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Operational research can do more for managers than they think!

A review of the OR approach in action highlights the many ways OR can contribute to more efficient and effective management

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How does the operational researcher work?

When it is necessary for managers to make decisions, OR can do more for them than many of them think. OR has developed powerful tools for comparing alternative scenarios quantitatively, for making the effects of decisions visible and hence open to discussion, and for reducing uncertainty in complex situations. The OR worker does not take decisions out of the manager's hands; but he does help him to improve the quality of his decisions and to shorten the time to reach them. This is achieved by revealing the consequences of possible decisions in as quantitative a way as possible. The intuition, experience and common-sense of the manager remain indispensable for the final two steps: the selection of a chosen solution and its implementation. Nevertheless, there is something strange about that intuition: sometimes "reasonable" (heuristic) solutions appear not to be the "best". Common-sense and a heuristic approach often fail because they are arbitrary in the selection of a starting-point in the sequence in which choices are made, in the selection of criteria to be considered when characterizing a process, and in the amount of effort undertaken in order to prove that the eventual "solution" really is the best one (or almost so). Neat examples of this phenomenon can be found in Geoffrion and Roy (1979). They suffer from sub-optimization, because the mutual influences of step-by-step decisions are not taken into consideration.

Figure 1

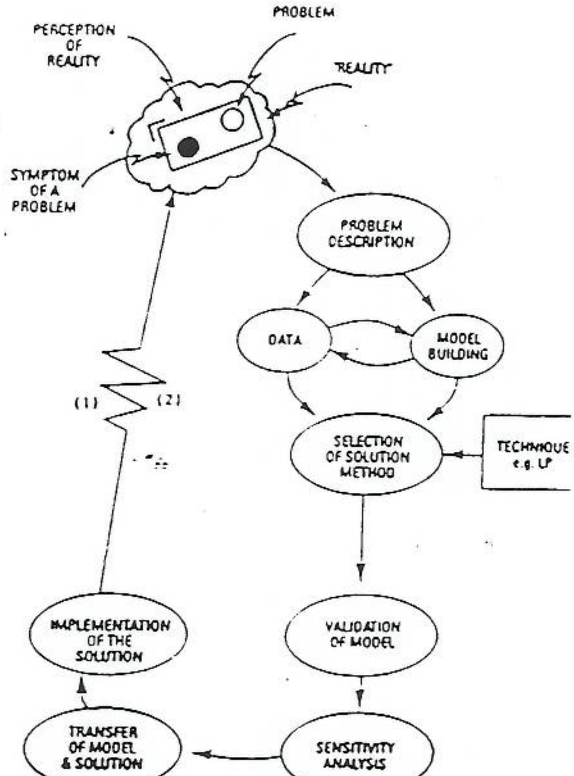

Figure 1 shows the way in which OR can support management problem-solving. Often, the manager and his staff do not understand precisely what their problem is. By means of a systematic and structured analysis, based mainly on interviews with local functionaries, the OR worker is able to give them insight into the matter. From these interviews, and by studying documentation from the client's organization — but also by questioning the purpose of the organization, its strategy, the available resources and the current procedures — a picture gradually emerges of the problem and its possible causes. A short report, soon after the beginning of the investigation, demonstrates to the client the areas in which the OR worker is busy, and the way in which he perceives the problem area. In this way, any lingering doubts concerning the OR worker's capabilities really to help solve the problem, vanish quickly. This is of the utmost importance to the gaining of confidence. In most cases, the client has had to overcome some hesitation before asking an external consultant for help. Generally speaking, he is ready to believe that the consultant has fund of theoretical knowledge — but will he be able take practical circumstances into account, and loc constraints?

Correct problem formulation and an indication (possible) causes offers qualitative insight, first of all the OR worker himself and then to the client and his sta This leads almost automatically to an appreciation of th best approach. Solution methods come into sight. On if at that moment quantitative details are required, will th "tool-kit" be opened that each OR worker has at h disposal. The client need not be more aware of that tha he wishes. As long as the problem is to be eliminated a desired, the selection of tools is mostly irrelevant to hir What counts is the solution itself, preferably at minim costs with (economical) advantages for his business. quantitative analysis is not always requisite: sometim the qualitative insight gained is sufficient for designing a improvement plan.

