. For example, assigning a senior nurse with many years of experience to a night shifts is substantially more costly than assigning the same shift to a newly educated nurse.

	Time	% of hourly rate
Evenings	From 18:00 to 23:00	27%
Nights	From 23:00 to 06:00	32.5%
Weekends	From 06:00(Sat) to 24:00(Sun)	42%

Table 1: Time-related supplements

We obtained real data for two wards in a Danish hospital, Ward A and Ward B. Ward A has 70 nurses and schedules 231 nurse-to-shift assignments each week, while Ward B has 64 nurses and a total of 205 assignments each week. Furthermore, Ward A has a great variability in the tasks that they perform, resulting in different competences required for different shifts.

These wards create the schedules manually, and the cost of time-related supplements is substantial in both wards. In Ward A, the supplements amount to 15% of the total salary costs for nurses or 8% of the total salary costs for all employees in the entire ward. In Ward B, they amount to 9% of the total salary cost for nurses or 3.5% of the entire salary cost for the ward.

To comprehend the immense extent of these supplements we compare them to the average fixed pay for a full- time nurse. **In Ward A, the time-related supplements correspond to a fixed annual pay for more than 18 full-time nurses, while in Ward B it corresponds to more than 11 full-time nurses.** In other words, each ward can hire one additional nurse for a mere 5-9% reduction of their time-related supplements.

Minimizing time-related supplements

We formulated a mixed integer programming model with the objective of minimizing time-related supplements to analyze the room for reductions. The model includes several constraints to ensure that lowering the cost does not negatively impact the patients or nurses.

min time-related supplements
s.t. pre-defined staffing requirements available personnel
legislation for nurses' working time
healthy and fair work schedules for each nurse

We assume a generalized planning horizon that omits various exceptions that occur from schedule to schedule and could bias the optimization. These exceptions include sick-leave, vacation and public holidays. As the generalized horizon is uniform, we can generate cyclic schedules, i.e., schedules that we can use repeatedly. We generate the schedules for a four-week horizon, as is current practice.

We consider several constraints that are needed in practice. The first constraint is to meet the current staffing requirements, thus obtaining the lowest expenditure for time-related supplements without reducing the service level offered to patients.

The second constraint relates to how we utilize the available personnel, as we do not want to lower the time-related supplements at the expense of overtime. We consider two scenarios for the availability. In the first scenario we assume all nurses are fully available during the rostering horizon (i.e., no sick-leave or vacation). In the second scenario we consider the average absentees of a nurse on an annual basis.

In general, employees in the public sector are entitled to six weeks of vacation every year. Additionally, nurses take 13 sick days on average during a calendar year [2]. In total, this corresponds to 15.07% absentee days during a year for an average nurse, where 11.51% correspond to vacation and 3.56% correspond to sick-leave. Thus, the second scenario sets the upper bound for each nurse as 85% of the contractual hours, instead of fully utilizing them.

Less than 25% of absentees are due to sick-leave, which we cannot plan. The remainder is vacation days, which the planners have some flexibility in assigning to the nurses. Moreover, having fewer resources available than required should not affect the time-related supplements, but rather spendings on float nurses or overtime.

The legislation imposes two types of constraints, which we will describe in their strictest form [1, 6]. First, each nurse should get at least 11 consecutive hours off for resting within every 24 hours. Second, they should get protected days off, which should on average be two days off for every workweek. The law states that these days should be distributed in an equal manner, with at least two protected days off within every eight days. For a protected day off we require a certain number of hours off between the adjacent work shifts. This number is 35 hours for a single protected day off, 55 hours for two consecutive days and 79 hours for three consecutive days.

Even though the legislation allows room for relaxing these requirements, for example by reducing the number of hours off or increasing the number of days between protected days off, we exclude all relaxation. The main reason is that all individual nurses need to accept any relaxation for their schedule, and

including them when estimating the possible savings paints an incorrect picture as the nurses should not be pressured into any relaxations.

At last we analyze the cost of including additional constraints for the nurses' working time. The constraints we consider are common, both in practice and in nurse rostering research. These constraints are not legally binding, but should ensure that the nurses get healthy schedules. The constraints that we analyze are:

1. Forbidding certain shift successions.
2. Restricting weekend work.
3. Restricting night work.

For forbidden shift successions, we defined a new constraint stating that when we assign a nurse to a night shift we cannot assign her to a day shift until two days have passed. This constraint should ensure that although the nurses need to alter their sleeping patterns they should still get sufficient sleep between shifts.

For restrictions related to weekend work, we define two new constraints. The former constraint ensures that the nurses have compact work weekends, i.e., either a nurse works on both Saturday and Sunday, or she works neither day. The latter constraint ensures that all nurses work a maximum of two weekends during the four-week horizon. We note that we can expect these constraints to affect our objective, as the supplements related to weekend work are rather high.

For restrictions on night shifts, we define a single constraint that should ensure a fair distribution of night shifts between the nurses. We round up the average number of night shifts per nurse needed to cover the staffing requirements and ensure that no nurse exceeds that number of night assignments during the four-week horizon. In both wards, this maximum becomes three night shifts per nurse. As the nurses obtain supplements for night work, we can expect this constraint to affect our objective.

Results

Table 2 shows the different scenarios we analyzed along with the corresponding reduction in time-related supplements. All scenarios include constraints for the pre-defined staffing requirements along with legislative constraints, while we alter the availability for personnel along with the additional constraints for healthy work schedules.

Scenario	Availability	Additional constraints	Reduction Ward A	Reduction Ward B
1	Full	None	34.92%	22.72%
2	85%	None	34.23%	22.17%
3	Full	Forbidding certain shift successions	34.92%	22.72%
4	Full	Restricting weekend work	33.01%	20.69%
5	Full	Restricting night work	34.16%	21.60%
6	Full	All three constraints for healthy schedules	32.37%	19.82%
7	85%	All three constraints for healthy schedules	32.20%	19.50%

Table 2: Results

By comparing the first two scenarios we see that the results are not sensitive when reducing the availability. Even though the availability percentage for each nurses differ between rostering horizons throughout the year, the average is 85%, making scenario 2 representative for the overall room for reduction when only considering legally binding constraints on working time. The savings in Ward A correspond to 6.3 years' salary for a full-time nurse, while in Ward B they correspond to 2.5 years.

By looking at the remaining scenarios we can see that adding more constraints for healthy schedules results in a slight decrease in the savings. Nonetheless, the savings when including all three constraints and assuming 85% availability (scenario 7) still correspond to 5.9 years' salary for a full-time nurse in Ward A, and 2.2 years in Ward B.

Discussion

As additional constraints for the nurses' working time are important in practice, we find it intriguing to see how little extra costs are incurred. Nurses are an immensely valuable resource, and having satisfied nurses and maintaining qualified resources significantly outweighs this small increase in supplements.

We acknowledge that the results slightly overestimate the possible savings, as we do not take the supplements related to public holidays into account. However, including public holidays in the analysis would not paint the correct picture, as the planners often lower the staffing requirements on such days. When assuming no reduction in the requirements, the added cost of public holidays corresponds to only 2-4% of the annual supplement spending in the two wards. Therefore, we can conclude that the potential for expenditure reduction is substantial even when accounting for public holidays.

In practice, the nurses can choose either to get the supplements paid out or to get time off as compensation. If some nurses rather choose time off than paid supplements, the expenditures in this category would be reduced even further. This assumption creates a bias in our comparison to current expenditures, as they include the choices of each individual nurse at each point in time. Nonetheless, the assumption is necessary to conduct a macro analysis, and the bias does not lessen our results, but on the contrary, strengthen them.

Another category for variable cost is related to substitute staff. Nonetheless, the allocation of float nurses is often not planned along with the original schedule, but added to it later on due to various disruptions, e.g., sick-leave. Additionally, the planners may react differently when absentees occur with the permanent staff. In some cases, they would call in float nurses, but in other cases, they would ask the permanent staff to work additional shifts, either as over-time or without exceeding their contractual hours. Moreover, an absentee nurse is not always substituted in the plan and the wards sometimes operate below the staffing requirements [3]. In all scenarios, we manage to create schedules using only the

permanent staff, i.e., without any cost for substitute staff.

Concluding remarks

We conclude that there is substantial room for reducing the expenditures and producing cost-effective schedules that simultaneously are satisfactory for the nurses. Moreover, we have shown that the additional constraints to ensure healthier schedules only have a minor effect on potential expenditure reductions. We hope that the results we have obtained become a motivation for the Danish health care sector to increase their use of optimization methods in personnel scheduling.

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By Marie Catharina Hartwell Pors (project done towards B.Sc. thesis
as an advisee of Allan Larsen and Satya S. Malladi)

Opportunities of Autonomous Shuttle Service: A Case Study

Autonomous vehicles (AVs) have gone from being sci-fi to being a reality. Waymo's self-driving vehicles have already been on the roads for years and in an article from 2018 they wrote: "Our self-driving vehicles just crossed 10 million miles driven on public roads." in addition to the 7 billion miles in simulation1. Implementing autonomous vehicles on a large scale could revolutionize transportation as we know it. AVs are predicted to make transportation safer, more effective, and less polluting than conventional human-driven vehicles, but there is a long way from today's transportation system to a fully automated transportation system. Until then there will still be a need for improvement on our overloaded infrastructure - in other words we will still need mass-transit services. Integrating AVs in the mass-transit systems will create opportunities for a more dynamic and demand-responsive system which could make it more effective, more attractive, and less expensive. In this case study, the focus will be on how autonomous shuttles can serve as a first mile and last mile shared-transportation operator and serve the travel demand on a closed area like a University campus. The case study is based on one of the pilot projects of the startup firm holo (https://www.letsholo.com/) on the main campus of the Technical University of Denmark (DTU).

Demand Responsive Transportation

We conduct a simulation study on the DTU university campus to assess the scope of advantages in operating an autonomous shuttle system. We model a demand-responsive autonomous shuttle system (DRASS) that manages incoming ride (pickup and dropoff) requests and deploys service to accepted requests. In order to assess its efficiency, we compare it with a fixed route autonomous shuttle system (FRASS) that operates scheduled services i.e. arriving at fixed times at various stops. The study focuses on determining whether or not an autonomous shuttle provides a more effective and efficient option for users.

Demand-responsive transportation services (DRTS) serve demand when it appears and are distinct from fixed-route services as they do not always operate with specific timetables and/or routes. The implementation of DRTS may vary in a number of aspects, for example, how requests are managed, how services are dispatched, etc.. DRT systems can be dynamic where requests appear in real-time and the route is updated according to the incoming needs using e.g. a mobile app. This real-time request system is assumed for the DRASS solution in this case study. There are a lot of possibilities for DRTS, especially when combined with autonomous vehicles.

Demand modelling

In order to optimize the usage of an autonomous shuttle at DTU main campus, it is necessary to generate realistic input data for the simulation study. To generate this input data it is crucial to investigate the movement patterns at DTU and the commute to and from DTU. Naturally, it is extremely difficult to assess the demand as the system doesn't exist yet and autonomous shuttles all over the world are still in the preliminary testing phases. To estimate the demand for the simulation study a dataset consisting of historical traces of connections to the university Wi-Fi network called Eduroam was used. In all buildings at DTU, students and employees can connect to this Wi-Fi network. The Wi-Fi data was used to obtain the origin-destination-time (ODT) matrices between buildings using information about the number of IP addresses that connected to the Wi-Fi in one building and then connected to the Wi-Fi again in another building at a later point in time.

The ODT matrices were extracted by Inon Peled and David James2. The ODT matrices were used to give an approximation of the movement flow around campus. It should be noted that there are some defects in this dataset including missing data and limited time scope. In addition there will be some uncertainties when using Wi-Fi data to estimate movement between buildings since sometimes devices will connect to a Wi-Fi just by passing by or being near a building, and the same person can be counted multiple times if they have more than one device connected to the Wi-Fi while other people's movement might not be accounted for in case they do not

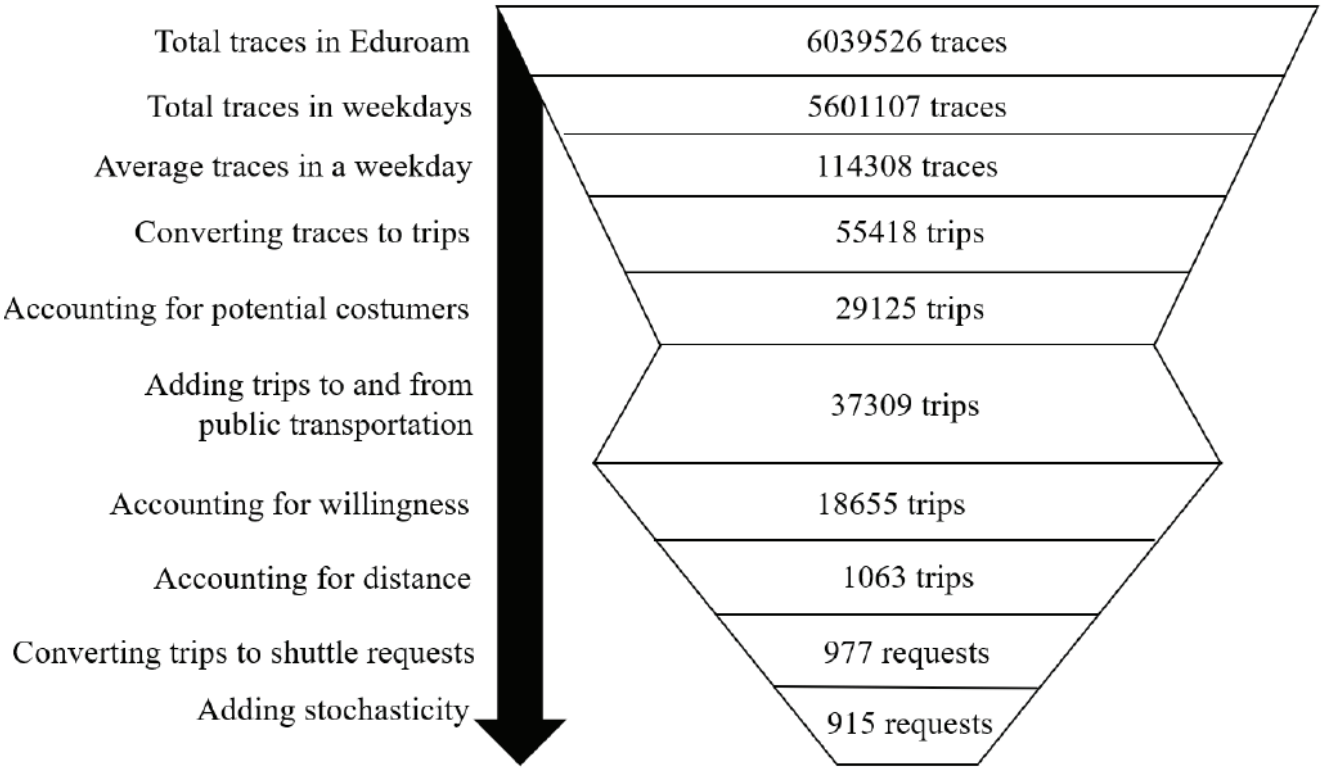

Figure 1: Funnel model showing the development of the Demand Modeling

log-in to this Wi-Fi.

