A Case Study Seminar for Solving Client Problems in Project Teams

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Abstract: We describe the course "Seminar on Case Studies in Operations Research" which is taught at Aalto University following a format where teams of 4-5 students tackle problems posed by firms and research institutes. In this course, students learn about team work and project management, hone their presentation skills, and produce final reports describing how they have sought to solve their client's problem using operations research (OR) techniques. During the past decade, 56 such projects have been carried out, and many have had significant impacts in business and society. Drawing on experiences from these projects, we identify preconditions which contribute to successful learning experiences; we also discuss possible pitfalls in organizing similar course based on this generic format.

Keywords: Operations research, teaching, project management,

1. Introduction

In most curricula on operations research, the majority of courses tend to have a strong methodological focus. In such courses, the students learn about specific OR methods – such as linear programming (Bazaraa and Shetty, 1993), simulation (Law and Kelton, 2002), or decision analysis (Clemen, 2009)–and deepen their knowledge of these methods by applying them to

pedagogical examples and by submitting individual classroom exercises. However, such courses may not encourage the students to reflect on what OR methods should be applied to a given problem in the first place, because this choice is typically implied by the course title. Real-life problems are also different from classroom exercises in that they tend to be rather complex and even ambiguous. More often than not, they require that several experts work together in close collaboration, in order to meet the expectations of an external client. The solution process, too, needs to be systematically structured, to ensure that it complies with relevant constraints of time, budget and quality.

The recognition of the above differences, combined with the problem-orientation of OR as a scientific discipline, suggests that there is a need for courses that involve action learning as a means of helping students to develop skills for applying OR in practice (Behara and Davis, 2010; Cherney, 2998; Revans, 1998). Indeed, when equipped with such skills, the students should be able to interact effectively with the client; to structure complex real-life problems with diffuse boundaries; to organize their work into a coherent and compelling project plan; and to work together as a team. These skills are much desired of recent OR graduates; but from a pedagogical perspective, it is not clear how courses for developing them should be structured, especially if courses are to be offered on an annual basis to a relatively large number of students.

In this paper, we describe the course "Seminar on Case Studies in Operations Research" which seeks to foster skills such as those listed above. In this course–which is taken annually by approximately 18 to 36 graduate and post-graduate students at the Systems Analysis Laboratory[1] at the Aalto University School of Science[2]–the project teams consisting of 4-5 students work on problems that are posed by firms and research institutes. Apart from applying OR methods, the student produce deliverables related to project management, hone their presentation skills and learn about the activities of the other project teams as well. Todate, the course has been running for 10 years and 56 student projects have been completed by mid-2011. The student feedback has been overwhelmingly positive, and many projects have had significant impacts on business and society. The overall format of the course is quite generic and can be readily adapted for use at other universities.

[1] http://www.sal.tkk.fi/en/
[2] http://sci.aalto.fi/en/

The rest of this paper is structured as follows. Section 2 describes the context of the course at the Aalto University and the learning objectives of the course. Section 3 describes the seminar format based on which the course is offered each year. Section 4 discusses some of the preconditions for successful projects as well as pitfalls that may be encountered.

2. Context and learning objectives

The course on "Seminar on Case Studies in Operations Research" was initially developed by the author in 2001-02 at the Helsinki University of Technology. Currently, it is being offered at the Systems Analysis Laboratory, which is now part of the Department of Mathematics and Systems Analysis[3] at Aalto University.

The overwhelming majority of the students in the course come from the MSc programs in (i) technical physics and mathematics[4] and (ii) industrial engineering and management[5]. These two programs attract exceptionally talented students and have some of the toughest entrance requirements in Finland. Most students are Master's students in their third, fourth or even fifth year of university studies, and about 15% are doctoral students. As a rule, the students will have studied operations research as their major or minor subject. For understanding the course design, it is helpful to bear in mind that the course is being taught to talented students whose educational backgrounds are somewhat different, whose knowledge of OR methods is rather good, and who may have started to apply their professional skills in various forms of part-time employment.

The learning objectives of the course are focused on the following:

1. *Problem formulation*: Most other courses in the specialization on systems and operations research[6] foster the development of mathematical and technical skills and have a focus on OR methods and tools. In this setting, one of the objectives of the course is to help the students develop their skills for understanding how OR methods can be matched to real problems. In particular, it is essential the students are exposed to real problems and faced with challenges in problem formulation (see also Behara and Davis, 2010, p. 25).

