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22

maj • 2014

Simulation af akutmodtagelse • OR i lufthavn • Energieffektiv transport til søs • Placering af søkabler

ORbit

medlemsblad for
Dansk Selskab
for Operationsanalyse
og
Svenska Operationsanalys-
föreningen

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Leder

Foråret har meldt sin ankomst, træerne er sprunget ud og vejret bliver hastigt varmere. For nogle af os er det eneste, der står mellem os og sommerferien en stor stak eksamensopgaver. ORbit 22 er klar til at blive sendt i tryk og byder på nogle spændende artikler om operationsanalysens anvendelse i praksis. Vi får et indblik i planlægning hos de nye akutmodtagelser og får et friskt pust fra havet med et besøg hos containerskibene. Med ORbit 22 tager vi også hul på en lille serie af artikler om OR i Københavns lufthavn.

Jeg vil gerne bruge denne leder på et redaktionelt nødråb. Vi har et mål om at udgive ORbit to gange om året, men redaktionen lider under kronisk mangel på materiale. Derfor vil jeg gerne opfordre alle medlemmer til at fatte pennen og skrive et indlæg til bladet. Skriv lidt om jeres seneste OR projekt eller om den seneste operationsanalysebog i har læst. I er altid velkommen til at kontakte redaktionen på editor@DORSnet.dk, hvis i ønsker sparring på en ide.

Kære virksomhedsmedlemmer: Hvorfor ikke bidrage med en virksomhedsbeskrivelse eller en smagsprøve på hvilke spændende operationsanalytiske projekter i arbejder på. Det er ren gratis reklame, der kommer direkte i postkassen hos målgruppen for fremtidige stillinger.

God læselyst,

Sanne Wøhlk

Aktuelt om DORS

Medlemsskab
Kontingentsatser for 2014

Personlige medlemmer (incl. ph.d.-studerende):	270 kr./år
Studerende:	60 kr./år
Firmamedlemmer:	3200 kr./år
Institutmedlemmer:	1800 kr./år

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Kära operationsanalysvänner

När jag sitter och skriver det här ledaren i mitten av mars så är det vår ute i luften. Termometern utanför fönstret visar på 15 grader – visserligen är det en glädjemätare till termometer jag har, men solen lyser och fåglarna sjunger för fullt!

Och även för SOAF våras det. 2013 var ett mycket aktivt år, som vanligt började med ett årsmöte för förra verksamhetsåret, denna gång vid SICS Swedish ICT AB i Kista. Deltagarna bjöds som brukligt är på spännande föredrag, inte minst av vinnaren av årets exjobbspris, Evanthia Kazagli, som deltog via videolänk från EPFL i Lausanne. SOAF arrangerade dessutom, tillsammans med Chalmers och Nordic Optimization Symposium, konferensen SOAK/NOS6 (Svenska Operationsanalyskonferensen, samt Nordic Optimization Symposium). Konferensen arrangerades i Göteborg och lockade 75 deltagare till de 50 presentationerna, vilket båda är fler än vad som brukar förekomma vid SOAK och NOS-konferenserna.

SOAF har dessutom just haft årsmöte för verksamhetsåret 2013, vid vilket tre nya ledamöter valdes in till styrelsen. Jag hälsar därmed Sara Gestrelius (SICS), Elina Rönnberg (Schemagi) samt Stefan Bengtsson (Stockholms läns landsting) välkomna, och passar på att tacka Ximena Karlsson, Marie Persson och Malin Forsgren för deras tid i styrelsen. Marie och Malin kommer vi dessutom se mera av framöver, då de glädjande nog kommer engagera sig i SOAFs intressegrupper för järnväg och sjukvård!

Jag tror att vi tillsammans under 2014 kommer fortsätta den positiva trenden med en aktivare förening och en ökad synlighet för operationsanalysen inom Sverige. Utöver detta diskuterar föreningen just nu ett nytt pris inom tillämpad svensk operationsanalys. Håll ögonen öppna, mer information kommer inom kort!

Markus Bohlin, ordförande SOAF

Indhold

Aktuelt om SOAF

Medlemsavgifter 2014:

- Individuell medlemmar (inkl. ORbit): 160 kr
- Juniormedlem (exkl. ORbit): 80 kr
- Akademiska institutioner: 1600 kr
- Företag med 1-5 intressenter: 1600 kr
- Företag med 6-10 intressenter: 3200 kr
- Företag med fler än 10 intressenter: 4800 kr

Svenska Operationsanalysföreningen

Betala in på postgiro: 19 94 48-2

e-mail: sekreterare@soaf.se

Internet: www.soaf.se

Genoptryk fra Connect

Operationsanalyse i Københavns lufthavn

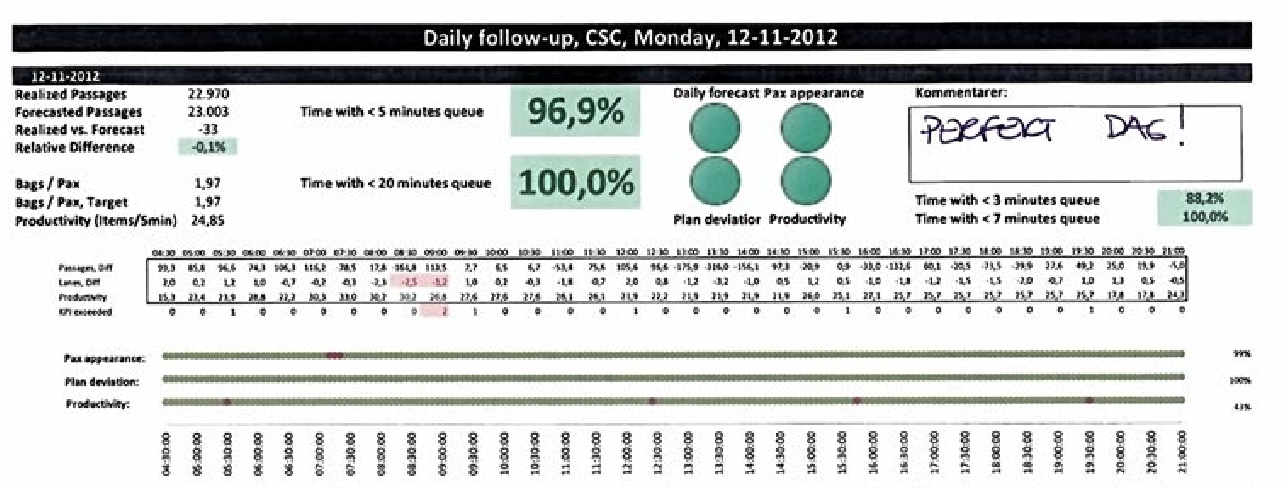
Operationsanalysen har for alvor fundet vej ind i Københavns lufthavn. Men den nye afdeling: *Planlægning, analyse og projekter*, er lufthavnen begyndt at anvende matematiske optimeringsmodeller og prognoseværktøjer til bland andet kapacitetsplanlægning. I de kommende udgaver af ORbit, sætter vi fokus på anvendelsen af operationsanalyse i lufthavnen. Her i første afsnit bringer vi et interview med afdelingens chef. Vi takker *Connect* for at måtte genoptrykke dette.

Hvor der er tal, kan vi hjælpe!

På anden sal i T3 møder du et skilt, hvorpå der står 'Planlægning, analyse og projekter'. Det er navnet på en af CPH's nyeste afdelinger, som blev etableret i efteråret 2010. Cirka 25 meter nede af gangen kommer du ind på et kontor med syv civilingeniører fra DTU – eksperter i optimering og de fleste med baggrund i matematisk modellering. Thomas Hoff Andersson er chef for afdelingen der også rummer et antal dygtige projektledere og forretningsspecialister. Denne afdeling er på rekordtid blevet en vital del af motoren CPH og ikke mindst den operationelle planlægning. CPH bruger dagligt nogle af verdens mest sofistikerede modeller for styring og allokering af check-in pulte og security spor – alle baseret på matematisk optimering.

Matematisk optimering – hvad betyder det på dansk, og hvordan kan det effektivisere vores hverdag?