The project approach

Successful application of OR is almost always achieved on a project basis. Client and consultant draw up an agreement describing as precisely as possible what the consultant is to do, at what costs, how much time he expects to need, and what assistance he desires from the client's organization. These are of necessity in the nature of estimates: adjustment occurs many times in the course of a project.

In practice the three-phase approach shown in Figure 2 has proved to be very useful.

Figure 2: Summary of the steps in an OR project

	Activities	*Description*
Phase 1	General survey	Discussions with client and staff. Interviews, study of documents. Global problem description. Generation of ideas for a possible approach.
	Reporting	Outline of results to be expected. Proposal for Phase 2.
Phase 2	Model building	Systematic description of the problem area. In order not to make the model too complicated, only the most relevant factors are taken into account.
	Verification	Discussions with client and staff: is the model correctly presenting the problem area, the organization, the methods, processes and procedures?
	Experiments	Translation of the model into a computer program. Calculations in various circumstances.
	Analysis	Investigation of results.
	Reporting	Presentation of the most important results, conclusions and recommendations. Proposal for Phase 3.
Phase 3	Implementation	Working out an implementation of recommendations. Teaching client and/or staff to work with the new method.

In Phases 1 and 2, the consultant is heavily involved in the project. Usually Phase 3 is carried out by the problem-owner and/or his staff.

Phase 1 – Preliminary analysis

Usually short, aiming at reconnaissance of the problem areas and a problem description with which the problem-owner can agree. For the problem-owner, this phase entails little risk. In his report, the OR worker indicates the way in which he thinks the problem can be solved and the consequences this will have for the organization. An estimate of throughput time and costs is usually indicated.

Phase 2 – Working out the proposed solution

Often this phase includes making a model of a piece of reality (e.g. the factory, the department, the group of machines) relevant to the problem. Experiments with the model provide insight into the interdependency of many parameters and reveal "which dials the manager has to turn" and to what extent, in order to obtain a desired result. This project phase produces conclusions and recommendations. In the course of this phase, intermediate reports are produced at the customer's request or if the OR worker feels the need for it. Instructions for the implementation of the proposed solution are often a part of the final report.

Phase 3 – Implementation

Usually, this part of the project is executed by personnel of the client organization. In the ideal case, the OR worker is intensively involved in that activity, so that he turns into what Eilon (1984) calls a "change agent". In most cases, however, the client wishes the OR worker to remain in the shadows, so as not to hand over power to him.

> Model-building plays an important part in modern OR projects, often in combination with discrete simulation. Models offer insight and the possibility to compare decision scenarios with each other, both in the qualitative and the quantitative sense. Almost always the computer is an indispensable tool in this. The driving force exerted by developments in informatics cannot easily be overestimated. A large part of the arsenal of OR techniques can be used on the PC, thanks to software that is becoming more and more user-friendly and also cheaper. In recent years, there has been an enormous growth in the ease with which a problem area can be represented by a model that the problem-owners consider sufficiently realistic. Large quantities of data can easily be stored in databases that are simple to access. The opportunities for OR to really contribute to the reduction of uncertainty in complex industrial situations, are large.

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OR in action 1: Location of manufacturing capacity

A multi-national enterprise is selling a certain series of products in all 12 EC countries. Demand per country is known. For historical reasons, there is a factory in 10 of the countries (see map), serving mainly the national market. But European unification is proceeding – the year 1993 is not far away. The attractiveness of delivery to the whole common market, from a smaller number of production centres, is increasing. The Board of Management of this enterprise is faced with the decision as to which of the 10 factories have to be closed and which have to be expanded.

Production centres in Europe

In this somewhat simplified scenario, the following circumstances hold:

- in principle, each factory can be expanded so as to produce the total EEC need presently met by the 10 factories: there is sufficient space, and the required staff can easily be hired;
- the costs of expansion differ strongly between countries, due to government subsidies, tax facilities, the level of wages and cost of living, and the size of the existing factory;
- in Ireland, Spain and Portugal, wages and costs of energy and water are relatively low and consequently so are the production costs; and
- production in these low-cost countries incurs high costs of transport, as the countries are situated far from the areas with the greatest demand (e.g. Germany and France).

