10 OR Applications at Bouygues

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Abstract

Bouygues SA, parent company of a group generating annually more than 23 billion euros sales of turnover, with more than 120,000 collaborators worldwide, was equipped with a research centre in Operations Research, the e-Lab, eleven years ago. Attached to the CIO of the Group, the e-Lab consists of about ten researchers and engineers. It is one of the few European research organizations in "optimization" of the private sector, working for a diversified industrial group (road, construction, electricity and maintenance, mobile multi-media telephony, television and real estate business).
The object of this paper is to illustrate with a few examples from studies or projects carried out by the e-Lab, the new and sometimes unexpected forms that optimization problems can take in the subsidiary companies of Bouygues today. We will present OR applications from a number of areas including contact centre workforce management, construction planning, TV advertising sale of space, salting fleet dimensioning and graffiti cleaning. Beyond the scientific challenge, these "applications" had various successes, and it seemed interesting to us to present the context and to express the flavor of their economic stakes, as well as the key difficulties that we had to face.

Introduction

Bouygues SA (public company), parent company of a group generating annually more than 23 billion euros sales of turnover, with more than 120,000 collaborators worldwide, was equipped with a research centre in Operations Research, the e-Lab, eleven years ago. Attached to the CIO of the Group, the e-Lab consists of about ten researchers and engineers. It is one of the few European structures of research in "optimization" of the private sector, working for a diversified industrial group. The subsidiary companies of the group are major actors in the sectors of:

- Road, where **Colas** – 8 billion euros of financial activity in 2003 – is present in many areas of transportation.
- Construction, where **Bouygues Construction** – 5,5 billion euros of financial activity – is present in the areas of building, public works, electricity and maintenance.
- Mobile multi-media telephony, with **Bouygues Telecom** - 3,7 billion euros of financial activity.
- Television, where **TF1** - 2,8 billion euros of financial activity - combines the general interest TV channel, paying thematic channels including the TPS group

(including LCI and Eurosport), and also diversifies itself in the edition and the distribution of by-products, the production and sale of audio-visual rights.

- Real estate business, where Bouygues **Immobilier** – 1,3 billion euros of financial activity – is present in all fields of realty promotion, apartments, complexes, offices, trade, hotels, land improvements.

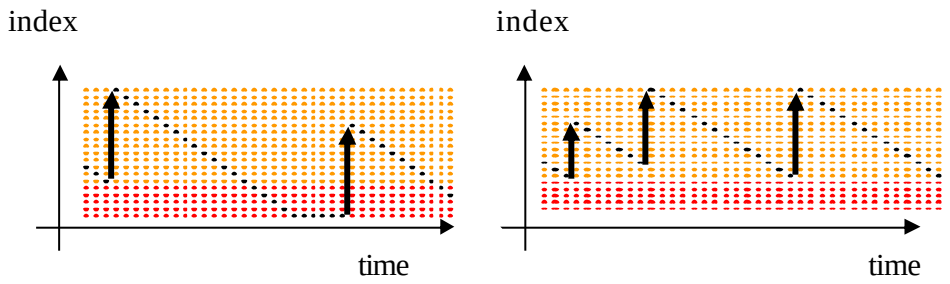
Somewhere between applied mathematics and scientific data processing, the e-Lab provides advice, develops prototypes and software components thus facilitating decision-making for all the subsidiary companies of the Group. It does this on topics such as the optimization of the company's processes, industrial asset management, service level agreement assessment, and the creation of services or the creation of innovative commercial offers. To calibrate itself, to develop its expertise and its software and to remain in contact with start-ups, the e-Lab also works apart from the Group, making best use of available opportunities. The Bouygues group conveys a strong image of entrepreneurial culture, which is far removed from mathematical contemplation; however, any mathematician in France keeps in mind Monge's famous "théorie des remblais et des déblais". This was established in 1781 and provides undoubtedly one of the literature's first problems of "transportation" (in this case of soil).

