Simulation tools improve planning and reliability of paint finishing lines

As a leading supplier of paint finishing lines to the automotive industry, ABB Flexible Automation employs advanced three-dimensional software for the simulation and examination of projected installations. Using such software it is possible, for example, to verify the efficiency of the material flow on the line.

Suppliers of industrial paint finishing lines usually have only a relatively short time in which to submit tenders for the lines and get them up and running. 'Simultaneous engineering' meets this need, but makes special demands on the reliability of the process and planning. To improve reliability, ABB Flexible Automation uses simulation software which allows the behaviour of projected installations as well as the associated physical and logistical processes to be examined in detail 1. Excellent results have been obtained with the software, eg for the following tasks:

- Development of systems and key technologies for paint finishing
- Process layout and planning of paint finishing lines
- Optimization of the material flow in paint finishing lines
- Design of components and system parts
- Simulation and visualization of the control technology
- Costing, including total life cycle costs

Simulators for these tasks are available in the following areas:

- Process simulation 2
- 3D material flow simulation
- 3D simulation of robot and paint application machine motions 3
- Simulation of control system and process visualization 4
- 3D simulation of fluid flow patterns, heat and mass transfer, including chemical reactions and electrostatic phenomena

The process and 3D flow simulation are used to investigate thermodynamics and fluid flow, and also in the design of the paint finishing system and components. For example, ABB employs them to model the processes taking place in the thermal incinerator used to clean the residual solvents in the exhaust air emitted by paint curing ovens 2.

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Using the software for the 3D simulation of object motion, it is possible to simulate and investigate the kinematic behaviour of robots and other machines. Extensions to the software enable the application of the paint to be simulated in all three dimensions. This allows 'dynamic' simulation of the interaction between the conveyor system, vehicle bodies and automatic motion machines in a paint booth, and of how it affects the paint finish 3.

The 3D material flow simulation is used to plan, check and optimize the production and logistics for complete paint finishing lines and systems.

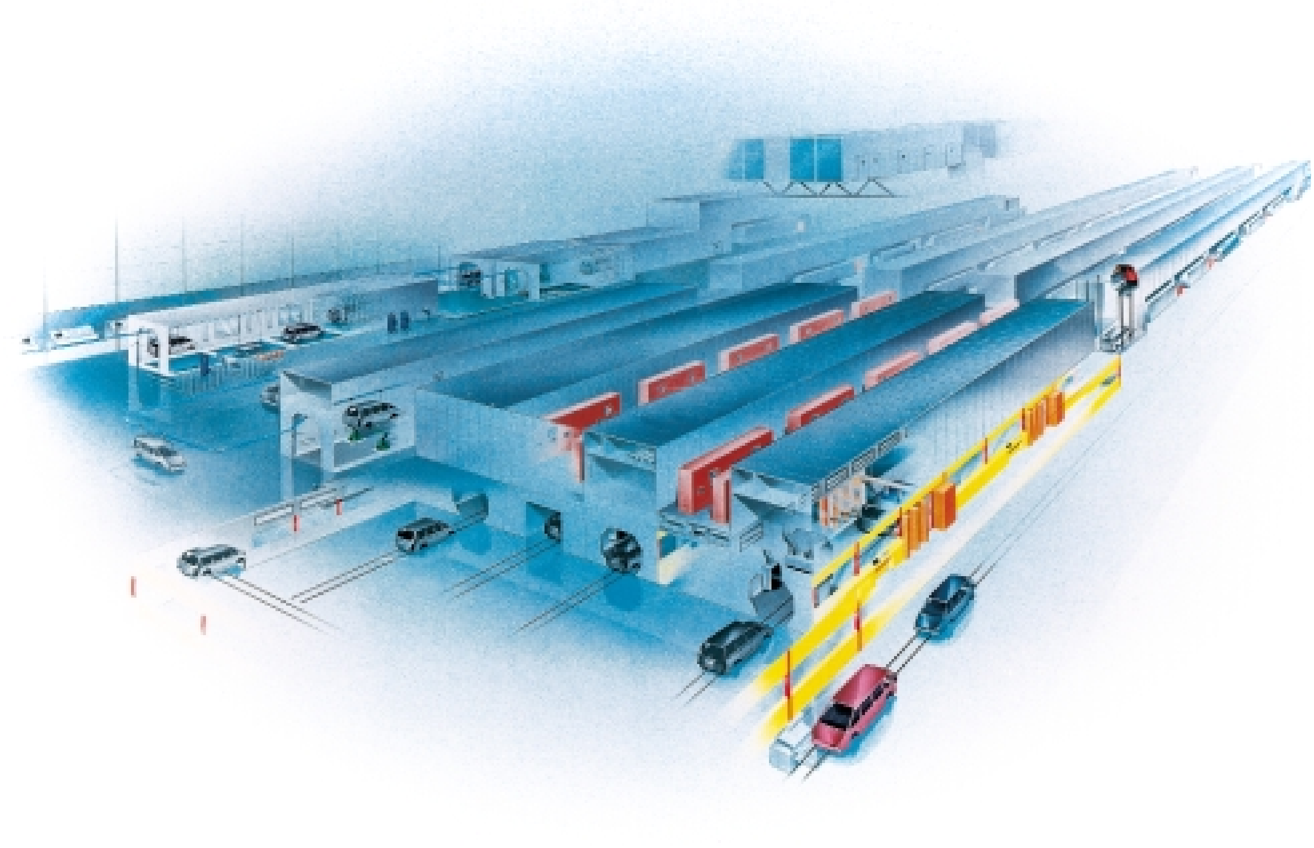
With the help of the process visualization, the control system planned for an installation can be simulated, tested and shown at the start of the project. The verified control model is afterwards transferred – as the process control software and process visualization system – to the real-world plant. An example of process visualization, eg of a heel venturi scrubber, is shown in 4.

