**O.R. helps French automaker overhaul its supply chain from a built-to-inventory to a built-to-order perspective.**

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# Renault Speeds Up D

In the face of a very competitive Western European market, French automaker Renault decided in 1999 to launch the "New Delivery Project" aimed at offering its customers all the diversity of the product range while shortening delivery times. Lead times between the customer order and the arrival in dealerships were to be reduced from six weeks on average to three weeks in Western Europe. The three weeks include the production and transportation of the customer vehicle.

The assumption was that if a client can get exactly the right model with the right color and all the options he or she wishes in a "reasonably short" delay (i.e. three weeks), Renault will gain benefits simultaneously on three levels:

- Reduction of car inventory level. (Thanks to short delivery times, customers can wait for their cars, so that dealerships can lower their stock levels.)
- Reduction of the price discounts designed to sell cars that do not match exactly clients' desires.
- Since all the options are available to customers with short delivery times, expectation of selling a more profitable product mix.

In other words, Renault decided to switch its supply chain from a built-to-inventory to a built-to-order perspective, while offering a more diverse product range with shorter delivery times!

Such an ambitious strategy required a tremendous speed-up of the entire planning process, ranging from the national sales companies (NSC) to the assembly plants via the headquarters. Let us examine this planning process. At the start of each month, NSCs all over Europe define monthly sales forecasts for every model for years Y and Y+1. Then the headquartered sales department reviews the figures with industrial planners so as to ensure that resulting productions comply with plants' capacities, those of Renault and of its suppliers. The discussion between sales and industrial departments may lead to the upgrading of industrial capabilities or to the lowering of sales targets, due to industrial bottlenecks. This planning process took nearly a month each month! The New Delivery Project required the planning process to be shortened to three weeks.

Alongside the planning process, customer orders taken in dealerships are sent daily to headquarters, which in turn

# Delivery

dispatches them to vehicle plants once a week. At the end of the supply chain, assembly plants perform daily the planning and scheduling of their productions. The New Delivery Project required the customer orders to go down a continuous pipeline from dealerships straight to assembly plants, thus bypassing the weekly dispatch by headquarters.

Unfortunately, except for the last step (the planning and scheduling in assembly plants), the whole planning process was supported by legacy information systems (IS) on mainframe environments. These IS represented a huge bottleneck. They could no longer deliver because of the wider variety of product range (more models, more options, more combinations of options, etc.). All the computations were performed by hours-long night batches. Simulations were naturally impossible, nor any kind of interactivity between end-users and IS.

In addition, severe misunderstandings between salespeople and industrial planners were caused by divergent product description languages and lack of thorough answers to basic questions: What are the objectives of the respective planning processes of sales and industrial departments? What are the decision variables of each other? What kind of common constraints should be taken into account?

### O.R. Rides to the Rescue

Since we were successful in developing the tools for the planning and scheduling in vehicle plants, our O.R. team was charged with handling the overhaul of Renault's supply chain management IS.

Renault's O.R. team staff varies from three (today) to eight members (at peak time in the project). The team works mainly on logistics, which is sourced to numerous optimization issues. Timid contacts were made with sales and marketing departments, but optimization issues are much less visible in these areas. The O.R. team focuses on the development of optimization components, while the logistics information technology department is in charge of the data management and GUI modules.

A thorough analysis led us towards in-house developments versus generic ERP software, because of the great specifics of Renault product range description (which fit poorly into generic tools frameworks) and the experience of the O.R. team, acquired from the developing of planning optimization tools for vehicle plants. However decision-makers, especially from the sales department, were more interested in "attractive" ERP software, the likes of I2, SAP, Manugistics and so on. Compared to the aggressive marketing of software suppliers, the dull image of the IT department did not help the O.R. effort.

