# Dramatic Reductions in Lead Time at Volvo Based on Restructuring the Design Process and Introducing Computers

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## Summary

For a relatively small company, Volvo has made substantial progress in design technology. In some areas, such as centralized design-development and paperless design processes, Volvo is on a par with some Japanese companies and ahead of some European and American rivals. They are keenly aware that design is a process just like typical manufacturing processes. Like manufacturing processes, the design processes must be studied, rearranged, analyzed for their pacing operations and required information, and redesigned for greater efficiency and higher quality output. Volvo is also the first place I have visited where there is an appreciation for the fact that conflict is an essential part of design, not a symptom that people can't get along.

## Background

Volvo was founded in 1927 and today has about 30,000 employees. In 1989 it sold over 400,000 cars while in 1991 about 310,000 were sold.[1] Most of its production capacity is in Sweden, but there are plants in Belgium, The Netherlands, and Canada. About 2600 employees work in engineering, design, and development. Volvo has been a pioneer in car safety and in car assembly methods. Among its most interesting plants is one at Uddevalla that has teams of people who assemble an entire car. At both Uddevalla and Kalmar the cars are carried by automatic guided vehicles (AGVs) rather than conventional moving conveyor lines. But both of these plants produce relatively few cars per year, about 18000. The big plant at Gothenburg makes five times as many using a conventional line arrangement. Their most productive plant is in fact the one in Ghent, whose output is about the same as Gothenburg's.

The question of whether teams or lines are better is not really the subject of my visit or of my European study in general, but it is interesting because it has implications for design and manufacturing in general. Henry Ford used teams in the early 1900s and found that the workers spent too much time fetching parts. Even walking a few feet takes too long. The moving assembly line was the solution. At Volvo, lines caused high absenteeism and employee turnover.[2] Several solutions have been tried, including one team per car

[1] It's amazing for an outsider to note the small population of such countries as Sweden and Belgium (8.6 million and 3 million, respectively). If the ratio of the US population to Sweden's population is multiplied by the size of Volvo, one gets 924,000, more than all the US car builders combined. Thus proportionately, Sweden's car industry is bigger than ours. In addition, Sweden has Saab, ASEA, Thyssen, SKF, and other fine engineering companies.

[2] They did the same at Ford, too. This is apparently why Ford raised its wage to $5 per day in 1914, an unheard-of and revolutionary action. It launched the US as a high-wage manufacturing country, a fact that benefitted millions of people for decades but is hurting us now as we try to compete against other, newly emerging nations.

(Uddevalla) and one team per system, such as exhaust or electrical (Kalmar). Both suffer from lost time due to errors because each person must remember many operations or look up instructions. By Volvo's own experiments, the actual assembly time in one of their cars is less than 18 man-hours, but in the factory it takes 30 - 40 due to logistics and rework overhead. Lines are better in this respect.

However, lines are difficult to use when several car models must be made at once in unpredictable ratios. Volvo does not capitalize on its freedom from this restriction in its non-line plants because each plant makes one model. Nissan seems to be ahead in using non-line arrangements with AGVs to make many models in what is coming to be called "lean-flexible" or "agile" production. Few US companies have tried this. It is not clear what the implications for design are, although my past reports on Nippondenso and Telemechanique show that design can play a big role in improving the producibility of high-variety products with only a few parts (less than 100, say). Volvo will have to learn agile production and give up some old habits, said one of my hosts. One of the new challenges is how to be flexible without being more costly. Right now, no one believes it is possible.

### Outline of the Ideal Car Design Process

My host, Mr. Kurt Larsson (General Manager of Computer-Integrated Manufacturing) explained the process they are moving toward. Design and development take place at the central facility in Gothenburg. Here, stylists, engineers, production engineers, and the prototype manufacturing facility are located together, a development that only some Japanese companies and Chrysler have achieved. Car development is based on forming project teams with a single design manager, a process that has been used in various forms for nearly 10 years. At present, the design manager does not have full budgetary control, so his power is less than it should be. Also, there are too many extra "helpers" on each project. Finally, complete paperless data flows have not yet been achieved.

