

Spicer Off-Highway Products Division— Brugge Improves its Lead-Time and Scheduling Performance

Nico J. Vandaele

*UFSIA, University of Antwerp
Prinsstraat 13
2000 Antwerp, Belgium*

Marc R. Lambrecht

*Department of Applied Economics
Katholieke Universiteit Leuven
Naamsestraat 69, 3000 Leuven, Belgium*

Nicolas De Schuyter

*Spicer Off-Highway Products Division
Ten Briele 3, 8200 Brugge, Belgium*

Rony Cremmery

Spicer Off-Highway Products Division

Spicer Off-Highway Products Division (a division of Dana Corporation) asked us to develop OR tools to improve the due date performance and to shorten the manufacturing lead time of its powershift transmission plant in Brugge, Belgium. We modeled the manufacturing system as a queueing model and used the model to analyze and evaluate improvement schemes (layout changes, product-mix decisions, lot-sizing decisions, and lead-time estimations). Next, we developed a finite scheduler to improve the detailed scheduling of the shop. Our modeling effort contributed to the successful combination of analysis, planning, and detailed scheduling. The plant increased productivity by 27.3 percentage points, decreased manufacturing lead times by a factor of two to three, increased its workforce by 41 percent, and decreased its operating costs. The division is now profitable.

Dana Corporation was founded in 1904 in Toledo, Ohio and now operates 330 production facilities and 38 research-and-development centers in 32 countries. It has 86,000 employees, and its 1998 sales were \$12.5 billion. The corpora-

tion consists of seven major business groups: automotive components, engine components, heavy truck components, off-highway systems, industrial components, automotive aftermarket group, and Dana commercial credit. The Spicer Off-

Highway Products Division is part of the off-highway systems group. It serves the off-highway vehicles market, including rough-terrain cranes, underground loaders, compactors, graders, excavators, dumpers, scrapers, specialty vehicles, and off-highway trucks. This group operates 15 plants. One of these plants is Spicer Off-Highway Products Division (SOHPD) located in Brugge (Belgium). SOHPD employs 680 people and realized \$150 million in sales in 1998. It serves the OEM (original equipment manufacturers) market with drive-train components, such as transmissions, torque converters, axles, and brakes. In producing transmissions and controllers, the division's core competence consists of the production of valves, clutches (shafts and gears), transmission cases, converter housings, and controller hardware and software. The Bruges plant is Dana's worldwide R and D center for powershift transmissions.

The Business Case

Success in the business of supplying drive-train components for OEMs depends on technological competence and on the ability to deliver fast and on time; otherwise, niche producers will rapidly take over part of the business. Moreover, the high-technology product line faces product proliferation, and consequently, we have to deal with small-volume production in a highly uncertain assemble-to-order environment.

At the start of the project, in 1993, the total (average) manufacturing lead time was 16 weeks, whereas the customer lead time was on average four weeks. In other words, the plant performs a lot of manufacturing operations before it obtains the

customer's commitment. The costs of mismatches are considerable (stock excesses and shortages, frequent rescheduling, inefficiencies in production, and so forth). SOHPD produces some 460 different end products; 80 percent of these end items have an annual volume of less than 50 units (the mode is five). This results in an enormous variety of make parts, mostly produced in small volumes. Fifty percent of the parts have an annual volume of less than 100 units.

Back in 1993, our case company had a hard time managing this complex environment. The plant layout was a typical job-shop arrangement and its MRP system (manufacturing resources planning) could not deal with capacity problems and detailed scheduling. The poor operational performance eroded sales, and a negative spiral of events forced the managers to downsize (going from 1,000 to 480 employees) and to start a series of reengineering projects. They asked the management science team of Katholieke Universiteit Leuven to develop a finite-capacity scheduling system to remedy the scheduling problem. At that time, management had already recognized the by now very-well-known flaws in MRP (ERP). The scheduling system in use was based on local, myopic priority-sequencing rules.

The management science team and the management team soon found out that, although finite schedulers are powerful tools, they could obtain the full leverage effect and the long-term impact of the modeling effort only by embedding the finite-scheduling routine in a much broader context. We had to include OR tools to answer such questions as: What

are realistic lead-time estimations, what are lead-time-minimizing lot-sizes, how does a change in layout (for example, cell manufacturing) affect lead times, what is the impact of order acceptance, work release, and due-date assignment on the performance of the scheduling system, what safety time buffer do we have to use? All of these questions are related to planning and analysis. We redesigned the project so that we could answer these questions.