[3] http://mathsys.tkk.fi/en/
[4] https://into.aalto.fi/display/entfm/Homepage
[5] https://into.aalto.fi/display/entuo/Homepage
[6] See the listing of courses on page http://www.sal.tkk.fi/en/teaching/

2. *Project-based team work*: The students are used to completing individual assignments, but they have less experience of team work. This motivates the second objective, which is to provide the students with as realistic a setting as possible for learning about project-based team work. As a result, the students are required to work in project teams for an external client who is genuinely interested in their contribution. These teams are also required to produce all the usual deliverables in support of project management, and they also have a formally appointed project manager who gets some extra credit for his or her duties.
3. *Communication and presentation*: The third objective is to foster communication and presentation skills throughout the project lifecycle, ranging from the exploration and clarification of client requirements to the presentation of project plans, interim reports, and final results. Such social skills are particularly important during problem formulation and the uptake of results.
4. *Domain knowledge and self-confidence*: When they work on their projects, the students become knowledgeable about a new problem domain by interacting with their clients and by reading relevant papers. At best, this process of systematic knowledge acquisition enhances the students' self-confidence and abilities for problem-based experiential learning so that they become better equipped to address problems even in other problem dmains.

3. Organization of the Course

Here, we outline the arrangements of the course, in the format that it is currently offered at Aalto University School of Science.

3.1 Roles and responsibilities

The roles and responsibilities of the course stakeholders are as follows:

- *Clients* are problem owners who are faced with a real problem that is potentially suitable for the deployment of OR methods. About two thirds of the clients are private firms, others are governmental research institutes and sometimes regulatory agencies. The clients are responsible for presenting the problem to the students; providing access to data; interacting with the students through the project (usually three or four meetings that last about two hours); and providing feedback on the results.

- The two *teachers* are the *professor* and the *teaching assistant*. The professor runs the overall organization of the course, which spans responsibilities such as the identification of clients and the initial selection and scoping of project topics (ie, assessing whether a problem, as described by the client before the course, is indeed suitable for the course); the assignment of students to project teams; the supervision of project teams, with an emphasis on the scoping of projects and the choice of methodologies; and the delivery of constructive feeback on the results produced by the teams. The teaching assistant provides various forms of practical assistance, for instance by maintaining the webpage and by informing the students how they can best access requisite software tools..
- The *students* work in *teams* so that each team has a project topic of its own, proposed by a clients. The students are expected to work creatively and with an open mind, and they have considerable freedom in problem formulation and the choice of methodology. In particular, the students are not just 'told' how to solve the problem: rather, they are encouraged to define the problem so that they feel they can provide useful results to the client on time (in three months) and within the 'budget' (5 credits, or ECTSs[7], per student).
- Each project team has a *project mana*ger with a few additional responsibilities for communicating with the client and the teachers (eg, finding dates for suitable meetings); providing leadership to the team; taking a lead role in the specification of project tasks and the allocation of team members to these tasks; and ensuring that all team member make a strong enough contribution to the project (ie, elimination of free riders). The project managers are told to approach the teachers, confidentially if need be, if they encounter major difficulties in their teams, no matter what the nature of these difficulties. The project managers get 2 extra ECTSs for their contribution.
- For each project team, one of the other teams will have the role of a *shadow team*. The responsibilities of the shadow team is to follow the activities of another team at arm's length so that its members will study the deliverables produced by the other team and, moreover, provide written and oral feedback on these deliverables in the joint meetings.

[7] European Credit Transfer and Accumulation System, see http://en.wikipedia.org/wiki/European_Credit_Transfer_and_Accumulation_System

Table 1. The overall structure of the course "Seminar on Case Studies in Operations Research".

Activity / Role	*Clients*	*Teachers*	*Project teams*
November-January	• Negotiations on prospective topics • Solicitation of project plans		• Registration for the course
Kick-off meeting, end of January	• Presentation of the client's activities and description of proposed project topics	• Description of course arrangements • Assignment of student to project teams	• Exchange of contact information • Selection of the project manager
February	• In-depth discussions with the project team • Delivery of data	• Meetings with teams to check the viability of their project plans • Suggestions for literature and methods	• Problem formulation • Project planning • Literature review • Dev't of project plans
First excursion, end of February	• Presentation of host client's activities • Feedback to teams	• Feedback on project plans	• Presentation of project plans
March	• Guidance to project teams	• Support when requested	• Work on projects • Dev't of interim reports
Second excursion, end of March	• Presentation of host client's activities • Feedback to teams	• Feedback to teams	• Presentation of interim reports
April	• Approval of results	• Support when requested	• Work on projects • Writing of final reports
Third excursion, end of April	• Presentation of host client's activities • Feedback to teams	• Feedback to teams	• Presentation of final reports
May	• Uptake of results	• Collection and archiving of project deliverables • Grading	• Corrections to final reports • Feedback on the course

3.2 Initial kick-off meeting

The initial kick-meeting is typically held at the end of January and lasts about two to three hours. It begins with an initial presentation of about 30 minutes where the professor explains all the practicalities. This includes, for instance, a short description of the motivation of the course; the roles and responsibilities of teachers, clients and project teams, as listed above; the grading of the course; the overall schedule during the Winter and Spring terms as shown in Table 1; pointers to material on project planning and management; the rules according to which students are assigned to teams; and the principles followed in the choice of reporting language (Finnish, English) and

the signing of non-disclosure agreements. He also stresses emphatically that project scoping is critical and that the project teams themselves are largely responsible for scoping decisions.