Reluctantly, we started developments of the planning tools with a well-known ERP software. The result could not be worse mid-course. We encountered cumulated problems from our supplier: badly managed transition of the ERP software from a client-server to a Web-based architecture, mismatch between the distinctive features of automotive product range and the framework provided by the ERP software, and misunderstandings between the in-house team and supplier's consultants. After a common agreement (the supplier did admit its failures), we reversed to in-house developments, trashing all the work done with the ERP software (a few men-years).

A MILP-based (mixed integer linear programming) optimization tool (3P) was rolled out in all the NSCs to help them fine-tune their sales forecasts so as to comply with industrial capacities and product range constraints. 3P implements MILP-based, multi-objective goal programming techniques. Taking sales forecasts as inputs, 3P minimizes mix changes needed to satisfy product range and capacity constraints. Sales forecasts are defined as goals, and the objective function is to minimize the sum of slack variables (representing mix changes). The trick was to perform goal programming while remaining in a linear framework, thus taking full advantage of powerful linear solvers like CPLEX or XPRESS.

This optimization is multi-objective, since it focuses first on model mix, then on critical options mix (engine, gearbox), then on secondary options mix. There is an optimization computation at each step, which takes as constraints the objective functions values of all the preceding steps. Such lexicographic implementation of multi-objective optimization may seem brute force; however this approach is well understood and comfortable for end-users. Indeed it is much more difficult for them to define compensation levels between objectives, that is to answer questions like "How much can one lower model mix quality in order to improve critical options mix?" and so on.

"Feasible" sales forecasts are then sent to headquarters, where industrial planners handle a MILP-based optimization tool (OPTIM), which also performs multi-objective goal-programming to define the optimal weekly output of car factories so as to satisfy the sales targets. In this step, very detailed industrial constraints are taken into account, as well as smoothing objectives in the dividing of monthly plant productions into weekly figures.

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| | REN Royaume Uni | | REN Belgique | | REN Pays Bas | | REN Suisse | | REN Autriche | | REN Italie | | REN Espagne | | REN Portugal | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DemFab | FabCalc | DemFab | FabCalc | DemFab | FabCalc | DemFab | FabCalc | DemFab | FabCalc | DemFab | FabCalc | DemFab | FabCalc | DemFab | FabCalc | DemFab | FabCalc |
| D4F | 4646 | 4619 | 289 | 275 | 170 | 162 | 156 | 156 | 122 | 116 | 3362 | 3362 | 1257 | 1257 | 616 | 616 | 21346 | 21349 |
| D7F | 729 | 949 | 505 | 480 | 237 | 226 | 46 | 44 | 162 | 154 | 2792 | 2792 | 1121 | 1065 | 208 | 198 | 17432 | 17453 |
| F4P | 1056 | 1056 | 106 | 106 | 938 | 938 | 109 | 109 | 22 | 21 | 89 | 89 | 321 | 337 | 12 | 12 | 8693 | 8693 |
| F4R | 581 | 552 | 219 | 219 | 358 | 358 | 505 | 506 | 52 | 52 | 120 | 120 | 572 | 543 | 11 | 11 | 6613 | 6614 |
| F5R | 725 | 725 | 24 | 24 | 283 | 283 | 299 | 299 | 14 | 14 | 76 | 76 | 245 | 245 | 20 | 20 | 3402 | 3402 |
| F8Q | 520 | 497 | 369 | 353 | 112 | 107 | 3 | 3 | 96 | 91 | 503 | 492 | 1855 | 1774 | 620 | 593 | 10248 | 9987 |
| F9Q | 2121 | 2026 | 2927 | 2796 | 1343 | 1340 | 219 | 209 | 1396 | 1319 | 3918 | 3743 | 10551 | 10078 | 926 | 885 | 62960 | 60064 |
| G9T | 275 | 262 | 272 | 259 | 184 | 175 | 36 | 34 | 307 | 292 | 337 | 321 | 545 | 519 | 175 | 167 | 9995 | 9521 |
| G9U | 128 | 120 | 61 | 58 | 0 | 0 | 27 | 26 | 15 | 14 | 89 | 85 | 295 | 281 | 0 | 0 | 1992 | 1899 |
| K4J | 2122 | 2122 | 259 | 247 | 376 | 375 | 240 | 228 | 120 | 120 | 669 | 669 | 1113 | 1113 | 536 | 509 | 14294 | 14294 |
| K4M | 3169 | 3169 | 314 | 314 | 928 | 928 | 459 | 459 | 74 | 74 | 1934 | 1934 | 1707 | 1707 | 165 | 165 | 25912 | 25922 |
| K7J | 25 | 181 | 42 | 92 | 53 | 67 | 13 | 134 | 6 | 5 | 110 | 88 | 0 | 0 | 0 | 0 | 3552 | 4266 |
| K9K | 743 | 706 | 482 | 458 | 89 | 85 | | | 156 | 149 | 1662 | 1579 | 2001 | 1901 | 745 | 709 | 20981 | 19936 |
| L7K | 286 | 272 | 55 | 53 | 149 | 142 | 319 | 303 | 35 | 34 | 125 | 119 | 217 | 207 | 20 | 19 | 3631 | 3455 |
| P9X | | | 0 | 4 | 0 | 5 | | | | | | | | | | | 0 | 42 |
| S9U | | | | | | | | | | | | | | | | | 45 | 45 |
| S9W | 0 | 1 | 14 | 14 | 8 | 8 | 18 | 18 | 0 | 1 | 125 | 119 | 0 | 8 | 39 | 39 | 768 | 836 |
| V4Y | | | 0 | 4 | 0 | 6 | | | | | | | | | | | 0 | 46 |
| SEE | | | | | | | | | | | | | | | | | 135 | 129 |
| Total | 17124 | 17237 | 5938 | 5746 | 5228 | 5205 | 2449 | 2527 | 2567 | 2456 | 15911 | 15578 | 21800 | 21035 | 4093 | 3943 | 212295 | 208003 |