A queueing-network approach was suggested. We linked queueing models and

Fifty percent of the parts have an annual volume of less than 100 units.

scheduling routines, and we integrated OR tools for evaluation, planning, and analysis with tools to perform detailed scheduling. A six-year-long fruitful cooperation between management scientists, managers, and machine operators started.

The Original Planning System

The process of producing powershift transmissions is roughly a four-step process. First are rough machining operations on raw steel parts (forgings, bars). This takes place in the cold (soft)-steel shop. Second, the steel parts are hardened through a heat treatment. The third step consists again of machining operations but now on the hardened parts. This takes place in the hard-steel shop. The fourth step is a final assembly operation in which the rotating steel parts are built into housings. The housings are produced in the casting department. Our study deals with the planning of the rotating steel parts and more specifically the planning of the cold-

steel shop (Figure 1). In Figure 2 we give a detailed view of the cold- and hard-steel shops.

Material handling is done by AGVs (automotive guided vehicle) and an AS/RS (automatic storage and retrieval system). The AGV system moves the parts from the cold-steel shop to heat-treatment and brings them back to the hard-steel shop. The AS/RS stores all the steel parts' work in process. The pallets containing the steel parts move automatically to the input section of the machining center when that particular operation is activated or released. Machine operators make use of a queue list (called the queue manager) and determine in a myopic way the sequence of the jobs to be done. They can activate the AS/RS: Parts are moved automatically to the machine and subsequently moved to a temporary stock location in the AS/RS, from which they move again to another machine center until all operations are performed. The shop orders are generated by an *MRP II* (manufacturing resource planning) system, discussed later. The manufacturing lot sizes are fixed at one, two, four, eight, or 16 weeks of supply (power of two reorder intervals). Due to the large variety of parts, the high precision required, and the small volumes, most of the steel shop was originally organized as a job shop, with a lot of general-purpose machinery grouped in a functional way, in which products follow their own routings through the shop. The cold-steel shop has 70 machines and it fabricates 556 parts, requiring a total of 3,484 operations. The MRP system generates some 10,000 shop orders per year.

To conclude the description of the origi-

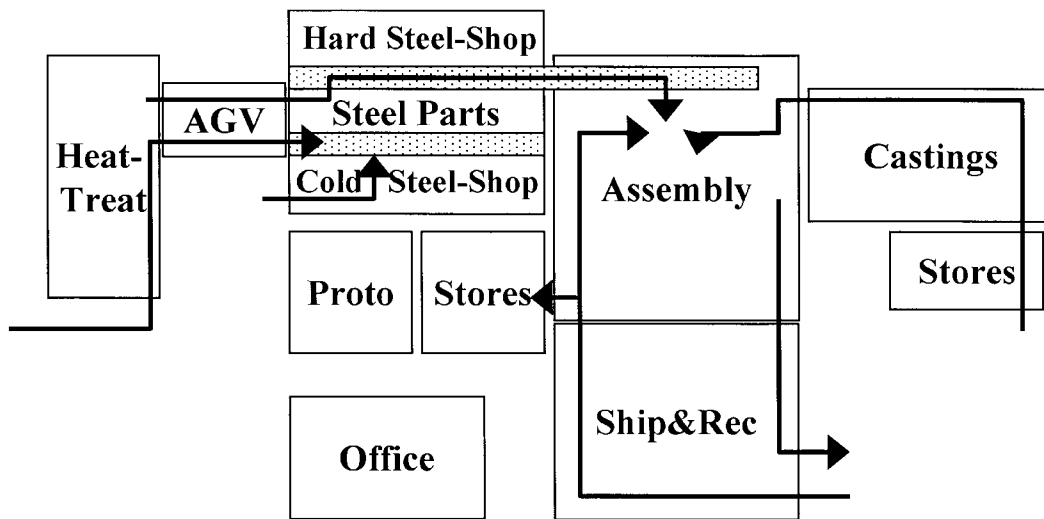


Figure 1: The four-step production process of powershift transmissions includes the cold-steel shop, heat treatment, the hard-steel shop, and final assembly.

nal planning approach, we have to mention the role of the MRP system. With respect to the final customer, SOHPD follows an assemble-to-order strategy. It results in a final assembly schedule (FAS), and the material-requirements routines translate the FAS into requirements for the hard-steel shop and the heat-treat department. The planned order releases of the heat-treat department in turn determine the production requirements for the cold-steel shop. The cold-steel shop and the heat-treat department typically operate in a make-to-stock environment. After heat treat, the plant switches to an assemble-to-order mode. In Figure 3, we summarize the lead-time structure.