The object of this article is to illustrate with about ten examples from studies or projects carried out by the e-Lab, the new and sometimes unexpected forms that optimization problems can take in the subsidiary companies of Bouygues today. Beyond the scientific challenge, these ten "applications" had various successes, and it seemed interesting to us to present the context and to express the flavor of their economic stakes. This is in part because the industrial mathematician must wear consultant's clothes in order to avoid dangerous situations that await him. For example, he/she must avoid the temptation to seek for a quality of answer that demands an excess of devoted energy and resource, compared to the potential value-added. We will start with mention of two "dimensioning" problems. The first of these calculates the cost of 25 years of maintenance of an urban road network subjected to the abuse of traffic. The second, for an English county, consists of estimating the size of the fleet of trucks necessary to salt the roads in winter. The next domain of interest is construction. Our third application tries to minimize the stock of cranes on a building site and our fourth will then seek to reduce the need to move those cranes around the site. Mobile telephony overflows with problems, however, we will be satisfied with two examples. Our fifth example seeks to plan rest days over a three month period for the customer representative's teams and our sixth addresses the promotional marketing campaigns designed to get SMS off the ground. Television will follow, where we will introduce our seventh application, the complexity of the process to sell TV-ads for the TF1 channel. And our eighth, which considers the sale of advertising "slots" to thematic channels. Next we have an example from cleaning services, our ninth, which will describe the optimization of graffiti cleaning. Finally, our tenth application, for the gourmets, will explain how seating schemes can be built automatically that satisfy various criteria such as the need for "harmonious" seating arrangements.

Road system maintenance over twenty-five years

Several cities in the United Kingdom manage the integrity of their road system via the private sector. This typically involves maintaining the road network in good condition for a 25 year period. The state of the network can be characterized by the weighted average of the indices (bearing pressure, adherence, visual) of the sections of roads which make it up. This can involve, for a town of 200,000 inhabitants, more than 1000 sections each noted by these 3 indices. The dealer is then charged with maintaining the whole of the network to a contract defined average and for each year. Any failure results in a penalty proportional to the variation from the necessary quality of service. A succession of failures can involve formal questioning of the contract. Also, locally, a particular road can be prone to contractual penalty if a critical success level is not reached, as determined by its indices.

Any road, individually, would expect to see its indices dropping naturally in the course of time, including due to the weight of the vehicles which use it. A truck of 7 tons can thus induce a wear of the road equivalent to that of, say, 10,000 cars. Fortunately, there is a set of maintenance operations, more or less heavy and more or less expensive, which can return some of the indices to their maximum level. The drawing below illustrates the fall of indices schematically as a result of aging but compensated by two (on the left) or three (on the right) maintenance actions.



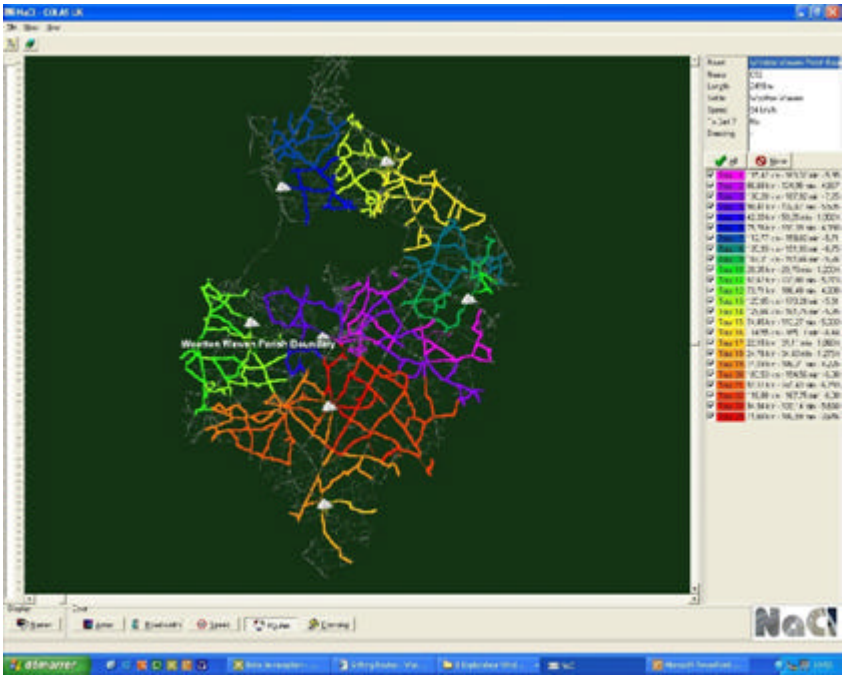
In practice, for a world leader such as Colas, subsidiary of Bouygues, the number of interventions as well as the type of materials to be used is defined by engineering rules dependent on the road and its environment. The complexity of the problem arises from the detailed scheduling of the operations for the 1,000+ road sections in management. The objective of the dealer is to set up a strategy of maintenance, which minimises the sum of the penalties of the operations' costs. Optimization then makes it possible to calculate the best price, of 25 years of work, by offering a scheme of estimated work.