### Concept Design

With these caveats, here is the process. It is based on "keeping control of the whole vehicle" as one data package and set of design tasks. First, there is the typical process by which concepts are produced and evaluated. As described by Mr Per Isaksson, it is surprisingly well-integrated in software, perhaps as well as at Toyota. (Starting in the 1970's, Volvo was one of the first car companies to integrate styling and engineering, says Mr Dan Ahlen, whose historical perspective is given later in the report.) This integration includes combining styling with aerodynamic studies, crash simulation, stress analysis, quality and fitup, interior design, and manufacturing planning. All of the output is fully CATIA-compatible, and Volvo is gradually standardizing on CATIA for its CAD/CAM.

In one sense, Volvo's concept design process is more computerized than Toyota's since stylists can work directly on the computer rather than with clay, although only three do it so far. The software being used for this is called ALIAS, made and sold by people who spun off from Silicon Graphics. It makes surfaces from Bezier polynomials; the stylist can deform the surface freely by grasping control points on it. A stylist demonstrated this for me with a model of a car seat. (Note that this "same" capability is the subject of research at MIT and is called "new to CAD" by Dassault Systemes. I do not know whether I am missing an important point here or whether research is not as far ahead as researchers think.) ALIAS is fully compatible with CATIA.

I asked the stylist what it was like to use this method. I wondered aloud if working with clay was primarily a hand-oriented effort that did not carry over into the CAD environment. (For example, would some virtual reality help him, though I did not ask him this.) He replied that he felt styling was primarily a matter of eyes, not hands, even if the output was a clay model. So when the output is a computer drawing, he is apparently quite at home.

Larsson pointed out that CATIA can be used to cut the stamping dies from the surface model, but CATIA does not help with the rest of die design, such as the clamps or analyses of formability. The closed nature of CATIA has kept Volvo from adding such software itself. Toyota's solution (write their own from scratch to do all these tasks) is too costly for Volvo.

Volvo is able to exchange concept design data with its studio in Los Angeles. Designs can be made there, sent to Gothenburg for milling into clay models, and critiques can be sent back electronically to LA.

### Detail Design

After the concept is approved, detail design begins. This is a much more disciplined process than concept design. The full dataset is parcelled out as individual part models and packaging tasks (grouping parts into relationships with each other such as under-the-hood). Part models are designed in detail while packaging studies are done by manufacturing and assembly people who simulate their processes. These people also produce soft tooling, capable of making only prototypes but otherwise quite accurate, from which trial cars are built and crash tested. When these cars are assembled, "no hammers are allowed," meaning that every assembly problem is recorded on the CAD model. These results, as well as crash test results, are fed back into the master database and the design is improved.

Thus technology enables a social problem to be solved along with a technical problem. The social problem is that people do not recognize the information value of mistakes, so they try to hide them. The technical problem is that people think the prototype assembly process is supposed to find errors in the tooling, whereas the real purpose is to find errors in the design. Keeping control of the data all the way around the design-prototype-error-reporting loop is essential for solving both problems.

### Side Comment

Larsson would like to extend to the factory floor the process of recording problems into the CAD database, because the employees have so much untapped knowledge about design problems. "First, we have to turn the company upside down so that the workers are on top. Then we have to facilitize them with terminals. Right now secretaries have terminals. Once the workers have them we could take advantage of multi-media computing and give them little TV cameras and microphones. They could document their problems directly into the database where designers could see them very vividly."

This is a great idea and it has research implications, too, because one must link the problems to the right places in the design data. How are those places to be found? The issue is larger than finding the design of the part that is in the TV picture, because a diagnosis must be made. It is likely that the part in the picture is not the one causing the problem. It takes a lot of knowledge to decide where the culprit is, and why (a process out of control, a supplier whose parts or materials have drifted out of spec...). So, again, we find that a product data model must have information links in it that say what affects what under what circumstances.

**Final Tooling Design**

Outside the prototype verification loop is the final design of the factory and its equipment. Fixture design is done by using numerical models of the parts so that they will fit together. This is also done if the machines and fixtures are to be bought from outside suppliers. It is not clear what percentage of all final tooling and factory design is done by computer, but the fraction is rising.

