Disruption Management — Operations Research between planning and execution*

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Abstract

For a large number of applications Operations Research has a proven track record: it can deliver high quality solutions for planning problems. Important examples can be found in the airline industry, logistics and production management.

This report will describe real-world examples of a novel way of applying Operations Research: As plans have to be adjusted to take last minute changes into consideration, OR can play an active role in such a situation by producing, maybe even in a pro-actively role, alternative plans. This type of activity is called *Disruption Management*.

1 Introduction

For a vast range of applications OR-methods has a proven track record of delivering high quality solutions to planning problems. Important examples can be found

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in the airline industry, production management and logistics. At the department of Informatics and Mathematical Modelling (IMM) at the Technical University of Denmark (DTU) a group of researchers has for the last year and a half been working on applying Operations Research in a new and exiting field: **Disruption Management**.

Generally, a disrupted situation or just a disruption is a state during the execution of the current operation, where the deviation from plan is sufficiently large that the plan has to be changed substantially.

The plan produced by OR-based decision support are to be applied on the day of operation for the application in question. In some situations the plan has to be adjusted to take last minute changes into account. Today, these changes are often made manually with hardly any computerized decision support at all. Due to new solution methods and increased computing power, OR can now play an active role in such a situation, maybe even pro-actively being able to produce alternative plans well ahead of potential problems. From a time perspective this re-planning activity comes after the traditional planning, but before or even during execution of the operation in question. We call that type of activity Disruption Management.

In the following, we first give real-world examples of disruptions from the airline and ship-building industry. We then describe a framework, in which most activities relating to the execution of an operation can be seen, and our two main cases. We discuss the challenges and key experiences encountered in the efforts of creating decision support tools for disrupted situations, and finally we sketch other application areas encountered for Disruption Management.

2 Examples of disruptions

The first example brings to mind the fairy tale of Hans Christian Andersen in which "one feather turned into five hens":

A Boeing 747 from a major airline is on its way from New York to London Heathrow. After a while, a passenger suddenly looses consciousness and the cabin crew decides that he may have a serious heart attack in progress. The captain decides to divert to Gander to get immediate help. A delay of the planned arrival at Heathrow is an unavoidable consequence, but at the current moment, the delay is not more serious than delays due to heavy traffic over London, so the Operations Control Center is informed, but takes no action.

When performing the necessary checks before take-off, the captain discovers that one of the checks fails. This would normally not pose a severe problem since there would be engineers capable of taking care of such a situation. However, in Gander this expertise is not present, and now the situation turns into a serious delay - a disruption from the planned schedule, which will affect passengers as well as the next planned activity of the aircraft and the crew.

The disruption can be solved in various ways, the most straightforward one being to fly in the necessary personnel to Gander to cope with the check of the aircraft. However, this gives rise to an overnight stop, and the passengers thus need accommodation. Unfortunately, there is a number of first class passengers aboard the plane, who are granted 5-star accommodation in such a situation, and such accommodation is not available in Gander, so this is not feasible.

The option solving the disruption turns out to be to hire a Boeing 747 from another airline, fly this to Gander to pick up the passengers and continue to Heathrow. This constitutes a very expensive solution. In addition, the airline is left with the problem of getting crew and aircraft back onto their planned activities as quickly as possible - not an easy task.

In the end, the passenger did not suffer from a heart attack, but from painful but rather harmless stomach problems...

The disruption just described was serious enough for those passengers involved, but after all not a major disruption. Major disruptions are closure of airports or airspace, which may be due to snow storms, strikes, or - as the tragic events in USA recently shows - events, which are beyond comprehension.

In ship-building, production plans usually allow some flexibility. However, the popular just-in-time approach to production aiming at increasing productivity and decreasing the cost of production gives rise to an increased demand for robustness in plans and calls for enhanced tools to handle disrupted situations. One would believe, that major disruptions in industry would always be related to complete production stops due to e.g. strikes, however this is not always the case.