Planning and scheduling the cold-steel shop are crucial. The problems encountered in this extremely complex cold-steel shop were summarized by Thierry Tant, manufacturing manager, in a meeting in 1997: The MRP system is a good calculator, but on the shop floor and on a

minute-to-minute basis, we suffer from anomalies caused by rigid lot-sizing rules, predetermined lead times, the infinite loading practice, uncoordinated material and capacity plans, and a sequencing of jobs based on myopic priority dispatching rules (called the queue manager). The availability of a dispatch list for each machine is a step forward, but it's not enough. Every single planner we have in the plant is fully aware of what is called in every handbook the garbage-in, garbage-out syndrome and, guess what, I am afraid this is exactly what we are experiencing.

The diagnosis is clear. Installing a finite scheduling system alone won't do the job. The real problems are rooted at a higher, more aggregated decision level; such issues as lot sizing, the capacity structure, order acceptance, and release policies are to be settled first. We have to reconsider all of our procedures and all of our parameter settings, we have to change our

shop-floor layout, we have to analyze the capacity structure, we have to involve our engineers to modify the design of our products and to improve the setup times, and we have to convince the sales-order-entry people that they are key players in the whole process as well.

All of this resulted in the development of ACLIPS: A Capacity and Lead Time Integrated Procedure for Scheduling [Lambrecht, Ivens, and Vandaele 1998].

The New Planning and Scheduling System

ACLIPS is a hierarchical model in which we link a number of applications into an integrated planning and scheduling sys-

tem. The management science team spent seven person-years developing and implementing the system. Implementation was gradual and was accompanied by a training program for the management team and the supervisors. We estimate that the training took a participation effort of 150 person-days. During the seminars, we focused on basic insight in operations management as described, for example, in Hopp and Spearman [1996]. We discussed the impact of variability and bottlenecks on response times. Stochasticity was a key concept in every discussion. We found this an extremely helpful way to involve many people, and it made them less resistant to

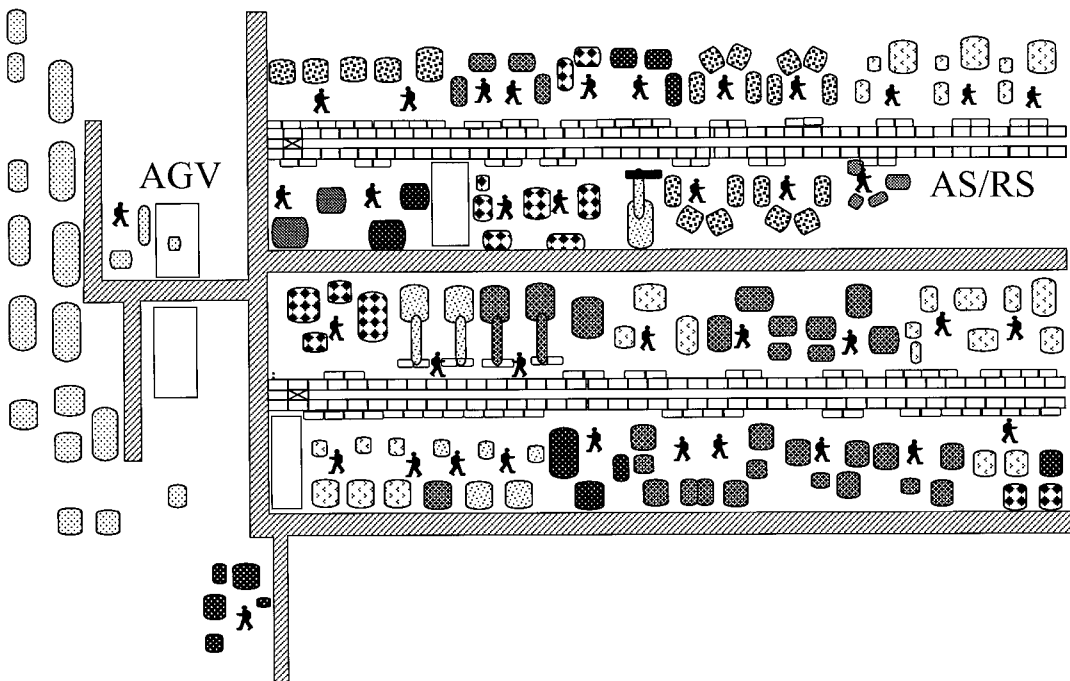


Figure 2: This detailed view shows the hard-steel shop (top part), the cold-steel shop (lower part), the AGV (automotive guided vehicle), and the AS/RS (automatic storage and retrieval system). All machines are arranged around two high-stacker cranes. At the start of the project, machines were typically arranged in a job-shop layout. Later on in the project, management decided to adopt cellular manufacturing

