orbit # 29

November • 2017

What is operations research • Subben's checklist • Reproducibility • allokering af varer på pluklager

ORbit

medlemsblad for
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for Operationsanalyse
og
Svenska Operationsanalys-
föreningen

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Leder.

I denne tid er der store debatter rundt omkring i forsknings-miljøerne. Forskningskvalitet, citation index, reprodicibility, big data og analytics er bare nogle af de emner der debatteres over madpakkerne og ved kaffemaskinen. Som medlemsblad er ORbit – også – en platform for disse vigtige debatter, hvilket ses i fuld flor i ORbit 29.

For at fremme debatten har redaktionen startet et lille nyt koncept, hvor vi fra redaktionens side beder et udvalg af læsere skrive en kort kommentar om et specifikt emne. I denne omgang bad vi dem besvare spørgsmålet ”What it Operations Research (to you)?”. Det er yderst interessant at læse svarene og derved få nyt input til den løbende debat. Vi vil stile imod at tage temaer op på tilsvarende vis i de kommende udgaver af ORbit.

Udover de debat-orienterede bidrag har ORbit 29 også mange andre spændende ting at byde på. Vores læsere har bl.a. bidraget med artikler om hvordan planlægning af industrirobotters arbejde kan laves så der undgås kollisioner samt om hvordan operationsanalyse er anvendt til at forbedre arbejdsgangene på et pluklager. Det er en sand fornøjelse at læse hvordan vores fag direkte medvirker til forbedringer i det omgivne samfund.

God læselyst!

Sanne Wøhlk,

Ansvarshavende redaktør

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Svenska operationsanalysföreningen

När du håller detta nummer av ORbit i din hand har vi i SOAF nyligen hållit vår konferens Svenska operationsanalyskonferensen, SOAK, 19-20 oktober tillsammans med Matematiska institutionen, Linköpings universitet. När jag skriver denna text har jag precis fått ett rykande färskt provtryck av programmet i min hand och har ett spännande event att se fram emot med hela 67 anmälda deltagare och 31 presentationer.

Årets SOAK har temat OA i praktiken och vi bjöd in två talare för att belysa detta ämne ur olika perspektiv, Anders Arweström Jansson (professor vid Institutionen för informationsteknologi, Visuell information och interaktion, Uppsala universitet) med Two shades of human thinking: Analysis and design of decision support systems for expert users och Jan Frelin (Forskningsledare vid FOI) med What causes all uncertainty?

Jag vill passa på att påminna om att vi nyligen gått ut med en inbjudan om att nominera en examensarbetare till årets exjobbspris. Har du handlett, eller känner till, en student som du tycker skrivit en bra uppsats, passa på att uppmärksamma detta genom att se till att denne nomineras! Mer information hittar på SOAFs hemsida.

Hälsningar

Elina Rönnberg,

ordförande SOAF

Indhold

Aktuellt om SOAF

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What is Operations Research (to you) ?

The Editorial board has asked some of our readers what Operations Research is to them. We are happy to see the variation in their answers and would like to thank the contributors for taking the time to think about this - almost philosophical - question.

There are many different definitions of OR, but the essential components of OR to me are:

• It is application-oriented – OR is concerned with situations that arise in organisations that need to be managed. These may cover a wide range of applications from operational level decisions (such as scheduling a trip for a delivery vehicle) up to developing strategies for the long term (such as producing a strategy for building and locating new schools in a region).

• It involves decision making – An OR study is not about increasing our understanding of a system just for its own sake. There is normally a decision, or series of decisions, that need to be made to manage the system better. The OR analyst needs to identify what are the objectives that are relevant to the situation under study and where decisions are needed that will affect those objectives.

• Modelling – To me, a key feature of the OR approach is to develop a model to address the issue being studied. An important skill in model building is to be able to include all relevant elements without the model becoming too complicated to be useful. Some models may be "soft" in that they are concerned with defining and refining the issue, while others may be "hard" in that they work with a well-defined mathematical model, where techniques have been developed or new ones need to be developed to provide solutions. Simulation models may also be built to allow experimentation in a controlled environment to address the questions being asked.

Engaging with these three components will also involve other activities that may take up a lot of time and effort, including interviewing people, collecting and analysing data, monitoring the use of a model and communicating findings to those making the decisions.

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He was President of the Operational Research Society in the UK in 2010-2011 and is currently Chair of its Publications Committee. He is also now President of EURO (The Association of European Operational Research Societies) until the end of 2018.

Operations Research is a fascinating discipline because it joins the elegance of mathematical thinking and the beauty of algorithm design with the ultimate goal of solving real-world problems.

The real-world application on which I have mostly engaged myself is timetabling. Timetabling is the activity of deciding the time and place of events such as courses, shifts, sport matches or public transportation services, while optimizing the usage of resources. Timetabling makes things really happen: attending two courses that we like during the same semester, being assigned to a favorite project topic rather than an arbitrary one, meeting people, catching a train connection, receiving surgical operations in time and more. Alternatively, timetabling permits to prove mathematically that a given setting or infrastructure is insufficient to accomplish a certain task: for example, for a parent to meet without idle times all teachers in a parent-teacher consultation at school or for an university to accommodate all classes of a semester using only the currently available teaching rooms. Timetabling is an activity that affects our lives to a large extent!

From the perspective of an Operations Researcher, the process by which these timetabling problems are addressed is a fantastic journey. The journey begins in the real-world with an in depth analysis of the timetabling process. The analysis requires talking with the people involved in producing such plans, trying to figure out which decisions must be taken and which constraints satisfied. It is crucial to learn from the expertise of human planners. At the same time, it is beneficial in this phase to put aside temporarily the way things are currently done and question whether they can be done differently, understanding what are the real needs and the real constraints and what are the reasons behind these latter. This process is very instructive also for one's own life. Then, the journey proceeds focusing on the representation of the real-world problem in mathematical terms: we strive for an abstract mathematical formulation of the problem that is the closest possible to the real problem to be solved. Once the essence of the problem is captured and brought in the mathematical world, it becomes possible to discover patterns possibly present also in other problems already solved by the scientific community. Reasoning at the mathematical level and building up on existing knowledge, we design solution algorithms. The implementation of these algorithms in computer programs makes it possible to leave mechanical arithmetical calculations to computers, while calling our ingenuity to address the efficiency issues of computing. Finally, the journey returns to the real world with numbers associated to mathematical symbols that correspond to actually practicable decisions and resource allocations, suggest novel solutions to problems and yield systemic improvements.

Traditionally, Operations Research, or (Prescriptive) Analytics, as it is also called, is the science of reducing costs and increasing profits of business enterprises by optimizing their supply chains. I think Operations Research is much more than that: it represents the scientific way of addressing problems that rank high in the political agenda: optimization of scarce natural resources, prioritization of investments, sustainability, robustness of infrastructures, humanitarian interventions and social fairness. Ultimately, Operations Research contributes in a substantial way to ameliorate our lives.

Marco Chiarandini is Associate Professor at the Department of Mathematics and Computer Science of the University of Southern Denmark. He has a Master degree in management and electronic engineering from the University of Udine, Italy, and a Ph.D. degree in computer science from the Technische University Darmstadt, Germany. His research focuses on optimization methods for automated timetabling, scheduling and routing with applications in the industry and the public sector. A central theme of his work has been the use of statistical methods for the analysis and configuration of optimization algorithms.

Er operationsanalyse (OR) et delområde af matematik? Nej. Er OR et delområde af økonomi? Nej. Er OR et delområde af datalogi. Nej. OR er et anvendt forskningsområde, men ikke et anvendt forskningsområde, hvor det er klart, hvad der anvendes. Der findes ikke en klar og indiskutabel definition af OR.

Blandt OR forskere i hele verden er der stor uenighed om, hvilke emner OR præcis dækker over. Dette diskuteres ved utallige frokostpauser på universiteter i hele verden. Der er utroligt mange områder, hvor man kan finde en OR forsker, der mener, at OR er et integreret delområde: Spilteori, finansiering, optimering, logistik, grafalgoritmer, og meget, meget mere. Det er faktisk meget sigende, at der her bruges spalteplads på at beskrive, hvad OR er for et forskningsområde. Hvis OR var et velbeskrevet område ville dette vel ikke være interessant.

Man kunne stille spørgsmålet: Når nu OR menes at indeholde så mange ting, så betyder ordet OR vel ikke ret meget? Et forskningsområde skal vel dreje sig om et entydigt og veldefineret emne?

Jeg tror, at denne misforståelse skyldes, at OR ikke passer ned i en traditionel papkasse. Typisk er et forskningsområde en papkasse, hvor emnet er skrevet på et klistermærke. Dette er ikke tilfældet for OR.

OR er et område, hvor der tages udgangspunkt i en praktisk problemstilling. Oftest problemstillinger fra erhvervslivet. Forskeren betragter modellen og metoderne, der aktuelt bruges til at "løse" problemet. Derefter forsøger forskeren at finde bedre modeller og/eller metoder. Forbedre den aktuelle performance, så der i sidste ende kan effektiviseres og tjenes penge. Muligvis er problemet ikke velbeskrevet, og problemet drejer sig derfor om, at finde en god beskrivelse/model. Validiteten af en model skal oftest testes på virkelige data. I andre tilfælde er problemet veldefineret, men metoderne mangler. Endeligt kan metoder være tilgængelige, men disse metoder er måske meget ineffektive.

Overskriften er, at der i OR tages udgangspunkt i en praktisk problemstilling. Enten en given problemstilling, eller også en problemstilling, der skal identificeres. Resultater fra andre forskningsområder indgår som redskaber, der "tages ned fra hylden". Ethvert redskab overvejes. Om det er avanceret eller banalt er sekundært. Det praktiske problem skal løses. Performance skal forbedres.

Kent Andersen er Lektor på Matematisk Institut på Århus Universitet. Kent fik sin PhD i Operationsanalyse ved Tepper School of Business på Carnegie Mellon University i 2004, han havde Marie-Curie European Fellowship I 2004-2005 ved Center for Operations Research and Economics (CORE), han var adjunkt på Københavns Universitet 2005-2008, han var PostDoc på Otto Von Guericke Universitet Magdeburg 2008-2010, hvorefter han blev ansat som Lektor i Århus i 2010. Kent's hovedinteresse er optimering med særlig fokus på heltalsoptimering og dets anvendelser.

Applications of Optimization 2018

Finder sted mandag d. 23. april 2018. Sæt kryds.

As an industrial engineer by education and as a business school professor by profession, my perspective on Operations Research (OR) is essentially that of the business unit, the company, and the supply chain. This is by no means in disrespect of other perspectives, where OR also has an important role to play, but it is my subjective perspective.

The discussion about Operations Research (OR) and its different roles has been going on for almost as long as the concept of OR has existed. Rather than signifying a *post mortem*, as has been suggested, such a debate can be a sign of health, particularly if it spurs revitalizing initiatives and constructive developments. One such recent initiative, which has also largely been adopted by the OR community, is that of Business Analytics (sometimes a.k.a. just Analytics or Big Data). This is a concept that very much appeals to my understanding of what OR is – or what it should be when applied in the business domain. In fact, some claim that this is essentially a return to the original intentions behind the development of OR, whereas others claim that it is something much more or even something radically different from OR.

A few years ago, before these terms began to appear in almost every academic journal and every trade magazine, I held an invited talk during an OR-day at Aarhus School of Business. The title I used for this talk was: “Business Analytics: More or less OR?” At the time, I thought this was a clever way of highlighting the relation(s) between the two approaches and it seemed to capture the dilemma, at least from an OR point of view. But now the answers to the questions are quite clear, at least to me. First, Business Analytics is not just OR, it is something more, particularly with respect to its increased focus on data mining, and on the descriptive and explanative elements. Second, Business Analytics does not imply less OR. On the contrary, I believe it will increase the interests and demands for prescriptive analyses in business settings. However, this requires that relevant data have first been captured and analyzed, and that the relevance of the data is indicated by an appropriate model designed to respond to Key Performance Questions (KPQ). This is not new. What is new is the availability of actual data that can be applied to models for which the data was previously perhaps merely assumed to be known input parameters. Moreover, models can now be designed for a level of granularity previously not considered possible. To a much larger extent than before, appropriate data may also be available for model validation purposes. Hence, it seems clear that OR analysts will be well advised to pay close attention to the data elements of their models, if OR is to integrate well with the Business Analytics wave.