This problem can be solved by using a *mixed-integer linear programming model*. Scarce resources are assigned as well as possible to a number of competing activities by optimizing a linear target function (e.g. profit), taking into account a number of linear restrictions (e.g. capacity of a factory, or the amount of money available for investments). "Mixed integer" indicates that there are discrete and continuous variables.

The dimensions of such an LP model are determined by the number of countries that have to be served, the demand per country, the number of factories, the capacity of those production centres, the operating costs, the costs of expansion (terrain, buildings, personnel) and the costs of closing (de-investments, arrangements for superfluous staff).

Basically, it is possible to apply the model manually, i.e. with the traditional pencil and paper. However, if the LP model has some realistic size, then this signifies a monk's task. Therefore the OR worker turns to his computer and translates the model into a computer program. Standard LP packages are available.

For the fictitious cost structure below, the LP model leads to the conclusion that production has to be concentrated in Ireland. This is mainly because of low expansion costs. If those costs were three times as high, then Germany – because of its central position and in spite of its high cost level – would become the most suitable place for concentrating production. If in Italy costs of expansion were zero (e.g. because of an already existing overcapacity of sufficient size), then the model would indicate Italy as the supplier for Italy and Greece, while the rest of the EEC would be served by Ireland. (See the table below.)

The model used is crude: the site of a factory in a country plays no part, and each country can only be supplied from one factory. Simplifications of this type can, however, be removed easily. It is also possible to set up the program by means of which the foregoing results were obtained, in such a way that the user can "play with it" – i.e. find answers of a *"what if ...?"* type.

Here are some examples:

- What would the solution look like if, in country A, the subsidies on investments disappear?
- What happens if in country B demand increases or decreases substantially?
- What would be the best decision if wages and costs were the same in all of Europe?
- If cost ratios change, e.g. because of a new oil crisis, where should production be concentrated?

FACTORY IN	COSTS OF EXPANSION	TRANSPORT AND PRODUCTION COSTS FOR:											
		B	DK	D	F	GR	GB	IRL	I	L	NL	P	E
Belgium	11200	475	860	1104	1211	615	1288	350	577	112	568	267	548
Germany	4000	577	823	1000	1400	597	1523	394	1246	114	623	286	466
France	6000	605	975	1350	950	624	1296	350	1253	124	591	243	405
UK	5000	594	894	1373	1196	665	850	262	1396	136	610	245	425
Ireland	1800	460	900	1569	1400	708	1061	170	1514	157	685	228	413
Italy	3800	1025	1195	1927	1988	395	2327	555	510	187	1087	276	450
Luxemburg	53100	535	843	1038	1192	574	1408	374	1149	90	612	264	438
Netherlands	10100	568	760	1196	1381	636	1319	344	1364	127	475	284	492
Portugal	24800	1212	1581	2562	2177	734	2300	475	1565	244	1296	70	[illegible]
Spain	16600	1044	1406	2181	1827	648	2027	448	1290	204	1129	176	150

Characteristics of the OR application

Experience has shown that OR workers are less frequently involved in solving real-life problems in industrial organizations than is possible (given the available tools) and desirable (in view of the need to design, develop, produce, distribute, etc., products or services). This may be due to managers not being aware of what OR has to offer. The fact that it is not always clear what can reasonably be expected from an OR consultant is also of influence here. It therefore seems useful to list some of the more important characteristics of the OR consultant's role:

- The OR worker does not pretend to produce an optimal solution, but one that is sound and executable and better than the existing method.
- The OR worker does not take decisions. This task belongs to the manager and to the staff to whom he has delegated this authority.
- The OR worker does not provide ready-made solutions that can be implemented without any effort on the part of the client and his staff. The client organization has to carry out such activities as data-collection, modification of methods and procedures, and sometimes even a complete reorganization.
- The OR worker indicates feasible decision alternatives and calculates their (financial) consequences. The manager can thus make a choice based on firmer ground than intuition and *fingerspitzengefühl* ("finger-tip feeling").
- The OR worker determines what cost-savings can be achieved after implementation of a developed solution. In general, such savings are not obtained immediately, because time is needed to eliminate existing problems such as excessive inventory levels.