Meget forenklet handler det om at bruge matematik som løsningværktøj af komplekse problemstillinger. For lufthavnen kunne et eksempel være hvordan vi fordeler vores check-in pulte under hensynstagen til flyselskabernes behov og ønsker. Kunsten er at kunne sætte alle de data, vi opsamler, i et forretningsmæssigt perspektiv. Skal du kunne optimere kapacitetsudnyttelsen, skal du også forstå de daglige processer, behov og præferencer – samt have evnen eller modet til at vægte disse i forhold til hinanden. Derfor er det vigtigt, at mit team kommer ud af kontoret og ind i motorrummet på de afdelinger, vi skal hjælpe. Hvor der er tal, kan vi være med til at gøre en forskel.



Daily follow-up, CSC, Monday, 12-11-2012

12-11-2012

Realized Passages	22.970
Forecasted Passages	23.003
Realized vs. Forecast	-33
Relative Difference	-0,1%
Bags / Pax	1,97
Bags / Pax, Target	1,97
Productivity (Items/5min)	24,85

Time with < 5 minutes queue 96,9%

Time with < 20 minutes queue 100,0%

Daily forecast Pax appearance

Plan deviatior Productivity

Kommentarer:

PERFEKT DAG!

Time with < 3 minutes queue 88,2%

Time with < 7 minutes queue 100,0%

	04:30	05:00	05:30	06:00	06:30	07:00	07:30	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30	21:00
Passages, Diff	99,3	85,8	96,6	74,3	106,3	116,2	-78,5	17,8	-164,8	113,5	7,7	6,5	6,7	-53,4	75,6	105,6	96,6	-175,9	-316,0	-156,1	97,3	-20,9	0,9	-33,0	-132,6	60,1	-20,5	-73,5	-39,9	27,6	49,2	25,0	19,9	-5,0
Lanes, Diff	2,0	0,2	1,2	1,0	-0,7	-0,2	-0,3	-2,3	-2,5	-1,2	1,0	0,2	-0,3	-1,8	-0,7	2,0	0,8	-1,2	-3,2	-1,0	0,5	1,2	0,5	-1,0	-1,8	-1,2	-1,5	-1,5	-2,0	-0,7	1,0	1,3	0,5	-0,5
Productivity	15,3	23,4	23,9	28,8	22,2	30,3	33,0	30,2	30,2	26,8	27,6	27,6	27,6	26,1	26,1	21,9	22,2	21,9	21,9	21,9	21,9	26,0	25,1	27,1	25,7	25,7	25,7	25,7	25,7	25,7	25,7	17,8	17,8	24,3
KPI exceeded	0	0	1	0	0	0	0	0	0	2	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0

Pax appearance: 99%

Plan deviation: 100%

Productivity: 43%

04:30:00 05:00:00 05:30:00 06:00:00 06:30:00 07:00:00 07:30:00 08:00:00 08:30:00 09:00:00 09:30:00 10:00:00 10:30:00 11:00:00 11:30:00 12:00:00 12:30:00 13:00:00 13:30:00 14:00:00 14:30:00 15:00:00 15:30:00 16:00:00 16:30:00 17:00:00 17:30:00 18:00:00 18:30:00 19:00:00 19:30:00 20:00:00 20:30:00 21:00:00

Baggrunden for oprettelsen af ’Planlægning, analyse og projekter’ var, at CPH stod overfor nogle store kapacitetsproblemer i check in. Finanskrisen betød at mange flyselskaber i større omfang end tidligere blev nød til at trimme deres trafikprogrammer, og lukke afgange der ikke var lønsomme. Som følge af dette øgede trykket på vores peaks om morgenen og eftermiddagen. For at klare denne kapacitetsudfordring blev CPH nødt til at få flere passagerer igennem check in og security på samme tid.

Så hvordan fik I overbevist nogle handlere med adskillige års erfaring om, at en algoritme skulle overtage deres opgaver med at fordele check-in pulte?

Det var naturligvis med en vis skepsis, vi blev mødt med. For det, vi reelt fortalte handlerne, var jo, at vi kunne planlægge bedre end dem. Men en computer kan altså rumme flere data end den menneskelige hjerne. På et tidspunkt havde vi samlet en række analytikere fra forskellige funktioner til en workshop, hvor vi med Lego-klodser lavede et spil, hvor deltagerne skulle optimere 8 x 8 felter. Dette arbejde var svært nok i sig selv, og når vi så løbende ændrede på et par forudsætninger, så blev det for alvor svært. Når denne proces så skal holdes op om 100 check in pulte, der åbner kl. 4.00 og lukker for de flestes vedkommende ved 21-tiden, så står vi her med en kompleks problemstilling der kalder på matematisk optimering.

Intet overbeviser mere end konkrete resultater. Vi har i dag øget kapacitetsudnyttelsen i check-in med næsten 30 %. Det handler om at undgå køen, for når køen er opstået har du reelt tabt. I modsætning til på motorvejen, har vi i CPH nogle værktøjer vi kan aktivere. Kunsten er at komme på forkant med køen, således at vi åbner spor inden køen starter i stedet for efter. Hele historien med pultallokering baseret på matematisk optimering er en win-win-win. Handlerne kan bruge deres ressourcer mere effektivt, flyselskaberne skal ikke betale handlerne for disse spildtimer – og kunderne bliver mere tilfredse grundet de kortere ventetider.

Men vi oplever jo fortsat køer, så hvor gode er I reelt til dette arbejde?

Gode, rigtig gode. Men kapacitetsoptimeringer skal jo sættes i forhold til omkostninger. Man bygger jo heller ikke kirker til juleaften. Vi har dage, hvor vores prognoser fortæller, at der kommer tryk på. Ingen prognose bliver bedre end dens input. Når vi ved ’hvor mange’ og ’hvornår’ der det forholdsvist let for at lave en præcis prognose, for vi ved at charterrejsende har en adfærd, low cost en anden og rute en helt tredje. I sidste ende er det flyselskaberne, der bestemmer hvor lange køer de vil tilbyde deres kunder. Det er et spørgsmål om pris, for handlerne skal naturligvis aflønnes for en time mere, hvis to spor skal åbnes en halv time tidligere, og formår de ikke at overbevise flyselskaberne om at dette regnestykke går lige op, idet du kan dine lukke spor tilsvarende hurtigere, så er den svær.

Selvom vi år til dato har en prognoseafvigelse på 0,6 %, vil der vil være enkelte dage, hvor der opstår peaks ingen kunne forudse og hvor vores prognoser rammer skævt. Eksempelvis hvis der ankommer 5 busser med cruisepassagerer en time tidligere end de plejer, fly der er forsinket eller andre forhold, som flyselskaberne har ’glemt’ at fortælle om. Vi prøver at hele tiden lære af historien, følge op på vores performance og indarbejde erfaringer i vores modeller. Ingen værktøj bliver bedre end de data vi kommer i dem, men det er unikt for en lufthavn at arbejde med optimering, som vi gør i CPH, Her tør jeg godt at sige, at vi ligger i den absolutte verdenselite.

Lidt facts om kapacitet i lufthavnen:

• I 2012 runder CPH formentlig 23.000.000 passagerer, hvilket svarer til at 4 x Danmarks befolkning passerer gennem Københavns Lufthavn

• 140 luftfartsselskaber flyver på Københavns Lufthavn, hvilket bliver til 260.000 starter og landinger om året

• Check in drives af handlere i samarbejde med luftfartsselskaber og er derfor ude af CPH's kontrol. SAS og Novia arbejder ud fra en målsætning om, at 85% af alle passagerer skal gennem check in indenfor 15 minutter, og at 95% af alle passagerer skal gennem indenfor 30 minutter. Den aktuelle performance er, at 85% kommer gennem check in på mindre end 15 minutter og 99% kommer gennem inden for 30 minutter. De afgange, der ligger i den tunge ende, er typisk charterafgangene i højsæsonen, mens de traditionelle ruteflyvninger sjældent har kører på mere end 10 minutter. Også her gælder det gamle mundheld: Man får, hvad man betaler for.

• Security arbejder ud fra at 85% af alle passagerer skal gennem sikkerhedstjek på under 5 minutter, og at 99% skal igennem inden for 20 minutter. Det hører til absolutte sjældenheder at 20 minutters-grænsen overskrides, idet den aktuelle performance ligger på over 99.9%. Når alle spor er åbne, får Security 3500 passagerer igennem pr. time – svarende til én passager i sekundet. Dette er i særklasse Europarekord.