Ending on a personal note, as the headline suggests, to me OR means intellectual challenges, interesting but sometimes also overwhelming. It suggests a way to structure analyses of business problems and a way to learn and teach that structuring. Once upon a time, an article that very much influenced my view on OR – or Management Science - discussed in depth the relations between the concepts of Management Science, Management Engineering, and Management Consulting. To form a successful area for research and application, all three of them are needed, but Management Engineering was suggested to be the body of knowledge bridging theory and practice. Dissemination and teaching plays an essential role in there. To conclude: OR essentially means a systematic approach to business modelling, probably the best rationale in the world for the education of business students.

Anders Thorstenson graduated as M.Sc. in Industrial Engineering from the Institute of Technology at Linköping University, Sweden, and obtained the tekn.dr. degree there in Production Economics. He has held academic positions at technical faculties and business schools in Scandinavia, the US and Hong Kong, currently as professor at Aarhus University. His main areas of interest are Supply Chain Management, Production and Inventory Control, and Business Analytics.

Operations Research (OR) to me, in short, is about f*inding how to do things better*.

Finding refers to all the models and methods in the field: from mathematical modelling to machine learning, from exact methods to (mat)heuristic. Purists in the field of Operations Research may focus on this *finding*, the development of methods and models, for very general problems independent of application.

Nonetheless, OR is an undeniably pragmatic field focused on the question *how to do* something. It's solutions form a concrete solution to a problem, for example in the form of a schedule, a plan, a set of decisions, a pragmatic advice. Maybe this is not surprising for a field that rose around military planning during the second world war: the generals had no time for hand waving, they needed concrete solutions!

Since then, the *things* that people have studied from an OR perspective have grown vastly: from health care to supply chain management to logistics to finance to energy to even agricultural applications such as forest planning. It is nowadays very common to specialize in such a field of application both as practitioner and as researcher, as being an expert on both the methods (*finding*) and the application area (*the things*) generally benefits one to reach the main goal: to do things better!

Interestingly enough, what *better* means, what the objective of all these efforts should be, is often left to practice. It can be for example to reduce costs, to increase speed of finding solutions, or to increase robustness of the solutions, that is, to have solutions that are also good when small changes occur. By reaching these goals, or at least improving current practice with respect to these goals, OR has increased the efficiency, reduced costs or increased revenue of many processes. For example, where would the airline industry be today without Revenue Management?

Experts in the search of the optimal (absolute best) solution, are well aware that this solution can be highly sensitive to the modelling of the problem. They are aware of the limitations of translating multiple objectives relevant for practice into their models – *and* of the effect of *excluding* characteristics of the problem. For example, including or excluding CO2 emissions when scheduling transportation could have a huge effect on the CO2 emissions of the proposed "optimal" schedules. Provided the impact the formulation of the objective may have on our solutions, and the impact our solutions have on our society, is it maybe time to start sharing responsibility for the choice of the objective? So that OR does not only make our world more efficient, but also a better, more pleasant place to live!

Evelien van der Hurk is an assistant professor in transportation in the Management Science Division at the department of Management Engineering of the Technical University of Denmark. She received her PhD in public transport optimization in 2016 from the Rotterdam School of Management, Erasmus University, The Netherlands.

Brief characteristics of the fields of Business Economics, Management Science, and Operations Research seem to be an appropriate starting point for addressing the question of what Operations Research is to a business economist with a professional focus on Management Science in general and on production economics and productivity analysis in particular. Business Economics uses economic theory and quantitative methods for the analysis and solution of problems related to all aspects of business. Operations Research is concerned with the development and application of quantitative methods with the aim of making better decisions not necessarily in a managerial context. Focus in Management Science is on organizational, managerial, and individual decision making based on economics and mathematics including the development and use of methods from Operations Research in the context of decision making in business. It is clear that the intersection between fields of Business Economics, Management Science, and Operations Research is non-empty and that no field is a subset of the others.

The ongoing development and application of a portfolio of quantitative methods from mathematics and statistics with the aim of optimizing the performance of any complex system may be considered a fairly standard definition of Operations Research. My professional focus is on fields in Operations Research of particular importance in Business Economics and Management Science. Indeed, I consider the associated fields constituent in a definition of the meaning of Operations Research to me. To be more specific, to me Operations Research is the ongoing development and application of a portfolio of quantitative methods for making business operations technical efficient in the sense of using as few inputs as possible in order to produce a given amount of outputs. Technical efficiency is a necessary but not sufficient condition for allocative efficiency. I consider the concept of allocative efficiency in the sense of utilizing the least cost mix of inputs and/or producing the mix of outputs that maximizes revenue a core issue within the combined area of Business Economics, Management Science, and Operations Research.

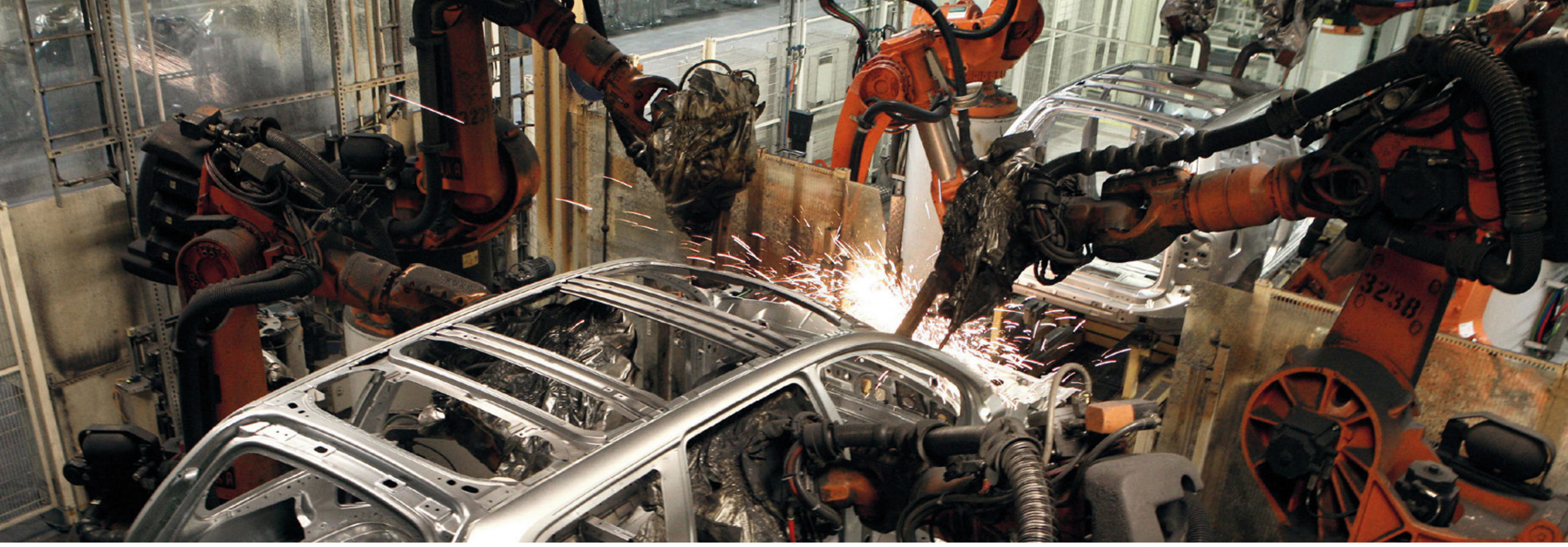
The fields of duality theory and convex analysis are for a number of reasons important in the context of production economics. The concept of allocative efficiency presupposes the existence of market prices, which are an integral part of the cost function, the revenue function, or the profit function in microeconomic production theory. Market prices that reflect the value of inputs and outputs are not always available. However, dual models associated with convex technologies allow for the establishment of virtual input and output prices, which in turn can be used as internal accounting prices.

The building of mathematical optimization models is a very integral part of Business Economics in general and of Operations Management in particular. I consider mathematical model building a highly important area in Business Economics as well as in Management Science and Operations Research. It is clear that it is not sufficient to build optimization models. The numerical solution of the models is also needed, when focus is on the identification of the best possible or optimal use of scarce resources, which is the standard challenge in business. The ongoing improvement of algorithms for the solution of optimization models is a necessary condition for decision making based upon the solution of optimization models, as is the development of general algebraic modeling systems. Problems within business economics concerned with the identification of the best possible use of scarce resources can be modeled as optimization problems, and many problems of this type belong to the family of combinatorial optimization problems. The large families of routing and scheduling models are examples. The technology as of today allows for the numerical solution of instances of routing and scheduling problems of a size that is relevant for decision making in business.

Many decisions in business are made under conditions of uncertainty. The model building of uncertainty and stochastic programming are other areas of particular importance in Business Economics. It is clear that the importance of an incorporation of uncertainty in model building extends beyond the area of operations management.

So to me Operations Research is the ongoing development and application of a complete portfolio of quantitative methods for making business operations efficient. It is clear that this is a huge field, and few if any can be considered experts within all areas. I consider in view of my professional focus on productivity analysis the fields of model building and optimization along with duality and convex analysis of particular importance.

Niels Christian Petersen, Dr.Merc. & Lic.Oecon. Professor in Business Economics at the Department of Business & Economics, University of Southern Denmark. His research interests are within the areas of productivity analysis and benchmarking with focus on Data Envelopment Analysis.



By Edvin Åblad

Intersection-free load balancing for industrial robots

At Fraunhofer-Chalmers Centre (FCC) in Gothenburg an area of research is the manufacturing process of the automotive industry, with the aim of improving the efficiency by modelling, simulation and optimisation of products and processes.

The sheet metal assembly of vehicles is central in the manufacturing process and hence of particular interest. Here, multiple robots cooperate to perform tasks, such as welds, on a car body. Performing all tasks as fast as possible, i.e., minimising the cycle time, is crucial to meet the demands of the automotive market and to make the production more sustainable; see [1].

Load Balancing with synchronization

To obtain efficient robot programs, FCC has developed the software Industrial Path Solution (IPS) to solve this load balancing optimisation problem, including task assignment, sequencing and collision-free path planning. The resulting programs tend to be 5% from an optimal solution, which is an improvement of existing industrial robot programs with about 23%. See [2, 3], for a stud welding line with Volvo Cars consisting of 200 welds and 10 robots.

To understand the complexity of this optimisation problem we can relate to the classic traveling salesperson problem (TSP), in which an agent is supposed to make a tour, visiting each of a number of cities, in the shortest time possible. The load balancing problem is however more complex. The most notable difference is that the robot paths are not explicitly given. When a robot (agent) is to move between two tasks (cities), the corresponding path is not trivial to compute since collisions with the car body as well with other agents need to be

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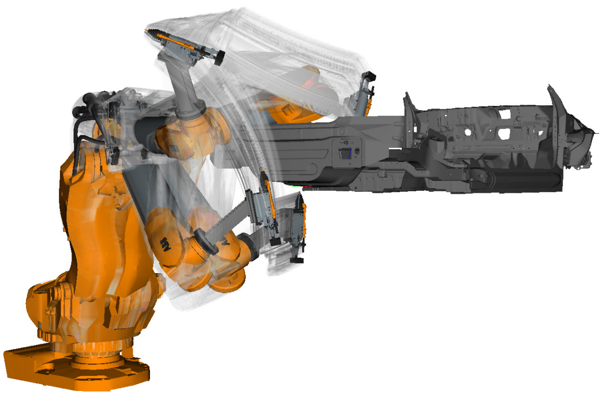

Figure 1 A collision-free robot path between two tasks.

prevented; see Figure 1, where the robot path is computed not to collide with the car body.

Other factors also complicate the load balancing problem. E.g., for each task there is a number of optional robot poses (cities), of which only the most favourable should be included in the program (tour). Also, there are multiple robots that share the tasks, by cooperating it is the completion time of all robots (so-called makespan) that should be minimised; this type of objective function typically complicates combinatorial optimisation problems.

The current approach to solve this problem (as implemented in IPS) is to first relax the robot-robot collisions constraint. Using this simplification it is possible to find the shortest collision-free robot path between each pair of tasks. However, even for advanced path planning algorithms, the computation of a single robot path is time-consuming (≈1—30s). Hence, to plan all the paths is impractical.

