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36

April • 2021

Mindeord • DORS Tutorial • Genbrugspladser skal have tømt containerne • The development of a container loading optimization software for Atlas Copco • Women in OR: an interview to role models in OR • (...)

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Editor

Dear Reader,

Covid-19 has kept us in home office for quite a while and affected our daily life. However, we seem to be over the peak going down the hill and getting back what used to be normal life. This is nice, because when you hold this ORbit in your hands (physically!), it means that I could enter my office and distribute ORbit to you - which makes me very happy.

We have compiled some nice articles for you, but come also with some sad news that you will learn in ”Mindeord”.

Positive news include that we have a new event series ”DORS Tutorials” that has run successfully in December last year where Filipe Rodrigues from DTU Management introduced us to reinforcement learning. It was a great success, so we are glad that this new format has received so much attention. Of course, we hope to run it next time in physical presence of participants.

Articles of this edition span a wide range of areas, so we hope we have something for everyones’ taste. Sanne Wøhlk gives us insights in her work within recycling, Jonas Olsen et al. show us their developments in container loading, Lavinia Amorosi et al. tell us their experience of being a woman in OR, and Alastair R. Main et al. introduce us into the RoRo Green project.

I wish you all a good reading!

Julia Pahl (Editor)

Aktuelt om DORS

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Svenska operationsanalysföreningen

Våren är här men den pandemi som vi hoppades skulle vara försvunnen vid det här laget plågar oss fortfarande. Många av oss har nu jobbat hemifrån i mer än ett år, och även om det nästan börjar kännas normalt så är det ju långt ifrån det. Vi kan nu iallafall se ett litet ljus i tunneln i form av ökad vaccinering, och kan börja hoppas på en mer social tillvaro såväl privat som i arbetslivet framåt sommaren eller hösten! Kanske kan vi till och med åka på någon enstaka konferens framåt vintern. Den 11 mars höll SOAF sitt årsmöte, den här gången självklart online. Innan själva årsmötes-förhandlingarna presenterades vinnaren i SOAFs årliga exjobbstävling, Tobias Karlsson. Tobias examensarbete med titeln “Optimization of Cable Harness Routing”, med Ann-Brith Strömberg som examinator på Chalmers, och med Edvin Åblad och Tomas Hermansson som handledare vid Fraunhofer-Chalmers Centre, vann med följande motivering. Tobias har tagit fram en automatiserad metod för att hitta de bästa sätten att dra kablar mellan olika komponenter, ett problem som blir alltmer komplext inom t.ex. bilindustrin. Avvägningar mellan kortaste väg, fördelen med att bunta ihop kablar i härvor, och lämpligheten att välja vissa vägar pga. risker och utrymmeskrav hanteras med multimålsoptimering och bivillkor. Dessa problem löses med hjälp av Lagrangerelaxering och specialanpassade heuristiker, och han har visat att ett litet optimalitetsgap kan på kort tid uppnås även på komplexa industriella testfall. Hans arbete visar på god förmåga att modellera system, använda väl anpassade matematiska optimeringsmetoder och implementera detta i ett industriellt sammanhang. Vid årsmötesförhandlingarna avtackades Daniel Oskarsson från styrelsen. Även Anders Eriksson tackades speciellt för sina många år som bland annat revisor för SOAF. Som ny styrelseledamot invaldes Ida Källén från Försvarets Forskningsanstalt FOI. Välkommen Ida! Slutligen ett par besked om kommande SOAF-initativ: Vi hoppas alldeles snart kunna dra igång en serie seminarier med intressanta föredrag inom operationsanalys och närliggande områden! Styrelsen har däremot beslutat att höstens SOAK-konferens kommer att skjutas upp till våren 2022, för att då förhoppningsvis kunna hållas i fysik form. Ha en bra vår och sommar!

Mattias Grönkvist, Ordförande, SOAF

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Aktuellt om SOAF

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Avgiften för företaget/institutionen beror på antalet OR-intressenter enligt följande tariff:
Akademiska institutioner: 1600 kr/år
1-5 intressenter: 1600 kr/år
6-10 intressenter: 3200 kr/år
över 10 intressenter: 4800 kr/år

I företagsmedlemsskapet ingår 2-6 exemplar av ORbit, beroende på företagets storlek.

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Af Lars Relund Nielsen og Sune Lauth Gadegaard, Department of Economics and Business Economics, Aarhus University

Mindeord

Det var med stor sorg, at vi modtog meddelelsen om, at vores kære kollega, Professor Kim Allan Andersen pludselig var afgået ved døden den 20. januar 2021 i en alder af blot 64 år.

Photo: Kim Allan Andersen

Kim Allan blev uddannet som cand.scient.oecon (matematik-økonomi) i 1984 ved Aarhus Universitet, og efter et par år som systemkonsulent ved Landbrugets EDB-center startede han sine ph.d.-studier i operationsanalyse ved Institut for Matematiske Fag, hvorfra han blev ph.d. i 1990. Indtil 2003 var han ansat ved Matematisk Institut først som adjunkt, senere som lektor, inden han blev ansat som professor ved Handelshøjskolen i Aarhus, som senere blev fusioneret med Aarhus Universitet, hvor han var ansat ved Institut for Økonomi til sin død. I en årrække var Kim Allan medlem af DORS bestyrelse.

Kim Allan var som underviser utrolig vellidt. Han underviste i en lang række fag omhandlende matematisk modellering, optimering samt produktions- og transportplanlægning. Hans forelæsninger foregik typisk uden brug af noter, hvilket affødte stor respekt blandt de studerende, hvilket også gjorde ham til en særdeles vellidt specialevejleder. Han havde en evne til at formidle svært tilgængeligt stof klart, præcist og pædagogisk, og gennem sin karriere modtog han flere undervisningspriser. Kim Allans popularitet som vejleder var enestående; i løbet af et år vejledte han ofte mere end 10 specialer og et utal af bachelor- og praktikrapporter. Flere hundrede kandidater har haft Kim Allan som vejleder gennem årene, ligesom han har været ph.d.-vejleder for adskillige ph.d.-studerende.

Som forsker var Kim Allan internationalt anerkendt, og han har skrevet artikler sammen med adskillige internationale top-forskere. Han var populær som sparring i forskningssamarbejder, og havde mere end 20 forskellige medforfattere på sine publicerede arbejder. Hans forskning er publiceret i flere top-tidsskrifter, såsom Management Science, INFORMS Journal on Computing, European Journal of Operational Research, Transportation Science og Mathematical Programming. Blandt hans væsentligste videnskabelige bidrag kan nævnes hans forskning inden for stokastisk optimering og multi-kriterie optimering, hvor han har leveret både dybe teoretiske resultater samt mere praktisk anvendelige løsninger på komplekse problemstillinger. Kim Allan søgte aldrig at besvare de nemme spørgsmål, men kastede sig ud i videnskabelige spørgsmål, som endnu ikke var velstuderede, og bidrog derved markant til grundforskningen inden for operationsanalyse og matematisk optimering. Kim Allans ukuelige nysgerrighed og lyst til at studere de dybere sammenhænge vil derfor stå tilbage som et monument over hans karriere.

Kim Allan var en dybt respekteret videnskabsmand og kollega på vores institut. Vi vil huske ham som den altid venlige, rolige

og eftertænksomme kollega, der helst lyttede, og når han talte var det velovervejet og betænksomt. Han udviste altid professionalisme, ordentlighed, beskedenhed og en uselvisk tilgang til problemløsning. Disse personlige egenskaber og kvaliteter vil blive savnet.

Kim Allans plan var at lade sig pensionere til sommer, hvor han ville fylde 65 år. Han havde glædet sig til at få tid til at dyrke sin store interesse for lystfiskeri, og særligt fiskeri efter laks i Skjern Å. Det skulle han desværre ikke få mulighed for.

I Kim Allans ånd vil det være passende at afslutte med et citat fra lystfiskernes bibel "The Compleat Angler" af Izaak Walton:

"For angling may be said to be so like the Mathematics, that it can never be fully learned; at least not so fully, but that there will still be more new experiments left for the trial of other men that succeed us." Izaak Walton, The Compleat Angler, 1653.

Vore tanker går til Kim Allans familie og hans kone, Birte.

Æret være Kim Allan Andersens minde.