• På årets travleste dag havde CPH 34.500 afgående passagerer gennem Security, hvor der var en maksimal ventetid på 10 minutter (i tidsrummet mellem 13.30 til 14.30), og 88% af passagererne var igennem på under 5 minutter.

• I CPH's løbende tilfredshedsmålinger ligger Security på en overordnet passagertilfredshed på 87, hvilket er rigtigt godt.

• Security inddrager store mængder forbudte genstande om året. Sidste år inddrog Security 16 ton væsker (kun med told og afgiftsskyld). 88 ton såkaldte registreringsfri væsker (vand og lign.) og mere end 16.000 stk. værktøj, knive og sakse.

By Tomas Gustafsson

Joint SOAF and NOS Conference

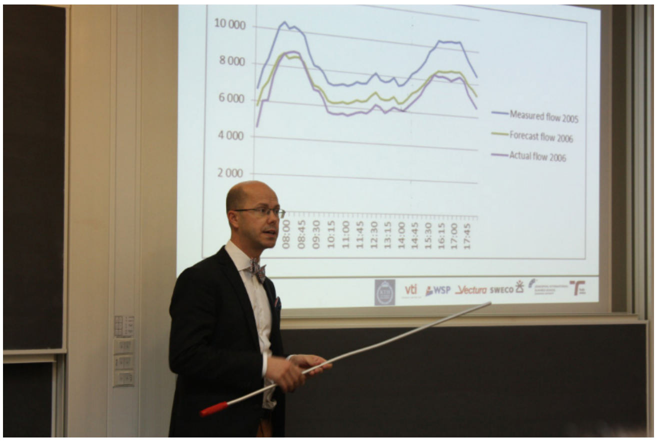


Figure 1: Jonas Eliasson

Figure 2: Marielle Christiansen

Last year in October, the Swedish Operations Research Conference, this year jointly organized with the Nordic Optimization Symposium, took place in Gothenburg between the 24th and the 26th. The conference was hosted by optimization group at the Department of Mathematical Sciences at Gothenburg University and Chalmers university of Technology. It is arguably the largest annual event organized by the Swedish Operations Research Association (SOAF), and this years' conference was a major leap in terms of size and general ambition. In total, there were three plenary sessions, 12 streams and 14 sessions, 50 technical talks, and there were at least 75 participants. Plenary speakers were Marielle Christiansen, NTNU, Anders Forsgren, KTH and Jonas Eliasson, KTH. All plenary talks were highly appreciated and generated a lot of discussions. The general feedback for the Conference was very positive and asked to be kept going. Thank you everyone who participated, in whatever form and shape!

Af Lasse Lundberg Andreasen

Studerende hjælper DONG med søkablerne

Vindenergi: Udlægning af kabler mellem DONG's mange havvindmøller er en kompliceret affære. To specialestuderende udviklede en helt ny løsning.

To studerende har som en del af deres speciale udviklet et computerbaseret værktøj, som sparer DONG Energy timevis af manuelle udregninger. Samarbejdet mellem DONG og de to studerende kom i stand efter et specialkursus på DTU Management.

Specialet *Optimization of the Cable Collection Grid in Offshore Wind Farms* blev bedømt til et 12-tal. Samtidig vandt Michael Lindahl og Niels-Christian Fink Bagger DONG's specialepris på 25.000 kr.

Michael Lindahl og Niels-Christian Bagger opdagede undervejs i kurset, at deres matematiske kompetencer kunne hjælpe til at løse et helt konkret problem for DONG. Det blev startskuddet til et succesfuldt specialesamarbejde, som samtidig er et eksempel på, hvordan erhvervsliv og DTU kan have stor glæde af hinanden.

Energiselskabet satser i disse år benhårdt på at høste vinden ude på havet i enorme havvindmølleparker. Den slags anlægsprojekter kræver udlægning af kilometervis af kabler mellem vindmøllerne, og de kan forbindes på et utal af måder.

Hidtil havde tommelfingerregler og fokus på bl.a. strømtab udgjort beslutningsgrundlaget, når DONG skulle placere de lange kabler. Men Michael Lindahl og Niels-Christian Fink Bagger valgte en radikalt anderledes måde at anskue problemet på.

Ved at bruge matematiske formler har de samlet beregningerne i et computerprogram, som drastisk nedbringer behovet for manuelle udregninger. De har dog samtidig stort fokus på anvendeligheden for medarbejderne i DONG, der ikke nødvendigvis har samme matematiske baggrund som dem selv.

Fungerer i et regneark

"Hos Dong foregår rigtig meget arbejde i programmet Excel. Vores værktøj skal bruges af DONG's ingeniører, og vi har derfor lavet et program, som arbejder sammen med Excel. Det vil sige, at når de åbner programmet, ser de noget, de er vant til at arbejde med", forklarer Michael Lindahl.

Michael Lindahl og Niels-Christian Fink Bagger mener, at det var den grafiske brugerflade baseret på Excel, som for alvor skabte interessen for projektet hos DONG. Men de to studerende havde også styr på mere end det rent faglige.

"Vi har nok været gode til at sælge os selv. Da vi skulle præsentere specialeidéen for DONG, gjorde vi meget ud af, at de kunne se værdien i vores værktøj", fortæller de.

Den udlægning bakkes op af Søren Frost Ahrenfeldt fra DONG, som også har været vejleder på specialet:

"De var utrolig dygtige til at præsentere idéen, og de havde sat sig grundigt ind i DONG's behov på forhånd. Vi blev hurtigt enige om, at vi skulle lave et specialeprojekt med dem, før andre kom os i forkøbet", siger Søren Frost Ahrenfeldt, ingeniør i DONG's Wind Power division.

Kend begrænsningerne

DONG opdagede hurtigt potentialet i værktøjet og var også interesseret i at gøre projektet endnu mere omfattende.

"De spurgte, om vi ikke også kunne importere kort- og havbundsdata ind i værktøjet. Men der er det vigtigt at holde fast i, hvilket problem, projektet egentlig skal løse. Der har vores vejleder, lektor ved DTU Management, Thomas Stidsen, været til stor hjælp. På samme måde har Søren Frost Ahrenfeldt også vist stor forståelse for, at projektet havde en tidsmæssig begrænsning", siger Niels-Christian Fink Bagger.

Fote: http://www.energimetropol.dk

Personfotos: Lasse Lundberg Andreasen

Michael Lindahl blev kandidat fra Danmarks Tekniske Universitet på eliteuddannelsen Industriel Matematik i Maj 2013. Her fokuserede han på operationsanalyse med stor interesse i at kombinere det teoretiske med det praktiske og lavede undervejs projekter med virksomheder som DSB S-tog, Københavns Luthavne og DONG Energy. Han har arbejdet med mandskabsplanlægning i Københavns Lufthavn og er i februar 2014 påbegyndt en erhvervs PhD hos MaCom A/S hvor han skal forske i optimering af skemalægning for universiteter.

Niels-Christian Fink Bagger blev kandidat fra Danmarks Tekniske Universitet på eliteuddannelsen Industriel Matematik i Maj 2013. Her specialiserede han sig i operationsanalyse med stor vægt på kombinationen mellem teori og praktisk anvendelse. Undervejs lavede han projekter med virksomheder som MaCom A/S og DONG Energy samt havde diverse studiejobs som software-udvikler og hjælpelærer. Han har derefter arbejdet med skemaplanlægningsproblemer på DTU og er netop i februar 2014 påbegyndt en erhvervs PhD hos MaCom A/S hvor han skal forske i samme problemstilling i en mere generel sammenhæng.

Lasse Lundberg Andreasen er freelance-journalist og fotograf. Han leverer tekster og fotos til bl.a DTUAvisen, Politiken og andre danske medier.

By Marcel Turkensteen

The Operations Research Day 2013 in Aarhus, November 13

An annual tradition of the students in Logistics and Supply Chain Management is the Operations Research (OR) Day. On this day, people working in companies explain about their experiences about using OR in the 'real world' (scientists hate to write this), which is most interesting for logistics students. The event was organized jointly by DORS (the Danish Operations Research Society) and Aarhus University, where PhD student Maria Elbek Andersen took a large share of the organization burden on her.