To this end, an iterative approach is used. Initially all path lengths are bounded from below by allowing collision with the car body. Each iteration then has three steps: (i) solve a min-max multi-agent generalized TSP, (ii) compute the corresponding collision-free robot paths, and (iii) update the bounds on the path lengths. By repeating these steps IPS will produce a well-balanced solution.

As a final step, the robot-robot collisions are taken into account by coordinating the robot using synchronization signals. A robot signals when it is about to enter a zone shared with another robot; if the zone is occupied then the robot is instructed to wait until it is clear.

Downside properties of the signals

The inclusion of signals in a robot program introduces several issues, most prominent is that the signals might cause robots to wait (be unproductive). Some other issues are that

• signals reduce the station´s flexibility. Since the synchronisation scheme is integrated in the robot programs, changing a program require a check whether the scheme is still valid;

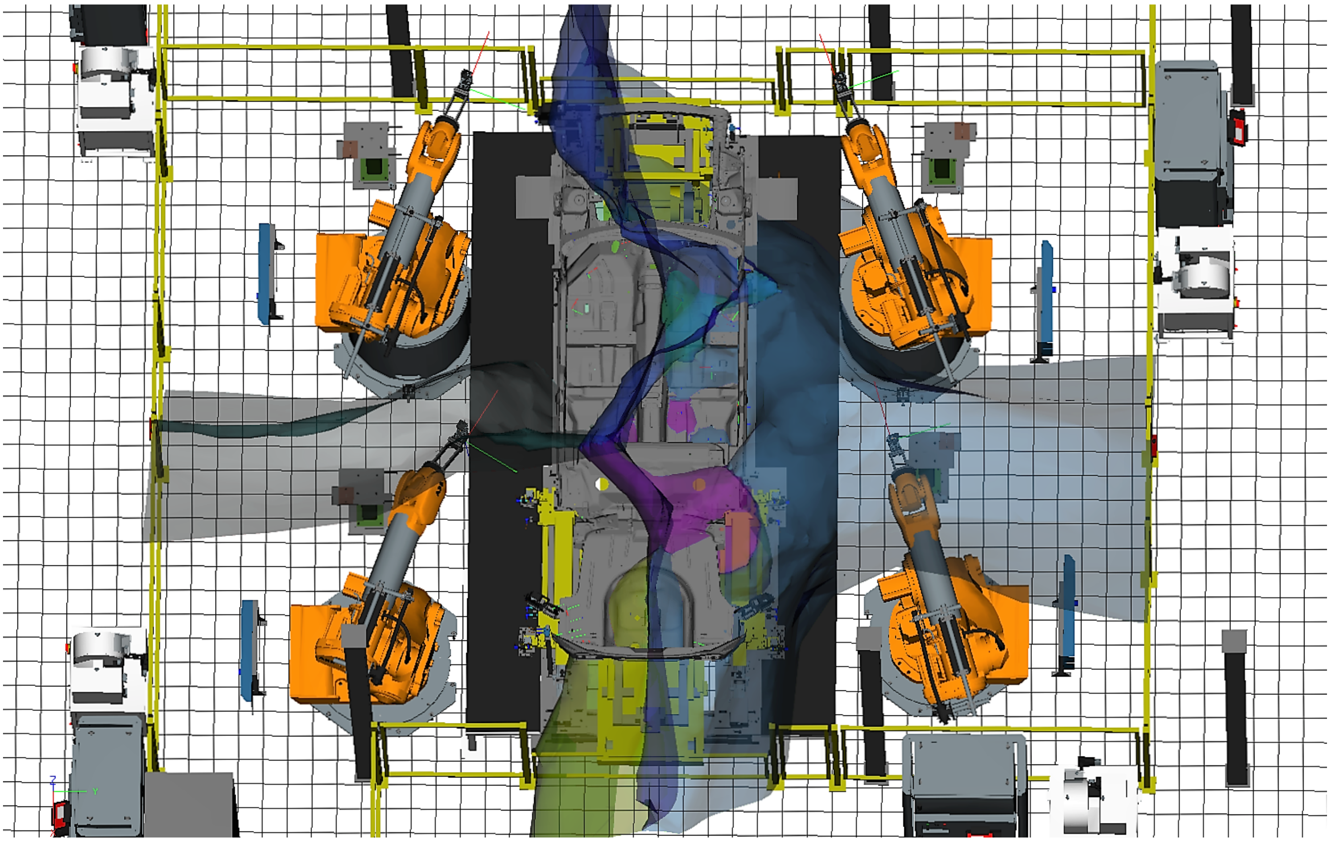

Figure 2 A non-overlapping geometrical partitioning of a robot station.

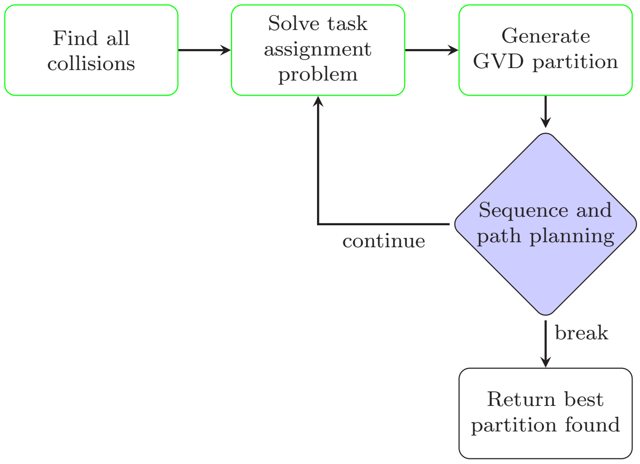

Figure 3 An overview of the intersection free load balancing algorithm.

• maintenance costs are increased, due to the longer times needed for replacing a malfunctioning robot and safely moving a robot home after a sudden production stop.

• each signal in the program will significantly increase the cycle time, because when entering a shared zone the robot must be able to stop. Hence, even if the zone is free the robot will deaccelerate and accelerate, increasing the duration of the path by almost one second. Which is a large increase since most robot programmes are less than a minute long.

To decrease the effects of these signals, iterative methods to reduce their usage has been implemented in IPS (see, e.g., [4]). However, this cannot completely remove the need for synchronization signals, but rather reduce waiting.

Intersection free load balancing

Motivated by the downsides of synchronization signals the SOAF-award 2016 winning master thesis [6] was initiated, aiming to remove the need for synchronization signals. This by constraining each robot to a separate virtual cell, defined by a geometrical partitioning of the space; see Figure 2. The thesis project investigated how to generate these partitions and if the resulting cycle times, for some industrial cases, were acceptable.

Algorithm

The resulting algorithm works in four main steps; see Figure 3.

0. Initially no robot paths are considered but only robot poses at the tasks. Compute the shortest distance between every pair of robots in all their possible task poses.

1. Assign each task to a robot by solving a task assignment problem, in which the cost of a robot-task assignment is based on the time from a corresponding home position. The model also utilise the computed robot-robot distances so that each assigned robot pose is collision-free of all other robots' assigned poses.

2. To get collision-free paths between the assigned tasks, space partitions are generated based on the computed assignments (as in Figure 2). This partition is defined by the so-called Generalised Voronoi Diagram (GVD), which is the surface that is equally far from at least two different robots.

3. As a last step the task sequences and robot paths are computed using algorithms present in IPS. We may choose to continue generating more partitions by preventing previous solutions to reoccur in future task assignment solutions.

Results

The algorithm was tested on some industrial settings, ranging from four to ten robots and up to 200 tasks. The results are impressive: some stations only increased a few percent in cycle time as a result of the enforced partitions. However, if the delay effects of synchronization signals are taken into account, these partitioned programs actually decrease the cycle time by 5—10%; see [6].

Our results indicate that there might be direct economic gains to be made in the sheet metal assembly. Our results also opens for future research in the area, such as: Develop an improved model for the task assignment, able to generate even better balanced intersection-free programs.

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His research interest includes computational geometry, multi-agent modelling, and combinatorial optimisation.

DORS' firma- og institutmedlemmer

Institutmedlemmer

- Afdeling for Anvendt Matatematik og Statistik, Københavns Universitet
- Afdelingen for Operationsanalyse, Aarhus Universitet
- Center for Research in the Foundations of Electronic Markets
- CORAL, Aarhus Universitet
- Datalogisk Institut, Københavns Universitet
- Institut for Virksomhedsledelse og Økonomi, SDU
- Institut for Planlægning, Innovation og Ledelse (DTU Management), Danmarks Tekniske Universitet

Firmamedlemmer

- A.P. Møller – Mærsk
- Copenhagen Optimization
- DONG Naturgas A/S
- DSB
- DSB S-tog
- Hermes Traffic Intelligence
- Københavns Lufthavne A/S
- MaCom A/S
- MOSEK
- Novo Nordisk (CMC Clinical Supplies)
- Optivation
- QAMPO
- Rapidis
- Transvision A/S
- Trapeze Group Europe A/S

By Richard Oberdieck

Reproducibility in Operations Research

In recent months, there has been an increasing awareness and discussion regarding the reproducibility of experimental results in the scientific literature. Just in September 2017, the former dean of Harvard Medical School wrote in *Nature* that "the spectre of irreproducible research haunts the biomedical community" [1], while the initial results from a large reproducibility project of cancer-related work published in high-profile journals such as *Nature* and *Cell* found that only 2 out of 5 papers (with a combined number of close to 3000 citations) were "substantially reproduced" [2].

However, although the focus of the scientific media has so far been on the reproduction of experimental results, the question of reproducibility is also problematic for areas with computational results rather than experimental results. This is surprising, given the fact that it should, in theory, be possible to simply share the code and the underlying data, and run the algorithms again to reproduce the results. Yet, even in computer science journals it is not always a requirement to share your code base, and in our field, operations research, the only journal (known to the author) which does require software and data to be part of the publication, is *Mathematical Programming Computation*, which however to date has only published 124 articles since 2009 [3]. Other than that, it is most frequently up to the authors themselves to determine how much of their code and data they want to share.

1. What is reproducible OR?

According to Scott Nestler, "reproducible research refers to the idea that the ultimate product of research is the paper along with the full computational environment used to produce the results in the paper such as code, data, etc. necessary for reproduction of the results and building upon the research" [4]. For operation research, we can in general identify four elements required for reproducibility: (a) the computer hardware, (b) the (commercial) software, (c) the data for the problem at hand, and (d) the code developed to investigate/solve the problem. Therefore, given a paper as well as these four components, any person should be able to reproduce the results of the given paper.

However, each of these components has issues and challenges attached to them, which will be discussed below. First, the computer hardware: in [5], published in *Automatica* in 2016, the authors ran their computational experiments "using a machine with Intel Pentium™,1.66GHz processor with 500 MB of RAM" [5]. Compared to other computational studies that are being published, this is not a lot of computational power to say the least. So how could that group reproduce the results from another research group, which uses maybe a university cluster? The truth is that by using more and more expensive hardware, the results become less and less reproducible. The same holds true for (commercial) software: while many software packages (e.g. IBM's CPLEX) have free academic licenses, this does not have to be the case. For example, the full editions of both MATLAB and GAMS do not have such licenses, and therefore any work requiring these software packages cannot be reproduced without purchasing these products. Third, the data: while there are no economic limitations (in most cases) with regards to the data, the main concern is privacy. Especially when considering data from industrial sources, researchers often have to sign non-disclosure agreements which prohibit them from any sharing of the data. This makes the reproduction of any findings virtually impossible, because even if everything else is in place, there is no way of knowing the data. Lastly, the code: this is arguably the easiest part of the four components, however there are still issues regarding code quality. In the authors experience, most code written in academic settings is of poor quality, especially when it comes to its documentation (i.e. user manuals, comments etc.).

2. Why should we care about reproducibility?

Ultimately, it is about scientific rigor. If person A can reproduce the findings of person B, then those results are more likely to be correct. If nobody reproduces any findings, then all papers simply become mattes of opinion, because no scientific consensus is built, or the consensus is never challenged (see [6] for an interesting commentary on this). Therefore, for science to function, we need to pay attention to reproducibility.