To model the demand for an autonomous shuttle at DTU, it isn't enough to only look at the trips around campus, but also the commute to and from DTU. It is also necessary to take into account which potential customers the autonomous shuttle would have. Whether people will be interested in taking the shuttle will depend on multiple factors e.g. the weather and their other transportation possibilities. The most significant group of potential customers are assumed to be the people who commute by public transportation and here it is their first and last mile trips from bus stops around campus to their final destination that is paramount to estimate. To include these first mile and last mile trips two additional data sources was used; the Danish National Travel Survey (TU) data and data concerning bus routes and schedules. These data sets were used to estimate the modal split and the distribution of potential customers at or around DTU campus.

The shuttle stops and route around DTU main campus was chosen according to the knowledge gained from these datasets and the final shuttle stop to shuttle stop requests was estimated. The stops and route around campus is shown in Figure 2. The Wi-Fi traces started at a count of 114308 on the average weekday and the final number of expected autonomous shuttle requests was 915 per day after adding trips from public transportation and accounting for multiple factors such as the expected potential customers, willingness to take a shuttle and the willingness according to the distance of the trip. The development of the estimated demand can be seen in Figure 1.

Figure 2: AnyLogic network showing the route i.e. the red dotted line and the shuttle stops

Simulation study

There are multiple purposes of this simulation study, the first of which is to gain insight into how this system might work and how well it will perform under the expected circumstances. In addition, the purpose is to optimize the DRASS to understand

under what conditions the system is performing most efficiently and thereafter compare it with the FRASS system to see which of these are performing best on multiple performance measures. Lastly, the goal is to determine whether or not the best performing system will improve the present situation. All these goals are important to consider while constructing the simulation models.

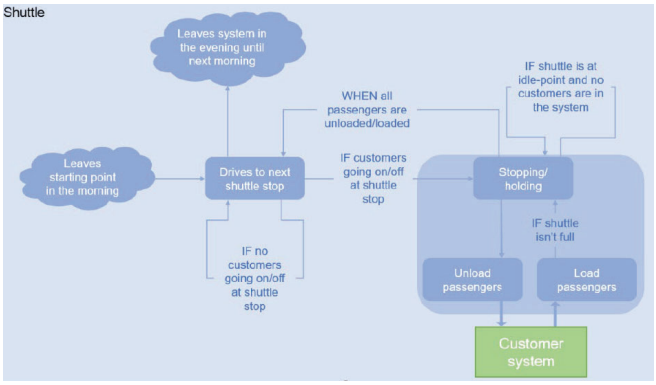

Figure 3: Conceptual model of the DRASS

Both the FRASS and DRASS solution are driving along the route and stopping at shuttle stops whenever a customer is going on or off the shuttle. The customers will only wait for the shuttle for 4-10 minutes because of the relative short distances. If the shuttle doesn't pick them up in time they will leave the system. The shuttle speed is set to be around 20 km/h and the capacity of the shuttle is fixed to be 15 people. The DRTS system chosen for the DRASS is a very simple solution where the shuttle only leaves a specific idle-point when there are customers in the system. When the simulation starts, one shuttle will leave the idle point when the first customer arrives in the system, the next shuttle thereafter won't leave the idle point until a customer appears at a shuttle stop that the first shuttle already has passed. The conceptual simulation model for the shuttle in the DRASS system is shown in the Flowchart in Figure 3. The simulation is performed in the simulation software called AnyLogic.

Experimental study

First a preliminary simulation experiment was conducted to generate benchmark statistics. Normally, a preliminary simulation experiment tries to mimic how some system already is performing, before making improvements, but since the system is not physically built yet, the purpose of this preliminary run is to have a base scenario to tune and improve upon. The preliminary experiment was tested with a single shuttle operating in both the DRASS and FRASS solution.

It is clear from the results of the preliminary experiments that one shuttle does not cover the demand. As shown in Table 1 over 55% of the potential customers were missed in both simulation system when only one shuttle was operating the route. The results from the preliminary experiment also shows that the shuttles are far from utilized to full capacity throughout the simulation time. The shuttle in both systems are driving empty almost half the time. This shows that one shuttle is not fast enough to cover the whole route and it is necessary to test the systems with multiple shuttles operating the route.

The FRASS and DRASS were then simulated with two and three shuttles. The FRASS solution still missed over 40% of the customers with both two and three shuttles operating and when looking at the simulation it becomes abundantly clear that the reason behind the low service level is that bus-bunching occurs. After a while, the shuttles would catch up with each other and then similar bad results as those from the preliminary experiment would start to occur. On the other hand, the DRASS solution obtains drastically improved services levels and with three running shuttles, more than 85% of the customers are serviced. The DRASS simulated with three shuttles would drive empty 47% of the total simulation time, which is 5 % more than when it was simulated with only two shuttles, but the performance otherwise is substantially improved by operating with three shuttles and we consider this solution to be better.

The DRASS solution with three operating shuttles was also

	Percentage of served customers	Percentage of time driving empty	Avg. number of customers in shuttle
FRASS - 1 shuttle	43.7%	48%	1.15
FRASS - 2 shuttles	54.7%	55%	1.10
FRASS - 3 shuttles	56.9%	66%	0.76
DRASS - 1 shuttle	42.7%	47%	1.17
DRASS - 2 shuttles	71.2%	42%	1.51
DRASS - 3 shuttles	85.8%	47%	1.29

Table 1: Results from the simulation study

compared with a “no-system” solution i.e. the present solution where people would just walk around campus by foot. The result is that the shuttle is faster 60% of the time, which inversely means that walking is faster than taking the shuttle 40% of the time. When looking more closely at the results, it is clear that the faster walking times are primarily on the shorter distance trips.

Discussion and outlook

The Wi-Fi data contained approximately 144000 traces per day and this was transformed into around 900 requests for the autonomous shuttle system. Whether this is a reasonable demand level is hard to tell, since there are a lot of uncertain factors at play. Most of the assumptions used in the demand modeling were based on facts obtained from several different data sources, but some of the assumptions were based on intuition. These assumptions could potentially have had a negative impact on the realism of the demand flow obtained.

From the simulation study it was discovered that the DRASS was performing significantly better than the FRASS when comparing the best performing setups. The huge difference on the two systems performance is due to the bus bunching that started occurring in the FRASS simulation. The problem of bus bunching is a well known problem that occurs everyday on scheduled bus routes. One way to limit this in a more demand-responsive system could be as simple as the suggested DRASS solution in this case study, though this will only be possible on low demand routes or in low demand time periods.

The best performing solution i.e. the DRASS operated with three shuttles, only performed slightly better in terms of transportation time when comparing it with the time it would take to walk the distances instead. The reason is probably the large share of short distance trips that is a consequence of using Wi-Fi data to estimate the demand, and also the short distances of this network in general. This result would presumably change if the shuttle could go by the shortest and fastest routes rather than by the fixed route, but because of the small area the shuttle is covering it will always be a relatively low improvement in transportation time when taking the low speed into account.

This simulation model makes a good foundation for a wider research of the possibilities of an autonomous shuttle system. Multiple different kinds of demand responsive autonomous shuttle systems could be interesting to research further. A small advancement that could improve the performance of the system is e.g. to implement a dynamic idle-point policy that is changing over time according to expected demand. Another advancement of the demand-responsive system could include a more flexible route where changes could occur according to the demand of customers in the system. The demand-responsive system could also work without having any route at all. The autonomous shuttle system would be fully dynamic and a new route would have to be calculated every time a customer puts in a request. This calculation could be contrived using improvement heuristics or metaheuristics e.g. the Nearest Neighbor heuristic or TABU Search.

There are many different opportunities in using autonomous shuttles in a more dynamic and effective way than what we know from mass-transit systems today. Though it is crucial to keep in mind the potential willingness to pay for these services, especially when talking about first-last mile solutions. There is no doubt that using autonomous busses and shuttles would lower the operational cost in the mass-transit system if they were to replace existing scheduled bus routes, but as long as autonomous vehicles are driving at 20 km/h the first-last mile might not be the most opportune usage.

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By Alexandre Orhan and Florian Binter

DORS Price Winning Master Thesis Article

Introduction

Liner shipping is a complex industry connecting manufacturers and customers around the globe thanks to liner shipping companies. Such companies operate networks to transport goods from one point to another by the means of high-capacity vessels. In the 1960's, the containerization innovation had a huge impact on the business. It just bumped as the new technology allowed to tremendously increase the quantities transported by trip. Nowadays, almost all maritime trade is done this way and it is therefore clear that studies should mainly focus on it. Also, in such a business, commodities are grouped into containers and onboarded on high-capacity vessels. Then, vessels and containers flow through a network where arcs are sailing routes operated by liner shipping companies and nodes are ports. Most often, a container's journey is composed of several consecutive vessels in order to reach its final destination. The process to unload/load containers from one vessel to another is known and referred as a transshipment.

One of the most serious issues that liner shipping companies have to face is disruption. There is disruption when one or several vessels get delayed resulting into significant deviations from the operational planning. Not only the originally delayed vessels but a bunch of vessels might be impacted due to ripple effects coming directly from planned transshipments. On-time delivery of cargo is also threatened. However, liner shipping companies are committed to reliability, and must therefore take action to limit the damages and improve their service. Several recovery actions exist but it might be complex to an human eye to promptly identify in a short notice the best decision given the complexity of the network. This is where Operations Research comes in. Modelling mathematically the network and the potential recovery actions enable the decision-maker to rely on a non-subjective and mathematical tool giving results within a short amount of time. This article presents mathematical models to guide liner shipping companies in order to recover from disruption events. This work has been performed as part of our MSc Thesis in collaboration with Maersk Line.

Summary

The first model investigated to deal with disruption in liner shipping is known as the Vessel Schedule Recovery Problem (VSRP) and has been introduced by Brouer et al. (2013). A model inspired from this work has been implemented and tested on four concrete cases provided by Maersk Line. The results prove satisfactory as they provide solutions at least as good as the real-life decisions made and within reasonable time. The model holds promise for helping as a decision-support tool. However, it does not handle container flow but only identify cargo as cost constraints on vessels either delivered on-time, delayed or miss-connected. Therefore, we proposed a more advanced model which includes cargo rerouting: the Integrated Recovery Problem (IRP). Containers are now also capable of flowing through the network, and they can reach their destination using alternative routes instead of being merely considered as miss-connected. The IRP is shown to present better results and while considering a larger network, to be able to propose alternative routes for containers when the operational planning is questioned. However, the downside is a high increase of the complexity of the model and thus the computation times.

Recovery actions for vessels and containers

When a vessel gets delayed, operators have to undertake decisions to limit the impact and get back to the schedule as fast as possible with as little cost as possible. Three different recovery actions are considered in the model:

- Speed up the vessel: as vessels sail at speeds sometimes far below their maximum speed, speeding up is an

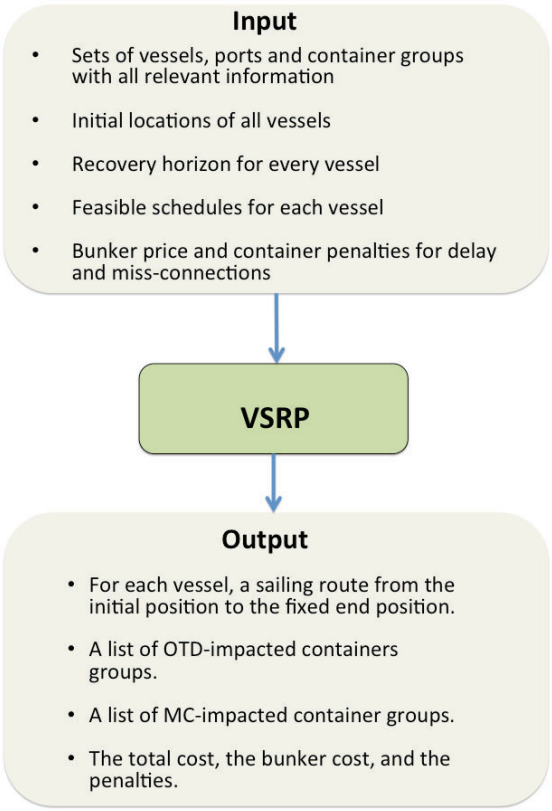

Figure 1: The VSRP model

efficient recovery action to be considered to catch up with the schedule. This might be especially helpful when sailing over long distances between ports. Nevertheless, it is a very costly solution due to bunker costs.