**Figure 1: A grid of the OPTIM tool comparing requested engine productions for each European country versus actual production levels compliant with constraints.**

But in order to be used in OPTIM, sales forecasts were first translated into detailed volumes for every vehicle option. Indeed, sales figures were defined by sales managers only in terms of models and a few highly visible options, which is clearly incomplete information for industrial systems. Again an LP-based optimization IS (SAPHIR) is used to generate detailed volumes for every car option as coherent as possible with historical statistical trends, while satisfying sales targets and product range constraints.

Industrial planners also plan the weekly output of power train plants so as to supply engines and gearboxes to vehicle plants. A MILP-based optimization tool (OPM) solves a multi-item, multi-period lot-sizing problem with finite capacities, demand and inventory shortages in order to generate a production plan for power train facilities. Again, the optimization is multi-objective since OPM must: (1) meet the demands of vehicle plants, then (2) maximize the satisfaction of security inventory levels of power train factories, and finally (3) minimize the overall costs (production, inventory and transportation costs).

On the vehicle plant floor, operators handle both the building of a production plan on a day-by-day basis with a MILP-based IS (CARNETS), and the car sequencing of each production day with a simulated annealing algorithm. The car sequence is built so as to smooth the workload on the assembly line and to minimize production costs in the paint shop due to color changeovers in the car sequence, which require the washing of painting tubes.

The O.R. tools described above are all live since the years 2000-2002 at Renault. They were implemented with an in-house MILP-toolkit that is interfaced with well-known linear solvers (CPLEX, XPRESS, LPSOLVE, COIN) and which integrates goal-programming techniques. This toolkit is the result of years of experience in goal programming, solvers tuning, memory and response times optimizations. It now represents a major asset to develop quickly O.R. proof of concept prototypes.