However, many people might argue that reproducibility is only a question for experiments, and that developments involving modelling, simulation and optimization do not need to be reproduced since computers are not going to make mistakes. Unfortunately, this reasoning is flawed, since it is humans who are doing the work. Whether it is a sign mistake, forgetting to divide by 100 or using biased data, there are a lot of ways which can make any computational results incorrect. As Fani Boukouvala from GeorgiaTech University says “Sometimes when reproducing I found mistakes in equations, but it was typically a simple mistake and it was clear it was a typo and not a serious error. However, sometimes a method is so complex that it would take too long to reproduce, so it is not worth the time.”

In addition, it is also a matter of pride: knowing that fellow researchers are able to obtain the same results that were obtained by one’s self is more validation than any peer review could ever give. It signifies that the research has been as closely examined as possible, and it still held up.

3. What can we do about reproducible operations research?

There are two extremes, and then there is the entire middle ground. On one side is the status quo, where nothing is published except the paper itself, which is normally not enough to reproduce the results. However even if it were, it would take weeks if not months (or years) to recode the same algorithms that already exist on a hard drive somewhere else. On the other side is the approach by *Mathematical Programming Computation*, where the code and the data is a natural part of the review process and all the results are reproduced before the article is even published.

There are also many different ways in the middle: from forcing the code to be available without any review, to enforcing the publication of data, even in a normalized form to protect privacy, and to use software packages which are freely available to researchers. In addition, “providing code, open-source software or webtools would really help. When proprietary software is used, providing all model equations would also help.”, says Prof. Boukouvala. Such a type of service would at least justify parts of the fees paid for the subscription to scientific journals.

While many of these options are wishful thinking, others are not. In general however, the topic is too important to simply continue with the status quo of not sharing the code and data. It simply does not make for good science.

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Richard Oberdieck holds a BSc and MSc in Chemical Engineering from ETH Zurich, and a PhD in mathematical optimization from Imperial College London. After the completion of his PhD, he joined the R&D department of DONG Energy/Ørsted, where he designs and develops advanced modeling and optimization tools across the entire organization. He is passionate about the bridge between academia and industry, and ways we can bring these two sides of the same coin together.

Af Michael Lindahl

Operationsanalyse skal forbedre universiteternes skemaer

Tusindvis af studerendes og underviseres hverdag styres af det skema som hvert semester bestemmer hvilker kurser der ligger hvornår. OR metoder skal nu hjælpe med at forbedre skemaerne og give store besparelser.

Hvert semester står universiteterne foran det enorme puslespil det er at få lagt et skema. Flere tusinde kurser skal have tildelt tidspunkter og lokaler. For at et skema kan fungere i praksis er der mange ting der skal overholdes. Kurser der følges af de samme studerende eller undervises af den samme må selvfølgelig ikke ligge på samtidig tidspunkt. Kurser har ofte også tilknyttet krav til lokalet som skal overholdes: Der skal være plads til alle de studerende der følger kurset og udover det, er der ofte også krav om bestemt udstyr der skal være til stede, som for eksempel en projektor eller bestemt laboratoriegrej.

Samtidig med at kravene skal overholdes er der også en masse ønsker til hvordan et godt skema skal se ud, hvilket i høj grad afhænger af hvem man spørger. De færreste ønsker undervisning mandag morgen eller fredag eftermiddag. De studerende vil gerne undgå at skulle skynde sig fra den ene ende af byen til den modsatte del fordi deres næste undervisning ligger der. Samtidig er der fra ledelsens side et stort ønske om at udnytte kapaciteten så meget som muligt for at undgå at der skal lejes nye lokaler og for at have mulighed for at afholde konferencer og andet i løbet af semesteret. Det er skemalæggernes job at afveje alle disse ønsker og opfylde så meget som muligt.

Sværere end verdens største sudoku

Alle disse mange og forskellige ønsker der skal opfyldes gør det til et utrolig svært og komplekst problem, langt sværere end at løse en almindelig sudoku eller at regne det bedste træk i et skakspil. På samme måde som et tal kun kan bruges en gang i en søjle, række eller kvadrat i sudoku, kan loka-

Skemalægning er en lang process fra den initielle planlægning til at det endelige skema er færdigt.

lerne kun bruges en gang i hvert modul og kurser der følges af samme pensum kan ikke ligge samtidig. Men hvor der i en sudoku skal vælges imellem 9 tal på en plade der er 9x9, har vi i skemalægning ligeså mange rækker som lokaler og søjler som tidspunkter i løbet ugen. Der skal heller ikke kun vælges imellem 9 tal, men imellem mere end 1000 kurser der skal placeres. For en almindelig sudoku er der ca. tusind beslutninger der skal tages, men i skemalægning med halvtreds forskellige lokaler giver det over fem millioner beslutninger der skal tages. Et tal der vil give selv den mest garvede sudoku løser sved på panden.

Antallet af måder et skema kan sammensættes på er astronomisk. Fordi der er så mange forskellige muligheder vil det være fuldstændig umuligt at kigge samtlige skemaer igennem og så bare vælge det bedste. Selv hvis de kraftigste computere havde fået lov at stå og beregne siden universets fødsel ville de stadig i dag kun have nået en brøkdel af løsningerne igennem. Det kan rent faktisk bevises matematisk at skemalægning er svært da det befinder sig i klasse af matematiske hårde problemer kaldet NP-hårdt. Det betyder at hvis vi fandt en effektiv måde at finde gode skemaer på ville vi samtidig have fundet en måde at bryde de stærkeste krypteringsalgoritmer på hvilket er meget usandsynligt.

Matematisk skemalægning

At benytte matematik til at lægge skemaer er en del af feltet operationsanalyse, der handler om at bruge en naturvidenskabelig tilgang til at analysere og løse beslutningsproblemer. På samme måde som fysikere studerer naturen og bruger matematikken til at beskrive den, analyserer operationsanalytikeren komplekse planlægningsproblemer og beskriver, ved hjælp af matematikken, hvilke regler og ønsker der skal opfyldes.

Når skemalægningsproblemet er beskrevet matematisk kan avancerede metoder bruges til at søge igennem de mange mulige skemaer og finde nogle af høj kvalitet. Derved kan der laves beslutningsstøtteværktøjer der kan hjælpe planlæggerne med hvor de skal placere de forskellige kurser. På den måde vil de være i stand til at opfylde mange flere af ønskerne.

Store besparelser at hente

En vigtig del i planlægningen er at sørge for at lokalerne udnyttes bedst muligt, så der ikke er en masser huller i løbet af ugen hvor de står tomme. At leje lokaler er dyrt og især at bygge nye bygninger er store investeringer for et universitet. Der er derfor stort potentiale for at kunne udnytte de lokaler der allerede er mere optimalt. Dette er især vigtigt i øjeblikket hvor regeringen ønsker at flere unge starter på videregående uddannelser og universiteterne derfor skal kunne optage flere imens de samtidig er presset af økonomien. På den måde kan vi få en mere uddannet befolkning uden at skulle investere millioner i nye bygninger.

Michael Lindahl er tidligere PhD studerende ved Danmarks Tekniske Universitet og MaCom hvor han lavede projektet "Strategic, Tactical and Operational University Timetabling". Han er idag Head of Analytics hos Portchain. Endvidere er Michael formand for DORS.

By Anders Aalborg Jacobsen

Company visit to Copenhagen Airport

In September, DORS visited Copenhagen Airport to learn about the company and see how they use Operations Research to optimize airport operation. Around 40 people showed up, and in particularly many students came to see how it is to work with Operations Research in the fastest growing air-port in Northern Europe.

Copenhagen Airport is the largest airport in the Nordics with more than 29 million passengers in 2016, the highest figure ever in the airports history. The objective is to create capacity for 40 million passengers a year. Currently, on the busiest days, more than 100.000 passengers travel through the airport, which calls for a well-planned operation. Since 2010, Operations Research has played a large role in Copenhagen Airport when it comes to operational planning. Within the department of Passenger & Terminal Services, a team of analysts applies Operations Research to optimize airport operation, and works with both short- and long-term planning.

Operations Research in Practice

After introducing the guests to the expansion plan of Copenhagen Airport the visit carried on with two talks. First, Head of Operational & Business Analysis Esben Kolind talked about the history of Operations Research in Copenhagen Airport, and how the area evolved into a vital part of airport operational planning. Esben Kolind also showed a live demonstration of models and demonstrated the two main sensor technologies used for passenger tracking in the airport.

Afterwards, Operation Analyst Anders Aalborg Jacobsen got a bit more into details of how Operations Research is used in the airport, and talked about his Master Thesis project concerning optimizing ground service equipment in Copenhagen Airport. Firstly, the talk focused on how the ground operation currently involves four competing hand-

Figure 1. Head of Business Analysis, Esben Kolind talks about the expansion plan of Copenhagen Airport.

ling companies, and how these companies are operating their own service equipment. This results in an accumulation of equipment consum-ing vital ground capacity in the airport. The talk touched upon the goal of starting to use shared service equipment among the handling companies, and demonstrated results from a route-model indicating that more optimal handling conditions may be found in the sharing of baggage carts.

Figure 2. Beer and Networking at O'LEARYS.

Time to Network

After the two talks there where beer and drinks alongside plenty of networking. Many guest used the opportunity to talk to the employees of Copenhagen Airport, to share airport traveling experiences and to get more into detail on how Operation Research can be used to enhance the passenger experience.

Copenhagen Airport was very pleased with the interest and would like to thank everyone who partticipated in the event.

Anders Aalborg Jacobsen works as an Operations Analyst in the department of Operational and Business Analysis in Copenhagen Airports A/S. The department engage in short- and long-term planning, forecasting and process optimization. He graduated from DTU in January 2017 with a Master's degree in Transport & Business Logistics.

SOAF' företagsmedlemmar

- Blekinge Tekniska Högskola
- Chalmers, Matematiska vetenskaper
- Högskolan i Skövde
- Industrial Optimizers AB
- Jeppesen
- KTH, Optimeringslära och systemteori
- KTH, Trafik och logistik
- LiU Kommunikations- och transportsystem
- LiU Optimeringslära
- LiU Produktionsekonomi
- Preference
- Riiplan
- RISE SICS
- Schemagi AB
- SJ AB
- Statens väg- och transportforskningsinstitut, VTI
- Sweco Society AB
- Totalförsvarets Forskningsinstitut, FOI
- Trafikverket
- Transrail Sweden AB
- Uppsala universitet, Beräkningsvetenskap

Af Kristina Hove Østergaard og Line Pedersen

Genallokering af pluk på Midsona Danmarks nye lager

DORS prisen anno 2016 havde endnu en gang fået indstillet specialer af meget høj kvalitet. Udvalget fandt dog et speciale der skilte sig ud fra de andre. Prisen gik denne gang til Line Pedersen og Kristina Hove Østergaard for deres speciale 'Genallokering af pluk på Urtekrams nye lager'. Specialet har fokus på at forstå det konkrete problem som Urtekram står overfor med planlægningen af deres nye lager og kommer frem til flere løsninger til problemet. Også løsninger som Urtekram har taget til sig. Problemet er meget kompleks af natur og tager udover selve allokeringen af produkter også hensyn til pakningen af pallerne. Specialet har en god akademisk dybde og er meget velskrevet med god rød tråd.

Bestyrelsen og redaktionen ønsker tillykke.

Midsona Danmark A/S (Midsona) er en virksomhed, som producerer og distribuerer økologiske fødevarer og body care produkter, samt produkter rettet mod personer med allergi og de markedsfører blandt andet brandet Urtekram. Midsona har de seneste år oplevet meget høj vækst og har både udvidet deres kundegrupper, men også deres primære markeder. Denne vækst har dog også ledt til en ny udfordring i forhold til lagerkapacitet, og Midsona oplevede, da samarbejdet omkring specialet startede, i januar 2016, en så høj belægningsgrad på deres daværende lager i Onsild, at de inden for få måneder ville mangle lagerlokationer. Derfor stod Midsona overfor en udvidelse af deres lager og i den forbindelse var det nødvendigt at flytte det nuværende område med småpluk, til et område i den nye tilbygning, for fortsat at sikre et godt flow og dette medførte, at plukkeområdets layout ændrede sig. Derudover var der, trods fokus på lageroptimering, ikke blevet ændret på plukkeprocessen og allokeringen af produkterne i flere år, hvorfor det ikke ville være optimalt blot at overføre den daværende allokering. Derfor ønskede Midsona sig et løsningsforslag til, hvordan produkterne skulle allokeres i det nye plukkeområde, som var baseret på det nyeste salgsdata, og som tog højde for de praktiske aspekter og udfordringer som man oplevede ved det daværende setup.