A major shipyard in Denmark, Odense Steel Shipyard, uses the approach of assembling the ship under construction in a large dock. Here, a gigantic portal crane is the prime tool. During December 1999, Denmark was hit by the worst hurricane ever registered. Among the damages of the hurricane was that the portal crane of OSS was blow over and onto the ship under construction in the dock. This caused an immediate close-down of large parts of the production, and even the task of removing the crane turned out to be immense. In the end, the crane had to be cut into manageable pieces just to remove it from the ship under construction. The activities of the shipyard was disrupted for several months.

3 The process cycle of an operation

Common for the two decision support cases to be described and the other cases we have worked on is that in order to carry out the daily operation, companies usually produce a plan. The time spent in producing the plan may be quite large: hours or even days. As the time of the operation approaches the plan is adjusted to changes. This is typically denoted the tracking process. The changes in the plan need not be done on-line since at least a day is available for the replanning. The methods used in replanning may not be the original planning methods even if these are still feasible with respect to generation time. On the day of operation the plan is implemented, and the operation is monitored during execution. When the observed situation deviates from the situation planned for, action has to be taken. The deviation can be marginal requiring no immediate action to continue operation. In case the impact of the deviation on the operation is substantial, either because the current plan becomes infeasible or because the result in terms of cost or benefits of running the operation according to the current plan changes, a disruption has occurred. In order to continue operations, intervention is necessary, either to resolve the infeasibilities resulting from the disruption or to decrease cost/increase revenue. The monitoring and re-planning process is referred to as the control process. As opposed to the tracking phase, the time for re-planning in the control phase is so limited that the methods used for generating the original plan cannot be used..

In Figure 1, the three processes are shown in the context of the daily operation of an airline company.

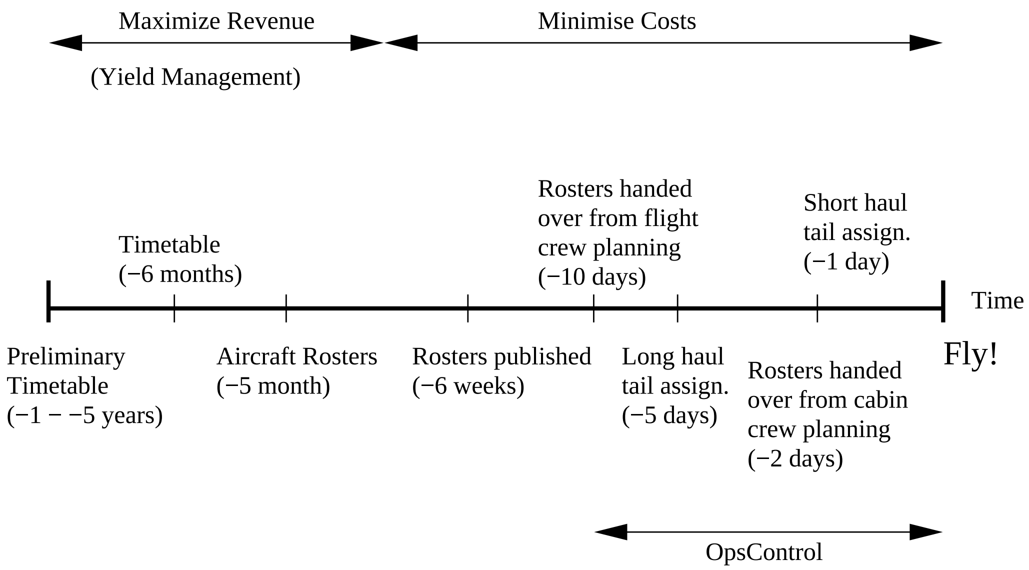

Figure 1. The time-line for the daily operation of an airline.

Generally, a disrupted situation or just a disruption is a state during the execution of the current operation, where the deviation from plan is sufficiently large that the plan has to be changed substantially. This is not a very precise definition, however, it captures the important point that a disruption is not necessarily the result of one particular event. For efficient disruption management, it is therefore necessary that the status of the system forming the basis for operation is monitored.