ACLIPS implementation. The queueing model can be used to evaluate the impact of a cell layout on lead times. Indeed, management decided later on in the project to implement cellular manufacturing. Analysis of the product mix (unique product, repeat orders, large and small volume orders) is another interesting issue that can be tackled with the queueing model. The tuning phase is an essential intermediate stage before diving into finite scheduling. Phases one and two are typically executed once a month.

Third is the scheduling phase, which fo-

cuses on three decisions: (1) grouping requirements orders into manufacturing orders, (2) determining the release date for each manufacturing order, and (3) determining the detailed sequencing of all operations. The queueing model (phase 1) produces target lot sizes, which indicate how requirements have to be grouped into manufacturing orders. Recall that the requirements refer to the planned order releases of the heat-treat department. Given the time-varying nature of these requirements, the manufacturing orders may actually differ from manufacturing order to

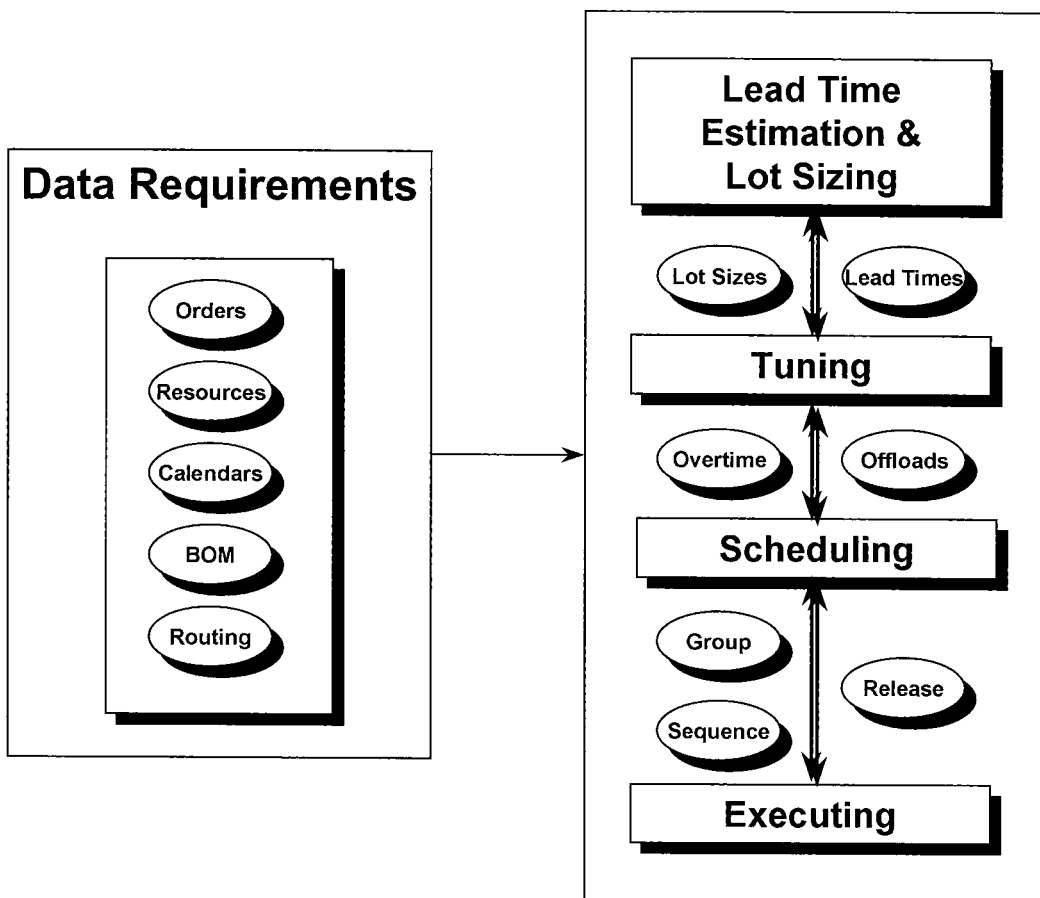


Figure 4: ACLIPS follows a four-phase hierarchical approach combining short- and long-term considerations and stochastic and deterministic planning issues.

manufacturing order, but on the average we aim for lot sizes that minimize the expected lead times (and work in process).