Problembeskrivelse

Udover at allokeringen på det daværende lager var baseret på forældede data og derfor ikke var tidssvarende, gav medarbejderne også tidligt i forløbet udtryk for, at der var en række faktorer og udfordringer, som besværliggjorde deres arbejde i hverdagen. Disse udfordringer var primært afledt af kravet til, at pallerne skulle opbygges stabilt, hvorfor tunge produkter skulle placeres nederst. Dette krav var afgørende for Midsona for at sikre en god leveringsservice, da det sikrer, at pallerne ikke vælter eller falder sammen, og at skrøbelige produkter ikke beskadiges under transporten. Det daværende setup var sat op med fokus på at minimere distancerne, og suppor-

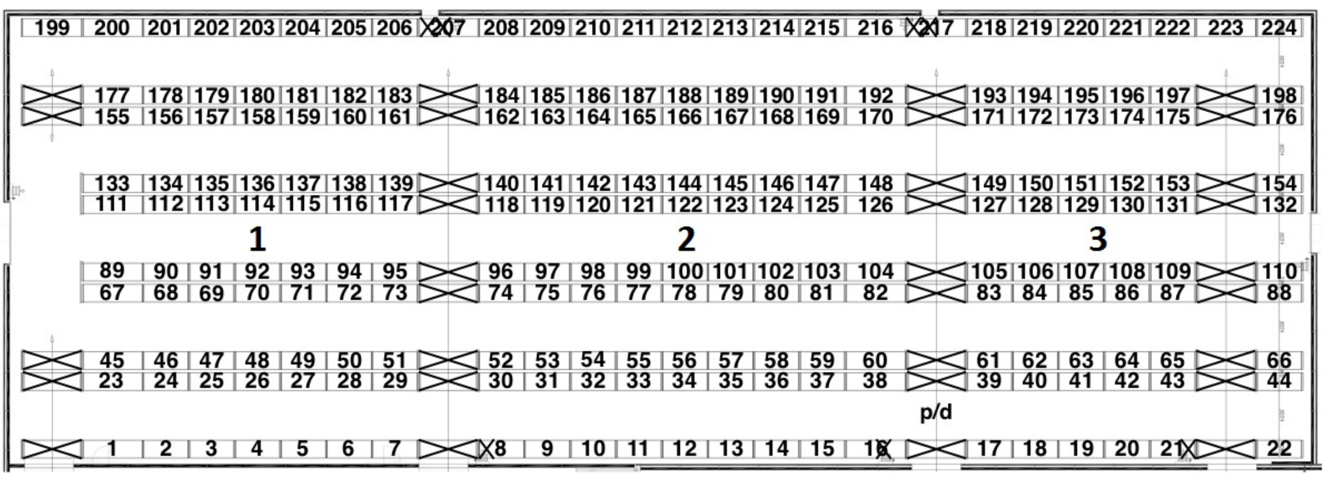
Kilde: Urtekram.dk.

tede ikke denne anden del af plukkernes arbejde, da allokeringen var fastlagt på baggrund af omsætning og at listen over ordrelinjerne, som blev brugt til at plukke ud fra, var sorteret alfabetisk efter lokationsnavnene. Det var derfor svært, specielt for mindre erfarne plukkere, at performe godt, da det var op til den enkelte plukker at identificere de lokationer, hvor tunge pluk var lagret og som det derfor var vigtigt at besøge først på ruten, for at sikre en god pakkestruktur. Dette fjernede derfor i praksis fokus fra at minimere distancerne og dette medførte uhensigtsmæssige ruter og et unaturligt, rodet flow på lageret. Samtidigt medførte det også, at paller af og til måtte pakkes om, og god performance afhang derfor i høj grad af erfaring og snilde, hvorfor det varierede fra plukker til plukker.

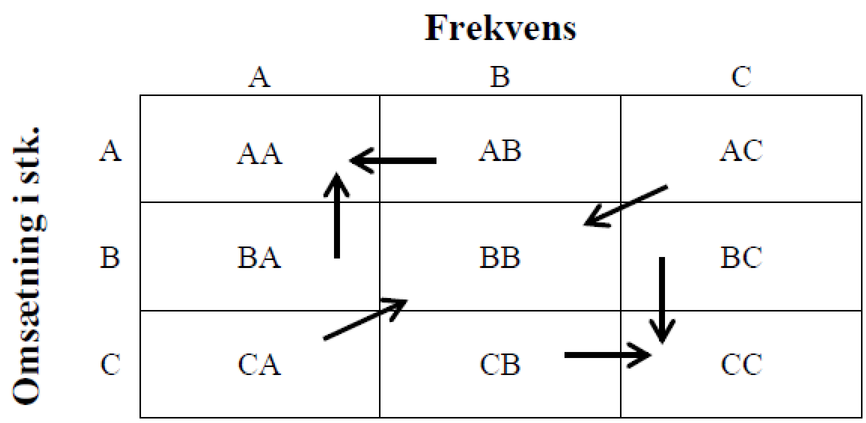
Midsona og plukkerne efterspurgte derfor i høj grad en løsning, der udover at minimere distancerne også supporterede dem i forhold til disse udfordringer og som kunne medvirke til en bedre plukkeproces, ved at bidrage til mere naturlige og intuitive ruter gennem plukkeområdet, og som dermed kunne reducere effekten af erfaring. Derfor blev det i fællesskab besluttet at afhandlingen skulle undersøge, hvordan Midsona med deres valg af metode til rangering af produkter og metode til rangering af lokationer, kunne allokere produkterne i plukkeområdet således, at det supporterede plukkernes arbejde, reducerede deres daglige udfordringer med stabilitet i forhold til vægt, og samtidigt fokuserede på at minimere distancerne.

Lagersetup efter udvidelsen

I forbindelse med udvidelsen af det daværende lager blev plukkeområdet, som tidligere nævnt, flyttet til den nye lagerhal, hvor layoutet er anderledes end tidligere. Det nye plukkeområde består af fem lange gange med reoler på begge sider, der går på tværs af den nye hal. Der er dog blevet lavet fire tværgående gange, som opsplitter de lange horisontale gange, og som dermed giver mulighed for at skifte mellem gangene flere steder. Dette opdeler plukkeområdet i tre primære blokke, hvilket kan ses i Figur 1. Reolerne til højre for den højre tværgående gang er i løsningen ikke anset som en selvstændig blok, men i stedet som en del af blok 3. *Pick-*



Figur 1: Tegning af reolernes placering i det nye plukkeområde. Kilde: Egen tilvirkning.



Figur 2: Inddeling i kategorier efter multi-kriterie ABC klassificering. Kilde: Egen tilvirkning på baggrund af (Flores & Whybark, 1986) .

up/drop-off (p/d) lokationen er i det nye setup placeret midt for de lange gange, hvorfor der ikke er ét naturligt sted at starte ruten, men i stedet er det muligt for plukkerne både at gå til højre og venstre fra *p/d lokationen*, hvilket betyder at blokkene kan besøges i forskellige sekvenser.

Figur 1 viser også, at det nye plukkeområde indeholder 224 pallereolfag, som alle kan benyttes til plukkelokationer i gulvniveau. Hver af disse indeholder 2-4 pallelokationer afhængigt af bredden, men enkelte pladser er dog spærret grundet forskellige forhold som branddøre og brandslanger. Samlet set er 689 plukkelokationer tilgængelige. I figuren ses kun nummereringen af reolfag, mens hver plukkelokation i praksis har et navn, der er en sammensætning af reolnummeret, niveau og plads i reolen fra venstre. Årsagen til, at niveau er inddraget i navngivningen, til trods for, at kun gulvpladser kan benyttes til *pluk* er, at det er muligt at opdele en plukkelokation i højden, så det giver flere lokationer, hvis de produkter, der er allokeret til lokationen ikke kræver ret meget plads som eksempelvis body care og krydderier, hvor lokationen kan opdeles i henholdsvis to og tre niveauer. Denne opdeling laves dog på et helt fag af gangen grundet konstruktionen af reolerne, hvilket betyder, at hvis et helt fag er fyldt med krydderier, kan der i stedet for tre lokationer, allokeres produkter til ni lokationer.

Teori og løsningsmodel

Optimal allokering af produkter i et plukkeområde er et velbeskrevet teoretisk problem, men udfordringen i forhold til den opstillede problemstilling, var imidlertid at den tilgængelige teori er baseret på et lagerlayout, som er rektangulært og som kun har én tværgående gang i hver ende af reolerne. Desuden anvender teorierne oftest kun et kriterie til at vurdere metodernes performance og dette er oftest distance. Derfor var det nødvendigt at modificere og udvide den allerede beskrevne teori således, at modellen kunne tilpasses det faktiske lagerlayout og de praktiske udfordringer som Midsona ønskede inddraget i løsningen.

I modellen inddrages metoder til rangering af produkter og metoder til rangering af lokationer. Disse rangeringer kombineres efterfølgende for at fastslå, hvilke produkter der skal allokeres til, hvilke lokationer. Det sikrer, at de produkter, der ud fra et givent kriterie skal prioriteres højest, allokeres til den lokation, der ud fra den valgte metode, vurderes at være den mest attraktive, ofte tæt ved *p/d lokationen*.

Metoder til rangering af produkter

Til at rangere produkterne blev *volume-based storage* og *multi-kriterie ABC klassificering* anvendt (Petersen II & Schmenner, 1999; Flores & Whybark, 1986). Begge metoder introduceres indenfor et *storage location assignment problem* med produktinformation (*SLAP/PI*), hvor rangeringen foregår på baggrund af forskellige produktkarakteristika (Gu et al., 2007). I løsningen blev parametrene udvalgt på baggrund af samtale med Midsona, og hvad der heraf fremstod som væsentligst. De inddragne produktkarakterisika var: plukkefrekvens, omsætning i stk. og kollivægt.

Ved *volume-based storage* danner ét kriterium grundlaget for rangeringen, mens *multi-kriterie ABC klassificeringen* tager udgangspunkt i to forskellige kriterier. Med udgangspunkt i disse, laves en *ABC klassificering* for hvert kriterium, som kombineres i en matrice. Efterfølgende reklassificeres produkterne i tre kategorier, som er illustreret i Figur 2. Afslutningsvist rangeres hver kategori baseret på et af de introducerede kriterier.