Personally, I like to find a red thread, a common theme that permeates the event when writing about it. If the day could be summarized in three words, it would be "jobs in OR". Operations Research (OR) is the quantitative field of research that aims to solve mainly logistics problems. Because the master in Logistics and Supply Chain Management (SCM) in Aarhus puts large emphasis on quantitative modeling, this is where our students can contribute the most to improving people's lives, for example, by making transport or electricity cheaper or better available. While I mention a red thread, I can add that quite a few of the presentations were about electricity.

After the short introduction by Simon Spoorendonk from DORS, the first presenter of the day was Bo Jensen. He is educated at the University of Southern Denmark and decided to start his own company after some years working. This company, Sulum, has developed a robust ILP solver that is used in practical applications, also in electricity generation from hydro-power. His punch-line: if you have the driven, are smart and socially capable, you can create not only your own job but also your own company.

The organizer Maria Elbek Andersen and Michael Binnerup from Danske Commodities

The second speaker was Michael Binnerup, a recent graduate from Logistics and SCM at the AU. He presented his job at Danske Commodities, a young and growing company. In the international trade of electricity, his VBA code helps his colleagues make decisions on which price should be paid and demanded for it.

The third talk was by Niels-Christian Fink Bagger, who works at the Technical University of Denmark. The presented project was on solution methods for a complex mathematical problem (a Mixed Integer Linear Programming problem, since you're asking), to connect off-shore wind turbines to the main grid.

After the lunch-break, Rasmus Carstensen and Anette Svejsø from TDC presented some of the OR challenges that they were facing. TDC is the provider of cable infrastructure in Denmark. The first problem had to do with the robustness of the network, where a decision is which nodes in the cable network should get a direct connection. The second challenge is the computation of the costs of the cable services that TDC charges its competitors and its own cable services provider.

Then, a former PhD student at Aarhus University, Tue Christensen, gave us a guided tour through his consultancy work at Trapeze. That includes a whole range of models related to bus planning in Aarhus – the assignment of buses to routes, the assignment of drivers to duties. Fortunately for Tue and for us, these problems are very challenging.

The final talk, in Danish, was by Eva T. Andreassen from energinet.dk. She is a graduate from Mathematical Economics at the Aarhus University and she presented a challenge in the energy markets: how can we ensure that sufficient electricity is produced, given that some of it is wind-generated, so that both supply and demand are stochastic?

In all, this was an interesting day. It showed that there were plenty of challenges for OR specialists in logistics, in particular in the energy sector.

Marcel Turkensteen works at the Cluster for Operations Research And Logistics (CORAL) at the Faculty of Business and Social Sciences. His research interests include the combination of environmental impact measurement and Operations Research and logistics decision modeling on routing and location.

CORAL, AU
annoncerer følgende foredrag:

• Monday, May 26, 13:00: Speaker: Mario Vanhoucken, Ghent University (Belgium) and University College of London (UK)

• Tuesday, June 3, 14:00: Speaker: Professor Dag Haugland, Department of Informatics, University of Bergen, Norway

Se CORAL's hjemmeside for detaljer.

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By David Pisinger

Energy efficient transportation planning for the giants of the sea

The liner shipping industry is in times of upheaval. The appearance of gigantic container vessels like Maersk's Triple-E vessels is shaking up the traditions of Liner Shipping. It is often necessary to have more shipping companies collaborate on filling the huge vessels, but the vessels are also designed to sail at lower speeds to save fuel. It is therefore of greatest importance to develop decision support tools that can help achieving good utilizations of the vessels' capacity while ensuring that the containers arrive on time. A research project involving Maersk Line, DTU and the IT University of Copenhagen has developed a number of logistic solutions ensuring good capacity utilization and hence also a good fuel economy. The project has received support from the Danish Maritime Fund and the Danish Strategic Research Council.

Bigger is better --- but more challenging

The new Triple-E vessels being introduced by Maersk Line are designed to be very energy efficient per shipped container. But having a capacity of 18,000 twenty-foot containers (TEU) it is challenging to deploy the full capacity, and collaboration with other shipping companies and feeder lines is frequently needed to create the necessary volume. The Triple-E vessels are designed to sail at 19 knots (35 km/h) which is well below the traditional speed of around 25 knots for the previous generation of container vessels. The slower sailing speed puts a pressure on the transportation chain to get the containers to their final destination on time.

Operations research (OR) is widely used within the transportation sector to provide a cost efficient and competitive

organization. However, application of OR within containerized liner shipping is quite scarce. The potential impact of OR on this billion dollar industry is enormous especially given the large concentration of players in the business. Maritime shipping produces an estimated 2.7% of the world's CO_2 emissions, of which 25% is attributable to container ships alone. An energy efficient liner shipping network is becoming increasingly important to all stakeholders. OR can help in designing effective and energy efficient logistic solutions to mitigate the carbon footprint of the liner shipping industry.

We believe that the lack of OR within liner shipping is partly due to barriers for new researchers to engage in the liner shipping research community. Constructing mathematical models and creating data for computational results requires profound knowledge of the domain and data sources. As part of the project we have therefore made a number of test cases available for the research community, creating a platform where methods can be compared on a set of known data instances.

In order to improve the green profile of liner shipping it is necessary to look at the whole supply chain: it is necessary to improve the stowage of vessels so that as most of the capacity as possible can be utilised, while making sure that the containers are stacked in an order that is easy to load and unload. By ensuring fast transition times in ports, vessels can sail slower on the trip between ports, saving a considerable amount of fuel. It is also necessary to design decision support tools that make it easier to design and adjust the routes of vessels, so that the vessels' capacity and route match the customer demand. Only by ensuring a good utilization of the available capacity, a low energy profile can be achieved per container. Finally, it is necessary to address the handling of disruptions, land transportation and repositioning of vessels, so that all parts of the supply chain are done in the most energy efficient way.

The ENERPLAN research project carried out in collaboration between Maersk Line, DTU and the IT-University has developed prototype decision support tools for the whole chain.

Vessel Stowage

Vessel stowage is about modeling how containers can be stowed in a containership and optimizing the model to achieve attractive properties of stowage plans like seaworthiness, minimum port stay, maximum intake, optimal trim, and maximum robustness to changes of the cargo forecast. In the ENERPLAN project and the related Baystow project

supported by the Danish Maritime Fund, we have since 2006 in collaboration with Maersk Line developed a 2-phase stowage optimization algorithm called QUAD. QUAD has four major contributions: 1) it is the first algorithm that can produce phase wise optimal stowage plans, 2) it is the first approach that is primarily built out of standard optimization components, 3) it is 10-100 times faster than the closest competitors, and 4) it is the first approach that has been experimentally evaluated on a large set of real data. QUAD can be used to drive a stowage planning optimization module, e.g. integrated in Seacos or another commercial stowage tool. The idea would be to compute a number near-optimal but different stowage plans that the stowage coordinator can then choose from as illustrated in figure 1.

QUAD can also be used to carry out analysis of cargo mix to achieve maximum intake. Our experimental results show that this can be done in a few seconds even for large container vessels with 99%-99.9% accuracy. Such computations can be used e.g. by string managers to optimize the profitability of their string. The work can also be used in vessel deployment to match vessel types to the overall cargo mix characterization of strings. Finally, it is also relevant for network design by providing precise models of vessel capacity as a function of cargo mix and physical restrictions like water depths and crane work heights.