The second decision is the determination of the release date of the manufacturing orders. The release date is set equal to the due date minus the lead-time estimate of the manufacturing order. The estimate of the lead time is equal to the expected lead time plus a safety time. The safety

A four-hour intensive training session on production planning and scheduling is part of the training program for all employees.

lead time depends on the customer service. The lead-time estimate is such that we expect to satisfy customer orders on time, at least 95 percent of the time. This requires knowledge of the variance and the probability distribution of the lead time. Each order is now characterized by a time window; we hope that the estimates of the time windows are robust so that the plant meets most of the due dates, avoiding a constant need to replan. We do not treat lead time as a fixed and predetermined parameter; on the contrary, we constantly adjust the lead time to reflect the actual lead times. In this way, we avoid the lead-time estimate becoming a self-fulfilling prophecy.

The third decision concerns the sequencing policy. In the previous step, a time window (expected lead time plus safety time) is created for every manufacturing order. Within these windows (one for every manufacturing order), we now have

to sequence all operations in detail. We opted for the shifting-bottleneck procedure [Adams, Balas, and Zawack 1988] for various reasons, one being its excellent performance as described by Ivens and Lambrecht [1996]. The shifting-bottleneck procedure has to be adapted so that it can be used to sequence the operations for our general job-shop environment, which include assembly operations, release dates, due dates, overlapping operations, multiple resources (machines and labor), setup times, calendars, and many other real-life features. This sequencing application can clearly be interpreted as a deterministic real-time scheduler. It does not conflict with the previously described stochastic applications; on the contrary, the applications are complementary.

In the fourth and final phase, we transfer the detailed plans to the shop floor on a real-time basis. Through electronic data captation, information concerning the execution of the detailed plans is fed back so that rescheduling can be done. The nature and frequency of rescheduling heavily depends on the dynamics of the situation and the level of responsiveness required.

Methodological Issues

Our model builds on two well-known OR tools: queueing approximations and job-shop-scheduling algorithms. We had to modify both and add features to make them suitable for practical applications. [Vandaele 1996; Ivens 1997].

We adapted the queueing model along the following lines. We wrote expressions for the expected lead time and the variance of the lead time as functions of the lot size. The model also explicitly includes setup times. Vandaele [1996] further ex-

tended existing approximations by including the following refinements: the average aggregate-batch-processing time, the squared coefficient of variation of the aggregate-batch-processing time, the selection of appropriate weights in the objective function, the determination of the squared coefficient of variation of the aggregated-external-arrival stream, a modified approximation for the variance of the lead time, the use of the lognormal distribution to approximate the lead-time-distribution function, and the introduction of the concept of customer service. Simulation experiments [Lambrecht and Vandaele 1996] show that the approximations are accurate. The scope of the theoretical job-shop-scheduling problem is too limited to be applicable in practical environments. Ivens [1997] extended the shifting-bottleneck procedure so that non-standard features, such as release dates, assembly structures, split structures, overlapping operations, setup times, transportation times, parallel machines, resource calendars, and alternative performance criteria, could be considered.

An efficiently written computer code is extremely important both in terms of internal memory requirements and execu-

tion time. We coded all mathematical procedures in C++ and designed a user interface (Borland Delphi). SOHPD did a tremendous job in making accurate data available.

Benefits and Impact

The benefits and impact of our project are summarized in Table 1. We first examine the quantitatively measurable improvements for both Spicer Off-Highway Products Division and the community at large. For SOHPD, we improved lead times, inventory turns, and productivity. To verify the lead-time performance with ACLIPS, we conducted the following computer experiments. In the first planning experiment, we evaluated the existing planning practice. The current planning practice involves the use of heuristically determined lot sizes (fixed at one, two, four, eight or 16 weeks of supply) and the use of local, myopic priority rules for scheduling. In the second experiment, we set the lot sizes as obtained through the optimization routine and did the scheduling with our extended shifting-bottleneck procedure. The exact problem size concerned 556 different components, 70 machines, 3,484 operations, and about 10,000 orders (cold-steel shop). To make things