Kombinationerne af metoderne og de inddragne karakteristika resulterede i ni forskellige metoder til rangering af produkter:

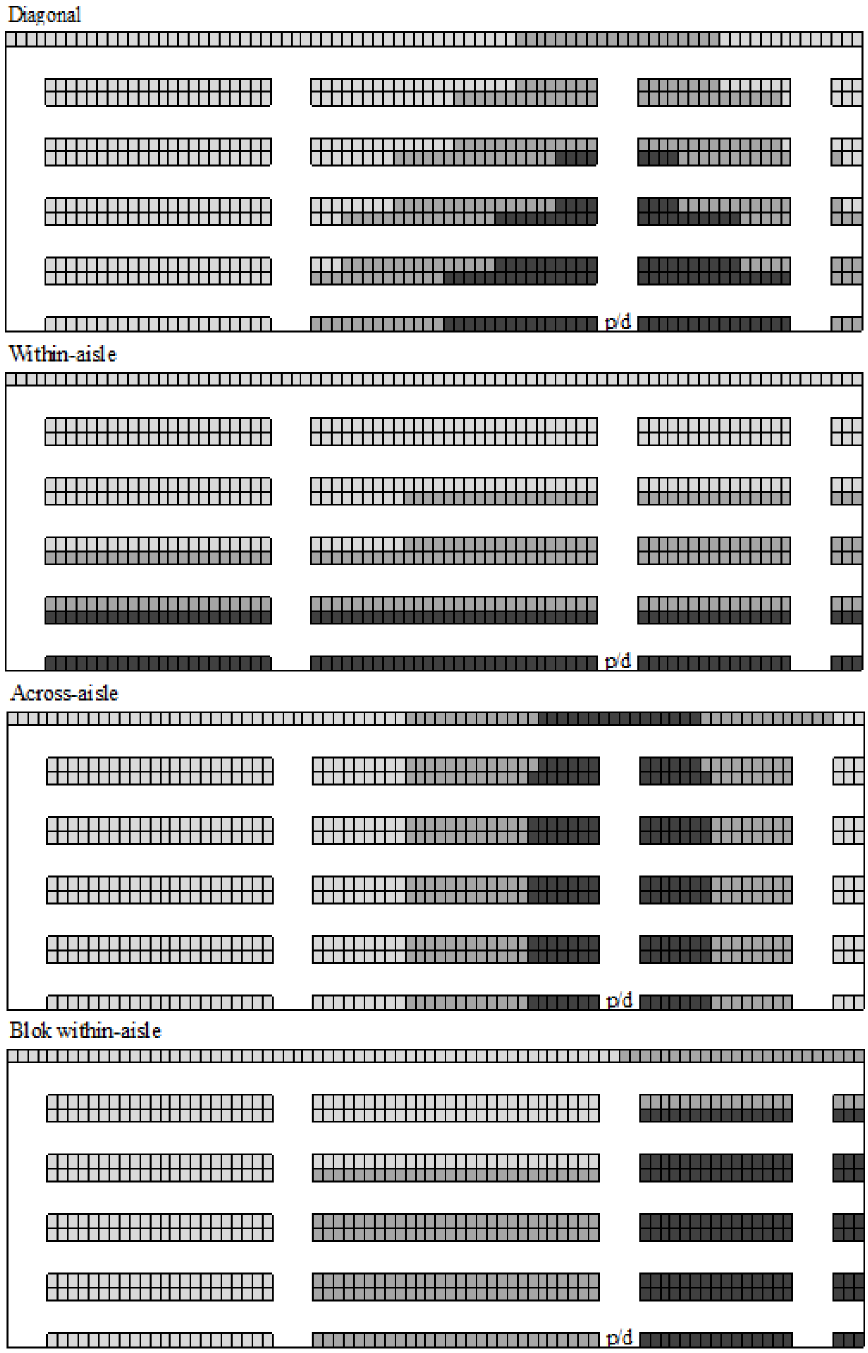
• Volume-based: *frekvens, omsætning, vægt*

• Multi-kriterie ABC: *frekvens – omsætning; sorteret på frekvens, frekvens – omsætning; sorteret på omsætning, fre-*

kvens – vægt; sorteret på frekvens, frekvens – vægt; sorteret på vægt, omsætning – vægt; sorteret på omsætning, omsætning – vægt; sorteret på vægt.

Metoder til rangering af lokationer

Til at rangere lokationerne blev der taget udgangspunkt i *diagonal, within-aisle, across-aisle*, mens der endvidere i afhandlingen blev introduceret en ny metode, *block within-aisle* (Petersen II & Schmenner, 1999). *Block within-aisle* blev inddraget, da den udnytter, at Midsonas lager er opdelt i blokke, hvilket ingen af de eksisterende metoder er i stand til. Denne metode fylder ligesom *within-aisle* lokationerne gang for gang, men for en blok af gangen. Lokationerne blev ved alle rangeringsmetoder opdelt i tre forskellige områder; de meget attraktive, de medium attraktive og de mindst attraktive. Som Figur 3 viser, afhang inddelingen af lokationerne og dermed placeringen af højt rangerede produkter meget af, hvilken metode, der blev anvendt.



Figur 3: Tilpassede metoder til rangering af lokationer. Kilde: Egen tilvirkning.

Samlet model

På baggrund af de nævnte metoder til rangering af produkter og lokationer blev en model, der testede de 36 kombinationer, opstillet. Modellen testede scenarierne ud fra to primære kriterier, som var distance og scenariernes performance på to vægtmål, som blev inddraget i afhandlingen for at sikre en løsning, der imødekom Midsonas ønske og deres praktiske udfordringer.

Det første kriterie, distance, blev i afhandlingen ikke anvendt på samme måde som i det meste litteratur, da distance- og ruteoptimering ikke var det afgørende kriterie for Midsona. I stedet blev distancerne anvendt til at give et estimat på den faktiske rute som plukkerne med den givne allokering ville vælge. Der blev i afhandlingen anvendt to heuristikker, *s-shape* og *combined* (Roodbergen & de Koster, 2001). Disse blev udvalgt, da de minder mest om de plukkeruter som anvendes i praksis, hvorfor de gav en øvre og nedre grænse for den rute plukkerne ville vælge, og dermed kunne de i kombination give en indikation af scenariets performance på distance. Desuden blev alle scenarier vurderet med udgangspunkt i, at ruterne kunne starte i både venstre og højre side af lageret, da der med det nye lagerlayout ikke længere er ét naturligt sted at starte ruten.

Det andet kriterium, vægtmål, blev inddraget som et supplement til distancerne, da plukkerækkefølgen, grundet vægt, var en af de store udfordringer for Midsona. Vægtmålene skulle derfor vurdere scenariernes performance ud fra hvornår produkter med en kollivægt, der karakteriseres som tung, blev plukket på ruten. Dette mål gav derfor information om, hvorvidt scenarierne supporterede Midsonas primære kriterie, at produkterne blev plukket og pakket i den rigtige rækkefølge.

Den samlede model testede de 36 scenarier med et repræsentativt datasæt bestående af 16.352 ordrer, dannet på baggrund af det nyest tilgængelige ordredata fra Midsona.

Evaluering af løsningsmetoder

Evalueringen af scenarierne viste, at hvis kriteriet distance blev anvendt, så var frekvens den bedste metode til rangering af produkter, mens der var et mindre entydigt billede i forhold til metoderne til rangering af lokationer, da *block within-aisle, within-aisle* og *diagonal* performede bedst afhængigt af om ruterne startede i venstre eller højre side.

Hvis i stedet kriteriet var vægtmålene, fremstod en tydelig tendens, der dog afhang af om ruterne startede i venstre eller højre side. Hvis ruterne startede i venstre side, var det fortsat metoderne til rangering af produkter baseret på *frekvens* eller *frekvens* kombineret med *omsætning*, der performede bedst, mens det ved ruterne fra højre, var metoderne baseret på *vægt*, der performede bedst. Dette skyldes, at de inddragne metoder til rangering af lokationer i højere grad supporterede et setup, hvor ruterne startede i højre side af lageret. Så man i stedet på metoderne til rangering af lokationer, var det, hvis ruterne startede i venstre side, *within-aisle*, der placerede det laveste antal tunge pluk sidst på ruterne, mens det for ruterne, der startede i højre side, var *block within-aisle*.

Når scenarierne blev vurderet ud fra begge kriterier opstod en række trade-offs da ingen af scenarierne fremstod som den åbenlyse løsning. Derfor blev der, med udgangspunkt i den generelle vurdering af de valgte metoder, foretaget en frasortering af scenarierne. Frasorteringen og vurderingen af scenarierne blev foretaget med udgangspunkt i en rangering af scenarierne ud fra de to kriterier, for at sikre, at kriterierne, der blev målt på forskellige skalaer blev vægtet ens, men også ud fra scenariernes relative performance på de enkelte kriterier samt en praktisk vurdering af scenariernes supporterende effekt i forhold til Midsonas problemstilling. Dog blev vægtmålene i vurderingen af de relative værdier prioriteret højere end distance, idet kriterierne ikke er sammenlignelige 1:1, og det blev fundet, at et lavt vægtmål var en forudsætning for en retvisende og brugbar distance, idet en kort rute aldrig vil kunne anvendes i praksis hvis produkterne plukkes i den forkerte rækkefølge.

Anbefaling

Den endelige anbefaling til Midsona var, at de skulle allokere produkterne i det nye plukkeområde efter *multikriterie ABC* med kriterierne *frekvens* og *vægt*, sorteret på vægt, mens lokationerne skulle rangeres efter *block within-aisle,* hvor ruterne startede i højre side. Dette skyldes at analysen viste, at denne metode samler de tunge produkter i de nærmeste gange i den højre blok, og samtidigt sikrer den, at de højfrekvente produkter fortsat er samlet i et mindre afgrænset område, da den multiple rangeringsmetode inddrager både *frekvens* og *vægt*. At metoden sorterer på *vægt* frem for *frekvens* medvirker desuden til, at de frekvente produkter bliver spredt i det bedste plukkeområde, hvilket reducerer risikoen for, at der opstår kø i gangene, hvilket var en anden udfordring Midsona stod overfor, da det kunne forsinke plukkernes arbejde. Denne løsning risikerer dog at være på bekostning af en længere distance, men der blev i analysen også taget højde for effekten af at forbedre vægtmålene for scenarier med en kortere distance, og det blev vurderet, at ingen scenerier havde så korte distancer, at vægtmålene ville kunne forbedres uden at distancerne blev forøget for meget. Dermed blev det fundet, at den valgte allokeringsmetode, *frekvens - vægt; sorteret på vægt block within-aisle*, samlet set er den metode, der supporterer plukkernes arbejde bedst, således at processen fremover vil være mindre præget af plukkernes erfaring og vaner.

Implementering

Afhandlingens resultater samt den endelige anbefalingen blev efterfølgende præsenteret for Midsona i juni 2016, sammen med en række forslag til mindre justeringer og ændringer til løsningen, som Midsona kunne afprøve og inkludere i deres endelige løsning, eller som de på sigt kunne benytte til at optimere allokeringen. Samtidigt blev også en modificeret udgave af modellen delt med Midsona, således at de fremover kunne opdatere og forbedre allokeringen i takt med salgsændringer eller erfaringsdannelse, da de også tidligere havde ytret ønske om en model, som de selv kunne opdatere mere frekvent.

Midsona valgte, da det nye plukkeområde stod færdigt, at implementere en løsning, der kombinerede den præsenterede anbefaling med deres daværende løsning, hvor en del af lageret var opdelt efter *class based storage*, hvor eksempelvis krydderier og bodycare var samlet (Le-Duc & de Koster, 2005). Indenfor klasserne og på det resterende lager var produkterne allokeret efter *multikriterie ABC* med kriterierne *frekvens* og *vægt*, sorteret på *vægt*, mens lokationerne var rangeret efter *block within-aisle*, som i den anbefalede løsning. Dog havde Midsona arbejdet med nogle af de variable parametre i modellen. De havde eksempelvis inkluderet flere produkter i A kategorierne, for dermed at sikre en lidt større spredning af de mest frekvente produkter, samtidigt med at flere af de tungeste produkter også blev inkluderet i denne kategori.

Efter at det nye lagerområde stod færdig og arbejdet var genoptaget i området med den nye allokering, evaluerede Midsona på hvorledes løsningen fungerede i praksis under endnu et besøg i februar 2017. Resultatet var, at mange af de forventede effekter af analysen var blevet indfriet og at løsningen derfor samlet set var en succes. Blandt andet havde Midsona oplevet en stigende produktivitet og plukkerne tilkendegav også, at det var lettere at lave en intuitiv rute uden for mange afvigelser, da de tunge produkter nu var bedre placeret på lageret. Dermed blev pallerne oftere pakket korrekt i første forsøg, med tunge kolli i bunden, der sikrer pallens stabilitet. Derudover tilkendegav plukkerne også, at der var mindre støj og trafik i plukkeområdet, da det blev flyttet til en del af lageret, som ikke i lige så høj grad interagerer med den øvrige trafik af paller på lageret. Midsona valgte desuden at anvende lokationerne over plukkeområdet til genopfyldningspaller, hvilket yderligere har lettet opfyldningsprocessen og reduceret unødig trafik i plukkeområdet. Den manuelle justering som Midsona valgte at inddrage ved at forøge antallet af produkter i A kategorien, har desuden medvirket til at reducere kø i gangene, da de mest frekvente produkter nu er spredt i et større men stadig lille afgrænset området.

Samlet set gav Midsona udtryk for at det samlede udbytte af samarbejdet indfriede deres forventninger, idet de har opnået driftsmæssige fordele ligesom grundlaget for fremtidig opfølgning og mere frekvent opdatering også er sikret.

Kilder

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By Torbjörn Larsson, Michael Patriksson, and Johanna Pejlare

Time out of mind: "Subben's checklist" revisited

A partial description of the development of quantitative OR papers over a period of 25 years

In ORbit 23, we brought a small article by Torbjörn Larsson and Michael Patriksson about "Subben's checklist". We now revisit the topic in more depth.