After the initial presentation, the clients give about 20-minute presentations of their respective project topics. In the first half of such a presentation, the client typically gives a brief decription its overall activities in order to set the context for the project topic. The second half describes the client's problem in more detail, with an emphasis on what the problem is about, what expectations are placed on the project team, and how the problem can be possibly approached with OR methods. After these presentations, the professor gives the students a 1-2 page hand-out on the project topic. This hand-out is structured under headings such as problem background, objectives and expected results; methodological possibilities for addressing the problem; and various requirements that may apply (eg, reporting language, course prerequisites, non-disclosure agreements). These hand-outs have been developed by the clients and approved by the professor, in order to help the students form an informed opinion about the project topic. It is also important that the students meet the clients already at this stage.

After these initial presentations, there is a pause during which the student are given 10-15 minutes to think about what project topics they would like to work on. Specifically, they are requested to list their three or four most preferred project topics (the exact number of topics on such a list depends on how many students are taking the course and how many topics are being offered), starting from the most preferred one, followed by the next most preferred one. Sometimes, the students wish to work in pairs, and this is permitted by allowing pairs of students to submit a joint listing of their preferred topics; but bigger teams are not allowed to submit joint listings. The limitation to pairs was introduced to eliminate the possibility that a large project team could 'block' some topic, because then it would be more difficult to achieve a balanced assignment of students to all topics. Also, from the pedagogical perspective, it is instructive to build teams where the students work with other students with whom they have not collaborated before.

Next, the expressions of interests are collected from the students and the teachers analyze them, partly assisted with an optimization software, with the aim of ensuring that (i) all projects have four or five students to work on them, (ii) as many students as possible get to work on the projects that are among their most preferred choices, and (iii) no students are forced to work on

project which they did not mention. The first of these three constraints is a hard one. The second and third are relevant, too, because the teachers seek to ensure that students are not asked to work on projects they are not interested in. Here, the optimization algorithm provides guidance for the formation of project teams; but departures are sometimes made based on other considerations (eg, ensuring a sufficient diversity of skills in the project team) that may have to be recognized. The shadow teams are also formed at this stage, following the principle that those students who were not allocated to their most preferred topics should have the chance to comment on the work produced on these topics.

The assignment of students to teams takes usually no more than 30 minutes. It results can therefore be presented at the end of the initial kick-off meeting so that the team members can get together and exchange contact information. In each team, the students are then asked to discuss together who will become the project manager. The project managers are asked to report to the teachers by email within a next few days and to confirm that all team members are on board and committed to the completion of course (this is important to exclude the possibility that some student would quit the course because he was not assigned to his first choice). Moreover, at the end of the kick-off meeting, the teams are given the contact information of their clients (emails, phone numbers), with the remit that they should now approach their clients and find a suitable date for the first client-team meeting.

Overall, the kick-off meeting is crucial because the students learn about all project topics, submit their expressions of interest and are assigned to project teams. In order to foster good group dynamics, no new students have been permitted to join the project teams once these have been formed.

3.3 Project Planning

About one week after the initial meeting, the teams have their first meetings with their clients who give a detailed remit of what problem thay are faced with and what they expect from the team. Based on this meeting, the project teams carry out a tentative literature review and, once they have formed a tentative plan for addressing the project topic, they present this plan to the professor in an informal 30-45 minute meeting where the focus is on how they the team members see the project topic and how they intend to structure their project. One of the reasons for this

meeting is to ensure that the team has started working and making progress. At times, the teacher presents suggetions for modifying the project plan (typically, the students are encouraged to clarify and limit their objectives, because they tend to overestimate how much they can accomplish). Based on these two meetings, the students then write their project plans and start working on the initial project tasks.

The project plans are presented in late February in a joint meeting which is attended by all project teams and teachers, and often by some clients as well. In this meeting, the teams give about 20 minute presentations on their project plans which are 5-6 pages in length, organized under standard headings (ie, background, objectives, tasks, schedule & division of work, risk management plan). Particular emphasis is given to the identification of risks and the elaboration of measures through which these can be mitigated. The project managers are required to send project plans to the teachers and their respective shadow teams before the meeting. This is necessary so that the shadow team will be able to comment on the written project plan and the presentation. This is followed by further comments by the teachers.