A wide range of simulation technologies are available today. The 3D simulation system described in the following is currently being used by ABB to determine object motion and material flow.

3D software for the simulation of material flow, machines and robots

ABB Flexible Automation Paint Systems employs 3D software named Igrip and Quest from the firm Deneb for the dynamic simulation of planned and actual paint finishing lines. Both systems run on SGI workstations. The main features of Igrip, which allows machines and robots to be modelled and simulated in three dimensions, include:

- A three-dimensional CAD module for generating plant graphics
- An object motion module for creating machines based on the CAD graphics and for determining the axes, degrees



Advanced software enables complete paint finishing lines to be realistically simulated. **1**

of freedom and possible motion patterns
- A work-cell module for producing complete work cells from individual machines
- An experimental module for determining the sequence control and evaluating the simulation

Quest is a 3D material flow simulator for the simulation of complex material flow in large installations. It comprises:
- A three-dimensional CAD module for generating the graphics
- A module for generating new component parts from the CAD graphics and for determining axes, degrees of freedom and possible motion patterns
- A library module with preassembled component parts which can be parameterized and programmed
- A modelling module for producing installations from component parts and determining their material-flow links
- An experimental module for determining the sequence control and evaluating the simulation

Igrip and Quest make use of the same 3D CAD module, allowing the drawn 3D objects to be used by both systems.

Areas of application for 3D simulation

Despite expensive hardware having to be installed, the decision to introduce the 3D simulation system has proved to be very worthwhile. The system constitutes the core of the 3D visualization package for paint finishing lines and their material flows. Currently, several departments are profiting directly and indirectly from the 3D simulation:
- *Sales* benefits from the on-line virtual representation of paint finishing lines and through the easier production of demonstration videos (with a video converter) and presentation documents (via hardcopy functions).
- *Planning* profits from the better reliability, detailed studies of critical areas, verification of the functioning of the material flow systems, and the visual representation of the planning results.
- *Project management* gains include the planning and checking of the control logic as well as ‘case studies’ involving alternative line components.
- *R&D* benefits from the 3D prototype development of new machines and plant components.

3D simulation as a planning and project management tool

The paint finishing line in an automobile factory takes up between 20 and 25 percent of the total volume of the plant. This figure gives a rough idea of the extent of the planning and project management involved.

To follow up on the invitation to tender for a paintshop, a considerable effort has to be made in a very short time, eg in preparing the offer and in the planning and project engineering. With 3D simulation, even details such as the paint finishing spray booths and the individual paint application machines can be shown very realistically **3**.