Numerical data are also used in ordering many of the parts from outside. To support this process Volvo has established a computer department equipped with data translators that will convert CATIA to many formats compatible with the suppliers' CAD systems. Volvo is also an invited partner in the German car industry's supplier data standardization project. (More on this in the VW report.) A chart shown by Mr Mikael Diedrichs indicated the size of data traffic now going on: starting in 1987, Volvo sent out about 2000 CAD models per year using disks and tapes; today the number is 12,000 and rising rapidly. Such models are typically 0.5 to 1.5 megabytes each. (In the same time period, says Diedrichs, BMW's traffic rose from 2000 to over 40,000 models!) Starting in mid-1990, direct telephone data transmission has begun using the X25/OFTP protocol. This European standard is being tested by Volvo and six of its suppliers. About 4000 CAD models per year are sent this way.

The shortcomings of CATIA limit the amount of factory simulation Volvo can do. For example, robots can be programmed from part data to spray paint but not to weld car bodies. Other software is used for that. Also, CATIA cannot hold large solid models of many parts so that interference checks (part-to-part, part-to-robot, etc.) can be done. The Japanese I visited said the same thing.

However, CATIA's firm solid model permits Volvo to employ data conversion and communication with suppliers with confidence, whereas they have no such confidence in converting ordinary 2D models made by drafting software. This shows that mathematical research efforts to create logically consistent 3D models have paid off in a serious way. CATIA's historical evolution from 3D to 2D (see Dassault report) may put it in a good position to solve the 2D conversion - transmission problem.

Altogether, they estimate that the use of CAD and numerical control has cut body engineering time by 50%. They are now turning their attention to power train design, namely engines and transmissions. This is discussed below.

### Origin and Maturing of Volvo's Current Product Design Methodology

According to Dan Ahlen, Volvo started CAD in body engineering in the early 1970s; by 1980 all of body engineering was being done by computer, using a mix of commercial and inhouse software. This has enabled Volvo to carry on several vital engineering activities in parallel rather than in series. One of these is checking that the separate designed panels fit together properly. This used to be done in a model shop. When the shop was satisfied, it built wood patterns from which stamping dies were made by copy-milling machines. The shop had all the "information" and thus tended to run the entire design process. The process stepped ahead when the shop released its information and not before. When numerical control took over, an important power shift in the organization occurred, not without some problems on the way. Volvo still views the design process as a matter of establishing, freezing, and releasing datasets.

The process of fitting up has also matured from pair-wise checks to a hierarchical check. For example, the size, shape, and tolerances of doors are driven by corresponding data for the door opening. This sort of thing cannot yet be done in power train design because that department still uses 2D drafting software.

Volvo also still struggles with the problem of individual power centers that do not see "the whole vehicle," a way of saying that implementing concurrent engineering is difficult. Most companies encounter similar problems: the product is complex and is thus divided into subsystems to reduce complexity and focus expertise on individual areas and technologies. Each subsystem used to be designed by its own organization, leading to a great deal of conflict as each group tried to optimize its system. Volvo has gradually converted from this departmental structure to a project structure, but the old problems still remain to some extent because the project leader does not have complete control.

### The Integrated Engineering Approach

The process of maturing the power train (and chassis) designs appears to be following a more deliberate path than in body engineering. Perhaps the participants learned from their 1970s experience. Perhaps body engineering is not as complex. In any case, Ahlen and Larsson have given the process a name: Integrated Engineering. They have also developed a procedure for accomplishing it and tried it out on some individual parts. Now they are in the process of trying it on entire engines. For this purpose, Larsson's department has taken on the responsibility for modeling design processes, redesigning the processes, and proving to the designers that they can cut 50% or more from the time they currently take.