- Omit a port call: when a vessel experiences a major disruption, a radical decision could be taken: omitting a port call. This enables a rapid recovery but at the cost of delays and miss-connections of the containers that were expected to transit by the omitted port.
- Swap port calls: this action is only relevant when ports are relatively close from each other, and when the second port has a higher importance in terms of containers' delivery than the first one. It is often used to ensure important cargo to be delivered on time. This impacts severely the first port but at least the company ensures on time delivery of important cargo to the second port.

Not all the possible recovery actions have been handled by the models. Some are sparsely used or too difficult to implement compared to the benefits to add them to the modelling.

Problem description: a directed time-graph problem.

A disruption problem raises the following question: how to recover from the disruption to get all vessels back to the planning as fast as possible while reducing the costs and respect physical constraints. Each problem includes a subset of vessels potentially impacted by the disruption event. The scope is set geographically by the vessels considered, their position, and their potential routes, and temporally by a defined time horizon which forces the vessels to recover before a certain time limit (passing through Suez canal for example). This limits the complexity and narrows the model to what is actually impacted by the disruption. The time horizon is discretized and split into time slots regularly covering the horizon. Three assets are then modelled: vessels, containers and ports. Vessels sail through ports at certain times, ports have fixed locations and containers locations depend on the vessels they are onboard. The vessels considered in the graph are composed of the disrupted vessel plus all the ones supposed to support their container transshipments.

We refer to a time-graph representation where nodes are associated to a tuple (vessel, port, time) and arcs define feasible legs of all potential routes of the vessels. Except for the initial and the final nodes that are fixed by initial conditions and time horizon constraints to be back on schedule, all other nodes are multiples as they represent sailing solutions at different speeds and on different routes (due to omitting/ skipping ports recovery options). All of this define a directed time-graph that represents the liner shipping network. There are actually as many independent sub-graphs as there are vessels. It is then all about finding the shortest paths for all vessels.

The idea in using OR to tackle disruption in the liner shipping industry is to help solving a trade-off problem between the main costs at stake:

- Bunker costs: the costs related to the bunker consumption. This accounts for 25 % in the total cost breakdown of Maersk Line.

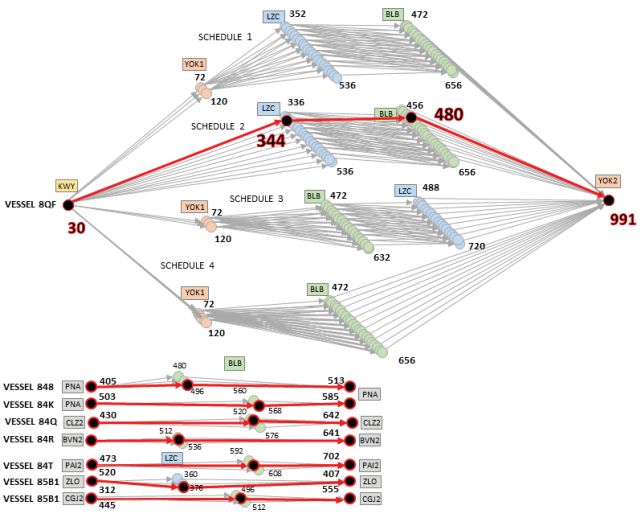

Figure 2: The Sarnia case results on VSRP

- Penalty for delayed containers: When a container group gets delayed, the liner shipping company suffers a financial penalty that represents customer satisfaction. It depends linearly on the number of containers in the container group. This is not an actual cost but rather a strategic cost integrated into the objective function that indicates how much the company would want to pay to avoid containers being delayed.
- Penalty for miss-connected containers: same as above, when a container group is miss-connected, the liner shipping company suffers a financial penalty that depends linearly on the number of containers in the container group. When a container is miss-connected, it receives both the penalty for being delayed and for being miss-connected. Miss-connections are considered twice as more severe as simple delays.

delayed or even worse misses a connection, then the model implies that it won't be delivered. There is no other option considered to get the container delivered whereas in real life it could be loaded on another vessel and follow an unplanned journey to its final destination. Yet this applies every day in maritime transportation. Also, one would expect from an optimization tool to include this feature. The IRP model is all about it.

In order to model the containers as objects flowing into the network we had to adapt our way of modelling the network as a graph. In the graph, additional arcs and nodes were created exclusively for containers and their spatial travel characteristics. Containers are no longer considered as linked to vessels but as objects that are free to switch from one vessel to another at the condition that both vessels call at the same port the first one before the other. Containers also

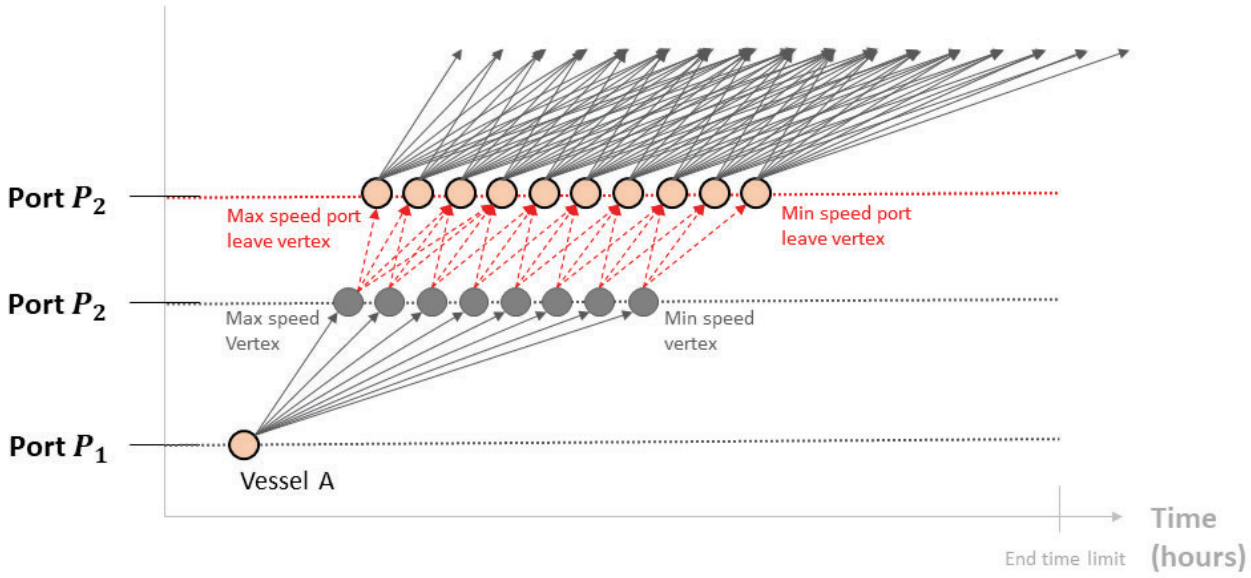

Figure 3: transshipment arcs example

enter the network through gate nodes linked to the first and last port calls (that are fixed and well-known). Miss-connexion arcs weighted with the miss-connexion cost are linking these gate nodes for each container groups. All these new features in the graph adds complexity to the problem as both vessels and containers flows are handled in parallel.

From the Vessel Schedule Recovery Problem to the Integrated Recovery Problem: handling cargo rerouting

The VSRP model was first developed and presented by Berit Brouer. As described previously, the objective function takes into account bunker costs and penalty costs for delaying or miss-connecting cargo. The assets are subject to a few constraints that ensure feasibility of the solutions:

- Constraints ensuring that a port call is either used in the solution or omitted;
- Flow conservation constraints;
- Constraints related to penalties in case of delays or miss-connections.

The main drawback of the VSRP is that it does not consider cargo rerouting. Meaning that when a container is severely

Data description

To test the two models, four use-cases have been provided by Maersk Line. They come from real situations that actually happened in the past years with Maersk ships. Each time, decision had been taken by operators without the support of any optimization tool. Although they are relatively small in size, they are known by Maersk to provide a wide and full overview of situations likely to happen within the business. They are referred to by their name: Sarnia, Eindhoven,

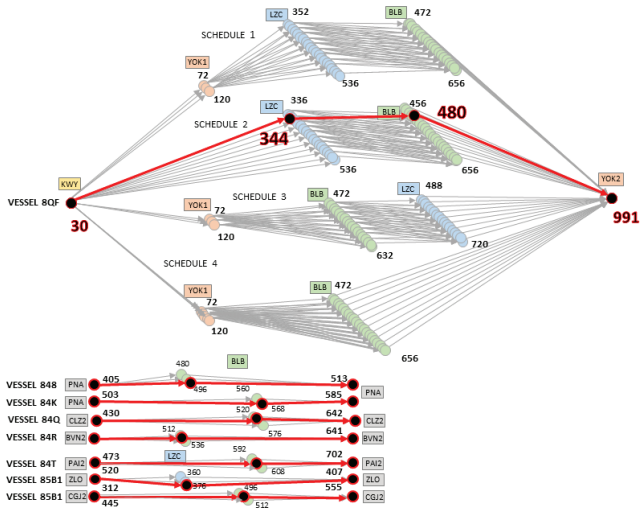

Figure 4: a graph rerouting example

INJHT and Ravenna. A mother vessel is delayed in Sarnia, Eindhoven is about a port closure while INJHT presents a berth prioritization use-case. Finally, congestion in one port is expected in Ravenna.

Results

The algorithms of both models were run for each use-case. Solutions and performance have been compared and faced to real-life decisions that had been taken by Maersk operational agents. First, it is worth to mention that both models provided solutions at least as good as the ones chosen by Maersk. For Eindhoven and INJHT, decisions that were made were optimal but using the models would have helped to save money for Sarnia and Ravenna. In Sarnia, decision was to speed up the delayed vessel whereas it turned out that this was more costly than omitting a port call as suggested by the models. In Ravenna, on the contrary, it would have been better to speed up the vessel to ensure deliveries instead of swapping port calls as it had been decided. Moreover, the two models gave

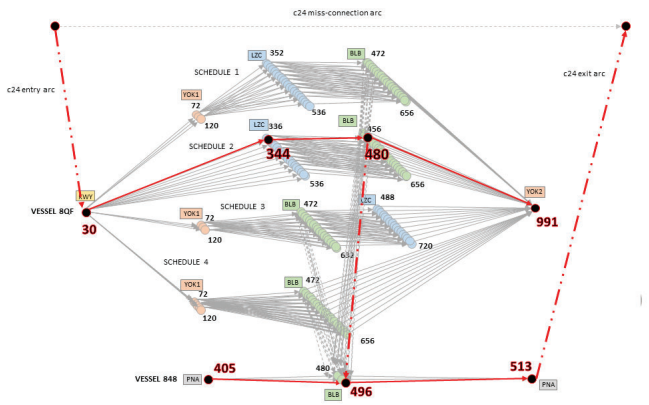

Figure 5: The Sarnia case results on IRP (vessels 8QF and 848 only)

the same solutions for the four use-cases as there was no place for cargo rerouting in any of the use-cases. In order to assess the new model's performance, vessels that are able to propose alternative routes for the delayed containers must be added to better evaluate cargo rerouting solutions. Another use-case was then built to test the potential benefits of the IRP. Starting from Sarnia, we then slightly modified the instance by adding an extra-vessel offering an alternative way to some containers to reach the final destination. Results were satisfactory as the IRP propose to reroute some containers whereas the VSRP just considers them as delayed/miss-connected. The IRP model proved itself satisfactory to propose better results than the VSRP on the condition that a wider network is considered by the model, thus all possible recovery actions for vessels and containers are perfectly assessed.

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By Line Reinhardt

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By Jakob Krarup

"Hi Jakob, you are known as a nice guy and a good organizer of this and that.
Besides, you are blessed with 11 grandchildren. What else have you done?"

A Review of Selected Research Papers: The First 55 Years

For an electrical network containing voltage sources, current sources, and ideal diodes, the current distribution appears to form an optimal solution to a linear programming problem. By inclusion of resistors this property extends to encompass quadratic programming as well. This relationship between a physical device and a mathematical problem was further elaborated upon in my M.Sc. thesis "Mathematical programming and electrical networks", defended in 1964. In hindsight, this thesis marked my initial, modest step towards documented research.