Summing up, the process cycle of an operation consists of three elements:

- planning, where the necessary resources for executing the operation is assigned to specific activities,
- tracking, where changes in the resource situation is monitored, and evaluated, and re-planning is done off-line and
- control, where changes are monitored, but re-planning is performed on-line.

Today the disruption management process generally lacks computerized decision support. As a consequence, decision makers often stop after having generated a single feasible option for recovery - time simply does not allow for generation of structurally different alternatives. Often, even simulation tools allowing a what-if analysis of the current situation is not available. In the area of disruption management OR could make a significant difference in the way that operations are recovered and to what quality. In an environment where time is a crucial and important factor OR-based decision support systems can offer substantial benefits in the recovery procedure.

4 Disruption Management - two cases

4.1 Managing steel plates

The CIAMM project is a collaboration between DTU, the University of Aalborg and a number of industrial companies among which are Odense Steel Shipyard. The shipyard is by far the largest Danish shipyard and is currently building the largest container ships in the world.

Ships are build in an assembly line fashion, i.e. several ships are under construction at the same time in different workshops at the shipyard. Hence it is extremely important that as little delay as possible is incurred in each of the workshops since a delay in one workshop influences the whole production. Each workshop maintains its own planning unit and additionally there is also an overall planning unit responsible for coordinating the flow between workshops.

The first station in the production of a ship is the steel plate storage, where the raw material for the ship is delivered. The steel plates arrive by ship in large bulks, each bulk containing plates to be used for different components and at different times. The plates are stored at the steel plate storage until they are requested by the cutting workshop.

The steel plate storage is an outdoor field with an 8 by 32 grid of stacks, in which the plates are stored. On average each stack contains 20 plates, which may be of differing size. The storage is operated by two portal cranes running on the same pair of tracks, and hence unable to pass each other. The plates are delivered in one end of the storage and are handed over to the cutting process at the other end. The organisation is illustrated in Figure 2.