Salting of roads in the English winter

The question in this application is simple: that is to say how does an English county set about planning for more than 1,000 kilometers of road to salt? The county in question installed 7 salt deposits, distributed around the county. What is the ideal size of the fleet of trucks ("gritters") given the need to salt these roads in less than 3 hours? In the centre of the United Kingdom, one notes on average 40 days per year of frost or snow, therefore there is a need for salting, which explains why winter maintenance, frequently delegated to the private sector, is of considerable importance.

We come across this time a problem well covered in the literature, relatively close to the famous Sales representative. One speaks about "Multi Depot, Capacity Constrained, Arc Routing Problem with Time Windows": several deposits, a limited capacity of the trucks, the objective to cover all the roads during a specified time window. The difficulty lies here in the size of the problem, since the county comprises some 27,000 sections of roads, of variable width (thus requiring a variable volume of salt). It is therefore a question of determining the deposit from which the salt for each road should be selected and for each deposit the fleet of trucks to be assigned to it. The engineer in optimization has to find a good compromise between the computing time of his algorithms and their performance in the number of trucks used. This can be particularly important as one extra truck can lead to 5% of additional invoice and, potentially, the loss of the tender opportunity.

An example solution with 24 trucks is shown on the figure below.



Minimal stock of cranes

In the suburb of Paris, close to Longjumeau, lies the technical base of “Les Sablons”, one of the largest centers of storage and maintenance of cranes in France.

The centre receives, up to 6 months in advance, orders to reserve cranes for the building sites of Bouygues. The contract indicates the number of cranes required, their standards (several configurations are possible depending on the work involved and any site constraints), the start and end date of the work, as well as the location of the building site to which the cranes need to be delivered. The centre manages a stock of more than one hundred cranes and must meet the reservations by assigning equipment (cranes, but also other materials like formwork or quartering) to its customers. As is well known, the activity of construction is cyclic and peaks of specific over-activity can appear which

leads the centre to rent materials from other partners, at prices unfortunately higher than its own cost prices.

At any moment, it is a question of assigning cranes to building sites:

- By choosing stocked cranes or rented cranes
- By respecting the quantitative, qualitative and temporal constraints of the building sites
- By considering the costs and availability of transportation capable of moving the cranes from the base to the building sites or in between two building sites
- By possibly making the decision to purchase cranes to increase stock.
- It is worth noting that this problem is similar to that of a car rental company, in that it is also possible to substitute, if necessary, a crane of higher specification than that requested (at the expense of the centre)

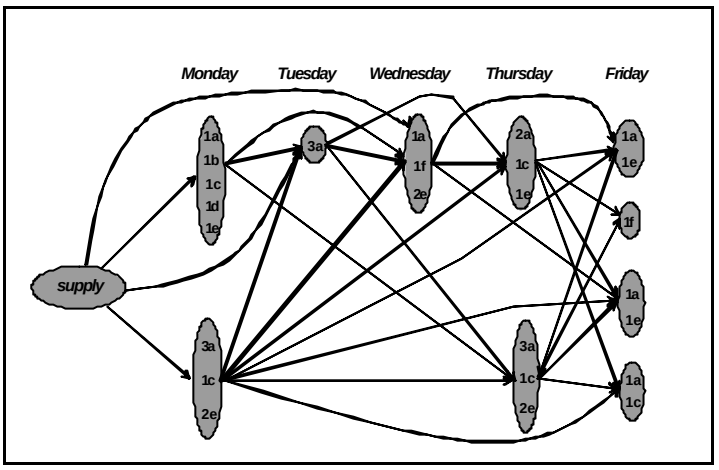
In its simplest form, this is a flow problem; therefore it can be treated easily with graph-based algorithms or by linear programming. However, further complexity arises from the need to include the constraint of maintenance, which obliges a crane to be checked at the end of a specified number of hours of use, and makes the search for good solutions more challenging.

