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# SIMIO APPLICATIONS IN SCHEDULING

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## ABSTRACT

Simulation has traditionally been applied in system design projects where the basic objective is to evaluate alternatives and predict and improve the long term system performance. In this role simulation has become a standard business tool with many documented success stories. Beyond these traditional system design applications simulation can also play a powerful role in scheduling by predicting and improving the short term performance of a system. However these applications have a number or unique requirements which traditional simulation tools do not address. Simo has been designed from the ground up with a focus on both traditional applications as well as scheduling, with the basic idea that a single Simio model can serve both purposes. In this paper we will focus on the application of Simio simulation in scheduling.

## 1 INTRODUCTION

Simio is a **sim**ulation modeling framework based on **i**ntelligent **o**bjects. The intelligent objects are built by modelers and then may be reused in multiple modeling projects. Objects can also be stored in libraries and easily shared. A beginning modeler may prefer to use pre-built objects from libraries, however the system is designed to make it easy for even beginning modelers to build their own intelligent objects.

A Simio object might be a machine, robot, airplane, customer, doctor, tank, bus, ship, or any other thing that you might encounter in your system. A model is built by combining objects that represent the physical components of the system. A Simio model looks like the real system.

Objects are built using the concepts of object-orientation. However unlike other object oriented simulation systems, the process of building an object is very simple and completely graphical. Using Simio's patented architecture for objects there is no need to write programming code to create new objects. For more information on Simio see the books by Kelton, Sturrock and Smith, or Joines and Roberts, or Pegden and Sturrock.

Simio is designed to support applications in both system design and scheduling, however in this paper we will focus on the applications of Simio in scheduling. There are broad applications for scheduling using Simio – ranging from manufacturing and transportation to healthcare systems. Although the Simio object-based model building approach is the same in both design and scheduling applications there are some key differences in the way the Simio model interacts with external data and the type and presentation of results that are generated from the model.

In the sections that follow we will begin by giving an overview of the scheduling problem, discuss alternative approaches to scheduling, and then focus on the Simio solution to solving the unique problems associated with simulation based scheduling. We will conclude with a summary of some recent applications of Simio to scheduling.

## 2 PLANNING AND SCHEDULING

Planning and scheduling are terms that are sometimes used interchangeably. For our purpose we will use the term planning to be the process of defining work to be done, and scheduling to be the process of then sequencing the tasks, selecting start and end times for each task, and allocating the limited resources to complete the planned work. In this context planning is a prerequisite to scheduling. The output of a plan is typically a list of work to be performed during a specific planning period. The scheduling process then turns this plan into a step-by-step sequence of tasks to perform in order to meet some specified goals; e.g. complete each job by a specified date (i.e. its due date).

An initial plan is often generated using a backward sequencing approach based on simple lead times for each job. For example, if a job must be completed by a specified date and has a planned lead time of 3 weeks, it must start at least three weeks before it is due. If this job has predecessor jobs they must all be planned (based on their lead times) to be completed before the required start date for this job. This backward sequencing is continued until the required start time is established for all jobs. Often this planning process works with a fixed planning period (e.g. a week) where each job start time is assigned to the starting time of a planning period. The planning process may also perform material planning to ensure that all the necessary materials are available at the beginning of each planning period. This is the role of a typical ERP/MRP/APS system.

The lead times that are used in this backward planning approach are comprised of both a processing time and a queue time. The estimated queue time is typically much larger than the processing time and intended to capture the time that the job must wait for limited resources in the system. In reality the queue time is unknown and is highly dynamic and depends on the current state of the system. However this is ignored in the planning phase and a single static queue time is used to generate a rough-cut master plan.

Taking a plan and turning it into a detailed schedule of work that fully accounts for the limited capacity of the system is a complex problem with no known exact solution, and hence we seek a good solution as opposed to an optimal solution. In some cases the scheduling phase is done manually using a spreadsheet or a scheduling board. However there are also finite capacity scheduling tools that are designed specifically for this purpose based on either a mathematical or simulation model of the system.