In spite of the advantages of the described software, it is not used for every project. Often, its use is restricted to cost/benefit estimations or, alternatively, it may be requested by a customer.

Two SGI workstations are currently available, each with a current user licence from Igrip and Quest. The same database is used by both of the machines. For the time being, up to five experienced staff members, two from Planning and three from R&D, are available for the simulation studies.

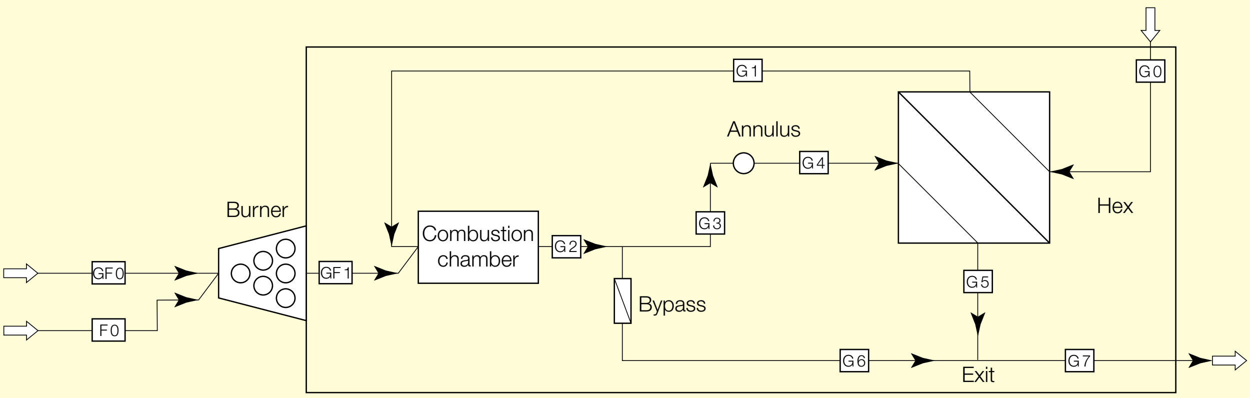
Use of the 3D simulation software is explained in the following by referring to two actual projects.

Project 1: Moving-crane pretreatment plant

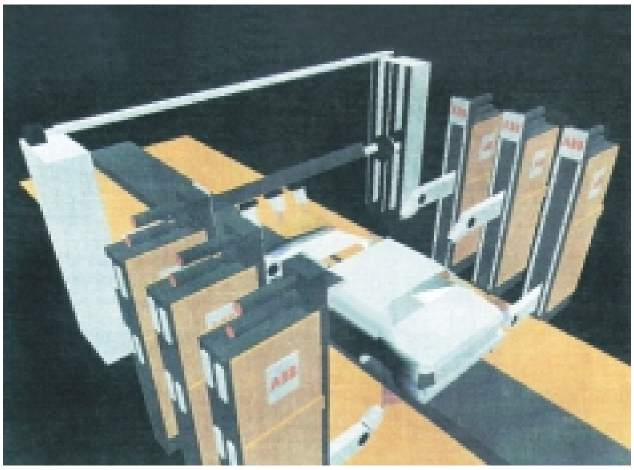
The object of the simulation study was to prove the proper functioning of a planned pretreatment and electrocoating line (PT and EC line). A simulation model was to be generated on the basis of the given geometry and the planned transport and process times of the real-world installation. The event-oriented sequencing logic of the control system that was planned had to be reproduced in the simulation model, checked and improved as necessary.

The planned PT and EC line was designed as a discontinuous, ie stop and go system with vertical dipping and removal of truck bodies. A production rate of 5 bodies per hour was planned. The line comprises 11 dip tanks and 2 empty tanks. The arriving truck bodies are mounted on dipping frames at the loading station. Five gantry-type cranes transport the frames from one dip tank to the next.