By David Pisinger

Call for Papers

Special Issue: Emerging Topics in Transportation Science and Logistics

Submission Deadline: August 1, 2021

In connection with the editorial restructuring of Transportation Science along topical areas, we are excited to announce two special issues, one focused on a look back at impactful research in our journal and one focused on emerging research directions. The Area Editors have compiled a Virtual Special Issue (Link: https://pubsonline.informs.org/page/trsc/a-deeper-look-at-transportation-science-by-topical-areas), highlighting papers from past Transportation Science issues that showcase the quality and breadth of research in their areas. As we look to the future, we invite authors to submit research papers that highlight emerging topics that will shape the future of research in transportation science and logistics.

The Emerging Topics in Transportation Science and Logistics Special Issue will feature new directions in transportation science and logistics research, promoting topics that have received limited attention in Transportation Science. We welcome papers covering new work in all areas of the journal, from connected, shared, automated or electrified mobility systems to new delivery technology like UAVs to innovations in public transit to increase access. We are interested in new applications in transportation and logistics that require significant changes from existing models and the use of new solution methods that can broadly impact knowledge in transportation science, such as novel applications of machine or reinforcement learning to leverage the massive explosion of data related to mobility. Further examples of emerging topics include papers on humanitarian and nonprofit logistics that address new disaster types, objectives, or other major differences in features from previous work. The special issue will also feature broad-ranging, cross-functional topics that challenge us to consider new perspectives on existing problems, new problems or solution methods involving features from multiple disciplines, and examining the impact of various transportation policies on stakeholders. Examples of new perspectives include modeling equity in access to transportation or developing improvements to the sustainability of transportation systems. Papers may explore econometric and simulation models for transportation policy decisions or policy and economic analysis of environmental incentives and regulations related to transportation activities. The review of papers for this special issue will heavily weigh the innovation, novelty, and societal importance of the work presented.

Proposed Timeline and Process

- Deadline for submission: August 1, 2021. Earlier submissions are encouraged.
- Two rounds of review, completed on a rolling basis as papers are submitted to meet the deadline for final decisions
- Fall 2022: Publication of special issue

Area Editors

Ann Campbell
Emerging & Cross-functional Topics

Jean-François Cordeau and Barry Thomas
Logistics & Routing

Yafeng Yin
Traffic, Demand & Network Analysis

David Pisinger
Modes & Industries

Submission

Submissions are open to all and will be peer reviewed according to the usual standards of the journal. Please submit your manuscript online via ScholarOne Manuscripts at http://mc.manuscriptcentral.com/transci. When choosing Manuscript Type in Step 1 of the submission procedure enter "Special Issue – Emerging Topics in Transportation Science and Logistics," otherwise your submission will be handled as a regular manuscript. The Instructions to Authors can be found on the Transportation Science homepage: http://pubsonline.informs.org/page/trsc/submission-guidelines.

David Pisinger, is a Professor of Management Engineering at the Technical University of Denmark with research interests spanning Maritime Optimization, Railway Optimization, and Energy models. Having a background in knapsack problems, David can be recognized on always wearing a backpack.

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- Institut for Virksomhedsledelse og Økonomi, Syddansk Universitet
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By Dario Pacino

DORS Tutorials – Introduction to reinforcement learning

Compared to many other OR societies, DORS is rather small. Nevertheless, we are an active community that participates in the organized events and has a genuine interest in learning. The board of DORS has, for many years, discussed the possibility of organizing learning events for our members; this year we have done it! We have launched the DORS Tutorials.

The DORS Tutorials are mean to be a series of annual events where our members can be updated on the latest OR techniques, learn more about existing methods, or get introduced to something new. Differently than seminars, we envision these tutorials to be filled with practical exercises and hands-on experience.

On December 17th, we held the first DORS Tutorial. Assoc. Prof. Filipe Rodrigues from DTU Management gave us a broad introduction to the topic of reinforcement learning, which is gaining more and more interest from the OR community.

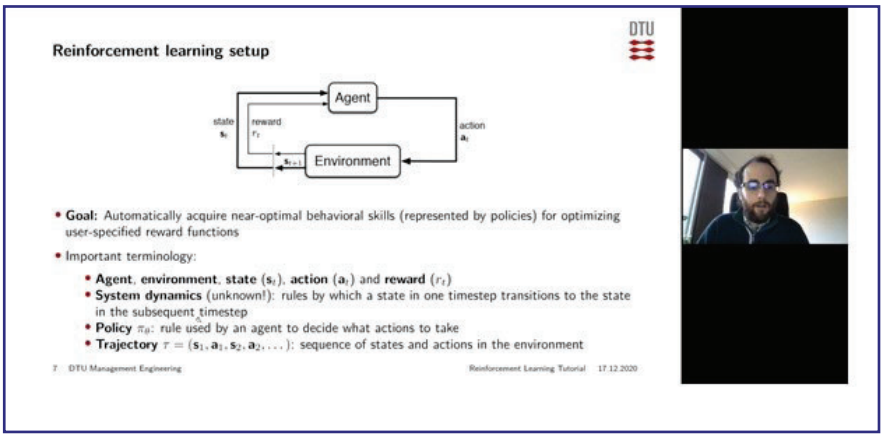

Figure 1: - A snapshot of the online lecture

Organizing the event was not easy. Due to the pandemic, we could not host the event physically, so we had to do it online. Seminars can be easily arranged online, but hand-on exercises are a challenge; we had to make sure that everyone had the right coding environment and that we could answer the questions that might arise.

Filipe started off motivating the use of reinforcement learning and briefly touching upon its history. He presented a taxonomy of algorithms, differentiating them between model-based and model-free, at which point I realized that there is much more to reinforcement learning that I initially thought. The lecture continued introducing topics such as policy evaluation, value functions, Q-learning and much more. Even though some of us felt the math on the lecture was a bit much, the hands-on session was very practical and really gave you the feeling that at some of all the interesting things taught during the lecture must have sticked in the brain somehow.

Filipe organized the hands-on session using Python Notebooks like the one in Figure 2.The textual descriptions in the notebook had all the necessary information to learn about the subject and get you started on the exercises. Partial code was also provided to ease the coding effort, and ready visualizations of the results gave immediate feedback.

Part 1: Simplified environment (Q-learning)

In this first part, we will consider a very simple environment where the goal is to drive the taxi to the target location indicated in the grid world by a red 'T'. The taxi is represented by a yellow rectangle. The 5x5 grid world has a few maze-like walls that prevent the taxi to take certain actions when in some positions (i.e. the action has no effect). The taxi has no intermediate rewards. Only one final big reward when it accomplishes the goal (reach the target and take action "pickup"). Note also that the taxi has no information about the environment besides its current position (row and column). It has no idea how the environment works and what leads to high rewards!

Let's formalize the MDP for this problem:

Actions: north, south, east, west, pickup

State: position of the taxi (5x5=25 possible states)

Reward: +20 if taxi at target location ("T") and action is "pickup", else -1 (penalty for time elapsed); trying to pickup in a location different than the target also leads to penalty of -10.

Implementation details: we have implemented the environment as a class extension of the popular OpenAI Gym. The `TaxiPickupEnvSimplified` class therefore extends the `discrete.Env` of OpenAI Gym, and provides the following methods:

- `state = env.reset()` - resets the environment to a random initial state and returns that state;
- `new_state, reward, done, info = env.step(action)` - takes the `action` passed in the argument (integer) and returns the new state, the reward obtained, a boolean `done` indicating whether the episode has terminated, and some extra `info` (not relevant to this environment);
- `env.render()` - visualizes the current state of the environment;
- `env.close()` - terminates the environment.

Suggestion: have a look at the `taxi_env.py` file to see how the environment dynamics in the `step()` function of the `TaxiPickupEnvSimplified` class are implemented.

Run Random Policy

Let us start by exploring the environment and the functionality described above using a random policy (i.e. taking random actions in the environment). Analyze the code below and run it (note that you can stop execution at any time). Make sure that everything makes sense to you.

```
env = TaxiPickupEnvSimplified()
env.reset()
for _ in range(1000):
    try:
        env.render()
        env.step(env.action_space.sample()) # take a random action
        time.sleep(1)
        clear_output(wait=True)
    except KeyboardInterrupt:
        break
env.close()
```

```
+---------+
| : | : : |
| : | : :|
| : : : : |
| | : | : |
|T| : | : |
+---------+
T: 15; Total earnings: 0
```

Figure 2: Python notebook for the exercise session

In order to handle the wave of questions that arrived as soon as we started coding, we decided to divide the online session into 2 rooms. One room was managed by Filipe himself, while the other was taken care by Daniele Gammelli, Filipe's Phd Student.

The hand-on session, aside from being about the exercises, gave also the opportunity for discussing more advanced topics between the reinforcement learning practitioners in the virtual room and the experts. I must admit, I was surprised about how well it all worked out.