## 3 MATHEMATICAL VERSUS SIMULATION MODELS

The scheduling problem is sometimes approached as an “optimization” problem (e.g. using ILOG or PP/DS in the SAP system). In this approach a mathematical model is formulated of the scheduling problem as a set of equations that are then “solved” using Mixed Integer Linear Programming, Constraint-Based Programming (CBP), or heuristics such as Genetic algorithms. Although newer solvers such as Constraint-Based Programming can solve relatively large and complex models, this approach has some limitations when it comes to generating detailed schedules. There are situations where complexities in the process cannot be accurately modeled, or where details must be expressly kept out of the model to avoid overtaxing the underlying solver. A high level of experience and knowledge is required to successfully apply these systems.

Simulation is a very simple, flexible, and fast alternative method for generating finite capacity schedules. In this case we build a simulation model of the system as opposed to a mathematical model. In the simulation model we describe the logic within the system at any level of detail that we desire. We can also model in detail the complex material handling (automatic guided vehicles, conveyors, robots, or other devices) that takes place within and between work centers.  Since we are simulating the model and not "solving" the model, we can include as much detail in the model as we desire without having a significant impact on the execution time.

When the model "runs" it acts out the behavior of the real system by simulating the actual movement of jobs through the system in a time-ordered sequence.  In contrast to a mathematical model, the simulation model also allows us to animate the system behavior and see the system executing over time.  This is not only useful for validation and verification of the system, but also for convincing stakeholders of the validity of the schedule.   Figure 1 shows an example screen shot of a running animation of a manufacturing facility.

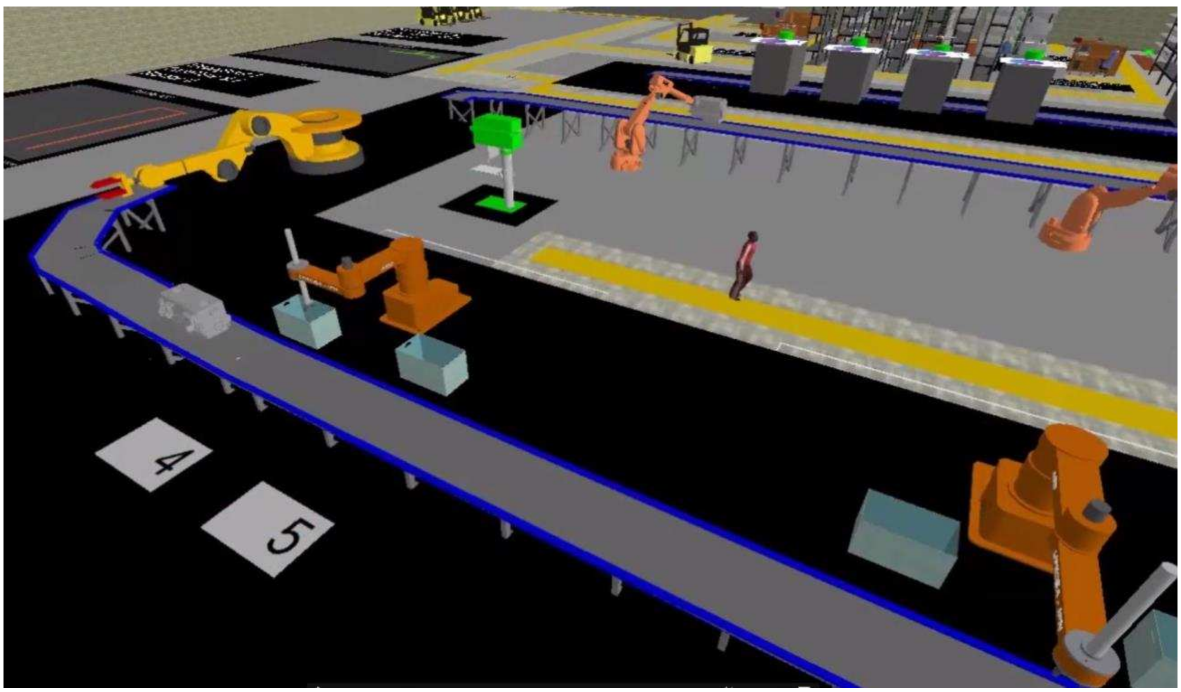



Figure 1:  Animation Screen Shot of a Manufacturing Simulation

The quality of the schedule that is produced by a simulation model is determined by the scheduling logic that is used within the model.  There are two critical scheduling decisions which are made repeatedly during the execution of the simulation.  The first is the resource selection decision that is made when a job can a utilize any of two or more alternate resources.  Note that this might be a resource such as a machine, an operating room, labor, or a material handing device.  Here a decision must be made as to which resource is assigned to the job.  In some cases the job (e.g. representing a production lot) may be split and assigned to multiple resources.  The second critical decision is the job selection decision that is made in the simulation when a resource becomes idle and there is more than one job waiting to be processed by that resource.  Here the decision to be made is which job to process next.  Both of these critical decisions are made by model specific scheduling rules.