Characteristics of the OR consultant

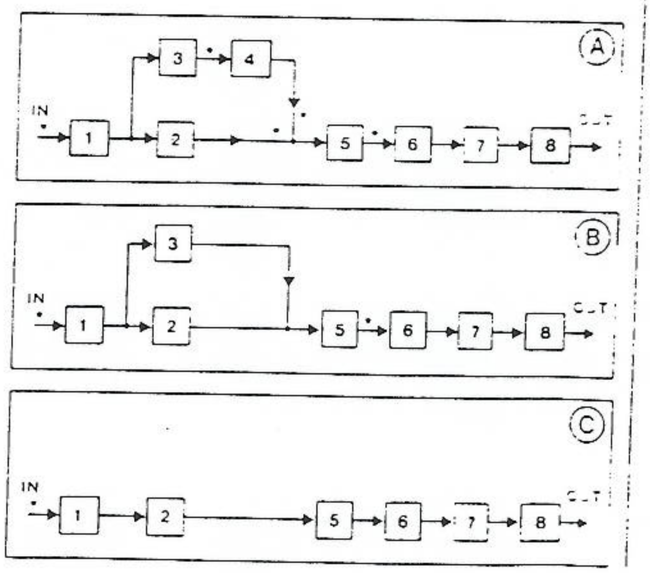
Especially during phase 1, when the tool-box is still closed, the OR worker has to rely on talents and skills that can be obtained only from practical experience. During the exploration of the problem area, it is of primary importance to establish good contacts within the client organization, to obtain the collaboration of people who perhaps see no problem at all, and to create confidence in the eventual success of the project. The consultant needs to find answers to such questions as: *Who are the key figures? What role do they play? How well (or badly) do they work together? Which (personal) interests are they pursuing?* and *What game do they play?* He also needs to have eyes and ears (and possibly a sixth sense) for the possibility of people feeling threatened by his investigation and therefore sabotaging his work. Right from the start, the consultant needs to make clear that his aim is to contribute to improvement of the local situation, and not to point out the shortcomings of persons. In short, the OR worker needs to be a broadly-oriented, experienced model-builder with feeling for and insight into the processes of a client organization, a person speaking the language of the enterprise, with professional skills, and not a pure "applier" of OR who sees OR models as the ultimate goal of his activities. He also needs to be

OR in action 2: Selecting the best factory layout

A factory is producing printed circuit boards (PCBs) in series from 5 to 250 pieces. The factory produces 1,000 types. Some years ago, management expected that customers would require ever-smaller batch sizes, with size 1 as a realistic possibility. With constant production volume, the manufacturing method would result in unacceptably long delivery times, as products would have to wait between the various processing steps (Fortuin and Korsten, 1988).

An internal project group, with experts in the fields of production methods, inventory management, organization and efficiency, logistics, planning and manufacturing systems, made an overview of possible solutions. After studying the advantages and disadvantages of each solution, three different production systems remained (as shown opposite). Then the fundamental question was: *Given a certain workload, which capacities in terms of personnel and equipment are required for each of these three cases, such that product throughput time and processing time are equal?*

External consultants were called upon. They soon came to the conclusion that the proposed manufacturing processes and the interaction of products through the factory were so complicated that computer simulation was needed. Consequently, one of the most often applied OR instruments was taken from the "tool-kit".



Simulation of the three possible systems showed that both the second and third systems would make the required throughput time possible. System B was chosen because the machine for production step 3 had been installed just before the investigation began. This layout has meanwhile been realized; it works to the full satisfaction of the company.

able to listen very well. Only in this way can he collect the pieces of the jigsaw puzzle that may show him the way to a practical and feasible solution. Moreover, he is client-oriented: the market does not ask for operational research, but wants assistance in problematic situations.

Application areas for OR

The analysis of processes and systems is, by definition, the most fundamental OR technique. In addition to this, mathematical research has produced a number of OR tools of a specialist character. Best known and most frequently used are mathematical programming, network analysis, game theory, combinatorial analysis, queueing theory, inventory theory and discrete simulation. In industry, their usefulness has been proven in the control of production processes (tuning of machines, determination of buffer sizes, scheduling of operations, choice of raw materials); in inventory control (optimal reorder levels, size of warehouses); and in the control of goods flows (control rules, reduction of throughput times, allocation of distribution points). For example, an investigation into 188 OR projects executed between 1981 and 1988 at Philips (Fortuin and Zijlstra, 1989) reveals that, in the company, "production" and "design of production facilities" are important application areas for OR (see Table 1). Discrete simulation turns out to be the most frequently used technique, closely followed by models in which probability theory plays a role (see Table 2). The most current type of OR project is a simulation study for the design of a production line.