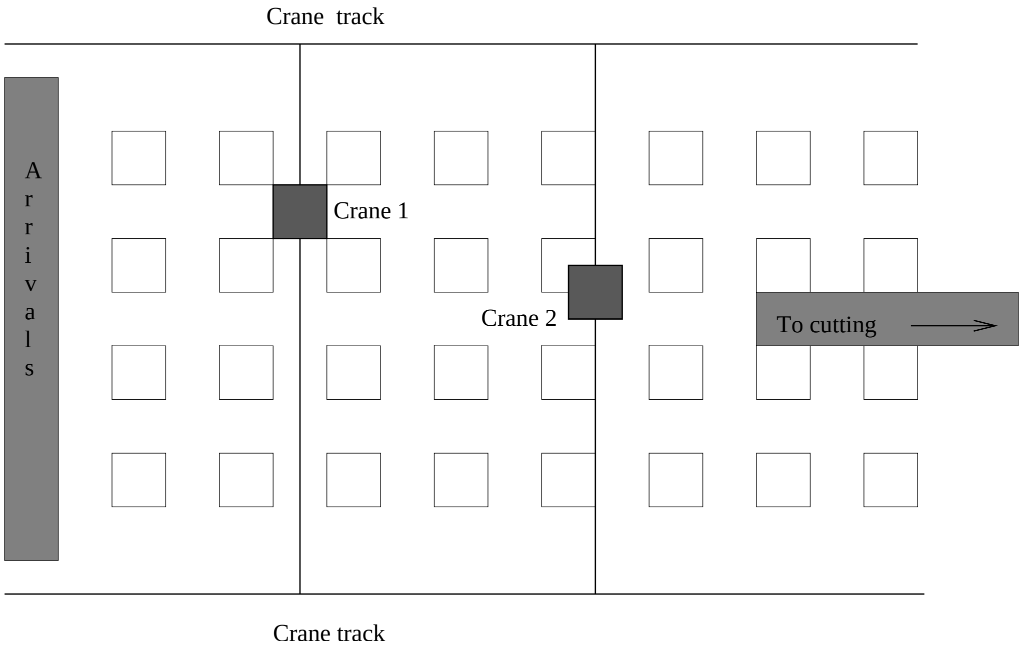

Figure 2. A 4 by 8 steel plate storage with 2 cranes

Currently, the storage is managed using a so-called block oriented approach, in which steel plates to be used in the same section of a ship are stored together. However, there are not sufficiently many stacks that each section can have its own, and the plates often arrive weeks or even months prior to the planned use date. The normal case is therefore that the topmost plates in a stack are not those to be used first, and hence have to be moved in order to get to the relevant plates. Such moves are obviously non-productive, and the goal of the project is to investigate alternative approaches to storage organization to minimize such dig-up moves, taking into account that the planned sequence of plates to be delivered from the storage often is changed due to urgent deliveries, and the organization of the storage should be able to handle such orders in an efficient way.

Currently two other organizations are investigated: The time slot organization and the self-adjusting organization. In the time slot organized storage, plates are arranged according to their planned use date, whereas the self-adjusting organization determines the location of each new plate and the location of plates moved in dig-up moves based on the current status of the storage and the knowledge on the future demands. In both cases, the quality of the solution as well as the sequencing of the cranes in order to avoid collisions are determined by simulating the activities of the storage for the rest of the day.

As mentioned in the previous section, there are at least two approaches allowing for disruption management in the daily operation: the control approach and the re-planning approach. In the control approach the storage and the cranes at the steel plate storage are continuously monitored and the next activity of each crane is decided based on the current status and with NO use of information on upcoming activities. Clearly, no efforts are wasted on planning for situations that does not occur anyway, which may happen in an environment with rapid changes. On the other hand due to the limited time horizon, suboptimal decisions are bound to be taken.

The alternative strategy is a re-planning approach. Here, a detailed plan based on the expected production of the coming day(s) is constructed prior to the day of operation, and the operation is run according to this plan. In a deterministic world an optimal operation results, but if disruptions occur some mechanism to take care of recovery is needed. Two different approaches are on-line re-planning, and building buffers into the original plan. The latter one is the current practice of OSS, however this leads to an efficiency loss. Re-planning without buffers, on the other hand, is dangerous since delays in one workshop will immediately affect the flow through the complete system.

Presently, a planning tool for the time slot organization and the self-adjusting organization has been developed. The running time of this tool is sufficiently short that it may also be used in a disrupted situation to re-plan activities. The tool is based on the heuristic method Simulated Annealing, in which each suggested new plan is evaluated through simulation. This simulation plays a crucial role in the project since it also provides the interface to the end-users, cf. below. The approach has been necessary for two reasons: the constraints of the problem are difficult to handle in classical mathematical models (e.g. that the cranes cannot pass each other), and the evaluation of a re-plan when disruptions are taken into account is by no means obvious.

Resultwise, both the time slot organization and the self-adjusting organization of the steel plate storage seem to be superior over the block oriented organization: in a number of generated realistic scenarios without disruptions, the number of dig-up moves is only 40 % of the result for the block oriented approach. For scenarios with disruption, pilot experiments indicate that the self-adjusting organization is more robust to disruption than the time slot oriented approach. Quantifying this statement awaits the complete sequence of experiments.

The project is now in the phase where OSS is establishing the necessary data support for on-line use of the methods. The decision regarding which method to use in the future will be taken before the end of the year.

Finally, though results indicate the potential of the decision support tool developed, much care must be taken when introducing such a tool in the organization. Here, our experience has been that simulation communicated through a Graphical User Interface (GUI) is a must.

4.2 Handling delays - a holistic approach

As reported by the Danish newspaper "Aktuelt" there are more than 22000 commercial flight daily in the European airspace and the control spread over more than a dozen national air controls there are many good reasons for disruptions in air traffic. In addition hereto airlines regularly face restrictive weather conditions, maintenance problems and staff shortage. All this put together results in more than 1 out of four European flight to be delayed by more than 15 minutes in the first quarter of 2000.