The meeting for the presentation of project plans–as well as the later meetings in late March and and the end of April–take place on the premises of some client. Because there are 4-6 projects each year, it is possible to choose three clients for such excursions. After the presentation of project plans, there is typically a short coffee break, whereafter the hosting client gives a general presentation of its activities, often with a focus on how operations research links to these activities. In consequence, the students learn not only about the projects but also about the clients as well.

3.4 Interim Reports

In March, the project teams work along the lines outlined in their project plans, and there meetings with the client and/or the teachers to the extent that this is necessary and helpful. However, to exclude the possibility that the teams request excessive tutoring, the clients are instructed so that there should be about 3-5 two-hour meetings for interfacing with the students. Also, the client discussions tend to be focused on the clarification of objectives and problem scoping. In more technical matters – such as what OR methods are likely to be the most appropriate ones – the project teams often turn to the teachers for advice.

In late March, the students present their interim reports in a joint meeting which is attended by all project teams, the teachers and which is held on the premises of one of the clients. The written interim reports are to be submitted the day before the meeting, thus allowing the teachers and the shadow team to provide constructive feedback. In these reports, the students are requested to give (i) a very brief summary of their accomplishments, (ii) to present an updated project plan for the rest of the course, focusing on changes and, in particular, (iii) to revisit their risk management plan. Typically, the interim reports are quite short, no more then 2-3 pages.

The presentations follow much the same structure as in the case of the project plans. That is, each team has about 20 minutes for their presentation, which is followed by 5-10 minutes of feedback by the shadow team, the teachers and the client (if the project client is present). In these presentations, the project teams should give their audience a good understanding of what they have already accomplished, what modifications they may have made to the initial project plan, and what the prospects for completing the project successfully look like.

3.5 Final Presentations

In April, the students work on their projects and devote an increasing share of their time to the development of final reports. These reports are usually about 25-40 pages. They are accessible to anyone in the internet, wherefore some reports contain results that are based on modified data (rather than confidential data which is used when delivering 'real' results to the clients). The students are also invited to write a 1-2 page account on 'lessons learned', discussing what they have learned and where they think their team performed well or perhaps less so. These accounts are an important way of learning about the teams have actually worked.

The final reports are presented in late April or early May in a final meeting which is hosted by one of the clients. The reports are presented using a schedule as before, but now the emphasis is on demonstrating what the project teams have really achieved. Written and oral feedback on the final reports and oral presentations are given by the shadow team, the professor and by the client's representative, if present. Further to this feedback, the students may be required to modify their final reports; but such revisions are usually rather minor. At the end of this final meeting, the professor explaing the final practicalities (ie, getting a final clearing from the clients; deadlines for submitting the revised reports; getting student feedback on the course).

Towards the end of the final meeting, the students are encouraged to bear in mind that in a few years' time, many of them will be working in organizations where they may encounter problems that are potentially suitable for the course. This mode of soliciting project topics has become increasingly important. It is also very good one, because these clients will have had first-hand experiences of how the course runs and what it feels like to work on such problems..

The course has typically received exceptionally good ratings: for instance, in 2011, all students reported that the course helped them develop their skills for working in teams; the course was useful in their current phase of studies; and that the presentations by the other teams were either very or somewhat interesting. Yet, the student feedback depends on how strongly the projects are supported by the clients and how interesting the project topics are to the students. It is therefore important to invest in the solicitation of interesting project topics and the assignment of students to topics that appear in their expressions of interest.

4. Examples of Case studies

The reports produced by the projects are available in the internet[8]. Table 2 lists a sample of problems that the 56 projects have worked on.

Table 2. Examples of problems topic addressed by the project teams.

Year	*Project topic*	*Client*
2002	A calibrated model for the pricing of credit default swaps	Sampo Pankki Co
2003	Models for forecasting mobile phone replacement sales	Nokia
2004	Multi-criteria decision analysis for the optimal selection of road pavement projects	Inframan Co
2005	Assessing the impacts of first-aid medical delivery processes on combat performance	Finnish Defence Forces Technical Centre

[8] The reports have been available on the webpage https://noppa.tkk.fi/noppa/kurssi/mat-2.4177/aiemmat_seminaarit by clicking on the links "Projektityöt 2002/ 2003/ ...", although a password may be required in the future to access these webpaged. For each year, there is a page where the project plans, interim reports and final reports are under the headings "projektisuunnitelma/ väliraportti/ loppuraportti", respectively. Although the project titles are in Finnish, almost half the reports have produced reports in English, particularly those where the client has been a multinational corporation.