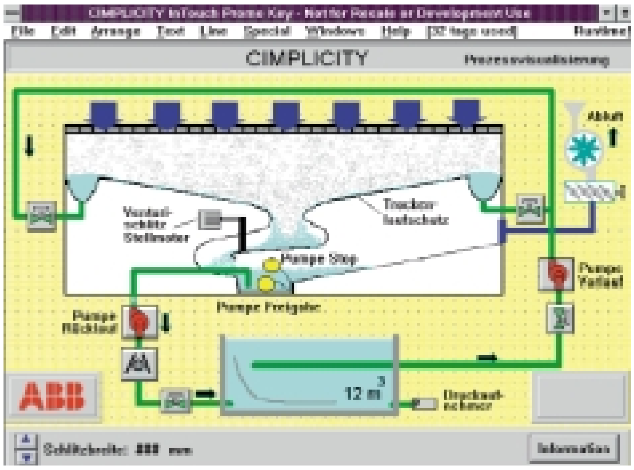
Example of process simulation: thermal incinerator used to clean solvents in the exhaust air of paint curing ovens **2**



Recuperative thermal incinerator												
Stream ID		F0	G0	G1	G2	G3	G4	G5	G6	G7	GF0	GF1
Mass flow	KG/HR	211.8725	25599.6002	25599.6002	25815.0627	24524.3082	24524.3082	24524.3082	1290.7531	25815.0610	3.6000	215.4725
Temperature	K	293.1	423.1	749.4	1023.1	1023.1	1023.1	707.6	1023.1	723.9	293.1	293.1
Pressure	ATM	1	1	1	1	1	1	1	1	1	1	1
Comp mass fractions												
O_2		0.000000	0.230000	0.230000	0.201928	0.201928	0.201928	0.201928	0.201928	0.201928	0.230000	0.003843
CH_4		0.800000	0.000000	0.000000	0.000007	0.000007	0.000007	0.000007	0.000007	0.000007	0.000000	0.786634
N_2		0.200000	0.758000	0.758000	0.753404	0.753404	0.753404	0.753404	0.753404	0.753404	0.760000	0.209356
VOC		0.000000	0.000001	0.000001	< 0.000001	< 0.000001	< 0.000001	< 0.000001	< 0.000001	< 0.000001	0.000000	0.000000
CO_2		0.000000	0.000000	0.000000	0.017936	0.017936	0.017936	0.017936	0.017936	0.017936	0.000000	0.000000
CO		0.000000	0.000000	0.000000	0.000039	0.000039	0.000039	0.000039	0.000039	0.000039	0.000000	0.000000
H_2O		0.000000	0.011999	0.011999	0.026632	0.026632	0.026632	0.026632	0.026632	0.026632	0.010000	0.000167
NO_X		0.000000	0.000000	0.000000	0.000054	0.000054	0.000054	0.000054	0.000054	0.000054	0.000000	0.000000



Simulation of an electrostatic paint-spray station with one overhead and six side machines **3**



Screenshot showing representation of an automatic control system, here for an H-venturi scrubber **4**

The frames with the mounted bodies can be swung during the processing time in the tank and tilted after removal to allow the liquid to drain off more easily.

At the unloading station the vehicle bodies are removed from the frames, which are then transported over the two empty tanks back to the loading station. Details of the planned PT and EC line that were available at the beginning of the study included the:

- Construction and dimensions of the installations
- Process sequence and process times
- Transport speeds and accelerations
- Draft of a path versus time diagram for the installation
- Draft of an event-oriented sequencing control system for the installation

Generation of the computer model

The model was generated using the Igrip simulation system. This has the advantage of allowing complex motion patterns to be easily entered at the work-cell level and represented in three dimensions. Furthermore, the planned sequencing control can be implemented via a user-interface belonging to the system.

First, the logic structure of the installation was analyzed and divided up into the following parts for simulation purposes:

- An indeterminate number of vehicle bodies
- 9 dipping frames for the vehicle bodies
- 5 gantry cranes (grips only) for transporting and tilting the frames
- 15 tank stations equipped to couple and tilt the frames
- A station for fixing the vehicle bodies to the frames
- A station for removing the bodies from the frames
- A supporting structure with dip tanks

Graphics of these components were drawn to scale in three dimensions, however in simplified form to ensure the fastest possible output during the experiments with the model. Afterwards, the components were assembled to form the complete installation. At the same time, the axes and degrees of freedom were defined. Views of the installation in operation are shown in **5** and **6**.