The coherence of all these O.R. tools results from the simple fact that they were hard-coded by the same team. It also demonstrates a complete mastering of Renault's O.R. tools by the in-house O.R. team, whose members are now recognized as O.R. experts within Renault.

With O.R. modeling, we brought a completely new approach to our end-users. Instead of focusing on how they do the planning (all their tricks, heuristics and so on), we define with them what the planning problem is (and not how they solve it): What are the constraints? What are the decision variables? Which objectives are to be optimized? Then we focus on what should be the characteristics of a "good" solution, so as to be sure to take into account all the business rules.

Such questions may seem very basic from an O.R. viewpoint, but they brought a great clarification to business people. An important lesson was that the modeling of the objective function must be validated by business people, even though O.R. technicalities are not easy to grasp for them. But since the solutions quality depends completely on this critical objective function, its modeling is not a mere technical issue.

We also impose the same language for sales and industrial departments, by defining a common body of decision variables, industrial and sales constraints, and objective functions. Each department selects in this body the items

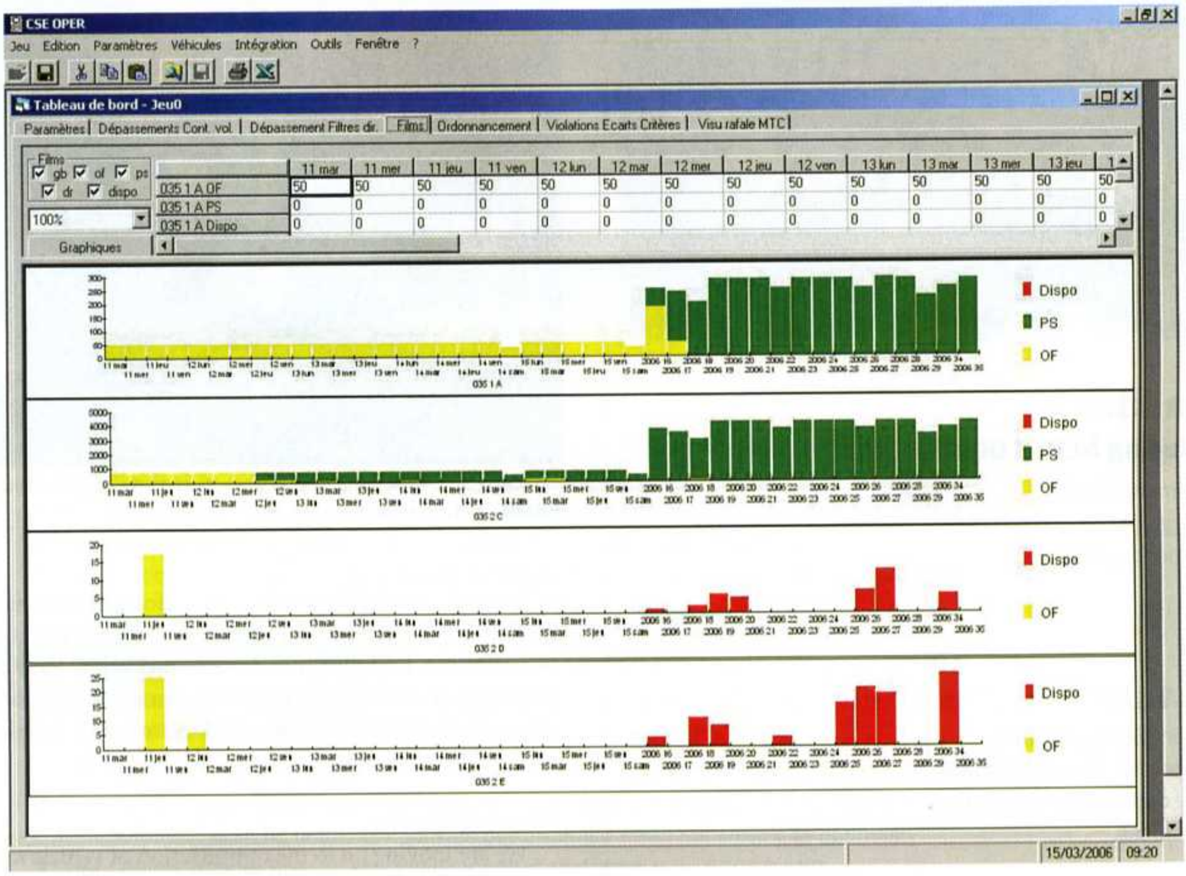


Figure 2: Visualization of the production plan on each assembly line in the CARNETS tool.

relevant to its process. For instance, the sales department focuses on monthly model mix and options mix satisfaction on a country-by-country basis, while industrial planners work on weekly model production volumes on a plant-by-plant basis.

All the O.R. tools were initiated with proof of concept prototypes that enable us to get validations from end-users before going into full-scale software developments. These prototypes were critical in getting user validation, since more often than not the business process is overhauled with the arrival of optimization tools, and it is quite difficult for end-users to validate on paper only the couple new process-new tool.

Thanks to the highly visible level of the New Delivery Project (it was called the CEO's project!), we could make the top management take the major and clarifying strategic decisions, so that O.R. tools can follow crystal clear and undisputed directions in optimization objectives. For instance, it was stated that in factory production planning, the satisfaction of customer delivery deadline outweighs cost optimizations. Period.