The main problem they face is demonstrating to people, management and engineers, that design contains inherent conflicts. When one person "improves" his part of the design, it can hurt some other part. When such "improvements" are factored into the design, or when problems with fabrication or assembly are discovered, changes must be made. The resulting revisions slosh through the process in waves lasting months.[3] The designers do not realize that this truly dynamic oscillation is due to their own actions, and they blame management for constantly changing its mind. "No one has an overall view of the process," said Ahlen. This too is typical of large design processes, as I can report from personal knowledge of research MIT has done in several US companies.

To counter this set of problems, Larsson's people have been constructing information flow maps for complex designs. Their first attempt was quite complex itself. It shows an entire power train part by part and system by system, seeking to represent how each affects the others (geometry, force, heat) as well as how it affects the customer (noise, power, smoothness). This diagram helped the designers to understand some of the interactions but it did not help with making the process more efficient.

To get a more specific model, the team has focussed on single parts and will move back to whole systems later. Two projects were described, one for a connecting rod and one for a steering knuckle. Both are critical engineered parts where weight, strength, and safety are vital issues. The design process for each was cut from typically 40 weeks to 20 or less. They are now confident that similar reductions are possible everywhere at the single part level.

I got some details about the steering knuckle project. (See Figure 1) This used to be a long and highly iterative part to design for two basic reasons. First, some design decisions had to be revised after the supplier was chosen. Second, some design details often led to the need for careful hand finishing of the parts to avoid stress concentrations and possible field failures. Both of these caused extensive delays while the part was redesigned and reanalyzed.

The supplier-related problem is interesting. The part is forged, and the issue is to choose the draft angle of the forging die. This angle is directly transferred to the finished part, so any FEM analysis will be affected by choice of draft angle. These analyses take a long time, and redefining the CAD model to change the angle also is cumbersome. Unfortunately, the supplier who won the contract often could not deliver at the original draft angle (smaller angles are harder to achieve). thus the lengthy design and analyses had to be done over. To avoid this iteration loop, the integrated engineering team had to convince the purchasing department to permit the supplier to be chosen early in the design process, before a design existed and thus before the supplier could bid. Competitive bidding is thus ruled out. The net effect is still a win for Volvo due to the reduced design time.

Figure 1 (at the end of this paper) is thus a time/technical structure, rather than a pure schedule. It is, however, only a summary of the detailed information that the team developed and hardly reveals the depth of understanding they had to reach. About 30 skilled and experienced people were required. Larsson's people facilitated the discussions, aiming to find a linear path through the design decisions. In particular, the things they did look to me to have been:

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[3] A recent PhD thesis I helped supervise attempts to model these waves: "Development and Verification of Engineering Design Iteration Models," by Robert. P. Smith, MIT Sloan School of Management, 1992.

- identify all the necessary design steps and the information they require and generate

- find where this information is really available (not just at the official end of a given step in the process, but often earlier in that step)

- find sources of iteration and identify the real reasons

- find opportunities to work in parallel

- find long lead time items and try to start them earlier (noting that the information they will need must also be provided earlier)

- find precedence chains that can be broken so that tasks can be resequenced (this requires classifying constraints, much as Nippondenso does, into "must have," "would like," "due to physical law or material property," and so on)

- find ways to design-out problems that will take a long time during manufacture and assembly (note that a wasted minute making each of a million parts adds up to a lot of time, more than may be needed during design to avoid the waste)

Larsson notes the following about such efforts. First, the 50% time reduction can be credited about half to resequencing the tasks and half to using new computer tools to accomplish each step faster. Second, the main thing is to understand each design process in detail "from the bottom up," admitting that each one will be different for technical reasons. These specific reasons (such as the critical need to choose the draft angle after the supplier is chosen) may not be transferrable to another part. Third, people with expertise in this process must accomplish the redesign of the process. BUT, since these people rarely believe that the process can be significantly speeded up, outsiders are necessary to make the process redesign happen.

I should add that the effort to rationalize the process is usually necessary before many of the computer tools can be written. Otherwise one will not know what information to provide for them. The same thing was discovered years ago about automating manufacturing operations: don't automate the existing manual process.