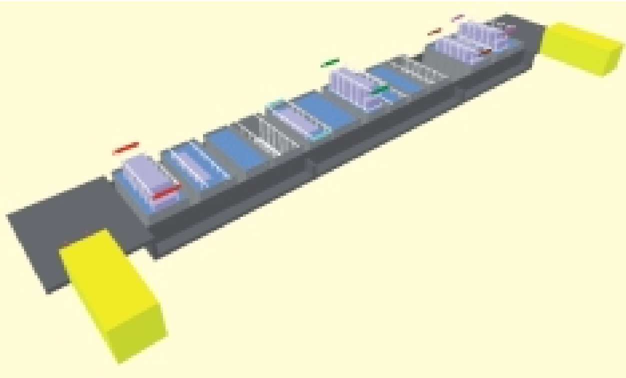
The material flow and control logic of the installation were described using control programs in ASCII format and allocated to the installation components. The gantry cranes, tank stations and dipping frames were each allocated a program describing the process sequences. Global variables are used to link the individual processes together.

The process description, eg in the case of a gantry crane, outlines the crane's sequencing control. This defines under what conditions and at which location a frame is picked up, lifted, transported, lowered and returned.

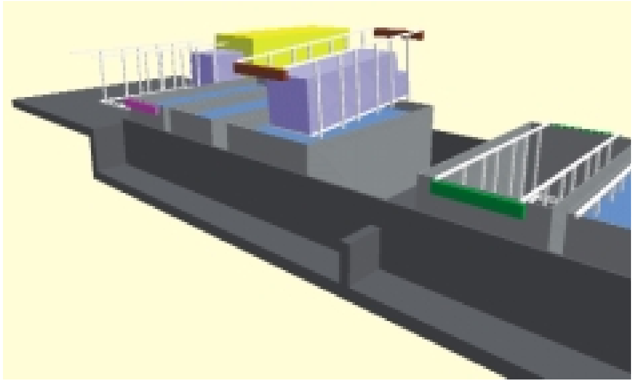
The process description for a dip station covers the pick-up, tilting procedure and return of the dipping frame. Similarly, the process description for a frame defines the pick-up and the removal of the vehicle body. All of the planned process, drain-off, raising and lowering times, as well as the accelerations and speed of operation of the gantry cranes, were entered in the computer model used for the simulation.

To study the behaviour of the installation in the event of disturbances, a mechanism was implemented in the model which allows a gantry crane to be taken out of operation for a defined period of time. This enabled the functioning of the sequencing control during stops and restarts to be investigated.

The cycle time and the production rate of the installation, plus the actual frame residence times in the tanks, can be recorded and displayed during a simulation run.



Front view of the pretreatment line.
The component graphics are shown simplified. **5**



Pretreatment line: the dipping frame is tilted after electrocoating of the vehicle body. **6**

Verification and validation of the model

The consistency of the model logic was checked by performing test runs. This involved checking the procedures in the modelled installation by means of visual inspection as well as checking and partial correction of the technical and logic parameters which had been set on the basis of the operational data obtained from the test runs.

The validity of the model as a substitute for the planned production facility was determined by checking the behaviour of the modelled installation, both as a whole and in detail, with the help of the given path versus time diagram. This was done in two steps.

In the first step all the process sequences contained in the path versus time diagram were simulated for the times specified by it. The material flow of the model was afterwards checked and corrected.

In the second step the time control was replaced by the planned sequencing control. Where the model deviated from the path versus time diagram, the sequencing control was modified. This followed discussions with the project management team.

Simulation experiments

The first experiment took place with the gantry cranes running at half their horizontal speed. In addition to the cycle times, the actual immersion times in the tanks were recorded. The cycle time increased by only about 23 percent. It was shown, however, that due to the longer times travelled by the gantry cranes, the frames were lifted out of many of the tanks too late. This resulted in the given process times being exceeded.

Further experiments were carried out to check the reliability of the sequencing control. In addition, each of the gantry cranes was disturbed at each sequence step immediately before it started to move away. This was done to determine whether the other cranes would be stopped by their own sequencers before collisions occurred. After the disturbance had been rectified, it was observed whether or not all the gantry cranes restarted and whether the defined path versus time diagram was adhered to.