The DESCARTES project is financed partly by the European Union, The partner are DTU, British Airways and Carmen Systems. The project aims at developing decision support tools for disruptions at the day of operation for airlines.

Currently, plans are made for aircraft, flight crew, cabin crew etc. based on the schedule of the airline company, which is determined at least 1/2 year prior to the actual operation date. Making such a plan is in each case complicated - for aircraft maintenance rules have to be taken into account, the right capacity must be at the right place at the right time, and the characteristics of each individual airport have to be respected. For crew, there are regulations on flying time, off-time etc. based on international and national rules, but also regulations local to each airline originating in agreements with unions. Furthermore, other aspects have to be accounted for: holidays, the plans for aircraft assignments, crew assignments and maintenance of the flight schedule is handed over from the planning department to the operations control centre (OCC) a few days days ahead of the operations date. The deadlines are different for different resources as eg. short-haul aircraft is handed over 1 day before while long-haul is handed over 5 days before the day of operation.

As the plan is handed over, it becomes the responsibility of OCC to maintain the resources so that the flight plan is feasible. Crew might get sick, flights may arrive late and not only the immediate situation, but also knock-on effects on other parts of the schedule cause serious problems, especially as flight crew, cabin crew and aircraft are not planned as a unit.

To produce recovery plans is a complex task as many resources (crew, aircraft, passengers, slots, catering, cargo etc.) have to be re-planned. When disruption occurs on the day of operation, large airlines usually react by solving the problem in a sequential fashion: aircraft, crew, ground operations, and passengers. Infeasibilities regarding aircraft are first resolved, then crewing problems are addressed, ground problems like engineering, stands etc. are tackled, and finally the impact on passengers is evaluated. Sometimes, the process is iterated with all stakeholders until a feasible plan for recovery is found and can be implemented. Like in many airlines, the controllers at British Airways performing the recovery have little computerised decision support to help construct high-quality recovery options. Often the controllers are content with producing only one viable plan of action as it is time consuming and complex work to build a recovery plan. Furthermore the controllers have little help in estimating the quality of the recovery action they are about to implement.

One recovery option that is almost always available is cancellation of flights or round trips. From the resourcing perspective, cancellation is ideal – it requires no extra resources and may even result in new free ones, and little re-planning is required. However, from the passenger side it is the worst option, since a group of customers does not get what they paid for. Determining the quality of a recovery option is (as was the case for the steel plate storage) difficult. The objective function is composed from several conflicting and non-quantified goals.

The project aims at developing better support for airline operations problems. There are already systems on the market that in a disruptive situation can help airline controllers resolve disruptions. However, to the best of our knowledge these systems only work on one resource e.g. cabin crew. In DESCARTES we aim for developing an INTEGRATED approach that can deliver decision support for several resource areas, such that the highly complex interaction between the areas are accounted for. The focus is at present on four resources: aircraft, flight- and cabin crew and passengers. New optimization methods for this highly time-constrained problem is developed at DTU and Carmen Systems.

The disruption management system is built around an infrastructure, the Umbrella, which facilitates message passing between the different stakeholders of the process (the managers of flight and cabin crew, aircraft, and passengers) and underlying systems performing the actual computations leading to recovery options for the current situation. Systems for crew recovery and aircraft recovery have been developed, and currently systems integrating the recovery of different resources are under development. In parallel, two simulators are developed: a consequence analyser, which walks through the rest of the day given a suggested option for a disruption and its knock-on effects, and a stochastic simulator, which allows strategic analysis of different over-all strategies in disruption handling. Also, alerting mechanisms will be included in the final system, because a disruption not necessarily is the effect of one particular event - it may be the result of a series of smaller events each of which in itself is not serious. The standard example here is that single crew members report sick with a frequency so high that by the end of the day, a major shortage of staff is the result.