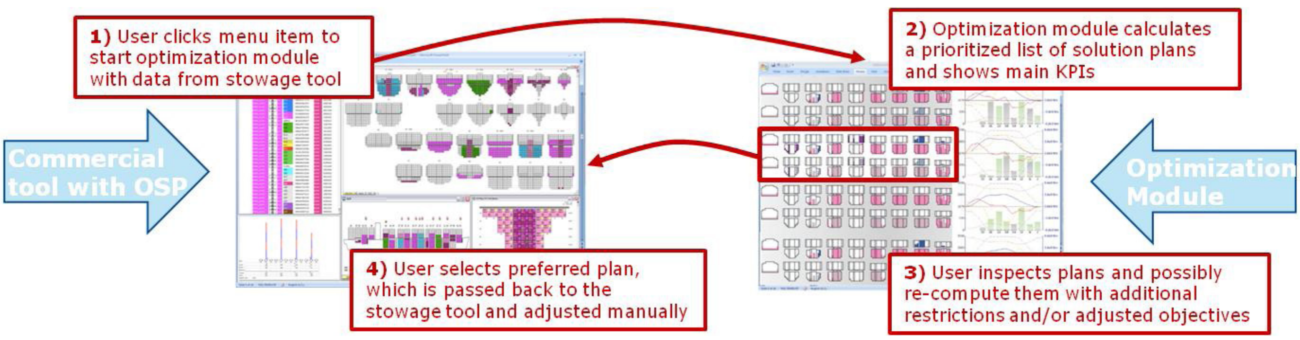

Figure 1: Illustration of stowage optimization, QUAD.

»Just focusing on overstowage, a 50\% reduction of unnecessary restows corresponds to an annual saving of APMM in the order of $6.5M. Comparable savings can be expected on other plan quality parameters.« (Sephen Barraclough, Portfolio Manager, Maersk Line IT (2008)).

Disruption Management

The operations centre at Maersk Line handle disruption scenarios every day, where one or several vessels have been delayed due to e.g. weather, port strikes or port congestion. In order to carry out container transports according to the overall plan and schedule, the operations centre needs to get the vessel(s) back on schedule mitigating delays in the entire transportation network.

The operations centre may have several techniques for recovering the schedule such as increasing speed, omitting port calls, altering the sequence of port calls in the schedule or any combination of these techniques. Each possible combination of these techniques constitute a possible recovery option with different implementation cost in terms of fuel burn and on-time delivery of affected cargo. It is a challenge for a planner in real time to completely identify the impact of every combination of recovery techniques on the network.

The vessel schedule recovery solver provides decision support to the planner by identifying a number of recovery options along with their cost and network impact. A prototype of the solver has been implemented and analysis of several real life cases show that the solver identifies better alternatives for recovery at lower cost and better on-time delivery performance within seconds. The solver can provide valuable support to the planner in identifying attractive recovery options presenting significant savings to Maersk Line, while achieving a high level of consistency in handling disruptions. By handling complex combinations of recovery techniques the solver will often be able to identify solutions without increasing and at times even decreasing the fuel burn. The solver hereby contributes to Maersk Line's commitment to the environment.

»The disruption management study has identified how complex the contingency handling process is when something unforeseen happens in the Maersk Line network. Today we are dependent on manual evaluation based on experience and time available to take the right decision. With a disruption tool several options can be identified, downstream consequences assessed and the most efficient solution be presented. This will have a large potential upside and also improve our reaction time to changes which inevitably will happen in our global network. Participating in the project has made it evident to me that we need to identify and develop the right tools for disruption management to reduce our operational expense.« (Steffen Conradsen, A.P. Moller - Maersk A/S)

Support for Network Design

The transportation network of Maersk Line is dynamic and continues to evolve with the market to meet the needs of customers and identify the profitable cargo transports. Network planners at Maersk Line are typically responsible for

a subset of the strings serving specific regions or markets. The network planner constantly needs to re-evaluate and possibly rearrange one or several strings to meet market demands or changes to strings in other parts of the network.

A program has been developed to evaluate the benefits of altering one or more strings while keeping the remaining network fixed. The program evaluates insertion and removal of port calls on a string based on changes to the cargo flow and the operational cost. The insertion/removal of port calls can be guided by the planner in order for the program to benefit from the planner’s experience and know-how.

The program can be an important decision support tool to the planner as the program considers all possible combinations of insertions/removals and identifies the solution that maximizes the revenue of the string and the network as an entity. The planner can guide the search and hence explore many possibilities before making decisions on how to adapt to the dynamic changes of the network.

»We now have a detailed insight into the global front line research into network design in liner shipping. We know what can be done and what cannot be done. By providing data and domain knowledge for the research community, we hope to move these boundaries.« (Mikkel M. Sigurd, Head of OR division, A.P. Moller - Maersk A/S)

Asia - Europe (AE11) - Eastbound

Port	Arrives	Departs	Transit
Valencia, Spain		MON	--
Barcelona, Spain	MON	TUE	1
Genoa, Italy	WED	FRI	3
Port Said East, Egypt	WED	THU	10
Singapore, Singapore	FRI	SAT	26
Shanghai, China	SUN	MON	35
Ningbo, China	TUE	WED	37
Hong Kong, Hong Kong	FRI	FRI	40
Yantian, China	SAT		41

MAERSK LINE

Repositioning of Vessels

Container vessels are regularly moved or repositioned between services in a liner shipping network, costing upwards of \$1 million per vessel. Since the world's liner shippers reposition hundreds of vessels each year, finding cost-efficient plans to reposition vessels is very important. Low cost repositioning are beneficial not only for shipping lines' balance sheets; they are also good for the environment as less money spent means less fuel used and less CO_2 released into the atmosphere. A repositioning scenario involves several vessels which may undertake a number of activities to lower the cost of reaching their goals, such as carrying cargo on an existing service, transporting empty containers, or slow-steaming. Repositioning problems tend to involve multiple vessels and are hard to solve because of the many different combinations of activities associated with different costs.

Figure 2 shows a piece of a repositioning problem from a case study we conducted with our industrial collaborator. A vessel must be repositioned from the CHX service to the Intra-WCSA service. One option would be to sail the vessel from TPP to BLB but that would cost around $900,000. Instead, the vessel can sail from TPP to YTN, join the AC3 service (taking over for a vessel already on the AC3) and sail to BLB for an order of magnitude less cost, as well as saving fuel for an entire trip across the Pacific.

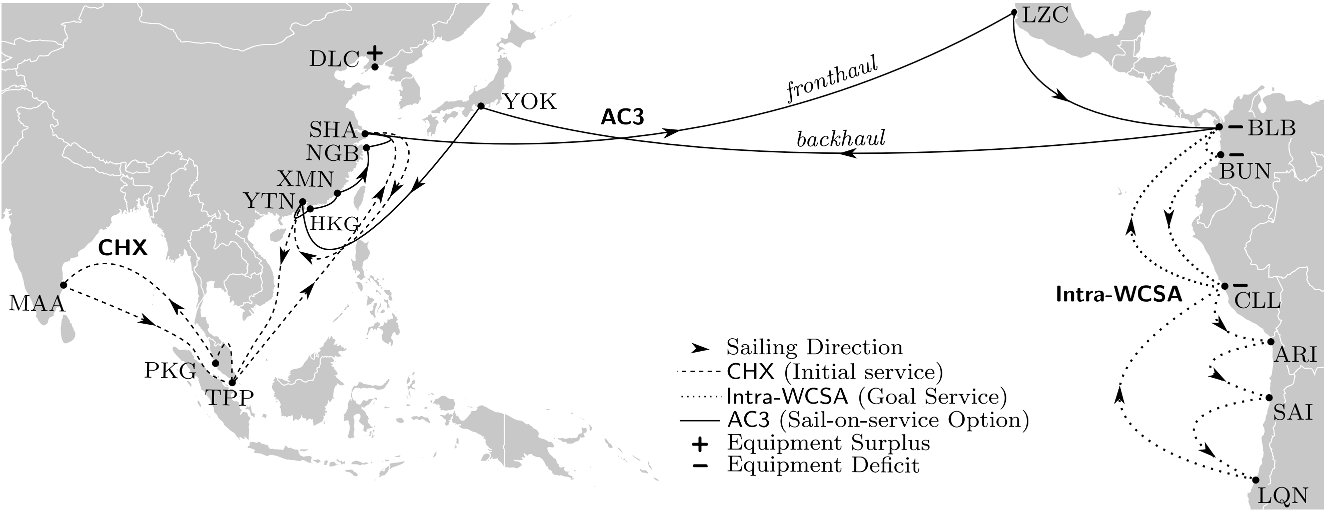

Figure 2: A repositioning problem, where a vessel must be repositioned from the CHX service to the Intra-WCSA service.