The experiment showed that the gantry cranes did not restart after the disturbance as required in every case. What is more, shifts in the path/time diagram were noted after disturbances had occurred. Although the cycle time was still kept to, the process times specified for some of the tanks were exceeded. Working together with the project management team, the sequencing control was changed until this problem had been solved.

The experiments performed on the model allowed investigation and improvement of the behaviour of the installation for different transport times and in the event of disturbances. On the one hand time and costs were reduced, on the other it was ensured that the installation could be taken into operation with a sequencing control that functioned correctly from the beginning. The three-dimensional, scaled simulation allowed all of the motion patterns of the planned installation to be replicated and observed.

Project 2: A complete paintshop

The purpose of this study was to verify by simulation the correct functioning of the planned material flow in a complete paintshop with spray booths, paint cure ovens, colour sorting system, inspection and repair areas. For the purpose of the simulation, a model had to be created that is based on the given geometry and the planned transport and process times of the installation. The projected material flow for a production rate of about 60 car bodies per hour had to be replicated in the model and checked.

As a basis for the scaled model of the installation, a 2D CAD drawing was used which shows plan views of the different levels of the installation.

The data required for the three-dimensional and technical design of the installation, the plant control, the car body variants and the car body production sequence, were viewed and refined after discussions with the project management team and with the customer.

Description of the model

Because of the size of the model it was decided to generate it using the Quest system. Graphic, logical and logistical simplifications were made after discussions with the project engineering team. The existing drawing was scanned into the simulation system via a CAD interface.

The installation components were reproduced using predefined modules and the relevant technical parameters, and then positioned at their respective locations on the layout.

The model components were linked in a logical relationship and parameterized to form the model installation. The sequencing and control logic was implemented via a programming user interface.

The paint finishing line is divided into three different levels, as follows:

- Level 1: Inspection, repair, buffers 7
- Level 2: Oven buffers, assembly/disassembly of skids 8, colour sorting area 9
- Level 3: Top-coat line, top-coat oven, primer line and primer oven 10

A simulation model was generated for each of these levels. There are no links over which material can flow between the levels. The limits of the system are the stations that lift the vehicle bodies from one level to another. These are simulated by means of sources and sinks with cycle times.

The extent to which the model components and the buffer were utilized was determined, as was the residence time of the car bodies in the system. A special feature was the recording of the cycle time for the transfer station and the flash-off time for the primer line on level 3.

Verification and validation of the model

The sequences taking place in the modelled installation were checked by visual inspection. The set technical and logic parameters were checked by referring to the operating data from test runs, and corrected where necessary. Working together with the project management team and the customer, it was checked how the models of the three levels behaved as a whole and in detail.

Simulation experiments

A range of experiments were carried out and evaluated during the verification and validation of the model. The results were analyzed immediately and put into effect in the simulation model. Checks were carried out in particular to determine the:

- Capacity and control of the buffers on level 1
- Number of transfer units on level 1
- Skid mounting on level 2 8
- Control of the transfer from the top-coat line to the top-coat oven on level 3 10

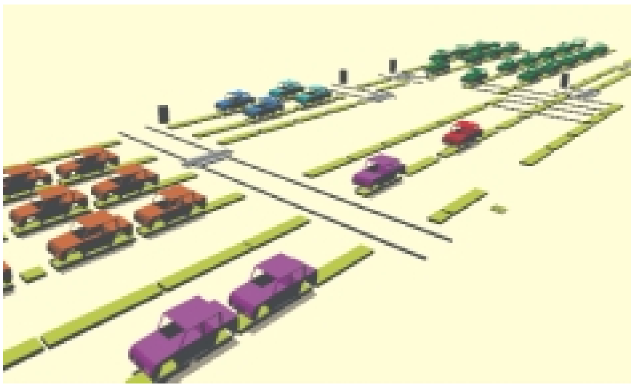
Faults and innaccuracies in the planning of the installation could be localized and corrected already during the modelling phase. By means of the simulation experiments it was shown that a transfer station could be saved on level 1. The control logic for the buffers and colour sorting areas and for the transfer stations could be tested and refined during these experiments. The correct functioning of the material flow in the paint finishing line was verified by the simulations.