1. Introduction – Tangled Up In Blue

In 2014, ORbit published a short paper (entitled »Subben's checklist and the quality of articles in OR«) by the first two authors of the current paper, devoted to the assessment of the characterization – and the quality – of a scientific paper in (quantitative) operations research (for short: OR). That paper was later slightly expanded, and eventually published in 2016, in the scientific journal *Computers & Operations Research*, then bearing the title »Subben's checklist" and the assessment of articles in mathematical optimization/operations research: in memoriam of Subhash C. Narula«. Professor Subhash Narula (fondly nicknamed "Subben"), previously a professor at Rensellaer Polytechnic Institute, Troy, New York, was for a few years in the 1990s the leader of the research group in mathematical optimization at the Department of mathematics at Linköping University, Linköping, Sweden. The checklist bears his name because he was the one contributing the most items in the list, which was constructed during a long conversation in 1993 with the first two authors of this paper. The conversation, one outcome of which became the checklist, centred around possible ways in which to characterize the quality of journal articles, as well as their "completeness."

The contents of the ORbit and C&OR papers are potentially quite useful as an introductory guide for scientific authors, especially for young researchers who have not yet grasped what characterizes a scientific paper, and what makes a paper good – or very good, perhaps incomplete, or in fact plain bad!

Subben's checklist – describing the necessary parts of a complete scientific article – is as shown in Table 1.

Subben's checklist, as well as the characterization of OR papers, may also fruitfully be utilized to assess important aspects of a paper, and for that it has become a quite useful tool. It has, for example, been utilized in a research methodology course in a PhD program at the Department of Technology Management and Economics at Chalmers University

1. Relevance	Motivation of study; need, benefit; why interesting?
2. Background	History, references, state of the art; framework, delimitations
3. Motivation	Shortcomings in existing knowledge or methodology
4. Remedy	Proposal of actions in order to remove the lack of existing knowledge or methodology
5. Hypothesis	Description of the research question(s) considered
6. Method(ology)	Choice of research methodology
7. Realization	Presentation of the new scientific contributions
8. Analysis	Validation of results, conclusions, consequences, and applications; future research opportunities

Table 1. Subben's checklist.

of Technology in Gothenburg, Sweden. It is also utilized at Mathematical Sciences, Chalmers, as a writing guide for PhD students in the area of operations research.

What has – we think – not yet been explored to a large extent is the possibility to utilize a writing guide, such as Subben's checklist, in the investigation of how the contents of articles in OR journals change over the years, and to assess – and perhaps quantify – the quality of articles. By means of one example scientific journal, namely the INFORMS journal *Operations Research,* we utilize Subben's checklist in particular to illustrate how the portions of the various constitutive parts of a scientific paper, as listed in Table 1, have changed over a period of 25 years. Through the use of the checklist we believe we may trace important changes in a given journal's style and focus – and indeed general changes in quantitative operations research and its output.

In particular we investigate and compare OR papers that either are among the most cited, or among the least cited, in order to try to characterize the two "extremes". As we shall see, well-cited papers are typically more "balanced" in their contents, while the least cited papers may – for example – include essentially one section only.

The next section describes the experiment. Section 3 provides an analysis of the appearance of the constitutive parts – as listed in Table 1 –, as measured in portions of the whole, over the years studied. The analysis in particular focuses on, and contrasts, the difference between papers with either many or very few citations, in order to produce – if possible – some characteristic differences between the most well-cited and the least cited papers. Section 4 investigates the development of self-citations, and the final Section 5 provides an analysis of the results, as well as concluding remarks including potential avenues of future study.

2. The study object – Things Have Changed

First, we collected the ten *most* cited – as well as the ten *least* cited – papers in the OR journal *Operations Research* during the years 1981 and 2006, respectively (i.e., volumes 29 and 54). The journal was selected based on several criteria, among which are its consistent high quality, its long history, and the fact that it is so well-known. A time span of 25 years was deemed enough to make it possible to trace major advances in the field, changes in publication practice and editorial principles, as well as the expansion of science in general. The year 2006 was elected mainly such that enough citing years could be included up until today, for the purpose of selecting papers to bring into the study – the idea for this paper was also born in the year 2016, and the collecting started then as well.

These in total 40 papers were then scrutinized, in an attempt to characterize their content *portions*, as distinguished among the following eight categories:

- Introduction (motivation, scope),
- Review (of the literature),
- Modelling (of the problem(s) at hand),
- Theory & mathematical analysis (of the problem(s) at hand),
- Applications & practice,
- Numerical analysis,
- Future research possibilities, and
- References.

As Theory and Analysis on the one hand, Review and Future research, and Applications & practice and Numerical analysis on the other, are three quite coupled units – which may or may not be united under one banner –, they formed three pairs of

Content categories	Proportion (%) 1981 (most cited)	Proportion (%) 1981 (least cited)	Proportion (%) 2006 (most cited)	Proportion (%) 2006 (least cited)
Introduction, motivation	11.0	13.4	9.5	14.7
Survey/Review/Future research	20.0	1.5	9.5	1.1
Modelling	8.0	42.0	10.0	14.7
Theory & Analysis	29.0	15.3	24.0	25.2
Application, practice, and numerical analysis	17.0	23.0	40.0	39.0
References	15.0	4.8	7.0	5.3

Table 2. Content proportions.

single items, resulting in a final collection of six categories. (The fact that section names in the journal are not uniformly phrased also made it natural to strive for the construction of a uniform presentation.)

Table 2 is a representation of the results of a thorough scan of the 10 *most* cited papers from 1981 and 2006, respectively, and the 10 *least* cited papers from those same two years, using Scopus. The proportions of the above-mentioned parts of the papers were measured through the utilization of the word count tool in Adobe Acrobat Reader.

3. Analysis, I – The Times They Are A-Changin'

According to the above table the 25 years from 1981 to 2006 reveal the following about the appearance of a *well-cited* paper in the journal *Operations Research*, based on our sample:

• All three categories [*Introduction, motivation; Survey/ Review/Future research, & References*] associated with the *history* of the field, and *connections* to other subjects, shrink quite a lot from 1981 to 2006: collectively this portion drops almost by half, from 48% to about 26% of the total. Scientific publishing grows fast, whence there is an increasing body of references to build upon – and connect to, when creating and writing science. It is therefore quite unfortunate that there is a *diminishing connection* to the past. (As will be seen below, this category still is much more well represented compared to the case of the least cited articles.)

• The *Modelling* and *Application, practice, and numerical analysis* parts collectively grow from 25% in 1981 to 50% in 2006. Partly we think it is due to the fact that modelling "exercises" over the years have become more serious (perhaps partly as a consequence of an editorial decision?), and more importantly, realistic (in contrast to "principle models" and academic "examples"), whence more details are not only available, but in fact necessary to include in order to sufficiently well describe the applications.

• The *Theory & Analysis* section does not vary a great deal in size over the years; it remains about ¼ of the total.

• In 1981, a *Future research* section is present in five articles out of the ten, while there are in total 24 future research suggestions. In 2006 only one article omits this section; in total, there are 31 research ideas mentioned among the ten articles analysed in that year.

• The average number of *References* (already mentioned in the first item) in an article drops slightly from 53 to 45 – a decline that is perhaps not a dramatic one, while certainly over the years the volume of available literature grows.

• The average number of *words* in the articles grow over time: In 1981, the shortest paper has 7216 words, the mean is 10,176, and the longest paper has 23,252 words. In 2006, the shortest paper has 9143 words, the mean is 12,196 words, and the longest paper has 16,836 words.

For the *least cited* papers we see the following development from 1981 to 2006:

• The sections on *Introduction* and *Motivation* are slightly longer than those in the well-cited papers, and they also grow slightly over time.

• The sections on *Survey/Review* and *Future research* are always very short – no more than 1.5% of the total article content. In 1981 we find two articles, each of which presents one future research question. In 2006, we find future research ideas in six of the articles, and in total 14 research ideas (among which six stems from one single article).

• The *Theory & Analysis* sections grow from 15% to 25.2% during the 25 years.

• The *Modelling* and *Application, practice, and numerical analysis* sections collectively defines the majority of the volume of the papers: 64% in 1981, and 52.8% in the year 2006.

• The *References* section is almost always shorter than in the most well-cited papers, while it – as the average portion of the paper – even drops from 7% to 5.3% over the time period studied. In the ten least cited papers from 1981 there are 87 references, while in 2006 they are 256. (Compared with the average values of 53 and 45, respectively, in 1981 and 2006 in a well-cited paper, the least cited papers hence have less than 9 and 26 references on average, respectively, during those two years.) One must remark, however, that the font used for the reference list is smaller than in 1981, and the page itself is larger in 2006.

• The average number of *words* develops as follows: In 1981, the shortest paper has 1320 words, the mean is 5142, and the longest paper has 8622 words. In 2006, the shortest paper has 7269 words, the mean is 10,901, and the longest paper has 17,368 words. The development is hence similar to that of the most cited ones, in that there is a clear increase in volume over time. Just as the case is with the reference section, the fact that the journal style has changed between the year 1981 and 2006 – allowing more words per page – obviously affects the outcome.

From the repeated browsing and reading of the *least* cited articles, there is also – to the naked eye – a feeling that many of them not only have a narrow focus, but also are structured such that they appear to be rather imbalanced and even bordering on being *incomplete*, with – for example – the majority of some papers consisting essentially of one or two very long sections, while other common sections are either non-existing, or very short.

For reference, a cursory look at all the articles in the first issue of Operations Research in 2016 (35, respectively 10, years after the years 1981 and 2006) shows a large increase in the providing of *motivations*, and particularly an increase in material on *modelling* aspects. On the other hand, the connection to the *related literature, application work*, and *numerical analysis* drop dramatically, and the same can be said about the *future research* section, which is always quite short. All the while, the papers also get longer with time, although – as we see above – the reference list actually shrinks. (Further, in 2006 and 2016 the font used in the reference list is smaller, while also the actual pages are larger, as compared to the year 1981 – thus in fact allowing more information to be included on the page.)

We have not investigated the possibility that some of the changes over the years – particularly the reduction of the survey part, and the increased portion of the modelling part – are results of editorial board decisions, or an organic development based, for example, on the needs to provide more information on increasingly complex models. That would however be an interesting future study.

4. Analysis, II: Self-citations – I and I

We recorded self-citations (to one or more of the authors of each article) over the issues studied. (Several years ago, citation studies tended to exclude self-citations, but nowadays they typically are included in the Journal Impact Factor measure.) In the year 1981, the number of self-citations for the ten *most* well-cited papers is 91 (9.1 on average per article), and in 2006 they are 100 (10 on average per article). The analysis of the ten *least* cited papers in 1981 and 2006 reveals that there are 15 such self-citations in 1981 (1.5 on average per article), and 33 (3.3 on average per article) in 2006. (The 2016 issue has 79 self-citations – 4.8 on average per article.) In any case, from the sources utilized we *cannot* conclude that a bad habit of self-citation is present in the material used.

5. Analysis, III: Changing of The Guards

As an additional source of information, we searched all of the above 40 analysed articles for the number of mentions of significant words associated with the development of an article (and utilized in the paper on “Subben’s checklist” – see also

Type	min 1981	max 1981	min 2006	max 2006	Sum:
Relevance	0	0	0	**1**	1
Motivation	2	**7**	6	**7**	22
Shortcomings	0	0	0	0	0
Remedy	**1**	**1**	0	0	2
Hypothesis	2	**3**	1	2	8
Realization	0	4	0	**28**	32
Methodology	2	**16**	7	13	38
Theory	6	**69**	17	35	127
Validation	0	0	0	**28**	28
Background	0	2	1	**3**	6
Question	8	**50**	9	22	89
Consequences	4	14	3	**22**	43
Analysis	25	11	21	**64**	121
Sum:	50	**177**	72	**225**	

Table 3. Count of significant words.

table 1). See table 3. For ease of reference, the year with the most "hits" for a given significant word is provided in bold font:

While the "buzz words" *theory* and *questions* – words that are associated with the core of the subject, and in particular the motivation for an article's presence – dominate in 1981 (followed by *methods* and *conclusions*), in 2006 *analysis, realization* and *theory* dominate. A look at the 2016 issue reveals that there is a stronger focus on *validation* and *analysis* – words that are associated more with the results of the research, and its post-evaluation, and in 2016 *analysis* dominates even more strongly.