The tutorial was well attended, and we were forced to impose a limit of 50 participants to be able to handle the hands-on session. I believe the first DORS Tutorial was a success, and I look forward joining the next one.

Dario Pacino an Associate Professor at DTU Management with a focus on transport optimization.

He is also the president of DORS, and the organizer of the first DORS Tutorial.

Af Sanne Wøhlk

Genbrugspladser skal have tømt containerne

Foto: Billede af genbrugsplads. Billedet er taget af Reno Djurs I/S

Det er søndag formiddag og du smutter på genbrugspladsen. Her smider du børnenes ødelagte løbehjul i jerncontaineren og slipper af med haveaffaldet. Måske spørger du pladsmanden om hjælp til korrekt sortering af de gamle bolde og giver porcelænsskålen nyt liv i re-use containeren. Inden du kører hjem snupper du måske en spand kompost til haven. Genbrugspladserne er blevet en integreret del af vores hverdag.

Der er 364 kommunale genbrugspladser i Danmark. De har i gennemsnit hver knap 90 tusinde besøgende om året og der passerer i gennemsnit 8,6 tusinde ton materiale igennem hver genbrugsplads om året (Ekeroth, 2019). Det resulterer i temmelig mange containere der skal tømmes hver dag. Det er dette daglige transportproblem der er fokus på her.

Beskrivelse af problemet

Hvert affaldsselskab er ansvarlig for et antal genbrugspladser. På hver genbrugsplads indsamles forskellige affaldsfraktioner (udendørs træ, flamingo, elektronik, osv.) i containere af forskellig type (høje, lave, med låg eller åben gavl, osv.). Indholdet af en container er bestemmende for hvilket behandlingsanlæg containeren skal transporteres til for tømning. Efter tømning skal containeren returneres – enten til den genbrugsplads den kom fra eller til en anden genbrugsplads på en sådan måde, at alle genbrugsplaser har samme antal containere af hver type ved dagens slutning som om morgenen. Til at varetage tømningerne, bruges et antal lastbiler med trailer, som kan transportere to containere ad gangen.

Det daglige transportproblem er dermed følgende: Givet en liste af containere der skal tømmes, lav planer for de tilgængelige køretøjer så alle containere samles op på deres respektive genbrugsplads, tømmes på rette behandlingssted, og returneres således at balancebegrænsningerne er overholdt. Den daglige arbejdstid for hvert køretøj, bestående af såvel kørselstid som tid til af- og pålæsning, må ikke overskride en forudbestemt grænse. Målet er først og fremmest at minimere antallet af køretøjer og sekundært at minimere den kørte distance.

Vi har altså at gøre med et pickup and delivery problem der ikke kun består af opsamlinger og leveringer, men af opsamlinger, tømninger og leveringer, hvor første par er paired og andet par er unpaired, men begrænset.

Vi er interesseret i at undersøge hvor stor besparelse man kan opnå ved at tillade denne form for fleksibel containerreturnering fremfor at kræve at alle containere returneres til deres oprindelige genbrugsplads.

Datagrundlag

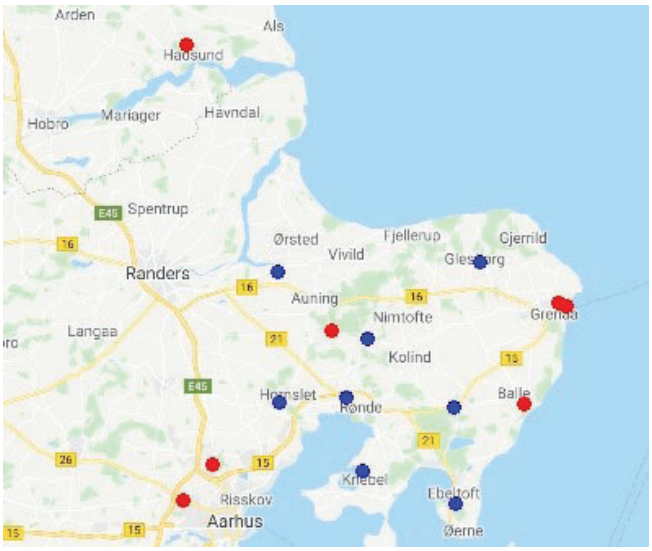

Figure 1: Placering af genbrugspladser (blå) og modtageranlæg (røde) på Djurs

For at besvare forskningsspørgsmålet har vi anvendt data fra 4 affaldsselskaber, Vestforbrændingen, Reno Djurs, Kolding kommune og Odense kommune, hvilket dækker 23 af landets 98 kommuner. Vi har i alt 989 datasæt fordelt på de fire områder. Hver datafil indeholder mellem 4 og 185 contai-

nere, der skal tømmes på en given dag, med et gennemsnit på 34. Antallet af genbrugspladser varierer mellem 8 og 28, mens antallet af modtageranlæg varierer mellem 8 og 18. Figur 1 illustrerer placeringen af genbrugspladser og modtageranlæggene i et af områderne. Antallet af containertyper, som er afgørelse for graden af fleksibilitet i systemet (få typer giver stor fleksibilitet), er mellem 5 og 9 generelt, men er ofte mindre den enkelte dag.

Løsningsmetode

Til løsning af vores pickup og delivery problem har vi udviklet en algoritme med inspiration fra Variable Neighborhood Search (VNS). Algoritmen er beskrevet i detaljer i (Wøhlk og Laporte, 2021). I det følgende beskrives kort hovedtrækkene i algoritmen. Ligesom VNS arbejder vores algoritme med to lag. I det ydre lag af algoritmen bruger vi fire nabostrukturer:

1. Relocate. Her flyttes alle tre aktiviteter for en tilfældig container fra deres eksisterende position i ruterne til slutningen af en tilfældigt valgt rute.

2. Swap. Her ombyttes alle tre aktiviteter for to containere.

3. Empty. Her tømmes den korteste rute ved grådigt at flytte alle tre aktiviteter for hver container på ruten til slutningen af andre ruter.

4. Return-swap. Her byttes genbrugspladserne der modtager de tomme containere for to containere af samme type, for at udnytte fleksibiliteten i returneringen.

Valget om at indsætte containere i slutningen af ruterne i Relocate og Empty skyldes at kapaciteten på kun to containere gør løsningsrummet temmelig restringeret. Det betyder at vi, i det indre lag som aktiveres for de ruter der er ændret i det ydre lag, skal have rykket rundt på containerne og aktiviteterne i den enkelte rute. Det gør vi med vores Pattern-swap nabostruktur. Samtidig betyder dette valg, at vi skal passe på at tidsgrænsen for ruterne ikke hæmmer søgningen for meget, og vi tillader derfor at den midlertidigt overskrides.

Samlet set vil algoritmen dermed foretage en ændring i der ydre lag, som påvirker et antal ruter og eventuelt gør at de overskrider deres tilladte tid. Det indre lag vil derefter forbedre rutelægningen i hver af disse ruter og samtidig forsøge at presse ruterne tilbage så tiden overholdes. Alt dette lægges ned i en Simulated Annealing struktur.

Fordelen ved fleksibilitet

For at besvare vores forskningsspørgsmål, har vi kørt algoritmen samt en version af algoritmen der låser alle containere til at blive returneret til deres egen genbrugsplads på de 989 datasæt. I 10% af tilfældene bevirkede fleksibiliteten i containerreturneringen at vi kunne spare en rute. I figur 2 ses besparelsen for kørt distance. På førsteaksen er antal-

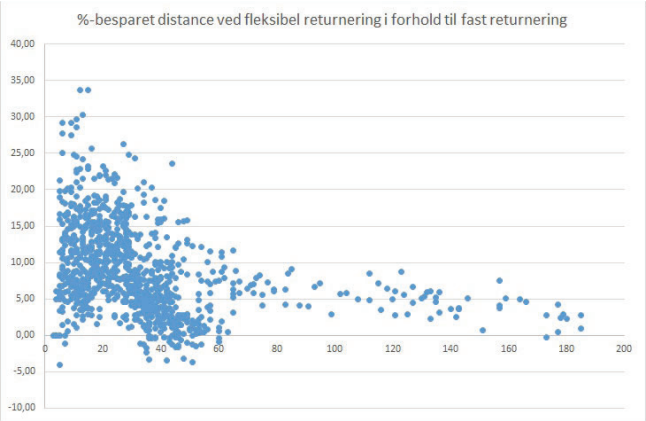

Figure 2: Procentvis besparelse i kørt distance, der opnås ved brug at fleksibel containerreturnering i forhold til at returnere containere til egen genbrugsplads

let af containere i datasættet angivet og på andenaksen ses den procentvise besparelse ved fleksibel returnering i forhold til returnering til egen genbrugsplads. Det ses tydeligt at der generelt er gode besparelser at hente i det fleksible system. Den gennemsnitlige besparelse er 8,2%.