At the moment there are few engineering models to back up the information flow model. Body engineering is ahead in this respect, as is body engineering's overall sophistication. "A few people there understand the whole process." Additionally, there are no systematic tools available for helping people who want to model and redesign design processes.[4] Existing methods such as PERT/CPM are mainly scheduling tools that model the process as once-through-each-task, thereby ignoring iteration. Also, they have no technical information content, only start and stop times and simple task precedences. The IDEF modeling method,

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[4] My colleagues at MIT and I have developed some ways of diagramming design processes that permit systematic rearrangement of task sequences to be done. However, the main tool is still personal interviews and hard thinking. A reference is [Eppinger et al].

developed by the Air Force about 15 years ago, creates a hierarchical model of information flows, but it is so complex that people who did not participate directly in making the model cannot understand it. The new European CIM-OSA model, part of a huge ESPRIT program, creates models that look a lot like IDEF models. These, too, are made manually by interviewing the participants. An example is in [Vaes].

## Organization of Concurrent Engineering Projects

In the last two years Volvo has fully adopted the project method for designing cars, using the "heavyweight manager" method identified by Prof Kim Clark of Harvard Business School. Each project "buys" engineers and, sometimes, components like engines from the engineering divisions of the company. These people stay with the project and have only one project to work on at a time. Some companies do not know whether it is better to focus engineers this way or to let them work on several projects at once. Volvo has found that engineers on a single project focus on reducing the design time whereas those on several projects tend to emphasize technical excellence in their individual parts of the design.

Volvo has established a technical center where most of this design activity takes place. It includes styling, engineering, manufacturing engineering, and prototype production lines. But true co-location of all the activities cannot be accomplished on all projects because Volvo is too small and must form partnerships with other companies around the world. This is complicated by incompatibility of data and by the fact that other car companies are not as advanced in computerizing their design processes.

## Conclusions

The Volvo people I met are quite sophisticated and have accomplished a great deal that other companies I know have not yet tried. Their efforts show that the problems of designing large and complex things requires a new view of the relationships between information, engineering, planning, and computing. I believe that several of the large Japanese companies I visited also understand this and have begun the process of really computerizing their design methods.

However, no one, not even the Japanese, have systematic methods for accomplishing this. There are two basic gaps. First, processes for designing things need to be better understood and modeled. I really think that many people do not understand how to design the things they are designing. That is, they do not understand the process in terms of what decisions are actually needed, when they are needed, what input information they require, what are the consequences of a bad decision, and so on. Second, the technical underpinnings of many designs are not well understood, except in the heads of experts who have found out by trial and error. This is less of a surprise, since the limitations of engineering models are widely recognized. The evidence for this is huge efforts to simulate complex things on computers or to build expert systems and neural nets to "capture the expertise." (See the University of Aachen report.) The combined result of these two gaps is that when one wants to "computerize a design process" one is often left linking human experts by electronic mail.

Furthermore, the current bottom-up efforts to streamline individual design processes have not yet yielded much general knowledge about such efforts except the observation that "each one is different." This is a sure sign that research is needed, since the claim that each one is different often can be countered once some general principles are teased out of the examples. The fact that outsiders (sometimes even university students) can diagnose individual projects gives hope that research will be successful.

## References


[Eppinger et al] Eppinger, S. D., Whitney, D. E., Smith, R. P. and Gebala, D. A., "Organizing the Tasks in Complex Design Projects," proceedings ASME Design Automation Conf: Design Theory and Methodology, vol DE-27, Chicago, Sept, 1990, pp 39-46.

[Vaes] Vaes, P., "CIM-OSA Case Study of the IC-Route," ECIM Department, Hogeschool Eindhoven, May 1991 (a capstone industrial project by a university student)