2006	Prioritization of new product features in software development	Nokia Networks
2007	Optimizing the yield of a bioreactor	Medix Biomedia Co
2008	Spatial regression models for adjusting locally dependent treatments in field trials	Kemira GrowHow Co
2009	Optimal timing of harvesting of forest stands	UPM Co
2010	An evaluation model for designing national helicopter emergency servives (HEMS)	HEMS Administrative Unit
2011	Analyzing the efficiency of Finnish health care units	National Institute for Health and Welfare

As shown in Table 2, the projects span a broad range of application domains and OR methods. The project topics are solicited through three main avenues.

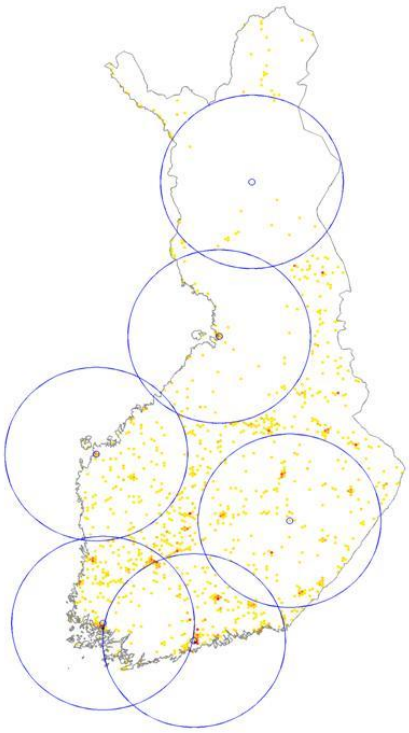
1. Every so often companies and research institutes approach the professor with timely OR-related problems and, in some cases, the course seems an adequate instrument for addressing these problems.
2. Some clients–like Nokia and the Technical Research Centre of the Finnish Defence Forces–have become regular clients and proposed topics from one year to the next. This is useful, because these clients have realistic and well-founded expectations and because the professor needs less time to solicit project topics from other clients.
3. A good number of project topics are proposed by alumni, i.e., students who took the course a few years ago and are now working in organizations where they apply and make use of OR methods.

In order to illustrate what can be achieved in these projects, we summarize results from the 2009 project on the evaluation model for the design of national helicopter emergency services.

Because Finland is a sparsely populated country, with 5.3 million people and only 41 inhabitants per square mile, helicopters are essential in the delivery of emergency medical services. Since the 1990s, such services were offered by independent associations that were responsible for the emergency helicopters in their respective geographical areas. These associations were not regulated, and the sites of helicopter bases (see Figure 1) reflected the interests of these local associations. In particular, no studies had been conducted to determine the nationally optimal sites of helicopter bases or selection of helicopter types.

In 2010, the administrative situation changed when the Helicopter Emergency Medical Services (HEMS) were brought under administrative control of the Ministry of Health and Social Services and the five Finnish university hospitals. In connection with this reform, the sites of helicopter bases and the choice of helicopter types were to be subjected to a thorough review under the direction of the HEMS Administrative Unit, which became the client of the project topic.

Figure 1. The sites of helicopter bases in 2010.



The project team was given two objectives in the redesign of HEMS operations: (i) to evaluate the suitability of alternative helicopter types for the delivery of medical emergency services and (ii) to give recommendations concerning the optimal sites of helicopter bases. To this end, the project team developed a large-scale optimization model consisting consists of three parts: a search algorithm, a simulation model, and a performance evaluation model.

In the search algorithm produced by the project team, a major input is the number of helicopter bases, typically in the range between 5 and 7. The algorithm then forms decision alternatives in the search space consisting of 52 prospective sites for helicopter bases and 9 helicopter types. For

every alternative, a one-year simulation run is executed to determine how the alternative, defined as a combination (i) the type of helicopters, (ii) the number of helicopters and (iii) the assignment of these helicopters to different sties, can be expected to perform with regard to two minimization criteria: (i) the mean time of reaching patients and (ii) the share of patient calls that cannot be handled due to concurrent patient cases or performance limitations. Because the search space is very large, Pareto-optimal solutions are generated using tailored genetic algorithms.