Besparelsen i antal ruter og i kørt distance kommer af to faktorer. For det første bevirker den fleksible returnering at lastbilerne kan vente med at køre retur til en genbrugsplads med de tomme containere til det er rutemæssigt hensigtsmæssigt – eller endda overlade det til en anden lastbil at levere tomme containere til den pågældende plads. For det andet gør fleksibiliteten at der er mulighed fra at fravige det traditionelle mønster (pick, pick, empty, empty, deliver, deliver) og i stedet ydnytte mere eksotiske mønstre når det er rutemæssigt hensigtsmæssigt. Hvor den første faktor forekommer hyppigt, ses anden faktor mindre hyppigt i vores løsninger. Yderligere detaljer om denne analyse kan findes i (Wøhlk, 2020).

Centraliseret planlægning

For et af affaldsselskaberne har vi endvidere haft adgang til information om de faktisk kørte ruter i en periode på et halvt år. Efter en gennemgribende rensning af datamaterialet, har

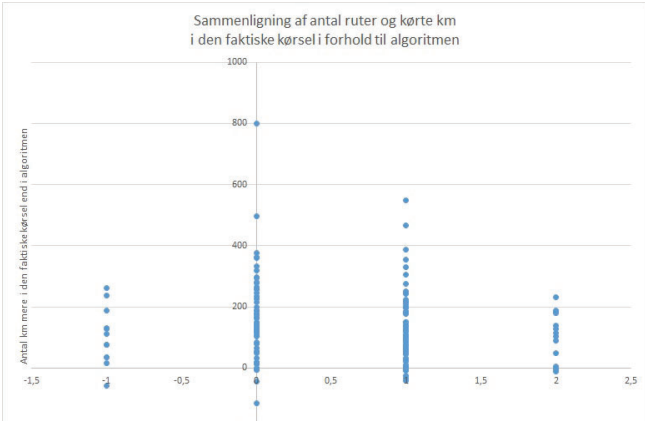

Figure 3: Besparelse i antal ruter (1. aksen) og kørt distance (2. aksen) ved brug af algoritmen i forhold til Current Practice

det givet os mulighed for at sammenligne algoritmens performance med current practice. I det pågældende område foregår arbejdet relativt decentraliserede: Hver fast chauffør tømmer fortrinsvist containere fra en eller to genbrugspladser og der bruges ekstra chauffører efter behov.

Resultatet af sammenligningen mellem algoritmen med fleksibel containerreturnering og current practice ses i figur 3. For at sikre en fair sammenligning, er der anvendt det dårligste resultat algoritmen har fundet over 25 gentagelser for hvert datasæt. I figuren angiver førsteaksen hvor mange flere ruter der faktisk blev brugt end det antal som algoritmen havde brug for. Som det ses af figuren, kan algoritmen ofte planlægge dagens arbejde med færre ruter end der blev brugt i praksis. Det ses også at der er dage hvor algoritmen har brug for en rute mere. Den situation opstår især når de faktiske kørsler, ifølge dataet, ikke overholder tidsbegrænsningen med de tidsestimater, der er brugt i algoritmen. Andenaksen i figur 3 angiver hvor meget mere kørsel (i km) der er brugt i praksis end den kørsel algoritmen har brug for til tømning af dagens containere.

Ikke overraskende, kan der ofte spares særdeles meget kørsel, både målt i ruter og i km, ved at anvende en sådan algoritme til planlægning. Algoritmens fordel kommer altovervejende fra to faktorer. Den centraliserede planlægning, der gør at lastbilerne i højere grad kan bevæge sig mellem pladserne og dermed transportere gode par af containere sammen, samt den fleksible returnering, der gør at chaufføren kan vente med at returnere containere og derfor opnår et optimeret kørselsflow.

Reality check

Ovenfor har vi betragtet problemet fra en skrivebordsoperationsanalytikers vinkel – dog med et reelt forskningsspørgsmål. Bag analysen ligger en række samtaler med vores samarbejdspartnere om ting som

- Hvor lang tid tager det faktisk at tømme en container?
- Giver det et mest retvisende billede at arbejde med åbne eller lukkede ruter?
- Kan containerne faktisk samles op i vilkårlig rækkefølge?
- Er det er problem hvis containeren returneres lang tid efter den samles op?
- Hvad hvis der ”returneres” før den samles op?

Mange af disse spørgsmål har vi debatteret med udvalgte partnere før, under og efter udvikling af algoritmen og for mange af spørgsmålene er der ikke et entydigt svar. En helt igennem spændende og givende proces, som varmt kan anbefales.

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Sanne Wøhlk er professor indenfor operationsanalyse på institut for økonomi, Aarhus uni-versitet. Hun interesserer sig for udvikling af algoritmer til løsning af transport- og rutelægnings-problemer, bl.a. indenfor affalds¬sektoren

By Jonas Olsson, Torbjörn Larsson, Nils-Hassan Quttineh - Linköping University, Sweden

The development of a container loading optimization software for Atlas Copco

The Atlas Copco distribution center (DC) in Allen, Texas, supplies spare parts and consumables to mining and construction companies across the world. (The development work described in this article took place in 2015 and 2016, and in 2018 this part of Atlas Copco became a separate company named Epiroc.) For some overseas customers, packages are shipped in 20 ft. or 40 ft. intermodal containers. Multiple orders from a customer are accumulated over several days or weeks and then shipped when the predicted volume utilization is high enough, or when requested by the customer.

Load planning

Prior to the implementation of our software, the planning of the container loading was entirely manual. Planning how to load the containers is difficult due to: heterogeneity of the packages with respect to size, weight, stackability, positioning and orientation; the set of packages differs vastly between shipments; it is crucial to avoid cargo damage. The items in the packages can be expensive, and cargo damage can ultimately cause costly downtime for the operations of the customer. Therefore, the planning often involved “pre-staging”, that is, attempts to physically perform the loading on the warehouse floor (see Figure 1). The purpose was to ensure that all packages would fit and that the container would be “sufficiently full” (to warrant the fixed transportation cost), while at the same time avoiding apparent risks for cargo damage by ensuring cargo stability (using bands, straps and airbags when necessary) and by considering limitations on how packages can be stacked. The DC management wanted to eliminate this time-consuming trial-and-error process.

The complexity and diversity of shipments and load planning called for an optimization software. The ambition was to be able to use plans generated by the software to load containers without pre-staging, while maintaining or improving volume utilization and quality of loadings (as defined by the DC operators). When loading, operators use forklifts equipped with small laptops, which could be used to show step-by-step instructions for placing each package (see Figure 2), while still allowing for minor adjustments of the placements. Management determined that an “off-the-shelf” solution would likely require too much tailoring, so it was decided that an in-house software should be developed.

Figure 1: Pre-staging of a 40 ft. shipping container

Figure 2: Laptop in forklift that could be used to visualize a step-by-step load plan

Research on container loading problems

Container loading is defined as three-dimensional packing of boxes into rectangular containers, such that some objective function is optimized subject to applicable constraints [1]. Only a small portion of the research on container loading

problems comprehensively addresses real-world constraints, and even when it is done, not all critical constraints are taken into consideration [2]. In the last couple of years, several academic articles have treated real-life loading problems [3, 4, 5, 6, 7]. However, even though data sets from companies have been used to evaluate performance of approaches, evidence of successful implementations in day-to-day operations of companies is still lacking.

Problem analysis

The packing and shipping container loading process at the Allen DC is illustrated in Figure 3. At Levels 1 and 2, items are put into packages. At Level 3, smaller packages from Levels 1 and 2 are placed onto consolidation pallets, which are loaded into the container together with larger packages. These pallets are made up of an open box on a pallet or a pallet wrapped in plastic, and their purpose is to prevent smaller packages from sliding and falling during transport. A load plan specifies Levels 3 and 4, that is, positions and orientations of smaller packages on consolidation pallets, and positions and orientations of larger packages and pallets within the container. A problem instance consists of packages to be loaded, an empty shipping container and available consolidation pallet types.