We are currently able to solve many real-world sized repositioning scenarios to optimality in less than ten minutes. The scenarios we are solving contain between two and eleven vessels. The problem difficulty increases significantly with each extra vessel, thus solving a ten vessel instance takes much more than twice the time of a five vessel instance. We continue to work on advanced solving techniques to ensure that all scenarios are solvable within ten minutes, which is an acceptable amount of time for a repositioning coordinator to wait for an answer from a decision support system.

»Repositioning a vessel between services can expose Liner Networks, trading in multiple regions, to expensive positioning voyages. Optimizing and finding solutions to utilize the vessel and reduce those costs therefore has a great value not only in reducing expense but also as to the environmental footprint from CO2 emissions.« (Shaun Long, Senior Vessel Deployment Manager)

Optimizing Inland Transportation

The transport of containers between (inland) customers and ports is an additional service offered by shipping companies. This intermodal transportation problem contains opportunities for the shipping companies to perform optimizations to reduce cost. Even though there are good manual techniques for performing optimizations, an automatized exact method exploring all possible combinations should be able to further reduce the cost. The transportation investigated in the problem is often done by truck, but rails and barges are used when available for large amounts of inland container transport. The transportation concerns deliveries of goods (imports) and pickup of goods (exports). Even though the transport by truck is mostly served by subcontractors, the transported containers are owned by the shipping company. Therefore in an import a full container must be delivered from a location to the customer where the container is emptied and the empty container is either taken to an export customer where it is filled or to a terminal for stowage. A major cost in these transports is the entry at a port or inland terminal. Therefore the desire is to follow an import service by an export service so that emptied containers are put to use immediately. To do an import followed by an export using the same container is also called triangulation of orders. Triangulating the orders also reduces the total distance driven by the truck. A method has been developed to find cost efficient routes using the concept of triangulations. Using this method for a transportation day should increase the number of triangulations and will thereby reduce the cost.

However, the cost efficient routes are found based on the orders placed. This means that if orders are sold using some knowledge available of their cost effectiveness in the final plan the cost could possibly be reduced even further. Since the method developed for finding cost efficient routes is very fast, it is possible to use it to evaluate the time window of a new order based on the already placed orders. This would give the sales representative a tool for evaluating the attractiveness of different time windows on a given order and use this to sell more attractive time windows and thereby reduce the cost of the shipping company.

»... the first phase made us realize that if either the Import or Export appointment window was adjustable, we could improve our triangulations by up to 60\% (based upon the analysis in Iberia). The next step would be to use the data that we have in our systems to suggest windows to our customers that enable triangulations. This is a huge step in the right direction that will allow us as a company to move away from customers telling us their appointment time desires to us suggesting an optimal time that enables a triangulation.«

Mike Andres, Head of Inland Operations BPO, A.P. Moller - Maersk A/S

Logistic solutions complement technological improvements

The developed prototypes in the ENERPLAN project have shown that a large potential exists for improving the efficiency of the liner shipping industry, hence also the carbon footprint. When discussing environment and sustainability, the focus is often on technological improvements. But technological improvements are costly, take time to implement, and production of the technological solutions should be included in the overall lifetime sustainability assessment. Logistic improvements have the advantage that they can be implemented quickly and do not need any investment in technology, meaning that environment and economy often go hand in hand.

Although the developed prototypes are promising, further research is needed to extend the developed prototypes to handle all operational constraints of a modern liner shipping company. Perhaps the largest contribution from ENERPLAN will be the detailed problem description and publicly available data sets, making it much easier for future researchers to contribute to green maritime logistic solutions.

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By Dawid Kozlowski

Discrete-Event Simulation of Joint Acute Units

1. Introduction

Recent reforms in the Danish healthcare system have imposed a significant change on the hospital structure. One of the main goals was to ensure an acute hospital service with the most vital specialties available 24 hours/day. The underlying assumption was that the availability of service should take priority over geographical proximity of acute hospital units (Christiansen (2012)). This implied closure of some hospitals, mergers of others and even the construction of new ones. The new acute hospitals are to offer an acute service with the most vital specialties present around the clock. Accordingly, an important objective in the reform process is the creation of joint acute wards (FAM) – admission centers for acute patients with a process-oriented acute service facilitated by the presence of multidisciplinary teams of medical specialists and newly developed patient pathways reflecting best medical practice.

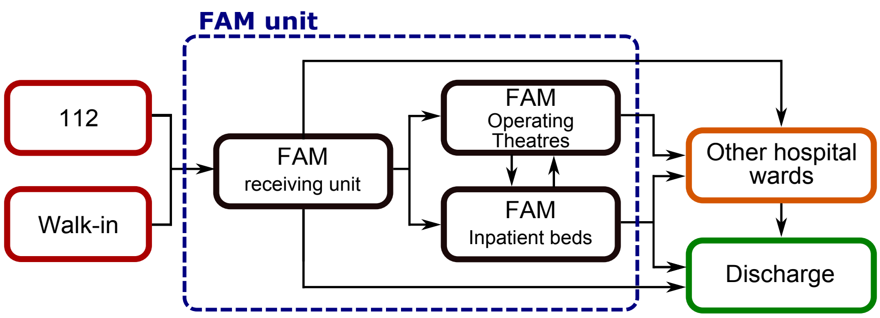

Figure 1. General overview of the new acute hospital structure in Denmark.

FAM units consist of two main departments. The first one is a patient receiving unit in which patients arriving to the hospital are received. The tasks of this unit are similar to the tasks of traditional emergency departments (ED). The second part of FAM resembles a traditional ward and contains a number of beds where diagnosed patients can be placed and treated as inpatients, but only if they are expected to be discharged within 48 hours. Otherwise, they are transferred to the standard specialty-oriented wards. It is anticipated that 70-80% of acute patients will be treated in and discharged from the FAM within 48 hours. This is a big change compared to the situation before the reforms when all patients who needed to stay longer at the hospital were immediately transferred to specialized wards. Finally, some of the FAM units also have dedicated operating theatres (OTs) for patients who require surgery. A general overview of the new structure is presented in Figure 1.

In order to meet the increased demand and ensure a good level of medical service, appropriate changes in the way patients are processed through the acute unit were to be made. For example, in the Region of Southern Denmark the so-called standardized time-based patient pathways (STPs) have been developed by teams of clinical specialists. Each STP includes a pre-defined set of processes (i.e., assessment, medical tests, consultation/action diagnosis) that have to be accomplished within a specific time limit. The requirement is that all emergency patients must be inspected by a specialist within a certain period of time from their arrival and that it should take no more than four hours to obtain an action (treatment guiding) diagnosis for any patient. STPs are symptom-based and are assigned to patients during triage. They are to ensure the consistency of patient progress and quality of services throughout the ED units in the region.

2. Challenges and needs

The implementation of the above changes is clearly a challenging task for hospital managers. Not only has a new structure been imposed on the acute units, but also the way in which patients are to be treated is a subject for modifications (e.g., by the implementation of the STPs). Furthermore, FAM units have to be prepared for an increased volume of patients due to closure of some smaller hospitals and emergency points over the next years. This results in different requirements for the use of hospital resources. What is more, all those factors increase the level of uncertainty in which hospital managers

have to operate and in consequence impose major difficulties on the dimensioning of the FAM units, since the quality and cost of service have to remain balanced. Because the environment of the acute units is changing dynamically, hospital administrators should be able to evaluate the effects of most of the upcoming changes on-site, prior to their occurrence.

Given the above requirements, we have aimed to develop and offer the management of FAM units an analytical tool designed to facilitate qualified decision-making in a dynamically changing environment. In order to meet the expectations of the hospital stakeholders the tool should comply with the following key features:

• It should be flexible enough (generic) to be easily applied in different FAM units.

• No advanced modelling skills should be required in day-to-day use.

• It should provide a cost effective means of testing various capacity decisions (e.g. staff levels and assignment of resources to specific tasks during the course of a day).

• It should offer flexible ways to define arbitrary patient groups and patient routing and to check if they conform to the imposed time requirements.

• It should provide information about the queues in front of the key resources and information about patient throughput given by specific patient type and time of day.