As an overview of the above results we remark that the *well-cited* papers over the two years studied have 402 word "hits" in Subben's checklist, while the *least cited* papers only have 112 such "hits". It does therefore appear that Subben's checklist fulfils its intented purpose quite well.

In a follow-up analysis, we complemented the search for *realization* by a search for the related term *implement*, bearing in mind the possible alternative meanings of the word. In the ten most *well-cited* papers in 1981, the word *implement* was used 30 times in the context of "algorithms", while it was used 34 times in the context of "practical realization". In the ten most *well-cited* papers in 2006, the word *implement* was used 14 times in the context of "algorithms", and never in the context of "practical realization," or "decision-making."

In the ten *least cited* papers in 1981 five papers mention the word *implement*. Among these the word relates to algorithms 16 times (13 of those reside in one article), while two articles refer to practice, in total six times. In the *least cited* papers in 2006 the word is used in eight out of the ten papers; in six articles, it is devoted to the algorithmic context only, the word-count being 25, and referring to practice in three, the word-count being ten.

In the 2016 issue *implement* refers to algorithms 16 times, and in decision-making contexts 21 times.

Can the journal Operations Research therefore be said to have become more "mathematicised" over the years? The overview in Section 3 certainly hints in that direction, partly because of an increased focus on mathematical modelling.

6. Evaluating science – What Good Am I?

The second list in the above-mentioned papers by Larsson & Patriksson (2014, 2016) refers to criteria for evaluating science. The list covers questions, research, and results from the scientific work done. It may concern all, or a subset of, the items *relevance, scientific foundation, generality, consistency, availability, scientific height and depth, originality, news value, integration, consequences, realization*, and *durability*.

While there is an abundance of material to study in order to assess these 13 criteria, a thorough study of the topic needs to be very well prepared, and it must therefore be relegated to potential future work.

7. Controversies in science – Ain't Talkin'

There certainly are scientific fields in which (typically senior) scientists have made strong remarks against the then current developments in scientific production, in particular regarding the item *relevance*. Among the fields of study where the authors of this paper have observed the harshest remarks are in the field of *transportation science,* where Gordon Newell (1925–2001) – a pioneer in transportation science in general, and queueing theory in particular – have stated that he favoured quality over quantity, and found that we (scientists) have failed to understand and model the behaviour of queues, and we have failed to treat travellers as they should be treated in our models, not as "a consumer good that can be sold to the highest bidder." (This and the following quotes are taken from Gordon Newell's article *Memoirs on highway traffic flow theory in the 1950s*, published in 2002. Gordon Newell feels that we have failed in developing new special techniques to the special problems that we are indeed facing, and we instead simply "rework and refine old procedures." He believes that the reason for the field not developing as strongly anymore – according to him – is that the scientists who contributed in the beginning were brilliant scholars in neighbouring fields who could bring in fresh ideas. Newell also states: "On the surface, it would seem that the subject has continued to grow and develop but actually, in my view, progress peaked in the 1960s and took a sudden dive in the 1970s." He further states: "The journal *Transportation Science* has degenerated into a journal of computer algorithms and 'optimization' relative to ad hoc objectives. There is seldom a paper dealing with some transportation issue or the answer to some question."

All of the above statements are well in line with the excellent statement by the mathematical optimization pioneer Arthur M. Geoffrion (1976): »The purpose of mathematical programming is insight, not numbers.« This statement is indeed correct, and should be emphasized and discussed more often, not only among scholars, but particularly with students.

(The above statement was in fact borrowed from a quote by R.W. Hamming, 1962, pp. vii, 276, and 395, in which the phrase "mathematical programming" is replaced by "computing".) In this day and age when it appears that so much is published that it is almost impossible to know whether every journal paper includes anything actually new, these quotes are (still) timely roll calls for all conscientious researchers, reviewers, and editors to keep repetition and mediocrity at bay. A particularly timely statement that supports Hamming's and Geoffrion's is Kenneth Sörensen's paper "Metaheuristics – the metaphor exposed" (2013), which argues that the research done in that particular field threatens to become unscientific – if it isn't already.

It is therefore quite promising that the analysis made above in Section 4 at least indicates a reduction of self-promotion.

8. Analysis of references – "Not I", says the referee

We have investigated the appearance of the reference lists, by looking at the mean age of the references over the three years. The basis for this analysis is the investigation of whether newer papers tend to also cite relatively newer papers – that is, if the history may be "shrinking."

The ten *most* cited papers from 1981 have – in total – 530 references (that is, 53 on average), while their ages sum up to 4590 years, from their year of publication. Hence the mean age of a reference among the papers analysed in the year 1981 is 8.66 years. Performing this analysis for the ten most cited papers during the year 2006 yields the result that there are – in total – 445 references among the ten papers (that is, 44.5 on average), and the mean age is 10.8 years. The conclusion from this sample is that history is *not* shrinking.

The ten *least* cited papers from 1981 have – in total – 85 references (that is, 8.5 on average), while their ages sum up to 654 years, from their year of publication. The mean age hence is 7.7 years. The ten least cited papers in 2006 have – in total – 256 references (that is, 25.6 on average); the mean age is 12.3 years. Also in this case we see that history is *not* shrinking.

In the first issue 2016 comprising 18 articles, there are 741 references (41.2 on average), and their mean age is 12.35 years.

In this set of data, the average age of the reference list increases somewhat (by 3.7 years from 1981 to 2016). This somewhat narrow analysis may indicate that the science presented in the journal Operations Research is of a less time-dependent variety, in the sense that it does not depend on quick changes in some technology, for example. The authors of this paper certainly value the fact that history is not entirely forgotten, and in fact almost all articles cite at least some classic book or article.

In order to form some comparison with at least one other similar scientific journal in the field, we also selected 40 papers from the journal Mathematical Programming, Series A. As with the case of the journal Operations Research, we chose the ten most, and the ten least, cited papers from the years 1981 and 2006.

The ten most cited papers in Mathematical Programming, Series A in 1981 have on average 19 references, and their mean age is 8.5 years. The ten most cited papers in 2006 have on average 28 references, and their mean age is 12.7 years. The ten least cited papers in 1981 have on average 7 references, and their mean age is 9.6 years. The ten least cited papers in 2006 have on average 20 references, and their mean age is 16.75 years.

As is the case with the journal Operations Research, for the set of data utilized in the journal Mathematical Programming, Series A, we find that highly cited papers have *more* references – while the less cited ones have slightly *older* references. Why that is the case should be investigated.

9. Subben's checklist and the quest for citations – Forgetful Heart

We hypothesized in Section 1 that Subben's checklist can be utilized to measure whether a paper is well-cited. In this section, we provide an investigation on whether the number of citations to a published article is positively correlated with its degree of utilization of the checklist. A quick test from volume 54 (2006), issue 3, of Operations Research indicated that we need to incorporate synonyms to the list. Hence the below original list of eight words was appended with the following 16 terms (the original terms are given before the dash), noting that the words do have the right meaning, when scanning the papers:

- Relevance – pertinence
- Background – history
- Motivation – incentive, reason
- Remedy – solution
- Hypothesis – theory, proposition, conjecture
- Method, methodology – approach, technique, plan, mechanism, design, system
- Realization – implementation
- Analysis – assessment

As a test bed, we have again investigated the ten *most* cited papers from the years 1981 and 2006, and the ten *least* cited papers from those years. We searched those papers to see how many times the eight words in Subben's checklist are mentioned; we then also allowed the above synonyms to those words.

For the ten *most* cited papers in 1981 (the one with the least citations having 17 ditto, the highest score being 412, and the mean value being 180) we found that the number of words mentioned in Subben's checklist (and their synonyms) in those papers ranged from 3 to 14 (with a mean of 8.9), and the total number of mentions of those words were 996. The mean length of these papers is 24.7 pages, and the number of references in those papers range from 30 to 159 – with a mean value of 53.

Among the ten *least* cited papers in 1981 (three having *no* citations, and no-one more than two) we found that the number of words mentioned in Subben's checklist ranged from 2 to 7 (with a mean of 3.7), and the total number of mentions of those words were 195. The mean length of these papers is 13 pages, and the number of references in those papers range from 1 to 15, with a mean value of 9.

Among the ten *most* cited papers in 2006 (citations ranging from 46 to 216, the mean being 99) we found that the number of words mentioned in Subben's checklist ranged from 1 to 11 (with a mean of 7), and the total number of mentions of those words were 726. (The word "system" is especially popular.) The mean length of these papers is 15 pages, and the number of references in those papers range from 39 to 58, with a mean value of 45.

Among the ten *least* cited papers in 2006 (citations ranging from 2 to 16) we found that the number of words mentioned in Subben's checklist ranged from 1 to 7 (with a mean of 4), and the total number of mentions of those words were 429. The mean length of these papers is 13 pages, and the number of references in those papers range from 14 to 43, with a mean value of 26.

As a conclusion of this test, we notice that the *most* cited papers in 1981 are quite a lot longer than the ten *least* cited ones (on average 24.7 pages versus 13), while a wider range of items in Subben's checklist is also represented much more in the *most* cited papers (8.9 words per paper among the most cited, versus 3.7 for the *least* cited). In 2006 the mean length is more even between the most and least cited papers, except for the reference list which – again – is nearly double in the well-cited papers, compared to the least cited ones.

We also studied the mean age of the reference lists; the motive was to see if we can trace a move towards newer references (perhaps then illustrating swifter shifts in the subject), or not. The mean age of the references in the ten *most* cited papers in 1981 is 8.7 years, while the mean age of the *least* cited papers in 1981 is 7.7 years. The mean age of the references in the ten *most* cited papers in 2006 is 10.8 years, while the mean age of the *least* cited papers in 2006 is 12.3 years. Hence, there appears to be no swift change in the subject matter. (A comparison with the journal Mathematical Programming, Series A, over the same years shows that the trend is similar, the latter journal having, on average, a reference list that is about two years older.)

A larger – and perhaps more detailed – study is further needed before we may state that Subben's checklist is sufficient as a tool to make a fair comparison between papers; for now, we encourage scientists to utilize Subben's checklist when preparing manuscripts, and to be generous with citations to the pertinent literature.

10. Final theme: Conclusions, questions, and potential future research avenues – There's Nothing That I Wouldn't Do

While there are books – such as the excellent one by N. Higham (1998) – that offer writing guides for the mathematical sciences, as well as good – and bad – examples of such writing, our approach and analysis concern *post-analyses* of the writing experience. In particular, we characterize – as well as we are able, utilizing the output through *one* scientific journal – the appearance of scientific papers in relation to their citation records, viewing the writing experience several years after publication and how this writing has been assessed by the readers.

Among the questions that we have asked ourselves are the following ones, to possibly be considered in future research:

1. Can the fewer references in later papers (see Section 8) partly be explained by papers more often citing surveys – rather than providing references to original papers? This question has not yet been analysed. (While general surveys do make connections to the past, they are never as detailed and precise as a dedicated one on the subject of the paper; an editor might however find it a positive feature that a reduction of survey material could yield more room for new material.)

2. Are authors more often these days citing the journals they publish in? (Some journals' editors recommend, or even *request*, that the authors try to locate pertinent articles in the same publication. Such a conduct is, however, obviously unethical.) In our limited material, we found the following: For the year 1981 – and for the ten most well-cited papers – there were 63 cites to *Oper. Res*. (among which 37 were from one paper only), while among the ten least cited papers there were five citations to the journal. In 2006, among the ten most well-cited papers there were 51 citations to *Oper. Res*., while there were 27 citations to *Oper. Res*. among the ten least cited ones.

3. Has the style of writing changed over the years, independently of the development of the subject, and such that it may have an effect on our analysis – perhaps as a consequence of the acceleration of research and publication?

4. Is any style change explained by the fact that the subject is more developed – *matured*, as they say?

5. Who are we writing for these days – as compared to who the readers were, say, 20 years ago? For example, do scientists write in order to convey knowledge, or mainly to document their work and increase their track record? And can it be detected?

6. What, among the results of our analysis, may be transferred also to other journals? In other words, can we establish similar trends also for several other journals of a similar nature?

We hope to be able to answer at least some of these questions in due course.

References – You Can't Repeat the Past

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