### The ROADEF Challenge

After the complete rollout of the supply chain management O.R. tools in the years 1999-2003, came the stress of the top management on further production costs optimization. We cited above an in-house car-sequencing tool based on a simulated annealing algorithm. It was rolled out in 1993. In 2003, plant operators were complaining about the poor quality of car sequences (too many color changeovers and mitigated satisfaction of assembly line constraints). They asked for an overhaul of this algorithm.

In order to benchmark the best O.R. algorithms, we submitted the Renault's Car Sequencing Problem to a competition among O.R. teams, the ROADEF Challenge, hosted by the French O.R. society (ROADEF). The competition attracted a record 55 research teams from Europe, Canada and Brazil.

The results were so astounding that we acquired the winners' code and put it into production in our plants. Although we did not expect such an outcome, we did specify the real-life problem with real-life data and impose execution time constraints (runs were limited to 10 minutes on a Pentium-IV PC). In return, we were able to plug-in quickly the winner's local search algorithm in our car sequencing tool with very few adaptations. This algorithm is clearly a

**The winning team in the ROADEF Challenge - three Ph.D.s from the University of Marseille - won out over senior researchers.**

best in class. One telling statistic: It performs more than 140 million evaluations of the objective function in the 10 minutes runtime! Decision-makers were thrilled by the ROADEF challenge. If only they could benchmark all Renault's IT software among world class competitors, and acquire the best for their business!

### Ongoing Issues

We are moving on to the optimization of vehicle routing from plants to dealerships via intermediate dispatching centers. It implies: (1) building a pool of cost and time-efficient paths through Renault's worldwide transportation network, then (2) assigning a transportation schedule (i.e. a path from the pool and departure/arrival dates) to every vehicle leaving daily the assembly line. The first step can be modeled as the K shortest paths problem under the following constraints: no circuit and no more than P arcs in a path. It is tackled with an adaptation of the Bellman algorithm, combined with heuristics. The second step is dealt with column generation, with the sub-problem modeled as a shortest path problem.

In conclusion, O.R. techniques made a major contribution to overhaul Renault's supply chain. Decision-makers do see the benefits of O.R. tools: cost reduction, better organization, cost-based decision-making and last but not least, better coordination between sales and industrial departments. Still, there remain uncharted fields in the supply chain to apply O.R. techniques: inbound logistics, which involve vehicle routing and 3-D bin-packing problems; optimization of logistics on a worldwide basis (instead of an European basis today); and twin optimization with our Nissan partner.

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