To the best of my knowledge, the first OR-unit in Denmark was established in 1959 by Aage Melbye at Regnecentralen, the Danish Institute for Computing Machinery, where DASK, the first digital computer in Denmark was inaugurated in February 1958. During the early years of the unit's existence I constituted the second half of the staff. The keen interest taken in OR has ever since been the main motivating force for my professional work as evidenced by a bibliography, almost exclusively on OR writings, comprising 185 entries as per today. Among these, 76 works are selected for this review, categorized as: 1) Location analysis and related areas, 2) Extremal paths, 3) Graphs and combinatorics, 4) Multicriteria decision-making, 5) Drawing of premium bonds, 6) Expository papers, 7) Miscellanea, and 8) Papers in preparation.

Of the remaining works (excluding a textbook and lecture notes in Danish, the majority of consultancy reports, and other ephemeral works) 41 are listed with but limited comments in the subsequent sections: 9) EURO and IFORS, 10) DAPS Society, European OR Seminars, 11) Portraits, and 12) Edited works.

To shorten the bibliographical data, six acronyms are used in the sequel:

- DIF-EU: Continuing Education in Management and Technology, Denmark
- DIKU: Department of Computer Science, University of Copenhagen
- DORSnyt: Newsletter, Danish OR Society
- IMSOR: Institute of Mathematical Statistics and Operations Research, Techn. Univ. of Denmark
- ORbit: Journal of the Danish and the Swedish OR Societies
- A/S Spadille: Spadille, Ltd., Consultants of OR and Industrial Statistics, Denmark

1. Location analysis and related areas

To facilitate the overview, the works are not considered in a chronological order but grouped subject-wise. The point of embarkation is the four so-called prototype location problems within discrete location theory:

1.1 SPLP/UFLP the Simple (or Uncapacitated) Plant (or Facility) Location Problem,
1.2. p-CENTER, p-MEDIAN
1.3 QAP, layout, the Quadratic Assignment Problem and related layout problems.

Afterwards follows

1.4 Hybrid models, combining SPLP/UFLP, p-CENTER and p-MEDIAN.
1.5 Location problems with push-pull objectives
1.5.1 Continuous location: the 3-point Fermat problem and extensions
1.6 Minisum vs. equilibrium allocation
1.7 Assessment of approximate algorithms
1.8 Locational decisions in practise problem formulation, case studies
1.9 Monographs, books, book chapters

1.1 SPLP/UFLP

This prototype location problem has been dealt with in the

literature under several names. Simple Plant Location Problem (SPLP), a term most probably coined by Kurt Spielberg in 1967, used to be the prevailing designation up to the early eighties but appears then to be succeeded by the more suggestive Uncapacitated Facility Location Problem (UFLP).

Together with Ole Bilde, a fellow Ph.D. student of mine in 1966, I came across a Swedish Ph.D. thesis, where the author presented an instance of SPLP with but 4 facilities and 4 clients and devised two near-optimal approaches for its solution. Ole and I were at that time aware of the potential of the branch-and-bound technique, provided that good bounds could be found with limited computational effort. This resulted in

(with O. Bilde) "Bestemmelse af optimal beliggenhed af produktionssteder", Research Report, IMSOR (1967).

Our bounds found by, what later was called dual ascent, appeared to be so good that the search tree often reduced to but a single node; furthermore, using paper and pencil only, instances with up to 29 potential facilities could be solved to optimality.
The notion that new important results should be published in an international journal, however, was at that time not foremost in our daily contemplations. There is no other explanation of the fact that the modest research report in Danish remained in a drawer for a full decade until Peter Hammer, Editor-in-Chief of several journals, heard of it and encouraged us to submit it to one of these,

(with O. Bilde) "Sharp lower bounds and efficient algorithms for the simple plant location problem", Annals of Discrete Mathematics 1 (1977) 79-97.

It was embarrassing afterwards to realize that numerous approaches for SPLP had been investigated elsewhere, and numerous codes had been developed, tested and compared over the years 1967-77. Nobody, apart from its reluctant authors, knew that our dual ascent technique would have outperformed them all.
Dual ascent was discovered independently in 1978 by Don Erlenkotter who in addition devised a dual adjustment procedure to further improve the bounds. The resulting algorithm called DUALOC, occasionally referred to in later literature as a variant of our approach, was at that time ranked as superior to any other algorithm for the exact solution of SPLP.
Both being seminal papers, together with DUALOC, "Sharp lower bounds ..." managed to generate much research both in Europe and the Americas as evidenced by later surveys where several direct successors are discussed. These two papers, as well as the 10-year old forerunner of "Sharp lower bounds ...", have also been considered in expository articles on Lagrangean relaxation.

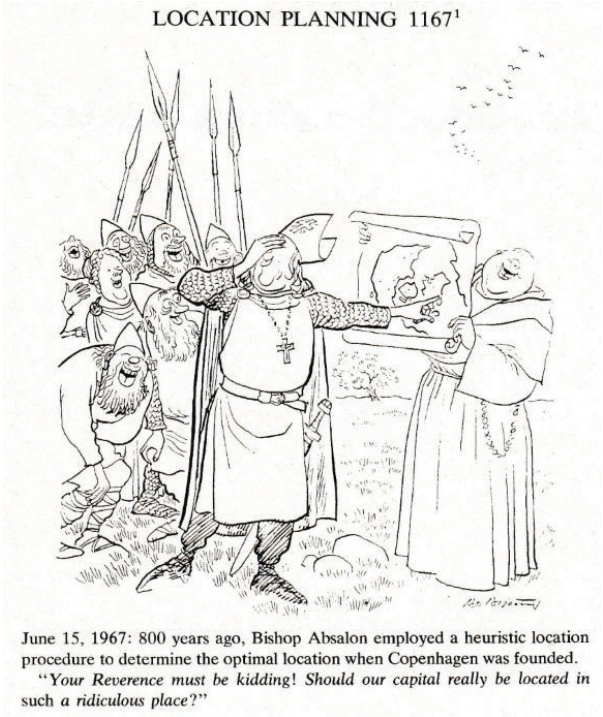

Figure 1: Reprinted here by permission of the artist, Bo Bøjesen

Ole Bilde and I carried on with

(with O. Bilde) "Plant location, set covering, and economic lot size: an O(mn)-algorithm for structured problems", in (L. Collatz et al., eds.), Optimierung bei graphentheoretischen und ganzzahligen Proble-me, Numerische Methoden bei Optimierungsverfahren, Band 3, Birkhäuser Verlag, Basel (1977) 155-180.

SPLP in general is NP-hard. Specially structured instances, however, are here shown to be solvable in polynomial time. The relationship established between SPLP and the so-called dynamic version of the economic lot size problem has been quoted in later textbooks and was also recognized as a source of inspiration to EURO Gold Medal Laureate Laurence Wolsey in his speech-of-thanks (Glasgow, 1994).
ISOLDE is the acronym for International Symposia On Locational DEcicions. The first ISOLDE meeting was organized in Banff, Canada, in 1978. By invitation of Jonathan Halpern, who sadly passed away in Copenhagen only three years after, Peter Pruzan, my co-author on a textbook, dozens of lecture notes, and about 40 writings in total up to 1990, and I contributed with

(with P.M. Pruzan) "Selected families of discrete location problems. Part III: The plant location family", WP-12-77, University of Calgary (1977).

A related, but more modest contribution was made at

"New trends in solving uncapacitated facility location problems", in IV Mátrafüred Conference on Mathematical

Programming, MTA SzTAKI, Budapest (1977) 21-23.

Six years after P. Pruzan and I published the longest journal paper I have ever authored or co-authored,

(with P.M. Pruzan) "The simple plant location problem: survey and synthesis", EJOR 12 (1983) 36-81.

Upon having accounted for the blurred history of the origin of the problem, we provide an extensive discourse on solution properties and computational techniques, spanning from early heuristics to the at that time most novel exact methods. Other subjects of concern include the relations to Set covering / packing / partitioning, subfamilies of SPLP solvable in polynomial time, analyses of approximate algorithms, transformability of p-CENTER and p-MEDIAN to SPLP, and structural properties of the SPLP-polytope. Along the way these findings are synthesized and related to other areas of integer programming.
Monique Guignard and Kurt Spielberg edited in 2007 a volume of Annals of OR titled "History of Integer Programming: Distinguished Personal Notes and Reminiscences". It was a pleasure to accept the Editors' honourful invitation to join the party with

"Dual ascent: variations of a theme", Annals of Operations Research 149 (2007) 137-145.

The sweet story about the Swedish 4×4 instance of SPLP which originally aroused my interest in the problem is here told. Dual ascent has later been successfully applied to other location problems, but, as is pointed out, has failed to work for a family of specially structured set covering problems, notably the notorious "Football pool problem" still being under investigation, cf. Section 8 below.

1.2 p-CENTER, p-MEDIAN

My interest in the "intractable" integers dates back to the early years (1958-64) during which I enjoyed the great luck of being affiliated with Regnecentralen, where the afore-mentioned DASK, the first digital computer in Denmark, was built and where Danish computer science literally was born. Equally fortunate was the participation in the two-week NATO Summer School on Contemporary Methods of Discrete Mathematics (Varenna, Italy, 1966), directed by Frank Harary and Bernard Roy. The invited lecturers included Steven Vajda, who, amongst others, rightly should be credited for having introduced Linear Programming in Europe and Asia and whose impact on my future career hardly can be overrated.

Among the key events attended subsequently on European soil in the development of integer programming / discrete optimization / combinatorial optimization were the meetings organized by Bernard Roy and Peter Hammer (Versailles, 1974) and Bernhard Korte (Bonn, 1975). To further emphasize

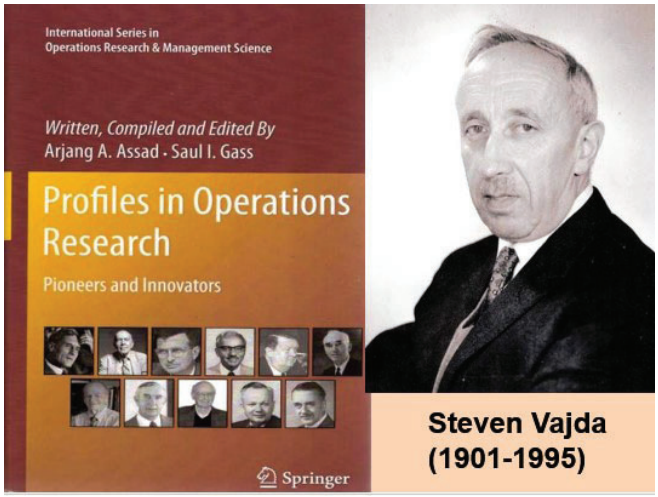

Figure 2: Steven Vajda (1901-1995): mentor and friend

the aims and scope of this emerging field, Peter Hammer was the main organizer of Discrete Optimization (Vancouver, 1977). The core of the meeting was 24 invited surveys. Peter Pruzan and I contributed with a lengthy treatise of p-CENTER and p-MEDIAN,

(with P.M. Pruzan) "Selected families of location problems", Annals of Discrete Mathematics 5 (1979) 327-387.

A companion meeting, largely devoted to discussions, was held in nearby Banff in the days after. I served as the secretary at one of the sessions,

"Report of the session on location and distribution", Annals of Discrete Mathema¬tics 5 (1979) 411-415.

Answers to one question tend often to generate new questions. A collection of open problems in the early 80s is assembled in:

(with P.M. Pruzan) "Challenging unsolved center and median problems", in (S. Walukiewicz and A.P. Wierzbicki, eds.), Methods of mathematical programming, PWN - Polish Scientific Publishers, Warsaw (1981) 181-189.

1.3 QAP, layout

The Quadratic Assignment Problem (QAP) is traditionally ranked among the prototype problems within discrete location theory and famed for being one of the hardest to solve.
Among the clients during my period as a consultant was a Danish company specializing in hospital layouts. One of their projects dealt with the design of a university hospital, Klinikum Regensburg, to be built in Regensburg, Germany. In 1972, an invitation to submit tenders was issued to several architects. As was explicitly stated in the announcement of the competition, among the criteria to be considered in the evaluation of proposals was the usual QAP-objective: find a layout minimizing the sum of "communication × distance" taken over all pairs of facilities (here, hospital units) to be located.

30 different hospital units (surgery, X-ray, canteen, et cetera ...) were to be located in a building, the shape of which was not fully determined a priori but supposed to result from "the most compact arrangement of the 30 units" suggested by the architects or determined by solving the corresponding QAP.
Since no algorithm at that time was capable of solving such a sizeable instance to optimality, we could do nothing better than generating a lower bound, hopefully below the objective function values reached by the competing architects. To this end a randomized heuristic was devised as described in

(with H. Marqvardsen and K. Schmidt) "Placering af punktformige afdelinger i et rumligt koordinatsystem", commissioned by Institut for funktionsanalyse og hospitalsprojektering, A/S Spadille (1972).

Besides additional details, the time element was explicitly included in

"A programme for the evaluation of alternative plans for the step-wise build-up of a hospital",
commissioned by Institut for funktionsanalyse og hospitalsprojektering, A/S Spadille (1972).

The most exciting part of the first report appeared in the same year,

"Quadratic assignment", DATA 3/72 (1972) 12-15.

Under the name Krarup 30a the Klinikum Regensburg instance of QAP became a standard benchmark problem due to its inclusion in the QAP library (QAPLIB) established in 1991 by Rainer Burkard et al. In spite of all attempts made by several researchers, however, it took no less than 27 years before Krarup 30a was finally solved to optimality by Peter Hahn et al.