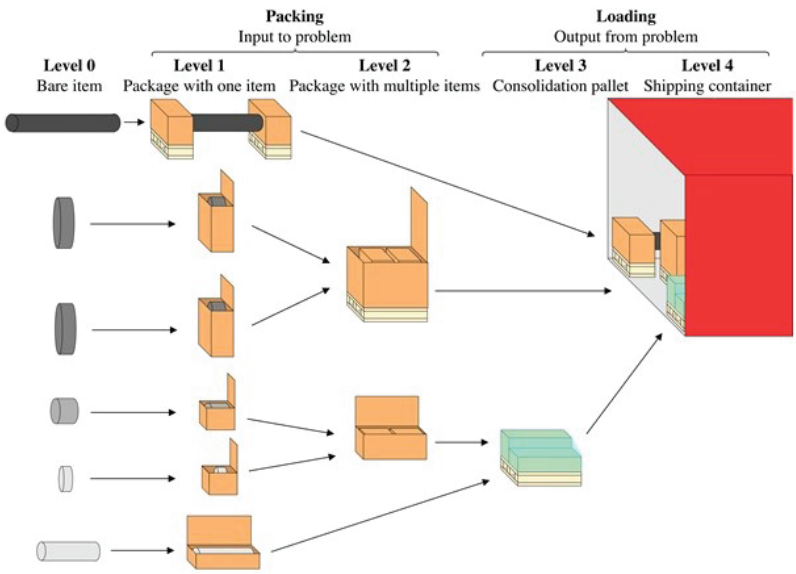

Figure 3: Packing and loading hierarchy

The packages have attributes that are inherited from their contents and packaging. Apart from size, the attributes are: 1) weight, 2) strength of packaging material if it provides support with edges or corners, 3) strength of packaging material if it provides support with only lid, 4) if a package is attached to a pallet, 5) whether the package has hazardous content, 6) if the pallet orientation differs from the agreed standard, and if so, how, 7) if the package must be placed on the floor, 8) if it is not feasible to stack a different package above, 9) if it is not feasible to stack a similar package above, and 10) reduced or increased stacking strength.

All loading aspects can be categorized as either hard constraints or goals. Seven categories of constraints are applicable to our problem: weight limits, weight distribution, orientation, complexity, stacking, positioning and stability (see [1] for details). Further, we identified four types of goals, described by measurable objectives describing the quality of a load plan:

- **Goal 1**. Fit all packages into the container, by minimizing leftover packages with respect to: i) number, ii) volume, and iii) weight.
- **Goal 2**. Achieve cargo stability: i) by using consolidation pallets for smaller packages, and ii) by supporting the sides of packages and consolidation pallets.
- **Goal 3**. Achieve container stability by placing center of gravity close to: i) lengthwise midpoint, ii) widthwise midpoint, and iii) floor.
- **Goal 4**. Avoid awkward placements by giving priority to: i) place pallets in the same direction as their pallet runners, ii) enable loading of pallets by forklift, and iii) avoid packages without pallets on the floor.

Development of a load planning software

In the development of a software for the container loading problem at the DC, we looked for algorithmic approaches that could deal with the problem's full complexity. The most promising one found was in [8], since its design has an advantageous flexibility with respect to adding and altering both constrains and goals, to ultimately reflect the judgements made by the DC shipping operators. None of this was however well-defined in the early stages of our work, which therefore included many experiments, for example pre-staging based on load plans generated by early versions of the software.

Algorithm for container loading

The software we developed is based on a two-level metaheuristic approach which consists of:

(1) a constructive greedy-type placement heuristic,

(2) a procedure to evaluate a complete load plan, and

(3) a method for tuning priorities in the placement heuristic.

The first component is on the lower level, while the second

and third components are on the upper level. The third component consists of a Genetic Algorithm (GA) which tunes the weights of a scoring function in the first component, to optimize the quality of the load plan obtained as measured by the second component. The load plan quality is rated by a fitness function that assesses the simultaneous fulfilment of Goals 1-4. Hence, a single-objective description of the problem is to maximize the load plan fitness. In more general terms, we impact a global objective (load plan goals) by making local priorities (placement scoring). Or in other words, placements made by the constructive heuristic are steered towards an overall good load plan. We call this a steering mechanism.

All hard constraints are taken into consideration in the constructive heuristic. We consider potential placements as combinations of a box, an orientation, and a point in a container. Starting from the lower inner left corner of the container, the placement heuristic constructs a load plan by placing boxes one at a time. When a box is loaded with a certain orientation, its lower inner left corner is placed at the chosen container point. To meet real-life demands on limiting cargo damage we paid special attention to stacking strength aspects using the McKee formula, which is commonly used in commercial software [9]. In particular, we considered that most of the strength of a box comes from the side walls.

In each step of the constructive heuristic, the potential placements that are feasible with respect to hard constraints are evaluated using a weighted scoring function, which prioritises between the potential placements. For example, one may conceive that the center of gravity heightwise could turn out lower (load plan goal) if priority is given to placing heavier boxes closer to the container floor (placement scoring). Similarly, one may achieve better horizontal stability, that is, preventing boxes from sliding and falling (load plan goal) if priority is given to support from other boxes or the container walls (placement scoring).

The multiple goals for loading and the heterogeneity of the problem instances make it impossible to find values of the scoring weights that yield satisfactory results for all instances, which is why the tuning is necessary. Referring to the steering mechanism, the local priorities are tuned to become consistent with the global objective. We use a GA for this, where the scoring weight values is a chromosome in the population, resulting in an individual (load plan) with fitness given by the load plan rating. Let **W** denote the population of chromosomes. Further, let **L** and **F** denote the complete load plans produced by the population and their fitness values, respectively. Our two-level metaheuristic approach is shown to the left in Figure 4. At termination, the load plan with the highest rating found is returned. Both the placement heuristic and the load plan evaluation are deterministic, while the GA is stochastic.

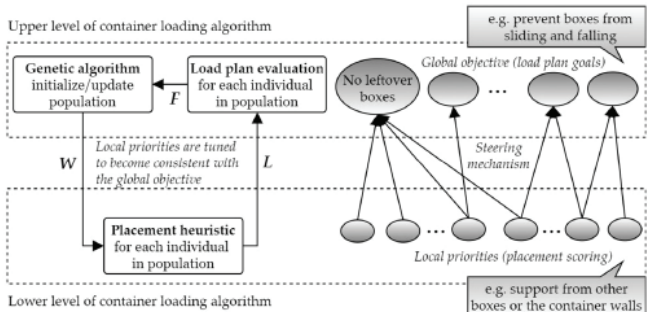

Figure 4: Illustration of upper and lower level of the overall approach: schematic of the algorithm, and interrelations of loading goals and placement properties

Stages of loading

Our algorithm is applied in four stages, inspired by the loading process in practice. The loading problem depicted in Figure 3 (Levels 3 and 4) is divided in four stages, as shown in Figure 5. In Stages 1, 3 and 4, placements are performed, while Stage 2 prepares for Stages 3 and 4. Each stage proceeds with the best partial load plan found in the previous one. Further, each stage has its own rating function and consequently its own scoring function, and therefore no scoring weight values are transferred between stages. The procedure to the left in Figure 4 is used in all four stages, with minor modifications for Stages 2 and 3. In Stage 2, consolidation pallets are considered as large boxes of variable height. In Stage 3, a “container” to be loaded refers to a consolidation pallet. Loading in stages facilitates design with various goals and constraints for different stages of the loading, which helps to generate feasible solutions.

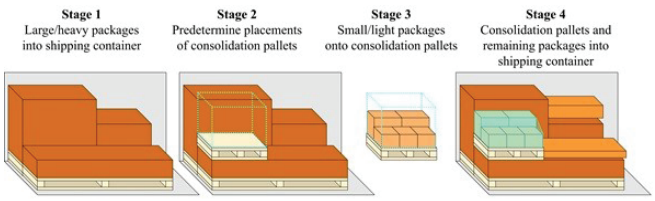

Figure 5: Stages of loading

Results

The optimization software was developed in Visual Basic for Applications (VBA) in Microsoft Access. It receives sizes and weights for packages from the enterprise software, and other package attributes from another application. The optimization software creates a load plan which suggests the placement of each package and consolidation pallet. The user can see the volume utilization (assuming all packages will fit) before running optimization, and interrupt whenever satisfied with the best available load plan. The load plan is displayed on a laptop in a forklift upon loading. Figures 6 and 7 show visualization and actual loading for two problem instances.