The resource selection and job selection rules work together, along with the simulation model logic, to produce the schedule. These rules can range from very simple rules such as minimize sequence dependent setups, to more complex hybrid rules that blend together theory-of-constraints for throughput optimization with make-to-order strategies that target due dates. The ability to easily incorporate custom rules for unique scheduling situations is an important advantage of simulation-based scheduling.

Note that the goal of both the mathematical model and simulation model is not to provide an optimal schedule (this is not possible since the scheduling problem is NP-Hard) but rather to provide a good feasible schedule that respects the capacity constraints in the system. In the case of a mathematical model we develop a set of equations and then use a heuristic to find a "good" feasible schedule. In the case of the simulation model we generate the schedule using heuristic decision rules that are built into the model to produce a "good" schedule. Simio provides multiple ways for the scheduler to then make adjustments to the system or the schedule and see how these changes affect the plan, hence possibly improving the initial recommendation.

## 4 DETERMINISTIC SCHEDULES

Regardless which approach we use to generate a schedule (spreadsheet, schedule board, mathematical model, simulation model) we must always use deterministic task times and assume away any unplanned random events (e.g. breakdowns); otherwise it's not possible to generate a detailed schedule. Simulation modelers are very familiar with the important role that variation plays in determining system performance and we wouldn't think of leaving variation out of a simulation design model; we know that it would lead to optimistic and unrealistic projections of system performance. However in scheduling we do exactly that because we cannot otherwise generate the schedule. Hence a fact that is often overlooked in scheduling applications is the following:

Deterministic schedules are optimistic – they over promise and under deliver.

Experienced schedulers realize that the optimistic plans that are generated by scheduling tools at the beginning of a planning period are frequently not met by the end of the planning period. Schedules which appear initially feasible become infeasible over time as variation degrades performance. Tasks sometimes take longer than expected, workers call off work, raw materials arrive late, machines break, etc., all degrading the original schedule. The original schedule represents the "happy path" that is seldom realized in practice.

## 5 RISK BASED PLANNING AND SCHEDULING

Simio explicitly addresses the optimistic projection of a deterministic schedule by exploiting the variation that is built into the simulation model to access the risk associated with a specific deterministic schedule. This patented approach is referred to as **Risk-based Planning and Scheduling (RPS).** RPS is used to generate schedules that minimize risks and reduce costs in the presence of uncertainty. RPS augments the deterministic schedule with risk measures that allow the decision maker to properly account for the underlying variation and uncertainty in the system.

RPS uses the Simio simulation model to fully capture both the detailed constraints and variations in the system. The simulation model can be as simple or detailed as required, and may include complex processing and material handling constraints such as ovens, forklift trucks, conveyors, moving operators, etc., as well as complex work crews.

RPS then uses this model in two ways. The first is to generate a detailed schedule. In this case the model is automatically executed by Simio in a purely deterministic mode; machines do not break, process times are always constant, materials arrive on time, etc. Note that there is no need to remove variation and unplanned events from your design model to use it in scheduling since Simio automatically does this for you. This is the deterministic (optimistic) view assumed by all scheduling systems. Once the schedule has been generated RPS then replicates this same simulation model with variation automatically added back into the system and performs a probabilistic analysis to estimate the underlying risks associated with the schedule. The risk measures generated by RPS include the probability of meeting user-defined targets, as well as expected, pessimistic, and optimistic schedule performance. Figure 2 shows a sample table that includes risk measures for on-time and on-budget probabilities that are color coded for risk levels; gray for low risk, yellow for medium risk, red for high risk.