The project is currently in its second year and first prototypes of the systems described above are being tested on real-life data in a closed environment. Later this year, the systems are to be tested with respect to speed and option quality in a simulated on-line environment again with real data.

Also in this project, the role of tools allowing the staff in the production environment to view and investigate the suggested solution options are crucial. The consequence analyser is valuable as a stand-alone tool, since it allows the decision makers to simulate the effect of potential decisions, and to develop a better understanding of the effect of different types of strategies (avoid cancellations by all means, return to plan as fast as possible, never leave any problems to the next day, ...).

5 Challenges and benefits

Disruption management systems face a number of challenges, some of which have already been mentioned:

- **Timing**: in order to be valuable, the option(s) generated must be available within a very short time frame compared to that used in the planning/tracking phase.
- **Data**: Usually, the data are distributed among several DB's and they are not necessarily in the same format.
- **Feasibility**: The feasibility of a proposed option often depends on complicated rules (which are sometimes violated by human controllers anyway).
- **Organization**: The control process resides in an organization of humans, and introducing change in an organization is by no means trivial.
- **Buy in**: From the controllers - see above. From management - either the necessity has to be obvious, or the economical potential must be large.

However, the potential benefits to be gained from introducing computerized decision support into the disruption management process are substantial:

- **Better working conditions**: For the controllers, the control process changes from firefighting to more qualified decision making.
- **Control less person dependent**: More homogeneous decisions and less vulnerability in case of staff changes.
- **QoS**: Better Quality of Service offered to the customers of the operation.
- **Resource utilization**: Better use of all available resource, and better overview.
- **Integration**: Improved decisions through integrated view of operation.

6 Other potential applications

Potential other applications are numerous - in the following we list a number of applications:

- **Container traffic:** Just as airlines are alloted slots for their aircraft at the airports, container ships are assigned slots at container terminals. Resources like stacker cranes, re-supply trucks etc. are planned on the basis of when the container ship is planned to arrive and when it is planed to leave again. If a ship is delayed a number of resources have to be re-planned. The shipping company may even have the possibility of redirecting the ship to another port, thereby saving time or re-establishing a profitable/sensible plan. In many ways there are a lot of parallels between the airline problems faced during the DESCARTES project and container traffic if aircraft are replaced by container ships, passengers by containers, and airports by container terminals.

- **Network operation:** Telecommunication companies sell communication bandwidth in point-to-point connections to users. Whenever there is an equipment failure action has to be taken. If the situation requires reaction other than the automatic rerouting of traffic which is common in telecommunication systems, a disruption has occurred and a Disruption Management tool could be used.

- **Substitution handling in primary schools:** The goal of the Danish primary schools is to educate children, but for the smaller children, the school also has a function of caretaking. Hence, situations, where staff report sick or are otherwise away from the school has to be handled by substitutes. This process typically has to take place on short notice immediately for the daily schedule begins.

- **Disruption management in health care:** The Danish society offers social care for elderly citizens, who stay in their own house or flat rather than in an elder-home. The same person may require visits up to 4 times a day, and the planning and execution of this daily operation is performed centrally by each municipal authority. Recently, a percentage of cancelled visits as high as 20 has been reported as worst case, although the normal percentage countrywide is 1 - 3 %. The cancellations are due to staff reporting sick - a typical disrupted situation.

  Also, cancellations and re-planning due to emergencies and other types of disruptions are everyday events in hospitals. A system enabling more efficient disruption handling will be able to increase the efficiency of use of personnel and equipment, both of which are scarce resources.

7 Conclusion

Disruption management is a potential application area for OR which in our experience has a huge potential and which offers substantial gains in efficiency for the users involved. The applicability ranges from industrial companies to the public sector.

Solution methods must be able to produce good and structurally different solutions fast due to the on-line flavour of the problems. A technical challenge is hence to develop methods, which produce robust and near-optimal solutions fast for real-life problems. Even with the tremendous development in the field of heuristics, this is by no means a trivial task.