The software has been used for two years. It has proven capable of generating satisfactory load plans within acceptable computation times, which based on the situation may vary from a few minutes to several hours. The software produces good plans also for loadings deemed difficult by the operators. Many benefits of the software have been identified by stakeholders: reduction in labour usage by eliminating pre-staging activities; reductions in lead time by eliminating delays in ordering containers; reductions in damage during transport by allowing DC operators to focus more on securing cargo; safety improvements by ensuring stability of containers; guarantee of the loading quality even when less experienced operators execute the loading

Figure 6: Laptop visualization of load plan and actual loading for a problem instance when 19 out of 28 packages have been placed

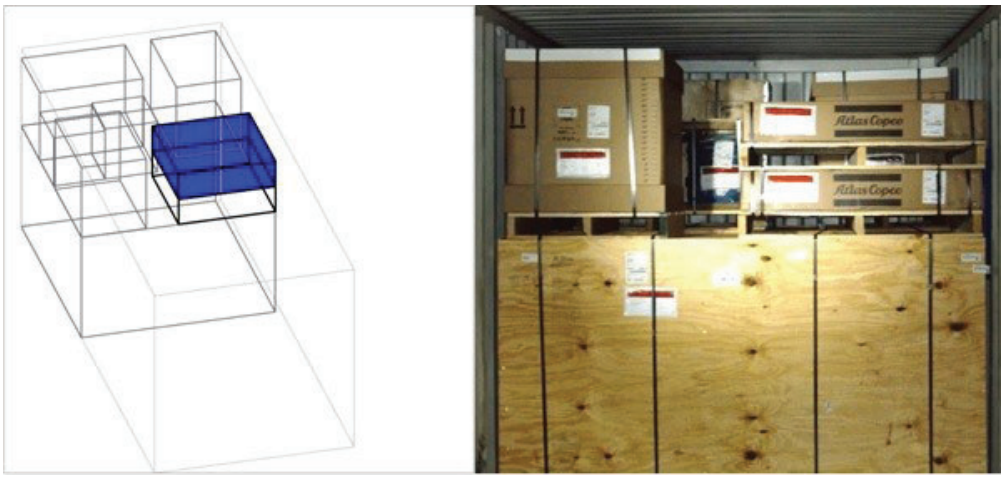

Figure 7: Laptop visualization of load plan and actual loading for a problem instance when 8 out of 24 packages have been placed

As mentioned, research on container loading problems dealing with several practical constraints is lacking [1, 2]. The design of our two-level container loading metaheuristic is very flexible with respect to the practical considerations that can be accommodated. Our solution approach should therefore also be well suited for other complex loading and packing problems.

This work was initially presented in a bachelor thesis by Jonas Olsson [10], which received the SOAF-award 2017. Nils-Hassan Quttineh was the supervisor and Torbjörn Larsson the examiner for the thesis. A streamlined version of the thesis with some additional numerical experiments was published in the European Journal of Operational Research in 2020, see [11]. Our presentation here is based on material from that article.

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The majority of the development work described in this article took place during two summer internships 2015 and 2016 at the Atlas Copco distribution center in Allen, Texas.

Currently Jonas is working in London as a senior logistics engineer for the global logistics company Expeditors. He is a member of the Supply Chain Solutions team, working on analytics projects involving supply chain network design and transport optimization, for both external and internal customers.

By Lavinia Amorosi, Rossana Cavagnini, Veronica Dal Sasso, Martina Fischetti, Valentina Morandi, and Alice Raffaele

Women in OR: an interview to role models in OR

Introduction

Is the gender gap still a topic in the academic world and in particular in Science, Technology, Engineering and Mathematics (STEM)? What difficulties did women who pursue a career in academia have to overcome? What are the differences among countries and what has changed compared to the past? As organizers of the 4th AIROYoung Workshop and as female researchers active in the Operations Research (OR) community, we have tried to find some answers to these questions by interviewing a group of prominent female professors and affirmed researchers in STEM belonging to different generations, with dissimilar careers and experiences. We have discussed with them about awareness, leaky pipelines, mobility, mentoring, society, role of education and more. Their motivating stories and opinions contained in this article have allowed us to extrapolate a portrait of what barriers women in STEM encountered in the past, but also what challenges and stereotypes are still to be overcome, striving to close the gap.

In this article, we interviewed:

- **Margarida Carvalho**, assistant professor at the University of Montréal, in the Department of Computer Science and Operations Research.
- **Anna Nagurney**, one of the historic figures of OR, is John F. Smith Memorial Professor of Operations Management at the Isenberg School of Management at the University of Massachusetts Amherst.
- **Dolores Romero Morales**, professor of Operations Research at Copenhagen Business School.
- **Ivana Ljubic**, professor of Operations Research at the ESSEC Business School of Paris.

Figure 1: Tips from our interviewed role models in OR

- **Martine Labbé**, is a professor of Operations Research at the Department of Computer Science at the Free University of Brussels, and the first woman to receive the EURO Gold Medal (2019).
- **Grazia Speranza**, is full professor of Operations Research at the Faculty of Economics and Business at the University of Brescia, where she currently serves also as Vice Rector.

This article is an extract of the original paper [1], published by Springer OR Forum, in the special issue dedicated to the 4th AIROYoung Workshop.

Past, present and future

Women participation in STEM has been a pressing issue

through the years. In fact, according to the data provided by UNESCO and the World Economic Forum, the percentage of women in STEM suffers from a phenomenon called the "leaky pipelines". At bachelor and master levels, this percentage is on average higher than 50%. Then, the percentage of women among people choosing to pursue a PhD in STEM worldwide is strongly reduced (43%). According to a European Union report, in EU the proportion of women among people achieving a PhD in natural science, mathematics and statistic is quite fair (around 46%), while the situation seems to be very unfair in the information technology and engineering field, where the percentage is lower than 30%. Moreover, the major leak is in the passage between having obtained a PhD and in being a researcher in STEM, where the percentage of women drops to 28%. Anyway, the situation is steadily improving, albeit at different rates in different countries, as assessed by the UNESCO SAGA program for Stem And Gender Advancement. In order to understand the evolution of the participation of women in STEM fields, we asked our interviewees to provide an insight of how much the behaviour of women involved in STEM research has changed during the years and what they are able to observe now in their universities.

Figure 2: Participants to the V Solvay Conference, October 29, 1927

At first, the interviewees have been asked whether and how OR women researchers have changed, with a special focus on their goals, attitude, beliefs and self-confidence. All intervie- wees agree that the situation improved significantly over the years, which was characterized by conference pictures in black and white with almost no women at all (See, for example, Figure 2).

These changes have affected both women's personal attitude and their relationship with the scientific community. Concerning women's attitude, Grazia Speranza says: "I see more good and determined young women. I see more self-confidence". Ivana Ljubi´c adds that women are also more ambitious than they were in the past.

Today, women seem also to participate more in scientific activities. Anna Nagurney states that it is more and more common to see women as organizers or keynote speakers at OR conferences and on editorial boards. One feature of women's behaviour, which may be a cause for the gender gap, could be found in the words by Martine Labbé, who says that women are "more assertive" than men and "I see many young female OR researchers who give up research after the PhD because they feel it is too difficult to get an academic position".

A shared point of view among the interviewees is the increased awareness of women's condition. Today, women are more open to freely talk about the difficulties they encounter due to the fact that they are female, according to Margarida Carvalho. This increased awareness has contributed to the development of special forums dedicated to female researchers. Anna Nagurney cites, as examples, Women in Operations Research and the Management Sciences (WORMS) by INFORMS, and Women in OR and Analytics Network (WORAN) by The OR Society, recently started in the UK; we also report Women In Society: Doing Operational Research And Management Science (WISDOM) by EURO. The situation has changed concerning networking too. Women tend to collaborate more towards solutions and to support each other, according to Margarida Carvalho. Ivana Ljubic states that networking opportunities have become more frequent and informal, and Anna Nagurney suggests e-lists as effective tools for exchanging information about opportunities, such as job openings, conferences, journal special issues and awards. A remarkable aspect is that support is coming also from male colleagues, as witnessed by Ivana Ljubic: "These efforts are also supported by many of our male colleagues, who help spread the message that diversity and inclusion will help our discipline to thrive and grow". However, a great deal of work has still to be done, starting from the lower levels of the education, as mentioned by Dolores Romero Morales; Anna Nagurney adds that even if the situation is getting better, "many of the top journals have never had a female editor in chief."