It was believed that the flexibility offered by Discrete-Event Simulation (DES) would make it an appropriate technique to be applied to meet the project objectives. DES allows for a comprehensive evaluation of performance measures of a given system under some projected set of operating conditions. A modelling of complex systems, such as EDs, that cannot be accurately described and evaluated by means of mathematical models, is considered to be one of the main advantages of the DES approach. Not surprisingly, DES has for many years been proved to serve as an effective tool used for process improvement in hospitals. The prototype model has been built and implemented in cooperation with Kolding Hospital which has been designated to be the acute hospital for an area populated by approx. 300,000 citizens.

3. Choice of the model design

3.1. Generic vs. Specific Models

In the healthcare simulation literature there has recently been much focus on 'generic' vs. 'specific' simulation models (see e.g., Fletcher and Worthington (2009) or Gunal and Pidd (2010)). The genericity of the ED models was of particular interest since the model to be developed in this study was intended for national use. The characteristics of generic and specific models have been compared by Fletcher and Worthington (2009). The authors point out that the main purpose of generic models is to make general observations about the design and performance of a service and to build a common understanding of a modeled system. Consequently, the design objective of generic models is to model common processes for a range of providers. Specific models, on the other hand, are built to make analyses of the design and performance of a local system and to propose detailed changes into it. Thus, their design objective is to build a bespoke simulation model of a local system, and even though there may be similarities between the local and other systems, their reflection is never an objective of model design. Consequently, as noted by Bowers (2012), specific (bespoke) models are typically more precise since they provide a scope to incorporate all detailed local variations in practice. By contrast, generic models give a good general insight of the modelled processes but may be difficult to apply locally due to a high level of abstraction. Nevertheless, an increased model precision often comes with a cost of increased data requirements and simulation run-time. Moreover, specific models can be expensive due to a long development period and may thus fail to provide timely results.

Because our model was aimed for use in different FAM units, its transportability potential had to be similar to the generic models. At the same time, a high level of model detail was required since the project was aimed to provide FAM managers with a fairly sophisticated operational tool designed to facilitate qualified decision-making and planning. As noted by Bowers et al. (2012), generic models only include the common and most significant processes from multiple locations, and may not be possible to adjust to detailed local conditions so as to provide the basis for qualified decision making. Accordingly, the simulation model had to offer a sufficient level of detail in order to meet the project objectives. The problem is that a successful application of detailed simulation models at different locations can be challenging (see e.g. Robinson et al. (2004)). We have decided for this reason to take a different approach with focus on the model reuse. Specifically, we have aimed to create a specific model for facilitated reusability at different FAM units.

3.2. Model Design for Facilitated Reusability

Model reuse is not a new concept, but it is has proved to be difficult in practice. Reuse in simulation modelling refers to the

isolation, selection and utilization of the pre-existing modelling elements in the development of new simulation models. Pidd (2002) discusses a spectrum of four different types of model reuse: code scavenging, function reuse, component reuse and full model reuse. Any type of reuse has a potential for reducing the time and cost of model development, validation and verification. However, there is a big difference between reuse of model elements specifically constructed for this purpose vs. the ones that are not. The adaptation of a model which was not designed with reusability in mind can be more costly and time demanding than building a new model.

Consequently, the idea is to take advantage of the reuse approach by building a detailed model of the ED that can be easily adjusted to local practice. Because EDs share many similarities, many simulation mechanisms can be used at different locations without need for many changes (e.g., control of staff schedules). At the same time, it is possible to identify elements that will likely require modifications for being adjusted to local systems (e.g., patient pathways, staff schedules, animation) and design them in a way that facilitates their reuse. Notice the clear advantage deriving from the fact that the modeller is aware of the scope of the model's reuse and the main purpose of the model to be applied in different ED units. This a priori knowledge simplifies the task of model design, since only limited possibilities for use of simulation elements can be taken into account.

Due to special model design, the reuse approach offers scope for transportability to local practice that is comparable to the generic approach. At the same time, similarly to the specific models, it facilitates complex analysis of local systems due to the low level abstraction and high level of model detail. Jun et al. (1999) point out that it is the level of model detail that often decides the success or failure of the application of the model. Not surprisingly, the confidence of stakeholders and the accuracy of the model increase with a more realistic representation of the system, which is typically brought by increased level of details and animation (see e.g. Harper et al. 2004). Moreover, as noted by Bowers et al. (2012), the reuse approach also enables stakeholder engagement in model adjustments, thus increasing model creditability which is especially important in healthcare applications.

Although simulation model reuse has been in focus of much research within the simulation community for more than 15 years, little work has been reported in the literature, especially outside the military domain. In the next section we present our novel attempt on the modelling of an ED that is aimed to achieve the benefits of model reuse. We first discuss decisions related to the scope of the model. Next, we briefly present an outline of the model structure with focus on elements designed for a facilitated reuse.

4. Model structure

Having defined the project objectives, a conceptual model of the FAM at Kolding Hospital has been created based upon a systems analysis. The goal was to get a common understanding of the processes at FAM along with an impression about their effects on system performance.

The processes within the ED, which is the 'front door' to the entire acute hospital, are crucial for the performance of the entire FAM unit and for meeting the objectives imposed by the reforms. Moreover, the dimensioning of this department is most challenging due to the variability in arrival and process rates and the number of different processes and resources involved when receiving patients. The systems analysis showed that the performance of the Kolding ED is not significantly affected by the dimensioning of the FAM bed department, since both parts of the unit have dedicated resources and there were no problems with patients' flow between them were reported. Accordingly, only the FAM receiving unit (ED) was put in focus for this project.

Patient admissions to hospital wards was not modelled explicitly as a capacity constrained process, since the majority of admissions was to the FAM bed department and no issues of patient blocking were reported to other wards. In fact, once an action diagnosis is accomplished, patients are immediately sent to the FAM bed department or other wards, if not sent home, in order to release capacity for new arriving patients. Any capacity problems that may occur in other departments were reported not to be of concern by the ED managers and were solved elsewhere. On the other hand, proximity of other wards was considered a significant factor since medical specialists in many instances (e.g. during night shifts) may be called in to the ED from other wards. The distances to other wards were for this reason to be explicitly included in the model along with internal distances within the ED. When medical specialists are on call-in duty to the FAM unit, they always prioritize the call-in over their work obligations at their departments. The transportation time has therefore been considered to be of key importance for the ED performance. The lack of an explicit representation of external hospital units (e.g. other wards) may be regarded as a limitation of the model, since the performance of other FAM units may be affected by interdependencies with external hospital wards. However, an explicit modelling of interdependencies would significantly change the scope of the entire model and require a detailed representation of all the processes involved. Hence, it would complicate the model and increase data requirements significantly.

Finally, in line with the literature, processes involving diagnostic tests were modelled as capacity unconstrained time distributions. Nevertheless, transfers to these facilities were explicitly taken into account as potentially long lasting events requiring the assistance of porter, nurse, young doctor or anaesthesiologist in case of trauma patients. For the same reasons blood samples, tests, and analyses were modelled as entities flowing in the system. This representation of diagnostic tests facilitates model reuse, since it eliminates extensive data requirements resulting from an explicit modelling. The model does however include an explicit representation of the diagnostic resources (i.e., X-ray, CT scanner, diagnostic specialists). Dedicated diagnostic facilities (e.g., X-ray) are easily included in the model in an explicit way by the use of these resource elements. However, when diagnostic facilities are shared by different wards, as is the case in Kolding, their explicit modelling is much more difficult since they are not only used by ED patients. Hence, one should be aware that detailed modelling of shared resources would essentially require detailed information about the demand for diagnostic procedures from other hospital units and working schedules for the diagnostic specialists, again significantly increasing model complexity and data requirements.