Figure 3: Announcement of the Versailles meeting, a milestone in the development of combinatorial programming / optimizaton

I met Peter Hahn for the first time at Discrete Optimization II, Rutgers University, N.J., 1999, actually held at my initiative as a follow-up meeting on its 1977-forerunner, and, once again, with Peter Hammer as the Chef d'orchestre. Peter Hahn reported here on his approach: total run time: 98.6 days on a Sun UltraSPARC 10 (360 MHz) computer! Peter and his team, however, had no knowledge of the real-world application underlying Krarup 30a and assumed that there were no symmetries that could be exploited in order to reduce the branch-and-bound search space. Had he known that, the run time would have been cut in at least half.
The long and convoluted story of this intriguing instance of QAP is told in

(with P. Hahn) "A hospital facility layout problem finally solved", Journal of Intelligent Manufacturing 12 (2001) 487-496.

In the early 70s there were only two consulting companies in Denmark focusing on applications of OR, Operations Analysis Corporation and Spadille Ltd., established and managed by Peter Pruzan et al. and myself et al., respectively. For several years, Peter and I were thus competitors by definition; nevertheless, we met regularly for joint research.
The keen interest in QAP, further motivated by other real-world projects, led us to consider the related area known as plant layout. Two joint papers resulted, the first being widely cited in later literature,

(with P.M. Pruzan) "Computer-aided layout design", Mathematical Programming Study (1978) 75-94.

(with P.M. Pruzan) "Layout planning, evaluation, and optimization", in (A. Prékopa, ed.), Survey of mathematical programming, Akadémiai Kiadó, Budapest (1980) 259-278.

1.4 Hybrid models

p-MEDIAN is a minisum problem as opposed to p-CENTER which has a minimax objective. In practise, however, it is at times necessary to consider both objectives simultaneously. Location of hospitals or other medical centres is a good example in this context.
How to solve convex combinations of p-MEDIAN and p-CENTER? Part of the answer, even in more general terms, is provided in

(with P.M. Pruzan) "Reducibility of minimax to minisum 0-1 programming problems", EJOR 6 (1981) 125-132.

Due to intrinsic properties of the minimax criterion, however, the results presented will in general apply for 0-1 programming problems only.
Inspired by an increasing interest in multicriteria 0-1 programming in general and the results obtained in "Reducibility of minimax … ", this line of research was further

pursued a year later in

(with R.E. Burkard and P.M. Pruzan) "Efficiency and optimality in minisum, minimax 0-1 programming problems", Journal of the Operational Research Society 33 (1982) 137-151.

The main goals here are twofold: 1) to establish relationships between optimal solutions to 0-1 problems for which the objective function is a convex combination of minisum and minimax criteria and the corresponding efficient solutions for the given criteria, and 2), based upon these relationships, to suggest a procedure for determining optimal and efficient solutions.
A first, and more ambitious attempt to consider all three prototype locations problems, SPLP/UFLP, p-CENTER and p-MEDIAN within a common framework was discussed at ISOLDE I (Banff, 1978),

(with P.M. Pruzan) "UNILOC, an algorithm for solving the union of center, median, and plant location problems", in (J. Halpern, ed.), Proceedings of International Symposium on Locational Decisions, Banff, Canada (1978).

Whereas this preliminary version of UNILOC was rather sketchy, the corresponding algorithmic tools – largely based on dual ascent – had first to be developed before the final result was ready for publication:

(with P.M. Pruzan) "UNILOC - a uni-location model", Regional Science and Urban Economics 12 (1982) 547-578.

Instead of treating each of SPLP/UFLP, p-CENTER and p-MEDIAN individually, UNILOC unites these three fractions of a pattern. Besides, an algorithmic complex comprising a set of modules is devised for its investigation.

1.5 Location problems with push-pull objectives

Depending on the context, facilities to be located may be regarded as friendly in the sense that closeness is an attractive property. Location theory, however, does also encompass the counterpart: the location of so-called obnoxious facilities where one frequently used criterion is the maximum distance between a facility and the closest user. In short, friendly ↔ pull ↔ positive weight; obnoxious ↔ push ↔ negative weight.
A first move in this direction was the short note,

(with R.E. Burkard) "Locational analyses involving both positive and negative weights", Studies in Locational Analysis 9 (1996) 31.

Much more significant, however, was the piece of research documented in

(with R.E. Burkard) "A linear algorithm for the pos/neg-weighted 1-median problem on a cactus", Computing 60 (1998) 193-215.

The exact algorithm proposed visits every vertex just once and runs thus, as the title says, in linear time. Embarking from this paper, Rainer Burkard published later a series of papers which in retrospect can be viewed as "variations of a theme".
An overview of various push-pull models within discrete location is provided in

(with F. Plastria, D. Pisinger) "Discrete location problems with push-pull objectives", Discrete Applied Mathematics 123 (2002) 363-378.

The discussion is restricted to models of combinatorial optimization and includes indications of reduction to standard models and/or algorithmic approaches wherever possible.

1.5.1 Continuous location: the 3-point Fermat problem and extensions

For a given triangle ABC, the 3-point Fermat problem posed around 1643 asks for a fourth point such that the sum of its Euclidean distances, each weighted by +1, to the three given points is minimized. The so-called Complementary Problem (CP) differs from Fermat in that the weight associated with one of these points is -1 (push) instead of +1 (pull)
CP is dealt with in the famous book What is Mathematics? (Courant and Robbins, 1941). With reference to a geometrical figure and for triangles having one angle greater than or equal to 120o, it is asserted that a certain point solves CP. "The proof is left to the reader ... .".

To prove something which is incorrect, however, is impossible. The correct solution for any triangle is provided in

"On `A Complementary Problem´ of Courant and Robbins",

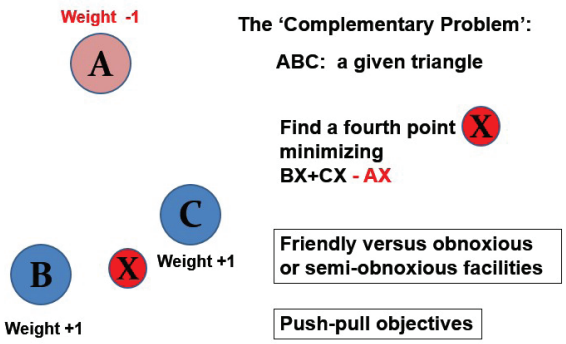

Figure 4: Complementary Problem (Courant and Robbins)

Location Science 6 (1998) 337-354.

Steven Vajda (1901-1995) has, strangely enough, joined forces with a co-author on a single paper only; the outcome appeared to become Steven's last paper and was published posthumously,

(with S. Vajda) "On Torricelli's geometrical solution to a problem of Fermat", IMA Journal of Mathematics Applied in Business & Industry 8. A special edition dedicated to the work of Steven Vajda (1997) 215-224.

It is here attempted to answer the question: what exactly did Torricelli do? We also discuss what Jacob Steiner (1796-1863) did not do. The latter refers to yet another blunder made by Courant and Robbins where all credit for the origin of the 3-point Fermat problem undeservedly is attributed to Jacob Steiner "... the famous re-presentative of geometry at the University of Berlin in the early nineteenth century.". Neither Fermat, nor Torricelli are even mentioned.
Galina Jalal, a bright M.Sc. student agreed in 1997 to pursue this line of research for her thesis work. As a side effect we first published the survey-type paper,

(with G. Jalal) "Single-facility location problems with arbitrary weights", in (F. Giannessi et al., eds.), New Trends in Mathematical Programming, Homage to Steven Vajda. Kluwer Academic Publishers, 1998, 101-114.

Several questions as to further generalizations of Fermat remained still to be answered. This led us in 1997 to prepare a draft version of a geometrical approach for solving the problem for arbitrary weights, be they positive, zero or negative.
Upon having earned the M.Sc. degree, however, Galina left academia and both authors had to engage themselves in other professional activities. Although undone work is a steady nuisance, the draft version lay dormant for about 4½ years until papers for the Rosing Festschrifft were solicited. Eventually the final result appeared as

(with G. Jalal) "Geometrical solution to the Fermat problem with arbitrary weights", Annals of Operations Research 123, Contributions in Location Analysis: A Volume in Honor of Kenneth E. Rosing (J. Hodgson, C. ReVelle, Editors) (2003) 67-104.

It is tempting here to quote from one of the referee's overall remarks: "This very interesting paper gives a complete geometric solution to the planar three points Weber problem with Euclidean distances, possibly including negative weights. All arguments use standard plane geometry only, and lead to simple classical geometric constructions, i.e. executable by ruler and compass. The methods are mostly correct, except from a number of easily corrected lapses [...]. There remain also an important number of imprecisions and incompletions in the arguments, which ought to be corrected and added in order to obtain the intended fully comprehensive and quite final treatment of this problem with a 350+ year history.".
I believe that the final version really represents "the intended fully comprehensive and quite final treatment ... ." Without false modesty, among my more recent works, this is one of the best. It was in this context a surprise to discover that a nonconvex problem could be solved by ruler and compass as also noted in a later review by Horst Hamacher.
In turn it is equally tempting to quote from our Acknowledgments: "A laconic statement thanking the anonymous referees for their valuable suggestions does not suffice in the present case. Considered as a whole, the reports received from three independent referees was none less than a true masterpiece of work, let alone the kind remarks made in their overall assessments. Neither as authors of scientific papers, nor as editors of professional journals have we found a more constructive input for a revision.".
My opening plenary talk at KOI 2016 (Osijek, Croatia, September 2016) was a tribute to Steven Vajda. The account on our work on the 3-point Fermat problem (3-pF) motivated Kees Roos, Technical University Delft, afterwards to prepare a first draft of an approach showing that a solution to 3-pF could be obtained via duality in conic optimisation. We joined forces, several other aspects spiced with historical notes were also included, and the final result appeared a year after:

(with K. Roos) "On the Fermat point of a triangle", NAW, Nieuw Archief voor Wiskunde, 5/18 No. 4, December 2017, (2017) 1-7.

Amongst others, the length of a Simpson line (Simpson, 1750) is here (to the best of my knowledge, for the first time) expressed in terms of the side lengths of the given triangle.

1.6 Minisum vs. equilibrium allocation

For the four prototype location problems discussed above, investigation of congestion at the facilities from an equilibrium point of view appeared in the mid 80s to be virgin territory. Under the assumption that the users so to speak 'solve' the allocation part of the problem on an individual basis by assigning themselves to facilities such that an equilibrium state is achieved, this phenomenon is considered in

(with J.-F. Thisse) "Optimal location under equilibrium allocation", in (L. Streitferd et al. eds.)
Operations Research Proceedings 1985, Springer-Verlag (1985) 409.

The same line of research was later pursued in

(with M. Labbé) "Optimal location: minisum versus equilibrium allocation", in (G.K. Rand, ed.) Operational Research '87, North-Holland (1988) 718-729.

where the underlying assumption is that the clients assign themselves to facilities such that an equilibrium state results. The main result is that the optimal location pattern may depend upon the allocation principle used.

1.7 Assessment of approximate algorithms

In 1977 Gérard Cornuéjols, Marshall Fisher, and George

Nemhauser published a paper in Management Science, "Location of bank accounts to optimize float". The paper appeared under the heading "Exceptional Paper" which presumably means that it was refereed beyond the usual standard applying for the Journal.
"Location of bank accounts ... " managed to attract a lot of attention. Yet, Peter Pruzan and I were not completely satisfied with all details as documented in

(with P.M. Pruzan) "Assessment of approximate algorithms: the error measure´s crucial role", BIT 26 (1986) 284-294.

Although SPLP/UFLP usually is formulated in terms of minimizing total cost, it is a special case of the more general account location problem or k-plant location problem (kPLP) studied by Cornuéjols et al.
For a specific family of instances of SPLP we show that SPLP itself, the strong LP-relaxation of SPLP and its dual are all solvable by inspection. Based on the relative deviation between optimal solutions to kPLP and the strong LP-relaxation or its dual, we show furthermore that "good" in some cases actually can be "arbitrarily bad". The overall observation is that the schism is due to the choice by Cornuéjols et al. of an error measure, based on a particular, data dependent reference value, which in this case has led to indeed questionable conclusions.

1.8 Locational decisions in practise

Various features influencing the formulation of a locational decision problem include the problem representation, performance criteria, availability of data, the restrictions imposed, and the computational aspects. All consultants will presumably agree that problem formulation is of crucial importance. Some views supporting this postulate are expressed in

(with P.M. Pruzan) "Locational decisions: Problems of optimal problem formulation, unpublished manuscript, presented at International Symposium on Locational Decisions, Banff, Canada (1978).

A related paper focuses on the influence of distance on modelling with respect to e.g. computational tractability and on the quality of the solutions obtained:

(with P.M. Pruzan) "The impact of distance on location problems", EJOR 4 (1980) 256-269.

A series of real-world projects were conducted in the early 70s. The first one deals with the location of a centre in the Copenhagen area for delivery of air cargo. Disregarding a report in Danish, however, no journal paper resulted. But I recall the initial solution, certainly not approved by the Lord Mayor of Copenhagen: the Town Hall square!
How to organize the daily distribution of newspapers; where should the temporary depots be located? These questions are addressed in

(with K. Schmidt) "Udvikling af OR-model til planlægning af et distribueringssystem", commissio¬ned by A/S Bladkompagniet, IMSOR (1972).