The interviewees have been asked to portrait the current situation at their universities with an eye to the trend in terms of percentage, differences between male and female students and if a balance has been reached in their countries. Ivana Ljubic teaches in a master program of data science and business analytics and she reports the following positive trend: "We have around 40% of female students, a significant portion of them coming from Asian countries. Contrary to common beliefs, these female students are very self-confident, do not feel inferior compared to their male counterpart." Anna Nagurney reports a positive trend too by telling us that "not that long ago, I had a class with all males, which struck me. The percentage of females in certain undergraduate programs in STEM has increased". Unfortunately, also bad news is reported. Martine Labbé declares that, at her

university, “regretfully, the percentage of female students has lowered! I see fewer female students than in the past”. Margarida Carvalho reports that “there continues to be a huge gap on the female students’ confidence” and Anna Nagurney refers to the leaky pipelines phenomena by saying “once one moves up the educational and professional hierarchy, we see attrition”. Anna Nagurney specifies that it “differs from country to country and there are still even countries in Europe, as you might be aware, where there are very few female professors in STEM fields”. In fact, the percentage of woman achieving the position of full professor in EU was, in 2016, around 16% gaining 2% with respect to 2013. On the other hand, all interviewees agree in saying that they do not notice any major changes in terms of performance of women with respect to the past, which may be the signal that a change in the way of thinking is the main path to gender equality and the gender gap relies only on this, instead of a lack of performances from the women’s side.

After having depicted the interviewees’ experiences through the years and the current situation, we asked them how we can be proactive and what we can do, as a community, in order to solve the issue. Dolores Romero Morales opens up a big debate about how we can face the issue, by suggesting to “put the seeds at primary schools” and, hence, to fight against gender gap by educating children. The same suggestion is given by Martine Labbé, who states that the education to gender equality “must start when they are teenagers. The society in general, and parents and school teachers in particular must work hard on that”. Another action could be to enhance the women participation. Grazia Speranza asserts that gender equality in STEM can be reached by “keeping the level of attention high towards the goal of gender balance. In committees, in juries, in round tables, among keynote and plenary speakers there should always be women”. Margarida Carvalho shares the same opinion and proposes to “giving minorities space to participate, e.g., by carefully deciding invitees for seminars, by challenging them to participate in research projects, and by building a comfortable and safe environment for them to be confident”.

“Mentoring plays an important role”, states Ivana Ljubic, also in accordance with Anna Nagurney, who tells us her nice school experience: “My 7th grade teacher, Mrs. Fuller, said to me, ‘Anna, one day you will be a Calculus professor”.

Positive comments from a role model or educator can sustain a student on her/his journey. Female and male students need to see female professors, who love what they do”. Last but not least comes a comment by Ivana Ljubic on the behaviour of institutions. She affirms “policy makers need to rethink the whole process of the academic recruitment and the imposed conditions for tenure, no matter the gender. The process is nowadays becoming extremely metric-oriented and less human in many dimensions. In the long term, this might lead to a dead-end with unintended consequences (among others, leading to even less diversity compared to what we have today)”. This is an important warning in order not to cancel what has been done in the past and to improve the situation for a fairer future.

What motivates you?

Finally, after listening to their stories, we asked our interviewees one last question: What motivates you today?

Some of them experienced the gender gap more than the others, but one thing we can see from all their answers is that the passion that pushed them to pursue a career in OR has not diminished. We report here their exact words, hoping that these will serve as inspiration and fuel for other young researchers, helping them overcoming the difficulties on their paths.

Martine Labbé: “Research! Solving interesting and challenging problems. Collaborate with nice and motivated people. This is really fun!”

Dolores Romero Morales: “I am very passionate in what I do, so that helps. But one of the things I find amazingly rewarding is the transformation I see in students”.

Anna Nagurney: “When I was an assistant professor, I would go up to famous professors at conferences, including one of the founders of OR, professor George Dantzig, and ask for advice. A professor told me: ‘Anna, you need to build your network, and do it through your students’. Having my PhD students succeed, and my undergrads, who work for innovative companies, makes this Academic Mom proud”.

Grazia Speranza: “Curiosity and new scientific challenges. Also, to be a role model”.

Margarida Carvalho: “The enrichment of working with diverse people, the belief that genes do not dictate our competence and the freedom for doing what we love!”

Ivana Ljubic: “Supporting young, brilliant and motivated students, sharing my knowledge and the experience with them. Collaborating with many gifted researchers around the world, brainstorming and learning from each other. Pushing the boundaries in research and discovering new areas”.

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[1] Lavinia Amorosi, Rossana Cavagnini, Veronica Dal Sasso, Martina Fischetti, Valentina Morandi, and Alice Raffaele. Women Just Wanna Have OR: Young Researchers Interview Expert Researchers. Operations Research Forum, 2(1):2, 2021. doi: 10.1007/s43069-020- 00039-8. URL https://doi.org/10.1007/s43069-020-00039-8.

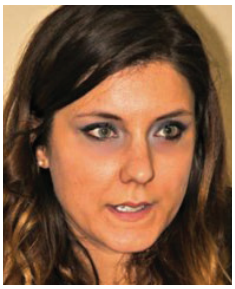
Martina Fischetti holds an industrial PhD in Operations Research from DTU. She currently works as Lead Engineer in Vattenfall BA Wind, leading the optimization focus area. Her main interest is in the application of OR techniques to renewable challenges.
With her PhD she won numerous awards, including EURO Doctoral Dissertation Award (EDDA 2019), Erhvervsforskerprisen (Best Industrial Ph.D.) (2019), Finalist for the INFORMS Franz Edelman Award (2019), Best Italian Researcher in Denmark (BIRD 2020), Glover-Klingman prize (2018).

She is founder and former coordinator of AIROYoung (young chapter of the Italian OR Society).

Rossana Cavagnini has a PhD in Operations Research from the University of Bergamo and Brescia. She has conducted part of her research activities at the Loyola University Chicago (U.S.A) and at CIRRELT in Montréal (Canada). Currently, she is postdoc at the Deutsche Post Chair – Optimization of Distribution Networks at RWTH Aachen University. Her research interests are in Operations Research and combinatorial and stochastic optimization applied to transportation and logistics problems. In 2017 she won the Transportation Science and Logistics Society (TSL) cross-region doctoral grant and in 2020 she was member of the organizing committee for the AiroYoung 2020 workshop.

Alice Raffaele is a PhD candidate in Operations Research at the University of Trento and at the University of Verona (Italy), where in April 2021 she also started a postdoc. Her main interests are the application of OR techniques to scheduling and routing problems, temporal networks, enumeration algorithms, and, last but not least, OR teaching to younger students such as Grades 9-12. In 2016, her master thesis won the AIRO Prize (an award of the Italian OR Society). She is one of the current coordinators and former social media manager of AIROYoung (the youth chapter of AIRO). In 2020, she was a member of the Organizing Committee of the 4th AIROYoung workshop.

Veronica Dal Sasso holds a PhD in Mathematics from the University of Padova. After the completion of the PhD, she held a Post-doc at Lancaster University, where she was committed on the OptiFrame project, a project funded by the European Union under the Horizon 2020 agreement. In 2018 she moved to Rome and works at Optrail as Operations Research Scientist. Optrail is a company devoted to provide innovative decision support solutions for the railway industry. She is founder and current treasurer of AIROYoung and she was part of the Organizing Committees for the 3rd, 4th and 5th Workshops.



Valentina Morandi holds a PhD in Operations Research from the University of Bergamo and Brescia. After the completion of the PhD, she held a Post-doc at Brescia University. In 2018 she became Assistant Professor at Free university of Bolzano/Bozen where she actually works. In 2019 she won the EUREGIO Best Young Researcher prize within the Tyrol-South Tyrol-Trentino EU region. She is the former treasurer of AIROYoung and she was involved in the Organizing Committees for the 4th and 5th AYWorkshops.

Lavinia Amorosi is Assistant Professor in Operations Research at the Department of Statistical Sciences of Sapienza, University of Rome. She received the Ph.D in Operational Research from Sapienza University of Rome in 2018. She has been visiting Ph.D at Lancaster University Management School, Lancaster, UK, in 2016 and at the Institute of Mathematics of the University of Seville, Spain, in 2017. Her research area is mainly on combinatorial optimization, with particular interest in network optimization and multi-objective programming, with application to real network problems in telecommunication and transportation areas where she published articles in international journals.

By Alastair Ronald Main, Ana Borda Zabla, and Eghbal Hosseini

RoRo Green Project - 13 million will make Danish shipping greener

Introduction

Since December 2020, there is an innovation project that will save Danish shipping companies many thousands of tons of CO2 and hundreds of millions of kroners annually with innovative, digital solutions for optimizing port operations and stowage of ships.