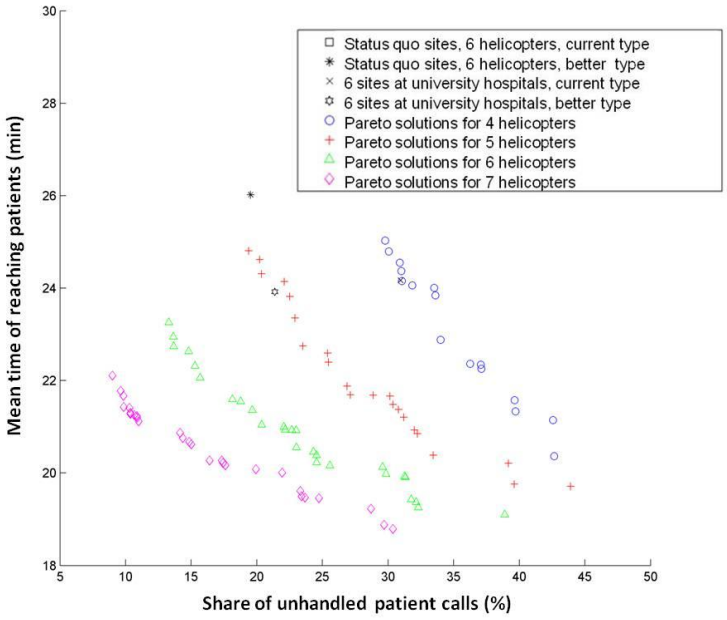
The simulation model uses past data and Monte Carlo techniques to generate a one-year sequence of patient cases that call for HEMS service. These cases are generated on a geographical lattice where Finland is divided into 20,000 hexagonal cells of about 7.7 square miles each. Estimates for patient case frequencies for these cells are inferred from statistical data about the population, its gender and age distributions and road lengths. The range and speed of alternative helicopter types are obtained from the manufacturers' performance charts in recognition of simulated weather conditions (temperature, elevation, air pressure) and technical parameters (mass, fuel consumption, maximum cruise speed). All this information is combined to determine whether a given patient call can be handled, considering the location of the patient, the nearest available helicopter, the nearest hospital, and the range and speed of the helicopter.

The project team placed considerable emphasis on presenting results so that they could be understood by aviation specialists, medical professionals and decision makers. The helicopter sites, corresponding helicopter ranges and shares of handled/unhandled patient calls in each lattice cell were illustrated with the help of GIS maps to show the main characteristics of different alternatives. The performance of different alternatives was visualized with regard to the two evaluation criteria, thus highlighting how much better Pareto solutions would be in comparison with the previous situation. The robustness of proposed helicopter bases was analyzed by examining in how many Pareto solutions they were contained. Furthermore, comparisons among Pareto-optimal sets for different numbers of helicopter bases were made to indicate how the level of service could be improved by increasing the number of helicopters.

The project provided important results which were discussed in the media and supported the final decisions. For example, the results showed that, in contrast to the status quo, that bases should not be located on the coastal line where half of the flying range extends over the Baltic Sea. The bases should be located in more densely populated areas where the number of patient calls is high

and where contemporaneous calls were found to be a major cause of unhandled patient calls. Practically all helicopter types turned out to be suitable for HEMS operations in all weather conditions, with some exceptions for the very northernmost part of Finland, which is the coldest and least populated part of the country. Among the technical attributes, maximum cruise speed was deemed to be the most important one, because fast helicopters reach patients more quickly so that fewer patients are left unhandled. Cost of helicopters was of less concern, because the overall costs are driven mostly by the personnel costs of medical experts.

Figure 2. The Pareto frontiers for different combinations of helicopter types and bases.



An examination of Pareto-optimal frontier suggested, for instance, that re-locating helicopter bases would reduce the mean time of reaching patients from 26 minutes to 21 minutes while the share of unhandled patient calls can be reduced from 27% to 21%. After the completion of the project, the decision to locate the helicopter bases next to university hospitals has been taken (which represents a significant improvement of the earlier status quo), and steps towards the selection of helicopter types are taken by organizing a competitive bidding process for helicopter operators. The HEMS Administrative Unit has acquired the rights to the software tools developed by the project team and is now using them in its planning activities.

5. Discussion

5.1 Rationales for course design

The course format we is motivated by several observations:

- *Team size*: It would appear that the 'optimal' team size for this kind of a course is four or five students. This is because in smaller teams of three, the amount of work required of each student could become excessive; moreover, if an adverse event would force one of team members to quit the course, the project would have to be completed by two students only and the genuine group dynamics would be lost. Conversely, in teams of more than six students, it is more difficult for the project manager to ensure that all team members make a comparable workload, whereby problems of 'free riding' may be become more pronounced.
- *Timing of the course*: A reason for offering the course from late January and to early May is that the professor can contact prospective clients in the Fall so that agreements on most project topics be reached before Christmas. It would be more difficult to start the seminar in September, because in this case the project topics would have to be solicited in Summer (which would be difficult due to holidays) or already in May and June (which could involve the risk of lacking client interest due to the long period between the specification of the project topic and the actual start of the project).
- *Forming of student teams*: Every student clearly wishes to work on the project that he or she is most interested in; but this cannot be allowed, because the resulting groups would differ too much in size. It is therefore necessary to have a systematic procedure where (i) the students provide information about which projects they wish to work on, (ii) this information is used for developing a tentative recommendation maximizing the match student interests and project topics so that (iiii) the teachers can take the final decision, in recognition of other possible factors as well. The second of these phases is supported by an algorithm maximizing an objective function which increases when students are assigned to their more preferred projects. The algorithm also ensures that each project team has 4 or 5 students and that pre-established pairs of students can work on the same project, if they wish. However, the professor has the final say in the assigment, the algorithm is but a helpful tool. The students are not given any detailed information about what preferences they have expressed; however,

they are given some facts about why the project assignment is good (eg, 80% get to work on their first or second most preferred topic,).