After deciding upon the scope of the model, the map of the Kolding ED presented in Figure 2 was used by the local staff as a communication tool to describe in detail the processes and patient flows within the ED. A process flow diagram of the system was created to form a basis for the model development. Specifically, it was possible identify elements of key importance for the performance of the unit by grouping the processes in the process flow diagram, along with elements to

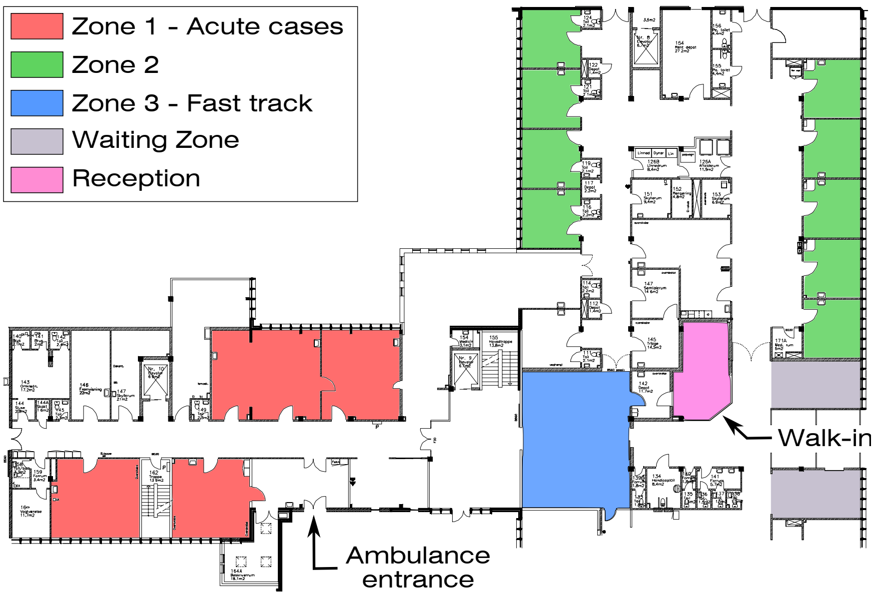

Figure 2. Overall layout of the emergency department in Kolding Hospital.

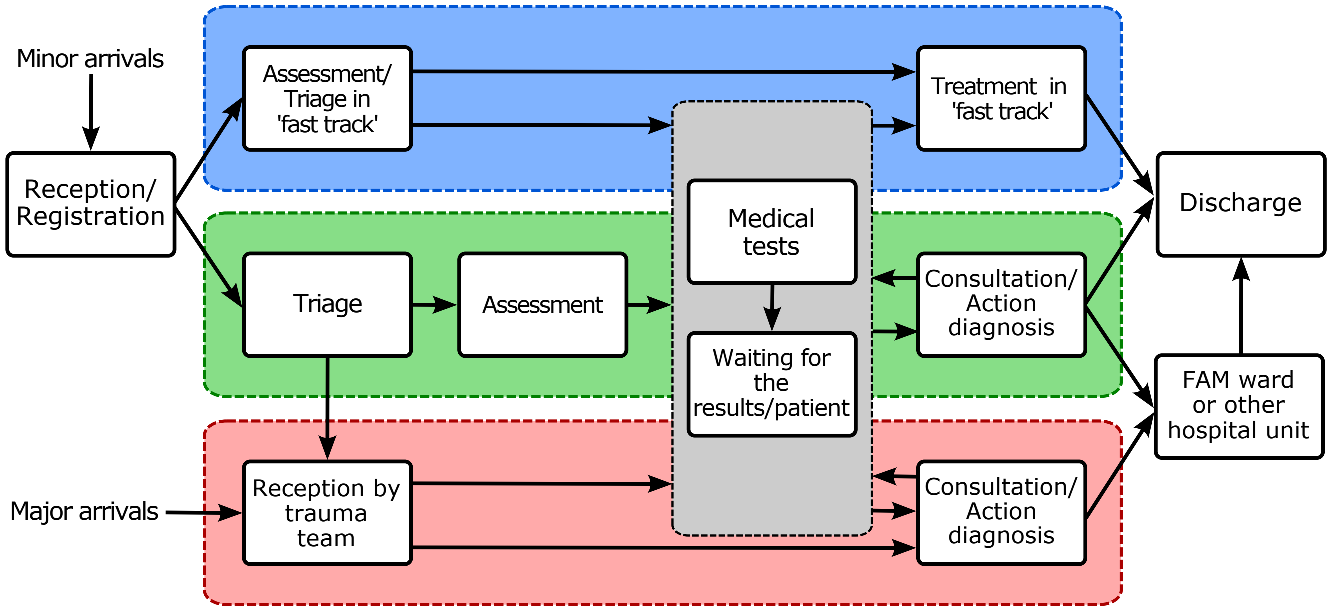

Figure 3. An overview of the conceptual model of FAM ED based on the process flow diagram.

be modelled in less detail or be excluded from consideration. The complex system was in this way decomposed into the more and less important elements. Moreover, an attempt was made to identify elements of the patient flows that are likely to be generic across Danish EDs. The resulting conceptual model is depicted in Figure 3.

As seen from the figure, we distinguish two types of patient arrivals: major and minor. Major arrivals are typically by ambulance or helicopter while minor cases are usually walk-ins. A typical ED consists of standard treatment facilities, independent 'fast-tracks' (areas dedicated to fast track patients) and trauma rooms for major casualties. For example, the three treatment areas of Kolding Hospital ED with fast track (blue), trauma (red) and normal (green) are shown in Figure 3.

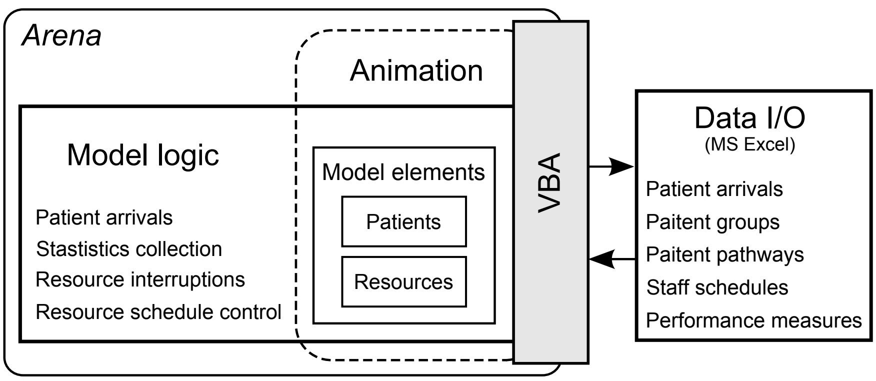

Figure 4. An overview of the model structure.

The next step was to transform the conceptual model into the backbone for the operational model. We have utilized the component-based model structure in order to facilitate model reuse. Specifically, the model is made up of separate building blocks (components), such as resources, patient entities and their animation counterparts, which were designed in a way that enhances their composability – the capability to select, adjust and combine these components to form a model that meaningfully corresponds to any local ED. In addition, the focus was put on the flexibility and ease of use of these components that would allow to adjust the system setting and test alternative system configurations (e.g., staff schedules or patient routing). Accordingly, components offer a useful mechanism to support reuse. It is important to notice that because of the specific model objectives and application/reuse domain, simulation components are assumed to have the same purpose, nature and behaviour at different EDs. Therefore, the complexities in model reuse related to multisolution modelling and the correspondence of the abstraction level are omitted.

4.1 Model components

The main components of the model (and key parts of any ED) are patients and resources (both stationary and non-stationary). These components need to be parameterized, in order to be used in the model. For example, number of available beds and rooms, patient characteristics and arrival rates, and staff schedules need to be specified. Data required to parameterize the model are defined in a data input/output (I/O) interface constructed in MS Excel, which can be perceived as another component of the model. Once being specified, patients and resources take part in a number of activities represented in the model during simulation run. In order to control these activities and govern the involvement of patients and resources in the processes, the model requires a number of control routines to be specified. These include for example a generation of patient arrivals, movement of staff and patients between stations, resource cooperation and interruptions. These routines are defined in the model logic, which also includes mechanisms responsible for collecting statistics and reporting them back to the data I/O. All routines are generic in the sense that they apply for any type of patient or resource. They are represented as a combination of modelling constructs (i.e., Arena Blocks) or VBA code, and form another model component that can be used anywhere in the model. Finally, patients and resources have animation counterparts used for animation of the processes in which they are involved. An overview of the model structure is presented in Figure 4.

A broader description of the key characteristics of the model components, interrelations between them and their reuse capability can be found in Kozlowski (2014). This work also discusses issues related to the aggregation of patient groups and the use of the STPs in simulation models. Moreover, it presents an example of using the model in relation to Kolding FAM. We hope that this work will bring about a more evidence-based discussion of the reuse modelling into the simulation literature and will be followed by examples of alternative approaches for the design of such models.

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