Today, it is a carefully coordinated operation when the freight is moved from land to water in a roll-on-roll-of (RoRo) port. Terminal tractors drive in and out of the ships where they unload or load semi-trailers and trailers, prudently directed by the dock workers. Even the slightest misjudgment or distraction can delay the entire operation. In fact, studies of the unloading and loading in the logistics company DFDS show that the company can save a lot of time in ports if the process is digitized and supported by related IT-solutions. This includes a significant reduction in fuel consumption for the company's ships and thus savings in both CO2 emissions and operational costs. For that purpose, the Innovation Fund Denmark is investing DKK 13 million in the ROROGreen project where researchers from the Technical University of Denmark, Roskilde University, the University of Southern Denmark, and Tal Tech in collaboration with DFDS and technology providers Ange Analytics, Kockumation, Lorenz Technology, will develop new services for optimizing loading and unloading operations. "Our hope is to create a solution for the industry where green transformation goes hand in hand with financial savings," says Dario Pacino, who researches optimization at DTU Management.

A laboratory the size of a cargo ship and RoRo Terminal

The researchers' way of improving RoRo shipping is to map and digitize how such a process takes place today. As the main partner, DFDS will make ships and terminals available, so that researchers can use them as huge and hyper-realistic laboratories. Other partners include Ange Analytics, Lorenz Technology, Kockumation and Taltech, which contribute knowledge and equipment in IT infrastructure, drones, robots, system implementation and camera technology. Drones, mobile robots, and sensors will be used by the researchers to systematically collect data from the loading of the ships. Thereafter, using artificial intelligence and optimization techniques, they will use the collected data to develop new automatic and digital solutions for faster loading and unloading of the ships. This will benefit both the climate and the economy. A company like DFDS will be able to reduce their annual CO2 emissions by an estimated 80,000 tons, because the ships, when loaded faster can sail with less speed and thus fuel consumption to reach the next port in time. With a reduced environmental impact and a more efficient loading, the shipping industry will become more competitive which will in all probability move parts of the Danish goods transport from trucks to the more environmentally friendly ships. For that purpose, one task is to map and thus make visible efficiency and emissions for several ports in DFDS's route network. "In addition, it is important that we get a robust validation of the project's digital technologies and their potential business, economic, and environmental benefits for the maritime industry," says Julia Pahl, who researches (among others) maritime logistics at the University of Southern Denmark at the Department of Technology and Innovation. The researchers expect that the project will benefit both the climate and the economic growth in the shipping industry, just as it can create jobs with Danish suppliers to the industry.

Algorithms for Stowage Planning with Focus on Prediction of Cargo Arrival Using AI

(Main contributors: Line Reinhardt and Eghbal Hosseini, Department of People and Technology Roskilde University, Denmark)

The personnel at the port plan the cargo to be placed within the vessel manually based on experience, so there is no guarantee for stability of the stowage. For rectifying any instabilities, ballast water is pumped into the tanks of the vessel.

But, ballast water can take more than 30% of a vessel's total weight with high effect on fuel consumption. Handling time is the next issue that should be considered. Unlike traditional RoRo vessels, which are totally emptied before new cargo trailers are allowed on-board, modern RoRo vessels can be designed so that loading and discharge operations can occur at the same time (dual cycling). In previous work [1] a model is design that assumes that not all cargo has arrived when loading is started. Also, this work proposes a heuristic approach to generate an optimal stowage plan with requirements of stability by using of the weight of cargoes instead of excess ballast water to reduce fuel consumption. Results show that 57.69% ballast water reduction, equivalent to 6.7% fuel savings and CO2 reduction can be achieved. The core of this task within the project is the research concerning the implementation of efficient models and algorithms for the stowage planning including dual-cycling to optimize efficient factors such as ballast water, the total fuel consumption, and handling time, so that the stability of the ship is satisfied. Heuristic modeling including multi-level or multi-objective formulations will be investigated to cover important objectives of the project. As such models are quite complex, heuristics and meta-heuristics will be used to speed up the solution process to make them applicable; Laying Chicken Algorithm (LCA) [2], Volcano Eruption Algorithm (VEA) [3], COVID- 19 Optimizer [4], Algorithm (CVA), and Multiverse Algorithm (MVA) [5]. Moreover, uncertainty and prediction of cargo arrival patterns will be part of the project as well as planning before all cargo has arrived. At this part, artificial intelligence methods such as machine learning, neural networks, and Bayesian models will be used.

Handling uncertainties in RORO shipping

(Main contributors: Dario Pacino and Alastair R. Main, DTU Management)

The contribution of this part of the project is to add a measure of the uncertainty related to unforeseen changes in, e.g., cargo weights, market demand, arrival succession and arrival time. This will be achieved by employing methods such as stochastic modelling, robust optimization, and chance constraints. These methods have not yet been applied in this specific area; however, they have been successfully implemented in container stowage planning. The aim of the optimization models is to support the decision making under uncertainty for the load crew using real time data and intelligent planning. This will make the process more efficient, enable increased port throughput and thus revenue. Furthermore, it would reduce handling time of cargo and thereby reduce fuel consumption of the RORO vessel. If successful, the models will also reduce the amount of ballast water needed to ensure stability of the RORO vessel, thus reducing deadweight and thereby fuel consumption. Experience within operations research suggest that it will be necessary to develop meta-heuristics which can incorporate uncertainties. The use of meta-heuristics has been shown to enable the deployment of near optimal solutions within realistic time. We may even try a novel approach to increase robustness of the stowage planning problem using DEEP-Q reinforcement learning. This novel technique adds an important dimension, i.e., the ability to learn from successes and failures in the creation of stowage plans. Furthermore, the ability to continuously learn from data allows adaptation to change over time which would provide a dynamic and sustainable solution technology.

Sustainability assessment and investment decision support tool

(Main contributors: Julia Pahl, Niels Gorm Malý Rytter and Ana Borda Zabla)

The contribution of the project is to assess the environmental impact and efficiency of digital and green investments in DFDS's RoRo terminals. Some of these digital solutions will be developed by partners of the project. To do so, emission sources need to be traced and mapped. This part connects to the data platform that will be developed. It further provides visualizations of the efficiency and environmental performance of selected DFDS RoRo terminals. For that purpose, useful key performance indicators are established that can show efficiency gains and emissions inventories. This part heavily uses statistical methods and simulation to determine the emissions assessment together with visualization model methods. The data that will be analysed will be gathered by technologies such as sensors, cameras, smart gate systems, drones, and mobile robots, that will provide identification and positioning of cargo trailers in the yard. This data will be accessible though the data storage and sharing platform for RoRo shipping that will be developed by Ange Analytics. The simulation tool will be also useful to evaluate the impact of the digital and electrification technologies. Methodologies such as multi-criterial decision support, clustering and forecasting algorithms will be applied to strategic decisions whether or not or to which extend to invest in new green technologies. The use of artificial intelligence combined with simulation may help in finding the optimal configuration of operations concerning different objectives for specific situations. Moreover, the application of Industry 4.0 concepts and tools such as digital twin and virtual and augmented reality will be analysed for use in efficiency and emissions assessments. This could open a new window for research.

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Alastair Ronald Main received his Bachelor in Strategic Analysis and System Design in 2018 from the Technical University of Denmark, DTU Lyngby. He graduated in 2021 from the same University with a Master's Degree in Engineering, i.e. Business Analytics with focus on Prescriptive Analytics. His master thesis explored the application of metaheuristics under uncertainty in the Danish Power bidding market for District Heating companies. Alastair R. Main is currently employed as a PhD student at DTU Management. He will be investigating the influence of uncertainty on the optimization of RoRoGreen stowage planning.

Ana Borda Zabala is currently a PhD researcher working in the RoRo Green Project, as part of the department of Technology and Innovation of University of Southern Denmark (SDU). Before starting her PhD, she received her B.Sc. degree in Industrial Technology Engineering (2018) and M.Sc. degree in Industrial Engineering (2020). She completed her university career by developing her Master Thesis about "Module design for simulating discrete operation flows in industrial plants based on Promind", while she was working as an intern in Sisteplant. Now, she is working in her PhD about sustainability assessment in RoRo terminal and ship operations.

Eghbal Hosseini is currently working on RoRo Green Project as a PhD researcher with Roskilde University, before that, he was working as senior researcher with Erbil Polytechnic University, and a lecturer at University of Raparin. He received B.Sc. degree in applied mathematics from University of Razi, in 2005 and M.Sc. degree in operations research at University of Kurdistan in 2007. He received Ph.D. degree in optimization from Tehran Payame Noor University. His research interests are meta-heuristic approaches, algorithms, multilevel programming problems and machine learning. From 2017 he has proposed five new meta-heuristics: Laying Chicken Algorithm (LCA), Big Bang Algorithm (BBA), Volcano Eruption Algorithm (VEA), Multiverse Algorithm (MVA), and Covid-19 Optimizer Algorithm (CVA).