- *Strict scheduling*: It is beneficial to have a strict schedule so that the students know at the outset when they will be required to present their deliverables. Such as schedule creates a sense of urgency and puts a fair amount of social pressure on the students, because no team wishes to report that "we have hardly accomplished anything" when the other teams are making good progress.
- *Presentation skills*: The three meetings for the presentations of project plans, interim reports, and final reports are useful. First, these meetings help the students develop their presentation skills by explaining *what* their problem is about and *why* they have chosen their OR approach. Second, these meetings allow the project teams to learn from the work of other teams, because all teams get a good sense of the accomplishments of other teams. Third, these meetings are a means of imposing a strict schedule.
- *Shadow teams*: Working in shadow teams trains students in making use of results produced by others, which can be a useful learning experience. The shadow teams also reduce the teachers' workload, because these teams make valid observations so that the teachers can focus on those points of criticism that have not yet been made.
- *No payments to anyone*: Although they often have commercial value, all projects are executed *de bono* so that no students get paid for their work. This choice is motivated by the desire to treat all students on equal terms (no one can complain that some other student was assigned to a project with higher compensation). Moreover, the non-payment principle makes it clear to the clients that the projects are exploratory studies and, although they can expect that the students do their best, there are no contractual commitments between the client, the university, or the students. If the clients require non-disclosure agreements (NDAs), or expect access to the software tools that may be produced by the project, they must state this at the outset so that students who do not feel comfortable with such requests can make informed decisions when submitting their list of preferred project topics.
- *Excursions*: All meetings for presenting project deliverables are hosted by the clients. Typically, the students get to hear one or few short talks on what kinds of activities the clients engage in and what the role of OR in these activities is. These excursions are practically held on Friday afternoons so that they serve as a smooth transition to the weekend. For example,

one such particularly memorable excursion was made to a large brewery which kindly invited the students to sample their new products.

5.2 Possible caveats

Practically all have succeeded in ensuring that the students have learned about team work, project management, and operations research. Yet some have encountered problems, due to one reason or another. Here, we discuss some reasons, with the recommendation that educators who consider possibilities of offering a course based on this format should pay particular attention to:

- *Data availability*: The clients may be eager to propose a project topic in the expectation that they will soon collect or receive for the students to work on. However, because there may be unexpected delays in the delivery of such data, a project topic should be accepted for the course only if the data will be available with absolute certainty. A project team will be much discouraged if its work is hampered by problems of data availability that are beyond its control.
- *Dropouts*: Unexpected reasons–such as prolonged illness–may force some students to quit the course. Thus, the teams should be large enough to remain functional even if they lose one of their members. Also, it is important that the project managers confirm at the outset that all team members are committed to the course, because this reduces possibilities for half-hearted participation.
- *Technical difficulties*: These can be usually mitigated by careful solicitation and screening of project topics and by matching required technical skills with the students' earlier courses. Yet, if difficulties are encountered, there is a potential risk that students who have the best knowledge of mathematical software tools are under pressure to put in more work. At times, ways forward can pursued by simplifying the problem formulation or by applying simpler approaches (e.g., Monte Carlo evaluation of a representative sample of predefined strategies instead of computation of optimal strategies).
- *Matching the number of project topics with the number of students:* At Aalto University, the students may register for courses as late as in mid-January, and the number of student who wish to take the course may vary 16 to 36, depending on what other electives are offered. Yet, the project topics must be negotiated a bit earlier. In consequence, the students are invited to submit their tentative registration in December, encouraged by the message that students who

register early are more likely to be assigned to their most preferred project topic(s). The clients, on the other hand, are told that the project will come to being only if there are enough students.

5.3 Building Impact

There are several ways in which the course generates impacts. First and foremost, as confirned by the positive student feedback, the students have indeed learned about operations research, team work and project management. Many students have been employed by the clients where they have subsequently built successful careers. Some projects have provided valuable information for decision making (eg, the HEMS project in Section 4), and some have served as a light-weight form of initial collaboration which has paved way for the establishment of research contracts between the client and the university later on.