Minimization of the number of formwork assemblies on the building site

The casting of walls constitutes, with that of the floors, the principal activity of a building site. Just one floor of a residential building of the type of those built by Habitat, the branch of Bouygues Building specialized in the housing in Ile-de-France, is made up of a hundred walls and requires about ten working days, using a limited number of vertical pieces of formwork (see left picture). Indeed, the renting of those formworks is expensive, and they encumber the building site when they are not used. A vertical formwork, or form, is a pair of metal panels between which the concrete is run and then left to dry overnight. The form can then be removed (by the crane) and re-used for another wall in the building site. There are forms of various lengths but the walls generally exceed the maximum length of a single form and several forms need to be assembled to cast a wall.

Inputs to this problem are thus the scheduling of the building site and the assignment of the material, which means knowing for each day the list of the walls to be cast and the set of formwork to be used on each wall. Given this one seeks to minimize the number of cranes and the number of times those cranes need to be moved to transport the formworks from wall to wall throughout the building site. Fortunately, when several forms must be moved from one wall to another, this operation can be done in only one crane movement thus reducing the need to assemble and reassemble cranes (each assembly operation can take about ten minutes).

A simple solution can be envisaged in which the first day is started without any planning or pre-positioning and the first walls cast, then the maximum of assemblies are recovered for use the following day, and so on, It can be shown that such a simple approach uses up to 10 to 20% of additional crane movements compared to an optimal solution. However, to find this optimum is not easy because it is a constrained flow problem, as depicted on the figure below (on the right), for which one seeks to minimize the number of edges used, symbolizing the crane's movements (thus re-used assemblies). This is enough to make the problem mathematically difficult, although with a little elbow grease the optimum can be reached in a few minutes of calculation for all the treated building sites.



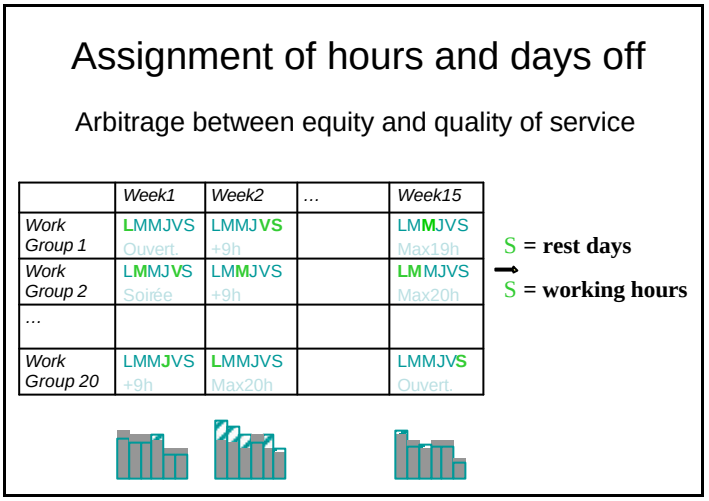
Planning of rest periods for client advisers

The introduction of the law known as "the 35 hours", which reduced the weekly duration of the work from 39 to 35 hours in France, was particularly complex for call centres, because it introduced, beyond the normal challenges of time and volume, new possibilities for smoothing over the year. Bouygues Telecom, the third largest operator of French mobile telephony, has 6 call centres which together comprise nearly 2,500 employees and treat a broad range of services with more than 30 types of different activities. The timetables of the agents must be built so as to cover (stochastically) the estimated load by activity. Specifically, it needs to be ensured that in each period of time the number of qualified employees is sufficient to answer the calls envisaged. In this context, the optimized smoothing of the work force, in the respect of the 35 hours, has obvious economic impacts if one wishes to maintain the quality of service as perceived by the customer. This is reinforced by the seasonal aspect of the workload of the call centres: Christmas brings new customers; Valentine's Day is synonymous with promotions, etc. We will concentrate here on "coarse grain planning", realized typically every 3 months, from which one subsequently determines the days off and the weeks of activity for individual teams.

The table below schematically summarizes two natures of constraints which govern the creation of 3 month schedules:

•**Horizontally**, one must make sure that the number of days off over the period is identical for all agents. One must also make sure that the distribution of schedules is equitable. For example the number of "night" or "openings" must be the same over the period, just like the number of "Mondays" or of "Saturdays" off.

•**Vertically**, it is the quality of service which is addressed. Here, it is a question of ensuring a sufficient number of people present for the load of estimated activity each day, as well as a minimum number of employees present at the start and end of the day.



There are in this problem multiple constraints of equality, and to a lesser extent a variety of presence (relating at the same time over each day and each week) which reinforce the difficulty of the problem and move it away from the search for a simple flow. The “magic square" aspect does not make for an easy resolution. A typical solution which previously occupied a good week for each of 6 planners can now be carried out computationally in a few seconds and with improved equality.