The three-dimensional, scaled replica of the paint finishing line, as used for the simulation experiments, won acceptance from both the customer and the project management team.

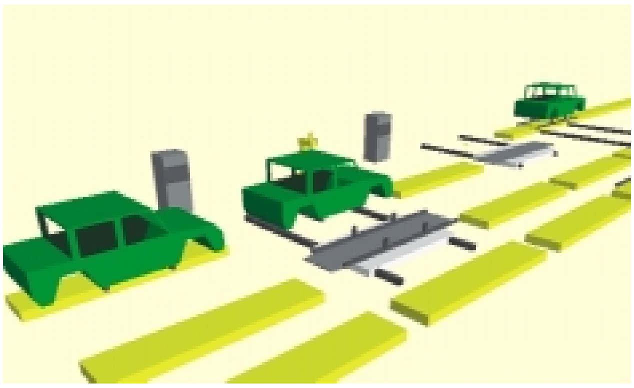
Future developments and application areas for 3D simulation

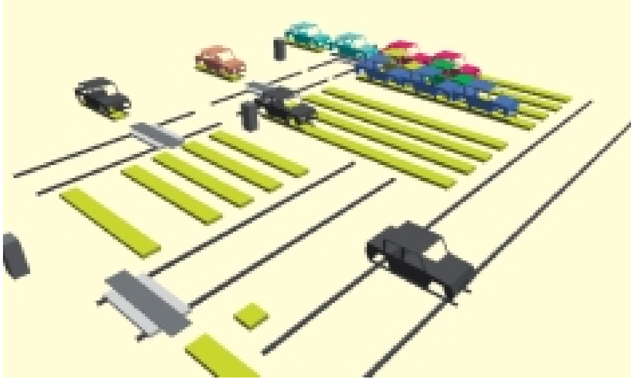
ABB Flexible Automation Paint Systems is currently employing 3D simulation with

Simulation of a complete paint finishing line: level 1 with inspection, repair and buffer areas **7**

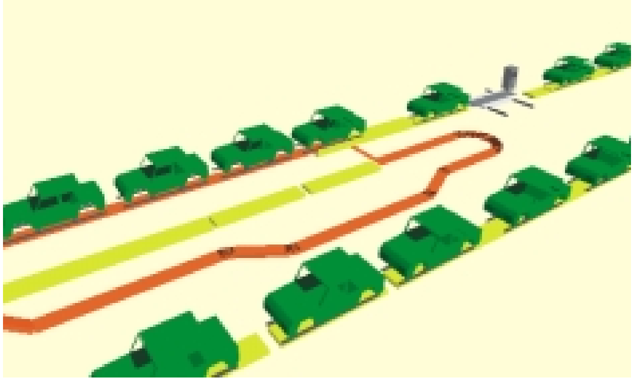


Simplified 3D representation of the skid assembly station on level 2 **8**





Colour sorting area for standard and special colours (level 2) **9**



Check on the control system responsible for the transfer from the top-coat line to the top-coat oven on level 3 **10**

great success. The next step could be to couple the simulation with other software systems so that data which have been entered once or already calculated can be used several times. Possibilities include:

- Access to commercially available 3D CAD systems and the simulation system via a common 3D graphics library
- Use of the control logic produced in the course of the simulation as robot and programmable controller programs for real-world installations
- Integration of the simulation in an engineering data management system, allowing the individual simulation components to be managed together with their product-related and component-related data and documents
- Compatibility of the model with other simulators

Due to the different data models in use and the absence of high-performance interfaces, a great deal of data still has to be exchanged between the simulation system and CAD system by manual or semi-automatic means. Changes to the layout which are necessary in the CAD system have to be repeated a second time in the simulation system. Often, there is no time for this in simultaneous engineering projects. What is more, errors can very easily creep into the calculations. For this reason, automatic harmonization of the CAD and simulation system alone would allow a large saving.

Also desirable are improvements in the linking of the hardware peripherals. At the present time, graphic data output on printers and plotters and the production of videos still make considerable demands on time and costs.

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