Upon further investigations it appeared that the real problem actually was to recruit and maintain a stable labour force of people willing to get up at 3.30 am!
Other examples consider the interplay between location of facilities and distribution of various goods. Among these is an important case study of the Icelandic fishing industry (Fiskifelag Islands): what kind of equipment should be allocated to which harbours; how should each boat in a fleet of fishing vessels be directed accordingly,

(with P.M. Pruzan) "Skitseforslag til en simulation af den islandske fiskeriindustri", DIF-EU (1967).

A luxury resort was to be built on literally virgin territory somewhere (cannot retrieve the exact location) in the Middle East. How to design the water supply network and, for each section, to decide upon the dimension of the water pipe:

(with Y. Gørtz and M. Lilholt) "Dimensioning of a water supply system", SIGMAP Newsletter 15 (1973).

Area selection methods have recently gained prominence in conservation biology. The goal of these methods is to optimise the efficiency of representation of species or habitat types to minimizing some measure of cost for a given representation goal. A typical problem is to identify the minimum number of areas to represent all species in some geographic region.
This nice location problem is here considered in terms of set-covering,

(with J.L. Moore et al.) "Heuristic and optimal solutions for set-covering problems in conservation biology, Ecography 26 (2003) 595-601.

Figure 5: How to find an optimum solution? Here it is!

Our approach gave rise to some discussion, part of which is summarized in

(with J. Moore et al.) "Complementarity analyses reveal extent of conservation conflict in Africa", dEbate response, Science Magazine (www.sciencemag.org/cgi/eletters/2935 335/1591), (2001).

1.9 Monographs, books, book chapters

The dual ascent technique devised for SPLP constituted part of my Ph.D. thesis,

"Fixed-cost and other network flow problems", Ph.D. thesis, IMSOR (1967).

Among the other chapters were "An algorithm for the fixed-cost transportation problem" by which the challenging Balinski instances for the first time were solved to optimality; furthermore, the preliminary version of "A wiring problem", an example of the extremal paths discussed in Section 2. A common feature for the three problem types studied, however, is the branch-and-bound (BB) algorithms devised for their solution. No doubt: these were the earliest BB-codes written in my country.

In 1981 Peter Pruzan and I took a look at what we had achieved so far within the area of locational decisions. A collection of our writings at that time was assembled in the monograph,

(with P.M. Pruzan) "A synthesis of 25 works on locational decisions and related areas", DIKU (1981).

This work, also considering questions as to the enumeration of feasible solutions to various prototype location problems, was never widely circulated but motivated us to submit two doctoral dissertations to the University of Copenhagen. Since both were partially based on a series of joint works, we had them printed in a single volume which could be read from either end, a fact which did not go unnoticed among several journalists affiliated with Danish newspapers.

Peter's dissertation is titled "Locational decisions and discrete optimization". Mine appeared as

"Discrete optimization and locational decisions", D.Sc. dissertation, DIKU (1981).

By invitation of Dick Francis and Pitu Mirchandani, the Editors of Discrete Location Theory, Peter and I enjoyed writing the opening chapter, afterwards acclaimed by several critics,

(with P.M. Pruzan) "Ingredients of Locational Analysis", Ch. 1 in (P.B. Mirchandani and R.L. Francis, eds.) Discrete Location Theory, Wiley-Interscience, New York (1990) 1-54.

Some ten years later an invitation was received from Panos Pardalos to join, what some colleagues of mine have referred to as his "slave factory":

"Warehouse location", in (C.A. Floudas, and P.M. Pardalos, eds.) Encyclopedia of Optimization V (R-Z), 544-549, Kluwer Academic Publishers, 2001.

2 Extremal paths

Discrete prototype location problem presupposes often the availability of a shortest path distance matrix. The first piece of work in this direction was commissioned by a staff member at the Parisian Metro. From time to time some metro stations are closed for renovation or other purposes and it was then desired to keep the staff (and occasionally also the users) currently informed about the shortest path, measured in estimated travel time, between each pair of stations. This all-pair shortest-path problem was solved in

(with O. Bilde) "A modified cascade algorithm for shortest paths", METRA VIII (1969) 231-241.

In hindsight, an appropriate subtitle would have been: "better than Floyd-Warshall". It is still somewhat of a nuisance to me that the Floyd-Warshall algorithm (FW), presented in 1962 without proof as but the laconic note "Algorithm 97" in Communications of the ACM, can be found in any textbook on the subject. Both algorithms belong to the class of "fixed matrix methods", that is, the total run time depends solely on the number of vertices in the underlying network. Furthermore, both are based on dynamic programming where the basic step is the "triple operation" dij = min {dij, dik + dkj} on vertices i,j,k; FW runs in three nested loops whereas two suffice for our cascade algorithm. Moreover, and opposed to FW, for each of the four cases studied, symmetry/non-symmetry, directed/undirected (a distinction not made by FW) we reach the theoretical minimum number of triple operations as each triple only is considered exactly once.

"A modified cascade algorithm … " was among the 20 papers constituting my D.Sc. dissertation, defended in 1982, and by the evaluation committee ranked among my best. Unfortunately, it appeared in a journal with but very limited circulation. Furthermore, to add insult to injury, at courses taught on graph algorithms in the early 70s I was forbidden(!) to replace FW with the cascade algorithm as lazy students preparing for their oral exams felt more comfortable with FW. Thus, although it cannot be justified from a scientific viewpoint, due to its more transparent structure and simpler correctness proof, FW must be expected to maintain its present position ... also in future textbooks.

Several consultancy reports in Danish not included here deal with banking. Among the problems considered was how to act on the spot market which in practise means under very strict time constraints as a bid from another bank can appear on a screen and, if not accepted, vanish within a few seconds after. Let G be a complete graph where each vertex i represents

a certain currency ci and where the weight wij of edge (i,j) is determined by the exchange rate applying for currencies ci,cj associated with vertices i,j. Thus, if an amount A is invested in currency ci , its monetary value in currency cj will be A×wij . Using logarithms, however, multiplications can be replaced by additions. Hence, to determine the most profitable path between each pair of currencies is actually an all-pairs shortest path problem defined on G. Together with a corresponding model for the Danish "kronemarked", this idea was implemented in a Danish bank in the early 70s and really managed to facilitate the day-to-day work.

Some problem formulation and rather grave textbook lapses have been pointed out in

(with M. Nordlund Rørbech) "LP formulations of the shortest path tree problem", 4OR 2 (2004) 259-274.

Much research has been devoted to models in which location of facilities and vehicle routing are considered simultaneously. As regards the latter, the Travelling Salesman Problem (TSP) asking for a shortest hamiltonian path can in no way be circumvented. The investigation of some extensions of TSP and TSP itself led to three papers, the first being motivated by an industrial application,

"A branch-bound algorithm for a wiring problem", BIT 9 (1969) 133-156.

The wiring problem arose in 1966 along with the construction of the third generation RC 4000 computer, manufactured by the Regnecentralen. Each instance represents a variant of TSP with n points to become connected to a fixed point, the transmitter of a signal. An exact algorithm is presented which returns a wire in terms of a simple path of minimal length including all n+1 points. The algorithm greatly facilitated the tedious work of mounting the wires and was applied for several years on a day-to-day basis.
A few years later TSP itself was on the drawing board:

(with K. Helbig Hansen) "Improvements of the Held-Karp algorithm for the symmetric travelling salesman problem", Mathematical Programming 7 (1974) 87-96.

Our implementation of the principles underlying the famous Held-Karp algorithm (1971) led to an algorithm which on average is 25 times faster. Instances generated at random and with up to 80 cities were solved to optimality. To the best of my knowledge, no larger instances were at that time (1974) solved elsewhere. Dick Karp was among those who afterwards sent kind congratulatory notes.
A variant of TSP is discussed in

"The peripatetic salesman and some related unsolved problems", in (B. Roy, ed.), Combi¬natorial programming: methods and applications, D. Reidel Publ. Co., Dordrecht (1975) 173-178.

which, in 1975, was an open problem solved by other researchers some decades later. The word "peripatetic" was suggested in talks held with Jack Edmonds. "I like soft questions", he said!

3 Graphs and combinatorics

Being among my mentors since the afore-mentioned Summer School (Varenna, 1966) Frank Harary was visited in Ann Arbor, USA, in December 1969. His interest taken in my work at that time with coordination of traffic signals in Greater Copenhagen led to two joint papers within pure graph theory:

(with F. Harary and A. Schwenk) "Graphs suppressible to an edge", Canadian Mathematical Bulletin 15 (1972) 201-204.

The problem is here to characterize the family of connected graphs having points of degree 2 which can be successively suppressed until only a single edge remains. The answer is provided in terms of four forbidden subgraphs,

(with F. Harary) "A class of planar graphs related to nonserial dynamic programming", SCIMA 2 (1973) 17- 34.

The so-called Secondary Optimization Problem (SOP) within nonserial dynamic programming deals with the number of computations involved when the corresponding Primary Optimization Problem (POP) is solved by dynamic programming. It appears that POP is solvable in polynomial time in n if n is the common range for all variables. A theorem states the relationship between the order of that polynomial and a class of planar graphs. Moreover, it is proved that the join Kn + Tp-n (where Kn is the complete graph with n points and Tp-n is a tree with p-n points) is maximal with respect to the property that it has no subgraph homeomorphic to Kn+3, 0≤n≤p.

In 1986 some visual aids to be used for teaching mathematics were developed at The Royal Danish School of Educational Studies. Among these was sort of a combinatorial game played on a data screen. If the student is successful, the final screen picture displays a given number of red apples, nicely placed with prescribed row and column sums in a subset of cells in an m×n matrix,

(with J. Clausen) "Arranging apples in an array", BIT 28 (1988) 552-568.

The problem had in 1986 been pending in the literature for 30 years. The greedy algorithm presented here will either find the optimal pattern or terminate with the conclusion that no such pattern exists. Furthermore, our correctness proof, established along with an account of earlier findings, appears

to be considerably simpler than any other proof hitherto proposed.
For a given, unweighted bipartite graph G with 2n non-isolated vertices, we consider the so-called Bipartite Cardinality Matching Problem for which the time complexity of the fastest exact algorithm is O(n5/2). In

(with J. Clausen) "A family of bipartite cardinality matching problems solvable in O(n2) time", Nordic Journal of Computing 2 (1995) 496-501.

we devise a greedy algorithm which either finds a perfect matching in O(n2) time or identifies a cycle of length 4 in the complement of G.

Starting in the mid 70s, András Prékopa (1929-2016) organised a series of biennial conferences in Mátra-füred, a small village in the hilly region north-east of Budapest. It was an excellent forum for OR people and mathematicians to meet and a great pleasure, as the years had passed by, to join the non-existing Mátrafüred Club of those who had attended these meetings at least ten times.
Among the participants was Tibor Illés, in 1988 working on the classical and generally unanswered question as to the existence of finite projective planes of a given order. While Tibor's angle of attack was based on combinatorial or number theoretical arguments, it appeared during our talks that this problem also might be approached from an optimisation point of view.
During a visiting appointment with Eastern Mediterranean University, North-Cyprus, where Tibor could be found in April 1996, the following problem was investigated:
A 0-1 matrix is called 4-block-free if it nowhere has a pair of rows and a pair of columns such that the four entries thus singled out are all 1's. Problem 4BF: what is the maximum number of 1's a 4-block-free m×n matrix can have? Two papers resulted,

(with T. Illés) "4-block-free matrices and finite projective planes", Report EMU AS 98-08, Eastern Mediterranean University, Faculty of Arts and Science, Famagusta, North-Cyprus (1998).

(with T. Illés) "Maximum 4-block-free matrices and knapsack-type relaxations", Pure Mathematics and Applications 10 (1999) 115-131.

A knapsack-type relaxation of problem 4BF is investigated; an account of its solution properties is provided, and issues as to the realizability in terms of 0-1 matrices of the solutions found are addressed. Along the way, some surprisingly simple proofs of earlier results are presented together with a new characterization of finite projective planes. A difference between the two papers above is that some very lengthy proofs have been omitted in the published version.

Though at a very moderate pace cars returned to the Copenhagen streets in the post-war years and it was quite popular among kids to watch the passage of a car and note the number x on its license plate. Instead of just recording the number, a knapsack-type game was played with a classmate around 1946-1947: who is first to express x as the product of two integers y and z such that y+z is as small as possible? To play the game well, we realized soon the usefulness of knowing that 1,001 = 7×11×13. Today, about 70 years later, the game has been passed to some of my grandchildren who also should convince themselves that simple, arithmetic calculations do not necessarily require a pocket calculator. As a side effect of the recent revival of the game I felt motivated to seek more insight into the intriguing number 1,001. An account of the findings is provided in

"On the intriguing number 1,001", CEJOR 24/3 (2016) 787-795.

Amongst others it appears that a set of 240 triples of 3-digit integers possesses a certain property which, together with a corresponding graph with 729 vertices and 240 cycles of length 3, may motivate further research.

4 Multicriteria decision-making

Interest in the conditions under which solutions to multicriteria problems can be shown to be efficient had grown enormously in the early 80s, not in the least due to the awareness that significant planning problems can only be meaningfully modelled if multiple measures of effectiveness are considered. In

(with R.E. Burkard, H. Keiding, and P.M. Pruzan) "A relationship between optimality and efficiency in multicriteria 0-1 programming problems", Computers & Operations Research 8 (1981) 241-247.

we establish the identity of the set of efficient solutions to multicriteria problems with any criteria and any constraint set and the set of optimal solutions to a parametrized unicriterion problem incorporating these criteria.
This line of research is further pursued in

(with R.E. Burkard and P.M. Pruzan) "Some relationships between multicriteria and parametric discrete optimization problems with bottleneck objectives", Mathematisches Operationsforschung und Statistik 15 (1984) 389-395.

where one criterion is a sum function while the remaining criteria are bottleneck functions. Depending on the nature of the feasible set, the sum problem may belong to a class of computationally tractable optimization problems which, when solved parametrically, will generate the set of all efficient solutions to the original multicriteria problem.