Table 1: Applications of OR in Philips
(taken from Fortuin and Zijlstra, 1989, in which 188 projects have been analysed)

Area	*No. of applications*
Design of production systems	71
Production	65
Transport and storage	31
Miscellaneous*	17
Training and courses	13
Performance of systems	10
Design of systems for transport and storage	9

* i.e. among others: portfolio analysis; measuring quality of information systems; and performance indicators

Table 2: Applications of OR techniques in Philips
(taken from Fortuin and Zijlstra, 1989, in which 188 CQM projects have been analysed)

Technique	*No. of applications*
Discrete simulation	79
Waiting theory models	70
Inventory models	37
Combinatoric analysis	36
Miscellaneous*	23
Mathematical programming**	16

* i.e. among others: the ordering of facts and figures (many projects begin with this elementary type of OR: sometimes it is all the client wants)

** contains many LP models

The foregoing examples refer to applications with a logistical character in a technical environment. However, outside the engineering world, application areas are easy to find: banks, insurance companies, agriculture, airlines, hospitals, education and government all use OR techniques to a large extent to run their "operations" more efficiently and to support their decisions.

OR and the computer

Software for applying OR techniques is getting ever more powerful and user-friendly, whereas prices continue to fall. Problems which an experienced programmer with a mainframe computer formerly required many hours to solve can now be solved on a personal computer by an individual with only an elementary knowledge of informatics. As a consequence of the interactive mode of operation, the user is able to see results much earlier than hitherto; testing possibilities thus becomes an easy task. Merely by "playing" with the computer, he constructs a model of the system under scrutiny: at first, strongly simplified (the so-called *prototype*), but gradually growing into something with all the relevant characteristics of that system. Acceptance of a decision support system, built in this fashion by people in the vicinity, can easily be obtained; and the implementation is similarly simple. Modern software also opens the possibility of quickly investigating a simplified version of the problem on a PC, and of judging the strengths and weaknesses of the solution method. After that, the real problem can be submitted to a large computer.

Of course, this coin has a less favourable side too. Since OR tools can be handled so easily, even by an "outsider", the probability exists that a package is being used in the wrong way. The assumptions on which the OR technique rests are perhaps not satisfied. The output then becomes incomprehensible or misleading, or does not tally with expected results. Disappointment follows. In order to avoid this danger, good-quality OR courses are indispensable.

Improving performance

Generally stated, OR occupies itself with the analysis (research) of activities (operations). It creates order in situations that are problematic for decision-makers by collecting relevant facts and opinions and returning these in a structured form to the client organization. In this way a problem, at first vague and not quantifiable, becomes open to rational discussion. Causes and possible remedies are identified. It then becomes clear which of the existing OR techniques can best be used, or which new technique needs to be developed to solve the problem in hand.

Modesty, however, is called for: OR is no panacea, and ready-made solutions do not exist. In all cases an effort is required to make the proposed solution applicable and effective. An OR model becomes active and helpful only after it is fed with reliable data. Often the collection of such data is a time-consuming and hence expensive affair. The OR worker therefore should not create too high a level of expectation, but remain realistic and point out that the client's own efforts are indispensable.

In industrial engineering circles, the merits of OR are not fully appreciated. It is believed that the OR worker can think only quantitatively and in terms of models, that his only aim is to use his tool-box as soon as possible. This misunderstanding can be found also in many curricula for industrial engineering. Of course, a good OR worker does have a thorough knowledge of OR techniques: but his effort is aimed at the client organization and its probem areas. In a problematic situation he does not try to maintain the existing system at all costs, which would imply finding the best parameter setting for it. The OR worker devoted to his profession takes a fundamentally different stance: he discovers the system performance that is required and then determines what is to be done in order to achieve that performance – if necessary by means of a new system.

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For the interested reader

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