## Point of Contact


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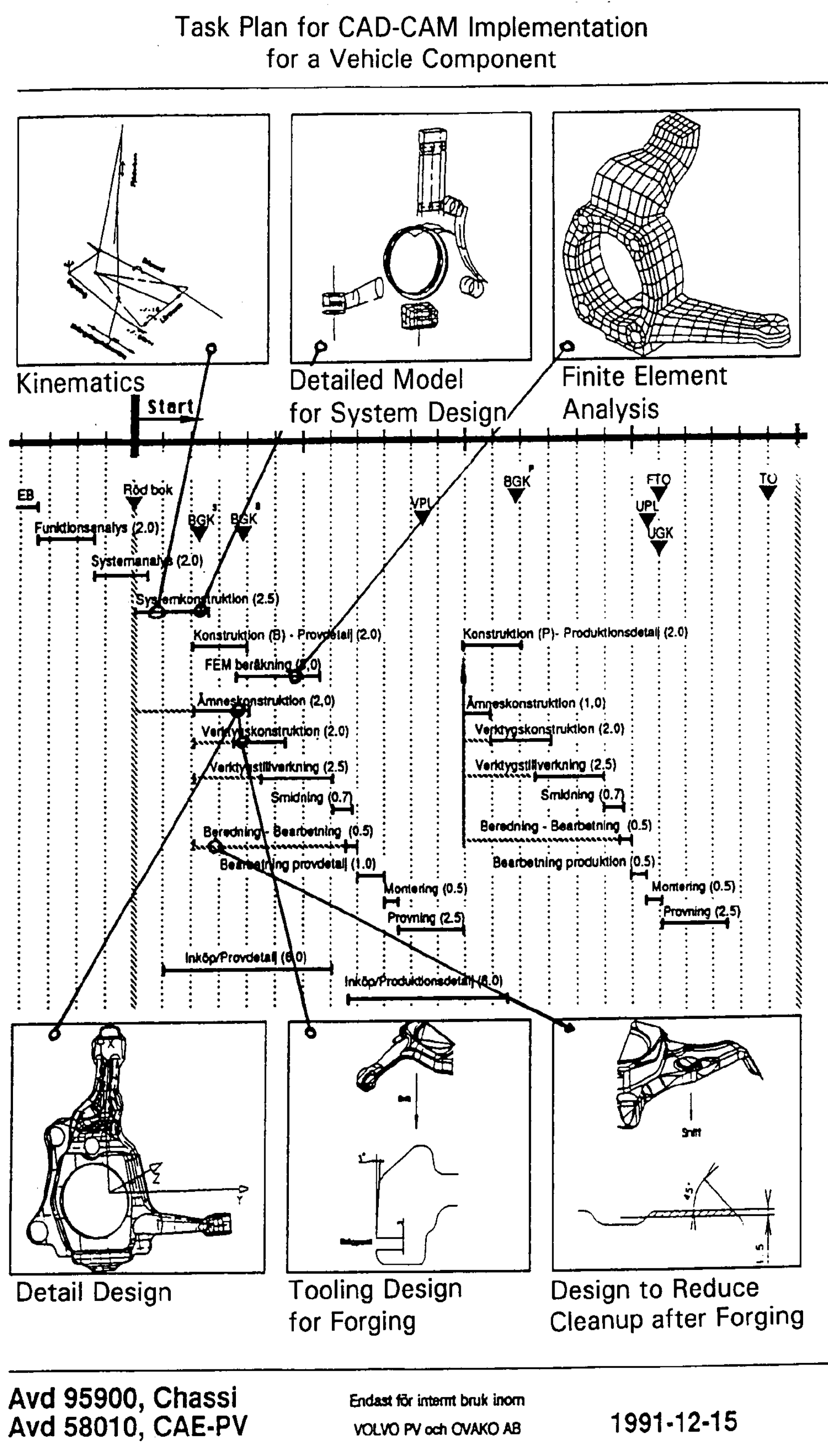


Figure 1. New Schedule for Designing and Prototyping a Steering Knuckle, Showing Key Information and When It Is Needed. This is a schematic schedule for the design, development, and testing of a car steering knuckle. It was prepared by the Volvo CIM team to present to its management the results of studying and drastically shortening the knuckle's design process. The schedule shows several tracks ongoing in parallel. The schematic also shows the kinds of information needed at various stages of the process. In particular, the draft angle mentioned in the text is indicated in the middle box at the bottom. (Courtesy Volvo Car Corporation. Used by permission.)