	SOHPD	Community at large
Quantitative benefits	50%–60% lead-time reduction from 3.5 to 6 inventory turns 27.3 percentage points productivity improvement	41% workforce increase 66% sales improvement
Qualitative benefits	Development of supporting activities OR/MS awareness, training programs Benchmark for new implementations	Leveraged MRP/ERP OR and competitive advantage

Table 1: Both SOHPD and the community at large gained quantitative and qualitative benefits from our project.

comparable, we used the ACLIPS model (the lead-time estimator and the finite scheduler) for both experiments but, of course, they had different parameter settings. The conclusion is that the average lead time (for the cold-steel shop) per order can be reduced by a factor of three to four. We figured out that 85 percent of the lead-time improvement is due to a better lot-sizing policy and 15 percent is due to improved scheduling [Lambrecht et al. 1998]; This lead-time reduction is based on a computer experiment. Real-life data show that the lead times for final products decreased from the original 16 weeks on average to lead times in the range of six to eight weeks. A lead-time reduction by a factor two to three is a realistic estimate.

A secondary effect of this lead-time reduction is a significant reduction in internal quality problems, and yearly inventory turns have increased from 3.5 to 6.0. A relentless search to reduce the total manufacturing lead time has led to a completely new layout of the plant, focused on cellular manufacturing. This was possible only after managers made a strategic decision, supported by activity-based costing-information, to outsource all noncore processes and components.

SOHPD also uses a simple but effective productivity-performance measure. The output of the company is translated into total numbers of standard hours produced

(earned hours) and compared to the total direct hours (present hours). The ratio of standard hours produced over total direct hours is a measure of the direct productivity. This measure accounts for all kinds of outages. The standard times for the operations are regularly adjusted to reflect process improvement. The combined effect is called productivity improvement in Table 2.

SOHPD's business success has had a measurable impact for the community. The measurable impact for the community can be derived from the overall business success of SOHPD. The total number of employees increased by 41 percent over the period 1993 to 1998. Over the same period, sales per full-time equivalent improved by 66 percent.

The qualitative impact of our project is important. The ACLIPS model is a small component in the network of logistics activities that supports the business strategy. The use of the OR model induced several other supporting activities. For example, the data required to run the shifting bottleneck-procedure are such that the systems department had to develop several specific tools to obtain the data in a structured and systematic way. Each machine operation is now identified by its five most important setup characteristics ranked in order of changeover time required. This allows us to implement a

	1993	1994	1995	1996	1997	1998
Direct productivity	60.6%	65.5%	67.5%	67.8%	70.6%	72.6%
Standard time reduction	0.0%	2.9%	2.3%	2.8%	4.2%	3.1%
Productivity improvement		7.8%	12.1%	15.2%	22.2%	27.3%

Table 2: Direct productivity equals earned hours (standard processing time) over present hours. The standard times are regularly adjusted; consequently, the sum of both measures fairly accurately describes productivity improvements.

sequence-dependent setup-time routine to minimize the setup-time loss. Indices to measure product variety were developed as well. SOHPD also developed a monitoring system to manage the projected availability of raw materials against the planned release dates of manufacturing orders. It thereby coordinates its capacity and material plans.

The ACLIPS project has fostered a general awareness for scheduling and planning issues throughout the whole organization. Operations management issues are on the agenda for training management and also for training shop-floor workers. As a matter of fact, a four-hour intensive training session on production planning and scheduling has become an integral part of the training program for all employees. A final qualitative benefit for SOHPD is that the production-planning and control system of the plant in Bruges is used as a benchmark for the implementation of a new Y2K compliant planning system for the plant in Statesville, North Carolina.

Finally, we believe there are also important benefits for the community. First, the insights obtained from the ACLIPS approach are applicable to a wide range of manufacturing companies. It remedies some basic flaws in MRP/ERP. Second, we have a more general reflection that puts our work in an industrial policy context. European manufacturers operate under severe cost pressures. The high cost of labor and restrictive practices are often

cited as major competitive disadvantages resulting in the delocalization of manufacturing activities. The SOHPD case shows that a focus on optimization accompanied by supporting, complementary activities can easily outweigh these disadvantages. Our project shows that a coherent bundle of OR tools creates a competitive advantage.

Executive summaries of Edelman award papers are presented here. The complete article was published in the INFORMS journal *Interfaces* [2000, 30:1, 83-95]. Full text is available by subscription at <http://www.extenza-eps.com/extenza/contentviewing/viewJournal.do?journalId=5>