5 Drawing of premium bonds

The annual or semi-annual drawings of premium bonds by the Danish Ministry of Finance and Danish credit unions were once made manually. Using a beautifully decorated device with small boxes, covered by glass windows, and containing wrapped numbers engraved on brass, Notarius Publicus and his team of associates were personally in charge of the whole affair, monitored by journalists and swallowing a lot of time. Upon the advent of computers, however, time was ripe for reconsidering the procedure. This series of writings, all obviously for a Danish readership, resulted:

"Om generering og anvendelse af tilfældige tal", Research Report, IMSOR (1965).

"Trækningsmodel: Eksponentielt fordelte differenser", IMSOR (1965).

(with A. Jensen and J. Nygaard) "Responsum vedrørende trækning af Østifternes Kreditforenings kasse-obligationer på elektronisk cifferregnemaskine" IMSOR (1965).

(with A. Jensen and J. Nygaard) "Trækning af finansministeriets præmieobligationslån", IMSOR (1967).

To cut a long story short, upon an initial investigation of random number generators, the mathematical foundations are here laid for a procedure where the key element is not to draw each bond separately but the difference between two consecutive lots where these distances are exponentially distributed. The model was implemented in the mid 60s and has, to the best of my knowledge, been used ever since. Besides, J. Nygaard has exported the model to a series of accountants and others responsible for day-to-day management of lotteries.
On the road towards a society where physical bonds and shares in terms of nicely printed documents no longer exist: how to draw unnumbered bonds is considered in

(with J. Nygaard) "Responsum til Boligministeriets Obligationsudvalg om trækning af ikke-numme-rerede obligationer", Betænkning nr. 793: Det obligations- og aktieløse samfund (1977) 109-121.

A variant to be used temporarily for numbered and unnumbered bonds is described in

"Trækning i en overgangsperiode af nummererede og ikke-nummererede obligationer", commissioned by Realkreditrådet, (1982).

6 Expository papers

It was once a habit that each issue of EJOR opened with an invited review. By invitation of Alan Mercer, in 1982 on the three Editors of EJOR, the first paper in the following series resulted,

(with D. de Werra) "Chromatic Optimization: Limitations, Objectives, Uses, References", invited review, EJOR 11 (1982) 1-19.

(with J. Clausen) "Combinatorial optimization: challenges and trends", in (L. Streitferdt et al., eds.), Operations Research Proceedings 1985, Springer-Verlag, Berlin (1986) 24-46.

(with J. Clausen) "The usefulness and beauty of combinatorial optimization", YUJOR 5 (1995) 3-19.

(with S. Fores) "On the origins of OR and its institutions", Invited Review, Central European J. OR 21.2 (2013) 265-275.

"OR i Danmark – erindringer om de første årtier", ORbit 28 (2017) 17-27.

The last paper calls for a comment. Together with Graham Rand, Lancaster University, a session was organised at EURO XVI (Poznan, 2016) on the theme "How OR found its way into universities". Graham covered U.K.; other contributions were solicited from Ireland, Iceland, Poland, and South Africa, and I accounted for the development in Denmark:

Frederik Johannsen, Managing Director of Copenhagen Telephone Company (KTAS) authored in 1907 the first paper on applied OR in Denmark. Besides, he had a remarkable talent for recruiting the right people including Agner Krarup Erlang, worldwide recognised for his pioneering works as evidenced by his inclusion in 2004 in "IFORS' Operational Research Hall of Fame". Also Arne Jensen was employed by KTAS until he in 1963 became the first professor of OR in Denmark and later President of IFORS (1971-73). Furthermore, an OR division was established in 1959 at Regnecentralen, the Danish Institute of Computing Machinery which experienced its 'golden years' up to 1964. Eight former RC-staff members became afterwards full professors of OR or C.S. and spread the message to various Danish universities.

Embarking from the abstract above and by invitation of Sanne Wøhlk, Editor-in-Chief of ORbit, the rather long story not told before on OR in Denmark up to around 1979, and with the text in Danish spiced with selected photos from my archive, turned out to become a series of personal reminiscences.

7 Miscellanea

Prior to the launch of a series of new loans (called rentetilpasning in Danish) to owners of private homes, the credit union Forenede Kreditforeninger wanted to make sure that no legal aspects afterwards could be questioned. To this end the mathematical foundation was established in
"Notat om rentetilpasningslån", commissioned by Forenede Kreditforeninger, (1975).

"Det matematiske grundlag for en parametriseret rentetilpasningsmodel", commissioned by Forenede Kreditforeninger, (1976).

Before the disintegration of the Soviet Union, refusnik scientists were a group of victims of political conflicts: Jewish scientists, who had applied for and refused permission to leave the Soviet Union. Refusniks were normally demoted to low-level jobs or lost their scientific positions altogether. Some of them had their academic degrees removed retroactively; some were in labour camps or exile. In all cases they were cut off from normal interaction with other scientists. My participation in the International Moscow Refusnik Seminar in December 1988, held under abnormal conditions in private homes, materialized in two writings,

"Frontiers of science", EJOR 40 (1989) 129-130.

(with J. Bennedsen and J.O. Eeg) "Report of a visit to Moscow, in (Y.B. Chernyak and J.L. Lebowitz, eds.), Frontiers of Science, Annals of the New York Academy of Sciences 661 (1992) 1-11.

In the spring of 1990 the European Commission announced the TEMPUS programme with the aim of devel-oping higher education in Eastern Europe. The intention was to make resources available for curriculum development, the provision of teaching material, training and retraining of indigenous trainers. The exper-iences in devising and setting up a two-year executive MBA programme at the Warsaw Business School are described in

(with S. Powell and S. Walukiewicz) "MBA studies at the Polish Academy of Sciences: experiences and perspectives of a new venture", OR INSIGHT 9 (1996) 25-29.

The final section comments upon the venture from an OR viewpoint, since it is unusual for OR scientists to
enjoy the luxury of designing an MBA course from scratch.
Still under the TEMPUS programme, and as the Danish member of a different consortium, a similar project
was carried out for The University of Mining and Metallurgy in Craców, Poland, in the late 90s.

During my 11 years (1991-2001) in charge of Operations Management, a course taught at Vrije Univer-siteit Brussels (VUB) as part of the MBA programme, assignments were prepared for the written exams held twice a year. Among these, the full text of 12 assignments, all emphasizing the significance of model build-ing, and all accompanied by detailed answers/solutions, are provided in
(with C. Vanderhoeft) "Belgium's Best Beer and other stories", Model building in optimisation, VUB Press, Brussels, 215 pp, 1999.

The purpose of making "Belgium's Best Beer" available to wider circles was twofold. In order to structure their preparations for an exam, students have a natural interest in seeing what they can expect. Moreover, this collection of assignments has proven to be a valuable supplement to textbooks and other teaching material used over the years, both during the lectures and the exercise sessions, and likewise for similar courses taught at University of Copenhagen and Warsaw Business School.

8 Papers in preparation

Steven Vajda was 94 years of age when we in 1995 wrote the following abstract of a paper to be presented at the IFORS 1996 conference in Vancouver:

For a given optimization problem it is not always obvious what its dual actually represents. Instead of resorting to rather fuzzy terms like "shadow prices" and "valuations" in an explanation of the main ideas, another approach is literally to visualize duality.
We have here collected a series of examples within linear, nonlinear, and combinatorial optimization where the notion of duality appears to be particularly conspicuous. The story embarks from a problem first formulated by Fermat around 1640 and its dual counterpart, a brain teaser proposed by T. Moss in 1755. Other examples of visible duality include König's Theorem, linear assignment and electrical networks, maximum flow in planar networks, and matching and disk packing.
Although Steven enthusiastically looked forward to a pre-conference tour with hikes in The Rockies, his daughter called me in December 1995 with the sad tidings of her father's dead after a short illness.
The material has by now lay dormant in a drawer for more

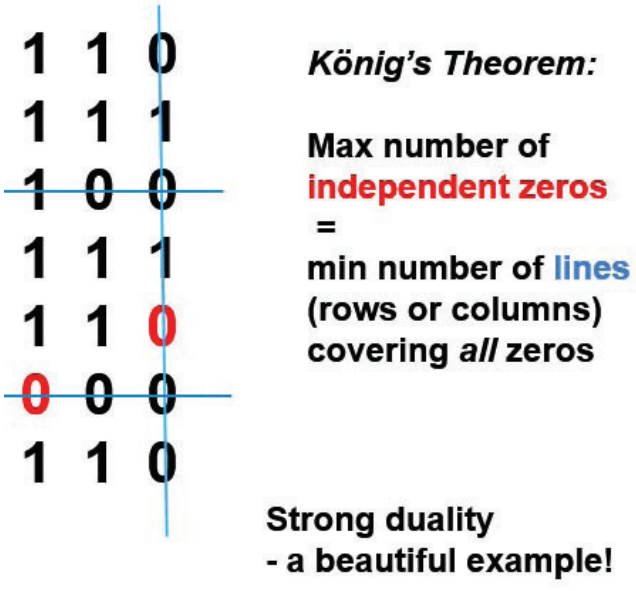

Figure 6: König's Theorem

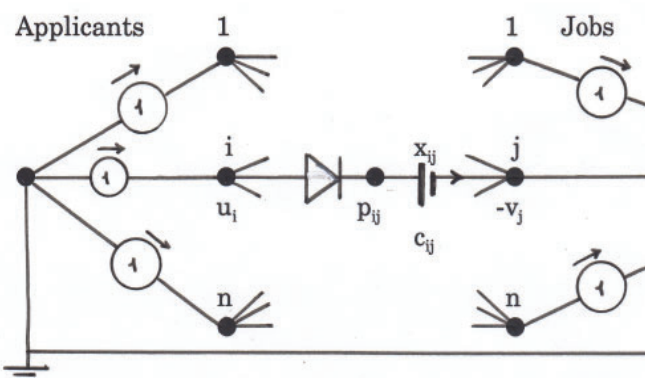

Figure 7: Linear assignment and the corresponding electrical network

than 20 years. Kees Roos, however, has recently agreed to join forces with me such that "Visualizing duality" now is back on the drawing board.

A football match can have three outcomes, "home win", "draw", and "away win", represented on a pool's coupon by "1", "x", and "2", respectively.

To win on the pools a gambler is normally interested in maximizing the number of correct guesses. The inverse problem, however, was the subject of brain teaser, published in a Danish journal in 2003: For a tournament with 12 matches, what is the smallest number ω12 of coupons to be filled in such that at least one has 12 incorrect guesses? A bottle of Scotch was offered for the best answer presented in one week. Having received no answers and using an invalid argument, the originator of the problem announced his own solution, ω12 = 512, and cashed the award.

Together with John Villadsen, Professor Emeritus and a relative of mine, lots of time was spent around 2005-2007 to crack the nut. In the beginning the search for relevant literature took us to nowhere and likewise for talks with experts on combinatorics who only could encourage us to seek our preliminary results published. Alas, two Finnish researchers came first. What they call "… the highly nontrivial football pool problem" is in P.R.J Östergård and T. Riihonen, "A Covering Problem for Tori", Annals of Combinatorics 7 (2003) 357-363, investigated in terms of covering an n-dimensional torus with n-dimensional grid graphs. Although some bounds are provided, the problem is still open as the exact value of ω12 remains to be determined. Anyway, a happy side effect of John's and mine endeavours so far has been material for quite entertaining talks delivered at various international meetings up to 2007.

9 EURO and IFORS

EURO, the Association of European OR Societies within IFORS, was founded on 29th January 1975 in conjunction with EURO I, organised in Brussels by J.-P. Brans. My first entry on the EURO scene followed shortly after: participation in the 1st EJOR Editorial Board Meeting, held in Paris on 21st June in the same year. The by now 44+ years spent with EURO have motivated several writings of which, but a few, relate to IFORS:

- (with C.B. Tilanus) "Report on EURO III", EJOR 5 (1980) 292-301.
- "Excerpts from a guest editor´s diary", EJOR 5 (1980) 289-291.
- "Profiles of the European working groups", EJOR 15 (1984) 13-37.
- "Hvad er EURO?", DORSnyt 65 (1986) 7-12.
- "EURO Gold Medal 1986: A parable on two-level parallelism", EJOR 38 (1989) 274-276.
- "EURO on the threshold to the nineties", President's Report 1989-1990. 18 pp. EURO, Fribourg,
- Switzerland (1992).
- "IFORS Specialized Conferences. The story so far ... and where do we go from here?", OR NewsletterApril 1993 (1993) 8-9.
- "EURO 20th anniversary: the prospective future". EJOR 87 (1995) 415-421.
- "EURO for begyndere ...", ORbit 1 (2002) 10-14
- ."Prologue: EURO 2000", EJOR 140 (2002) 165-166.
- "EURO Summer School XXI: Rapport fra Det Kuriske Næs", ORbit 5 (2003) 18-23.
- "Ten minutes, no slides", Speech-of-thanks by the EURO Distinguished Service Medal Laureate 2009. Available at the EURO web site, www.euro-online.org/display.php?pageid=258 (2009).
- "Extending the Boundaries of IFORS", IFORS NEWS 8,4 (2014) 21-22.
- "EURO – per aspera ad astra", in (L. Zadnik Stirn et al. eds.) Proceedings of the 14th International Symposium on Operational Research, Bled, Slovenia, September 27-29, 2017. (2017) 555-560.