Scheduling of marketing campaigns on SMS

More than two French out of three now have a mobile telephone and make use of it to communicate with their preferred customers, friends or stores. Unlike television or a regular telephone, the mobile telephone is an individual medium, which makes it an advertising medium of choice. Voice mail (VMS: Voice Mail Service) or notification by messages (SMS: Short Message Service) makes it possible for the telephone operator to target his customers, either to propose new offers or to win their loyalty.

Advertising campaigns via mobile phones continue to grow in number as they utilize fully this inexpensive medium, individualized, providing information direct to the ear, and having a very effective rate of return. There are, of course, operator issues to consider too: machines need to be used to transmit the messages, customer representatives must manage the "return" calls of the customers, analysts must interpret the successes of the campaigns broadcasted, and so on. The e-Lab considered this problem of planning advertising campaigns on mobile media, not from the marketing

point of view – which would also be interesting - but from the viewpoint of the use of operator resources.

More formally, we are here within the framework of a scheduling problem of elastic (the campaigns can be stretched) and preemptive (they can be stopped and begin again) tasks under capacity constraint. Each campaign candidate for scheduling can be characterized by a start date, a completion date and a volume of messages to be sent out by one or more channels of communication. Typically, one speaks about several hundreds of campaigns per year. It is also necessary to consider the complete set of messages in a given campaign in order to decide if that campaign is selected or if it should be rejected. A value for return on investment and a preferred period can also be associated with a campaign. However, the latest completion dates for a campaign can often be the most important factor as, for example, a bunch of flowers after Valentine's Day loses its fragrance!

In solving this problem, each channel of communication typically has a maximum capacity, estimated every fifteen minutes. Planning consists both of checking the feasibility of the campaigns (that the appropriate volume and type of messages can be transmitted within the capacity constraints of the channels), and of maximizing the return on total investment.

Last minute sales of advertising slots

If one observes three months of advertising on a television channel like TF1 (watched by more than 8 million viewers every night), one can count more than 30,000 advertising slots filling more than 4000 tv-breaks. Advertisers also change their plans dynamically, changing the slots they are using as advertising campaigns develop and in light of the popularity of particular programmes at any given moment. They can cancel some of their reservations of slots or transfer them to other channels or to different slots on the same channel. They can also generate new slots in an attempt to maximize their audience and thus to ensure the best possible media plan for their products for a minimum budget. Altogether, more than 500,000 transactions a year are carried out in the channel's advertisement slots.

With each new request for reservation, the advertising department of TF1 has different options:

- accepting the request,
- refusing it,
- offering a similar slot that the advertiser would likely accept.

In making a decision, the company must take into account the current state of filling of slots and the profits that would be brought by the new request. However, they also need to consider the estimated future state of the system, including potential additional requests as well as the possibility of already reserved spots being cancelled.
Here we touch well-known problems of "yield management", management of a perishable asset (the advertising slot) which must be filled as well as possible before a deadline (the broadcast time). Further, there is a global over-capacity of slots but a local

under-capacity (the "Prime Time"). "Yield management" approaches are widely used, certainly by airline companies, but also by casinos, the hotel industry, cruises and even on golf courses.

Things, however, get more difficult here than in the airline industry since the assumption of fluidity on the aircraft (losing 1 place out of around 200 can be regarded as a negligible fraction) is not valid any more. Indeed, in the 240 seconds that typically constitute a tv-break, 7 or fewer advertising slots will be aired. Thus, not filling one advertising slot, means 14% of the tv-break is lost, against less than 1% in a regular airline. Analysis of slot filling strategies in television advertising must therefore also take into account the "leftover carpet" induced by the size and number of the advertising slots.

Theme channels: Creation of spot sales "packages"

During the 3 last years, the cable and satellite channels have seen a clear progression (330M€ advertising expenses) and have, via MediaCabSat, a reliable measurement of their audience (around 12 million subscribers). The advertisers now have a way to analyze and build their campaigns, while TF1's advertising department (uniting the management of Eurosport, LCI, Télétoon, TV Brei and others) can structure its commercial offerings.