The projects have fostered to scientific publication activities. In rare instances, the project team has written a paper based on the final report; but this option seems viable only if the project manager is a doctoral student who needs publications for his or her dissertation: for instance, the paper Renjish Kumar et al. (2005) on the evaluation of the end-user usability of office applications is a streamlined version of the final report. More commonly, new uses of methods by projects have been reported in separate papers. Thus, for instance, some results from the 2004 project *Multi-criteria decision analysis for the optimal selection of road pavement projects* appear in Liesiö et al. (2007). This project also catalyzed later research projects which won recognition in the INFORMS Decision Analysis Society's Practice Award Competition in 2007 (Mild and Salo, 2009). The 2006 project *Prioritization of new product features in software development* inspired, in part, the illustrative example in Liesiö et al. (2008). New methods for ratio-based efficiency analysis (Salo and Punkka, 2011) were applied in the 2011 project *Analyzing the efficiency of Finnish health care units*. These examples highlight close connections between project topics and ongoing methodological research in the department.

The results of some projects have been read not only by the clients but by other stakeholders as well. For instance, the evaluation report of helicopters for the Finnish Border Guard, which was carried out as a project in 2009, caught the attention of the HEMS Administrative Unit which then approached the professor with the proposal that a comparable analysis of helicopter

emergency medical services should be conducted. Thus, it seems important that the project deliverables can be widely accessed: apart from fostering the generation of worthwhile topics, it helps prospective clients understand what kinds of topics can be posed to the project teams and what accomplishments these teams consisting of eager students are capable of.

6. Conclusion

The seminar course described in this paper helps students improve their skills in applying OR through a structured process of action learning where they address problems posed by external clients, working in project teams consisting of 4-5 students. At Aalto University, this course has been quite popular and very much appreciated by the students. Overall, this course is best seen as a complement to more 'usual' courses where the students learn the methods and tools that are needed to complete these projects successfully. Thus, the course format is likely to work best in the later stages of a Master's OR program. At this stage, it is also easier to get a strong enough client commitment, because the clients can expect useful results and because the students are potentially receptive to employment offers.

Finally, it is worth noting that organizing such a course can be a rewarding experience for teachers. First, because the teachers can choose interesting project topics, the coaching of highly motivated project teams gives excellent opportunities for learning about new topics and also for building impact by leveraging fresh talent on challenging problems. Second, the close interaction with students makes it possible to observe quite closely what the students have really learned from other courses and, specifically, where their possible weaknesses may be. Third, because many clients are former students, the course helps see how former students now reflect on their university education, which may lead to suggestions for improvement. And, on a more personal note, it can be quite rewarding to see how former students move on in their lives and careers, building on the skills they acquired during their formative years at the university.

References

Bazaraa, M.S., H.D. Sherali, C.M. Shetty. 1993. *Nonlinear Programming: Theory and Algorithms, 3rd Edition*. Wiley and Sons, New York.

Behera, R.S., M.M. Davis. 2010. Active learning projects in services operations management. *INFORMS Transactions on Education* 11(1) 20–28.

Bertsekas, D.P. 1995. *Dynamic Programming and Optimal Control, Vol 2*. Athena Scientific, Belmont MA.

Cherney, I.D. (2008). The effects of active learning on student's memory for course content. *Active Learning in Higher Education* 9(2) 152–171.

Clemen, R.T. 2009. *Making Hard Decisions: An Introduction to Decision Analysis, 2nd Edition*. Duxbury Press, Belmont CA.

Law, A.M., W.D. Kelton. 2002. *Simulation Modeling and Analysis*. McGraw-Hill, New York.

Liesiö, J., P. Mild, A. Salo. 2007. Preference programming for robust portfolio modeling and project selection. *European Journal of Operational Research* 181(3) 1488–1505.

Liesiö, J., P. Mild, A. Salo. 2008. Robust portfolio modeling with incomplete cost information and project interdependencies. *European Journal of Operational Research* 190(3) 679–695.

Luenberger, D.G. 1997. *Investment Science*. Oxford University Press, New York.

McEwen, B.C. 1994. Teaching critical skills in business education. *Journal of Education for Business* 70(2) 99–104.

Mild, P., A. Salo. 2009. Combining a multiattribute value function with an optimization model: An application to dynamic resource allocation for infrastructure maintenance. *Decision Analysis* 6(3) 139-152.

Renjish Kumar, K.R., I. Hirvonen, I. Leppänen, T. Kuronen, J.K. Nurminen, A. Salo. 2005. An evaluation model for the end-user utility of office applications. *Proceedings of the Ninth IASTED Conference on Software Engineering and Applications*, ACTA Press, November 14-16, Phoenix AZ, USA.

Revans, R.W. 1998. *ABC of Action Learning*. Lemos and Crane, London.

Salo, A., A. Punkka. 2011. Ranking intervals and dominance relations for ratio-based efficiency analysis. *Management Science* 57(1) 200–214.