The journal version has appeared as
"EURO – PER ASPERA AD ASTRA", ORbit 30 (2018) 13-19.

Edited volumes

- "EURO III Special Issues", EJOR 5, nos. 5,6 (1980), EJOR 6, nos. 4,7 (1981).
- Editorial: "Excerpts from a guest editor´s diary", EJOR 5 (1980) 289-291.
- "Report on the European Working Groups", European Institute for Advanced Studies in Management,
- Brussels (1981).
- (co-editors J. Lesourne and H. Welling) "Letters from the IFORS President'", EJOR 25 (1986). Editorial 421-422.
- (co-editor P.M. Pruzan) "Systems Science, Fourth EURO Summer Institute Special Issue", EJOR 37 (1988) 1-148. Editorial: 1-7.
- EURO Brochure Summer 1993, EURO, Fribourg Switzerland (1993). Editorial: "From the 1989-90 EURO

Figure 8: Almost all Past Presidents of EURO lined up at EURO 2012 (Vilnius, Lithuania). A comment was heard: "Look, he still has the red jacket from EURO 1995 in Jerusalem!"

President", 2-3.

- (co-editors C. Roucairol et al.) "10th EURO Summer Institute: Combinatorial Optimization", EJOR 83(1995) 249-430. Editorial: 249-252.
- (co-editor D. Pisinger) "Combinatorial Optimisation", EJOR 125 (2000) 219-323. Editorial: 219-221.
- (co-editor D. Pisinger) "O.R. for a United Europe", EJOR 140 (2002), 165-530.
- Editorial: "The EURO 2000 feature issue of EJOR", 167-169.
- (co-editor D. Pisinger) "Special issue: EURO 2000, CEJOR 10 (2002), 1-112. Editorial: 1-2.
- (co-editor L. Sakalauskas) "Heuristic and stochastic methods in optimization", EJOR 171 (2006) 723-890. Editorial: 723-724.

10 DAPS Society, European OR Seminars

Together with Professor Stanislaw Walukiewicz, Systems Research Institute, Warsaw, DAPS Society was founded in 1978 with the aim of establishing a framework for senior researchers and M.Sc. students specializing in OR to meet. Close contact with both EURO and IFORS has been maintained throughout; 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 in 1984. Upon 40 years of service I stepped down in 2018 as President of the Society and was succeeded by Vagn Ro Knudsen, our Treasurer since 1978. We have in 2018 published an account of the Society's activities during the first forty years,

(with V.R. Knudsen) "DAPS Society, European OR Seminars: the first forty years", ORbit 31 (2018) 24-31.

11 Portraits

In chronological order this section covers portraits or profiles of a series of highly esteemed personalities, almost exclusively OR pioneers. Homage is paid to some of them "on the occasion of … " whereas other writings are obituaries:

- (with P.M. Pruzan) "Jonathan Halpern (1940-1981)", EJOR 12 (1983) 1-2.
- "'Lille p', Bech, og den unge himmelstormer", DATA 6/88 (1988) 29-32. - a tribute to Peter Naur (recipient in 2005 of the Turing Award) on the occasion of his 60th anniversary.
- "Steven Vajda, 1901-1995", Ricerca Operativa 25 (1995) 99-103, YUJOR 6 (1996) 1-4, OPTIMA 49 (1996) 12-13, DORSnyt 107 (1996) 20-23, EJOR 92 (1996) 437-439, Recherche opérationnelle / Operations Research 31 (1997) 1-5, New Trends in Mathematical Programming, (F. Giannessi et al., Eds.), Kluwer Academic Publishers, 1998, 1-4.
- "IFORS' Operational Research Hall of Fame: Agner Krarup Erlang", Intl. Trans. in Op. Res. 11 (2004) 117-119, reprinted in ORbit 6 (2004) 17-18.
- Dorit S. Hochbaum, doctor honoris causa ved Københavns Universitet", ORbit 7 (2004) 19-22.
- "Steven Vajda", Ch. 2 in (A. Assad and S.I. Gass, eds.), Profiles in Operations Research, International Series in OR & Management Science 147, Springer Science + Business Media (2011) 31-43.
- (with H. Welling) "Heiner Müller-Merbach, Past IFORS President, 28 June 1936 – 30 May 2015", IFORS NEWS 9,3 (2015) 7.
- A shorter version, partially in German, has appeared as (with L. Suhl, H. Welling) "Heiner Müller- Merbach (1936-2015), OR News 55 (2015) 68-69.
- (with G. Rand) "Maurice F. Shutler (1931-2015)" , EJOR 252 (2016) 699-700.
- An excerpt has appeared as "In Memoriam to Maurice F. Shutler (1931-2015)", CRORS News 3.1 (2016). Another version, targeted for the U.K. readership, is "Maurice Francis Shutler (1931-2015)", INSIDE O.R. March 2016 (2016) 24-25.
- (with C.M. Brugha) "Jean-Pierre Brans: portrait of a fiery soul". Invited paper, CEJOR 2019/1 (2019). http://link.springer.com/article/10.1007/s10100-017-0498-3 .

Modesty is a virtue but, under certain circumstances, I have at times been invited/requested or even ordered to produce a self-portrait:

"Életrajza I, "Mylife", Part II", Szigma XXIV (1993) 95-98.

- J.Krarup: Levnedsberetning", commissioned by Ordenshistoriografen, 21 pp, august 2001.
- Jakob Krarup: Interview, EWG-DSS Newsletter 12 (2013) 2-5.

12 Edited works

The majority of edited works relates to EURO in one way or another, cf. Section 8. The remaining four are

(co-editor R.W. Cottle) "Optimization methods for resource

allocation", English Universities Press, London (1974).

- (co-editor S. Walukiewicz) "Proceedings of the Polish-Danish Mathemati¬cal Program¬ming Seminar, Polska Akademia Nauk, Warsaw (1979).
- (co-editor S. Walukiewicz) "Proceedings of DAPS-79", DIKU (1980).
- (co-editor P.L. Hammer et al.) Editors' Choice, Discrete Applied Mathema¬tics (1998, 1999, 2000).

Acknowledgment

The original version of "A review of ... " was solicited about a year ago by EURO for a specific purpose. Bearing St. Luke 14:11 in mind, 'For whosoever exalteth himself shall be abased: and he that humbleth himself shall be exaltet', I hesitated in the beginning to submit "A review ..." for publication. With reference to the forthcoming ORbit 33, however, DORS circulated on 18 September 2019 a 'Call for Articles' and, still most reluctantly, I decided to give it a try.

It was a great pleasure thereby to become acquainted with Julia Pahl, who earlier this year succeeded Sanne Wøhlk as Editor-in-Chief of ORbit. My debts to Julia for having undertaken the arduous task of nicely combining the lengthy text with selected illustrations and giving the article a final finishing touch is hereby gratefully acknowledged.

Jakob Krarup Professor emeritus, Ph.D, D.Sc. & h.c., DIKU (Dept. of Computer Science, Copenhagen University). President of DORS 1977-79, of DAPS Society 1978-2018, and of EURO 1989-90. EURO Vice President of IFORS 1991-93. DORS Representative of EURO and IFORS 1977-79, 1983-2008. Honorary Member of DORS (2016). krarup@di.ku.dk

By Julia Pahl and Marco Chiarandini

”Who-is-Who” in OR at SDU?

We decided to add a new section to ORbit presenting colleagues working in operations research and thus to learn about the “who-is-who” in Denmark. In this number, we focus on the University of Southern Denmark (SDU).

We find our colleagues working in different departments and research units which reflects well the multidisciplinary nature of our discipline. Every colleague was asked what are her/his research interests and currently running projects, so that you can get a good overview on “what’s currently going on?”

Do not hesitate to contact the colleagues for more information!

Department: Technology and Innovation (ITI), SDU Engineering Operations Management

People: Julia Pahl, Devika Kannan
Related Research Areas: Production and Supply Chain Planning, Maritime Logistics, healthcare logistics, Closed loop supply chain network design, Fixed-charge transportation problem, Sustainable Procurement; Circular Procurement; Supply Chain risk management; Green and Sustainable Supply Chain Management

Current Main Projects: Interreg Baltic Sea Region and European Regional Development Fund Project ECOPRODIGI: the project’s goal is to bring eco-efficiency and digitalisation to maritime industry, Landesforschungsförderung Hamburg, “Maritime Load Dependent Lead Times (M-LDLT)”: the goal of the project is to investigate the phenomenon of maritime load dependent lead times (M-LDLT). These are triggered by delays and insufficient information management between maritime logistic chain partners. The project includes a thorough analysis of the causes and system-wide improvements from an operations and information management perspective. Another focus is on energy efficiency and the minimization of waste in terms of resources such as energy, time, and other critical resources.

Center for Sustainable Supply Chain Engineering, Institut for Teknologi og Innovation

People: Kannan Govindan, Gang Chen
Related Research Areas: Supply Chain Network design, Supply chain risk management, Green / Sustainable health care, Green logistics, supply chain coordination, Circular Economy, Circular Supply Chain, Industry 4.0, Sustainable Manufacturing, Smart Manufacturing, Green Supply Chain Management, Sustainable Supply Chain Management & Reverse Logistics, Digital Supply Chain; Maritime Shipping; Pricing and Revenue management; Container terminals; Sustainable shipping

Current Main Projects: European Social Fund in synergy with the European Regional Development Fund Project for 2014 – 2020 “Development of innovative closed loop supply chain models”; Reducing Cost of Energy in the Offshore Wind Energy Sector through Supply Chain Innovation (ReCoE); Interreg Baltic Sea Region and European Regional Development Fund Project ECOPRODIGI: the project’s goal is to bring eco-efficiency and digitalisation to maritime industry

Department of Mathematics and Computer Science

People: Marco Chiarandini
Related Research Topics: Algorithm design, timetabling, scheduling, routing
Current Main Projects: Intelligent traffic systems with Odense Kommune, Health care technology for people with dementia with Nyborg Kommune, scheduling and routing of photographers with ESoft, Data Science for University Management with DTU and MaCom, Flight route optimization

with Foreflight, Ferry route optimization, Packing optimization with Cabin Plant.

Social Sciences

People: Konstantin Pavlikov, Ying He, Niels Christian Petersen

Related Research Areas: chance-constrained optimization, facility location, risk management, vehicle routing (Konstantin Pavlikov), Decision Analysis, Decision Making under Risk/ Ambiguity, Operations Management, Pricing Management (Ying He), Productivity Analysis, Data Envelopment Analysis, Operations Management (Niels Christian Petersen)

Current Main Projects: development of algorithms and software for chance-constrained problems, travelling salesman and related routing problems (Konstantin Pavlikov), Existence and Design of Probabilistic Selling in Vertical Market, Two Stage Decision Making Model under Ambiguity, Dynamic Pricing under Habit Formation and Satiation (Ying He),

Related Research Area: Current Main Projects: Directional Distance Functions, Homotheticity and non-parametric estimation of production frontiers, Non-convex production possibility sets, Efficiency analysis with ratio data (Niels Christian Petersen)

Source https://via.ritzau.dk/nyhedsrum/syddansk-universitet/mi?publisherId=12056383&item=image-13570557, Krediteringer: SDU...

By David Pisinger

Stefan Røpke modtog Transportforskerprisen 2019

Hedorf Fondens pris for transportforskning blev den 18 november tildelt til Stefan Røpke, Professor på DTU, for hans arbejde indenfor transportoptimering i mere end 15 år.

Prisen blev overrakt af formanden for Hedorfs Fond, Lars Frederiksen, i forbindelse med konferencen "En grønnere vej" som foregik i Børsens historiske lokaler.

Stefan Røpke modtog prisen for sin store viden om ruteplanlægning indenfor vejbaseret godstransport. Stefan har blandt andet udviklet algoritmen ALNS (Adaptive Large Neighborhood Search) som er blevet brugt til at løse en lang række forskellige transportproblemer.

I sin takketale fortalte Stefan Røpke at han vil bruge de kommende år til at undersøge hvordan CO2 udledningen fra godstransport kan reduceres ved brug af avanceret optimering.

Hedorfs Fonds pris for Transportforskning
Prisen er oprettet af Hedorfs Fond og uddeles i samarbejde med Transportøkonomisk Forening - TØF.

Formålet med prisen er at bidrage til en øget forskningsindsats på transportområdet og uddeles som en anerkendelse til en internationalt anerkendt og etableret forsker, der har gjort sig særlig fortjent ved en betydelig indsats inden for udviklingen i Danmark inden for transport, logistik og tilgrænsende fagområder med en væsentlig orientering mod godstransport.

Dette kan især dreje sig om:
- Opnåelse af ny erkendelse inden for transportforskning
- Faglig, herunder pædagogisk udvikling til gavn for transportrelaterede studier
- Brobygning mellem transportforskningens mange discipliner.

Transportforskningsprisen, som andrager kr. 75.000, bliver uddelt ved et særligt arrangement tilrettelagt af Hedorfs Fond og TØF i København.