TF1's advertising department not only has to come up with an attractive offer for the advertisers, but also needs to be rational with respect to the use of the slots to be sold. Various types of packages (sold, typically, in the form of a fixed number of runs of an advertisement) can be assembled and offered for sale. This is done in order to deliver advertising to a chosen target audience while respecting constraints of coverage over the week, of potential competition within the slot, in addition to constraints related to capacity. The overall goal is to maximize sales potential with respect to the market's rules. More formally, the problem is similar to "packing" (several sets of 30 seconds clip-packages being configured ahead of time for the week to come) in "knapsacks" (advertising slots of approximately 3 minutes). Moreover, one has to consider additional constraints such as:

- Needing to include a number of runs in certain time periods (for example, at least 5 messages in prime-time).
- Constraints of incompatibility to respect agreed levels of competition between advertisers of the same branch of industry (for example, not more than one car advert in the same tv-break).
- Cumulative constraints (for example, reaching a minimum number of 150,000 viewers from 4 to 10 years old).

Of these constraints, the main technical difficulty lies in the constraint of audience, in particular for channels undergoing a strong variation of audience in the course of the day. Getting decisions right on the sale of advertising slots is important because one can obtain profits higher than 15% in value, by building optimized packages each night.

Dynamic Routing of a fleet of anti-tags vehicles

Each evening, teenagers express their creativity and mark their territory by tagging Paris' walls. Each day, technicians chart these drawings by size, accessibility and location. A fleet of trucks, based in Saint-Denis, comes then to clean these transitory masterpieces, so that the tags are erased less than two weeks after detection. Several hundreds of mural works are thus destroyed daily by a fleet of about thirty trucks, each one carrying out up to ten interventions a day.

The subsidiary company of Coved, itself a subsidiary of Saur, in charge of this maintenance, must also face more immediate demands such as offensive graffiti that must be eradicated within 3 hours. By definition, these interventions cannot be planned in advance, and disorganize the planned schedule. For each such immediate call, trucks have to be rerouted in the most effective way to minimise disruption to other cleaning

in a row and one will seek to vary the tables on each occasion, in order to have different people meet. Experiments undertaken with 15 managers, 4 tables and 3 days, with only one characteristic per manager already create a frightening headache resembling the famous "social golfer problem" of the literature.

A few working hours are enough nevertheless to create an operational tool carrying out these plans of tables in a few seconds. Besides being of some assistance on an unrewarding task and improving the tables' "quality", one can notice that:

- The clarification of the "rules" by the organizer is itself a profitable exercise, often more so than their implementation.
- Having a fast tool makes it possible to better cope with the risks and disruption caused by unexpected events such as last minute no-shows.

Conclusion

The resolution, sometimes approximate, of these 10 "games" had various impacts. For example, the management of customer's service timetables gave birth to a start-up company, number 4 worldwide for planning schedules in call centres, with more than 300,000 agents worldwide, and an annual sales turnover exceeding 20 million dollars. Similarly, the rationalization of the advertising sale of space was as beneficial for TF1 as "yield management" was in its time for Air France. Planning subjects, such as casing assemblies or campaign advertising schedules are now integrated in quite active software suites. The dimensioning tools for maintenance work were used to calculate complex and innovating commercial offers. When confidentiality considerations allowed it and after academic purification we subjected the majority of these problems to the scientific community in order to enrich and refresh its catalogue of problems. May these problems help rejuvenate the image of operational research for our readers!

In the descriptions above, we deliberately only gave a flavor of the optimization techniques employed. Typology and the constraints of operational problems guide the search of the techniques to be adopted, mixing "bestsellers" including Dynamic Programming, Flow Algorithms, Constraint Programming, Linear Programming, Local Search, Lagrangian Relaxation, and more recent approaches. Our missions are usually rather short (30 days in average) but frequently renewed since optimizing a step in a process often encourages improvement in the whole chain. In any case fast prototyping is our best asset to convince our customer and it also enriches the dialogue: reactions to first solutions often reveal forgotten or implicit constraints. Another crucial point to transform studies into effective optimization applications is our indispensable ability to plug our algorithms into any information system. As for our consulting tariffs, money clearly concerns our customers and makes them identify important questions - we never work for free. Nonetheless, our mission is not to be profitable but to boost scientific innovation in the group, with an unfailing support from our top management. This corporate position allows "innovative dumping" on some valuable projects that we consider beneficial for the Bouygues group.

Finally, since most potential customers do not know what “applied mathematics” can do for them, an important aspect of our job is to detect optimization problems in the group. In this context, giving a view of what OR can do in a diversified industrial group has been the main goal of the present article.