| | Target Ship Date - Plan | | Target Ship Date - Risk Analysis | | Target Cost - Plan | | Target Cost - Risk Analysis | |
|---|---|---|---|---|---|---|---|---|
| Order ID | Value | Status | Expected | OnTime Probability | Value (USD) | Status | Expected (USD) | OnBudget Probability |
| Order 14 | 12/12/2014 9:39:50 AM | OnTime | 12/12/2014 10:50:54 PM | 93.34% | 134,801.1328 | Overrun | 137,991.6704 | 6.66% |
| Order 15 | 12/11/2014 11:32:55… | OnTime | 12/12/2014 11:23:22 AM | 79.47% | 126,547.2111 | OnBudget | 132,261.0780 | 51.73% |

Figure 2: Sample Risk Analysis Results

By providing up-front visibility into the inherent risk associated with a specific schedule, RPS provides the necessary information to take early action in the operational plan to mitigate risks and reduce costs. RPS provides a realistic view of expected schedule performance. Specific alternatives such as overtime or expediting external material/components from suppliers can be compared in terms of their impact on both risks of meeting schedule targets, and costs of mitigating those risks, thereby providing a customer-satisfying operational strategy at a minimum cost.

Once an RPS model is built it can then be deployed using Simio Scheduling Edition. This version of Simio has a customizable interface that is specifically designed for use in day-to-day RPS applications; all of the functionality related to model building is removed to focus the interface on activities related to using the model for operational planning and scheduling. Figure 3 shows a Gantt chart with risk measures that are displayed in the Scheduling Edition of Simio. This is one of many possible ways of viewing the resulting schedule.

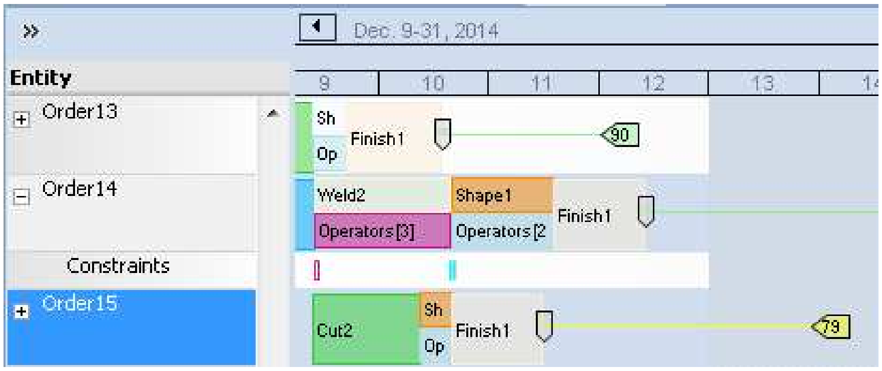
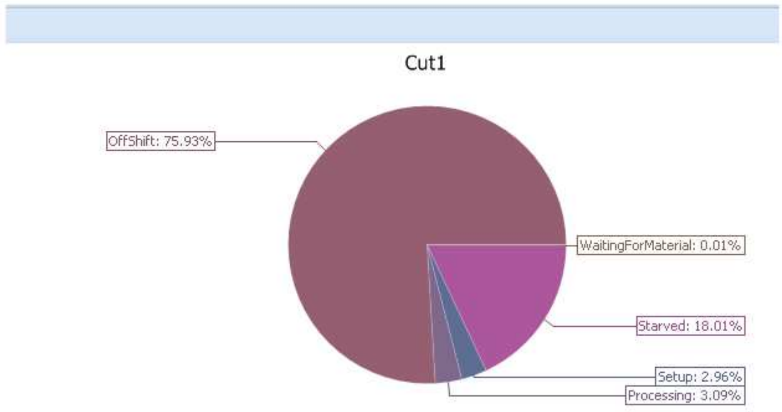



Figure 3: Sample Gantt chart showing Risk Measures in Simio Scheduling Edition

## 6 SCHEDULING FEATURES IN SIMIO

Although in theory any general-purpose simulation language can be used as the basis for a finite capacity scheduler, there are a number of unique characteristics of this application domain that demand a number of special modeling features that are not included in a simulation tool focused on design applications. These features have been built into Simio from the ground up and include the following:

1. **Integration with external relational data sources.** The data for schedules typically comes from ERP or other business transaction systems. It is essential that this relational data can be automatically downloaded into the simulator and held in memory for fast access. In many cases it is also necessary to integrate with real-time manufacturing execution systems (MES) to initialize the model to real time data and to automatically trigger rescheduling when a resource fails. Simio provides data binding to easily access external relational data, as well as integration features for MES systems. Simio also provides a standard interface for the popular Wonderware MES system.
2. **Transaction logging**. In design applications our focus is on summary data such as averages, maximum/minimum, half width, etc. In scheduling we must focus on detailed tracking of individual entities. Simio provides this functionality by logging all important transactions (e.g. resource seizes, constrained waits, etc.,) during model execution.
3. **Specialized Reports**. Schedulers expect special reports such as work-to list, tardiness reports, etc. The ability to easily generate and customize these reports is essential. It's also important to be able to publish and disseminate these reports to mobile devices for sharing across the enterprise. The Simio Portal Edition provides this critical functionality by allowing Simio models to be uploaded to the Microsoft Azure cloud for rapid execution on a scalable number of processors, and then results shared across any number of authorized users on mobile devices. The results can be displayed using custom dashboards created for each application. Figure 4 shows an example custom dashboard depicting the scheduled activity for a specific resource (Cut1).




**Operations**

| Resource | StartTime (Date-Hour-Minute) | EndTime (Date-Hour-Minute) | Entity | Duration (Days) (Sum) |
|---|---|---|---|---|
| Cut1 | 12/1/2014 8:00 AM | 12/1/2014 1:28 PM | Order03 | 0.228 |
| Cut1 | 12/1/2014 1:28 PM | 12/3/2014 9:50 AM | Order08 | 1.85 |
| Cut1 | 12/3/2014 9:50 AM | 12/5/2014 10:28 AM | Order10 | 2.03 |
| Cut1 | 12/5/2014 10:28 AM | 12/9/2014 11:50 AM | Order13 | 4.06 |
| Cut1 | 12/9/2014 11:50 AM | 12/11/2014 8:59 AM | Order16 | 1.88 |
| Cut1 | 12/11/2014 8:59 AM | 12/12/2014 2:34 PM | Order18 | 1.23 |
| Cut1 | 12/12/2014 2:34 PM | 12/16/2014 11:12 AM | Order20 | 3.86 |
| Cut1 | 12/16/2014 11:12 AM | 12/18/2014 10:02 AM | Order22 | 1.95 |

Figure 4: Sample Custom Dashboard

4. **Customizable scheduler interface.** The person that uses the simulation in a scheduling application has no need for model building. This user needs a special user interface (Simio Scheduling Edition) to view and run the model, generate schedules, analyze schedule risk, view reports, and publish the results for others to view. The interface is easily customizable for each application.
5. **Interactive Gantt chart display.** The best way to view the resulting schedule is with a Gantt chart. Simio's built in Gantt charts provide this functionality, and also makes it easy for the scheduler to manually edit the schedule from the Gantt chart. Typical edits include dragging jobs from one resource to another, or entering downtimes for a specific resource.
6. **Specialized scheduling rules.** The quality of the generated schedule is largely determined by the scheduling rules that are specified for selecting resources and operations. A complete set of rules must be incorporated into the simulation tool to support a wide range of manufacturing applications. Simio makes it easy to select from standard scheduling rules (minimize changeover, earliest due date, shortest remaining processing time, critical ratio, etc.) and also create and add custom rules to a model.
7. **Risk-based Planning and Scheduling**. Since all deterministic schedules are by nature optimistic, it's important to allow the schedule to assess the risk associated with a specific schedule. Simio's patented RPS features provides automatic risk measures associated with a schedule.

## 7 EXAMPLE SCHEDULING APPLICATIONS

Simio's scheduling features can be used across many application areas. Although the application to scheduling in manufacturing is obvious, Simio scheduling also has important applications in areas such as transportation/logistics and healthcare.

One example of Simio's scheduling application in manufacturing is BAE Systems.Defense contractors need to reliably plan and predict production resources to meet the military's needs on time and within budget. Contract managers seek more effective production resource risk mitigation methods. They demand accurate and timely key risk indicators (KRIs) for materials, labor, and equipment. BAE Systems (BAE) used Simio's Enterprise Edition software that includes risk-based planning and scheduling (RPS) functionality. The feature integrates traditional planning and scheduling features with stochastic modeling for risk analysis. Simio's scheduling software provided planners and schedulers with a customized interface for generating schedules, performing risk and cost analysis, investigating potential improvements, and viewing those parameters in 3D animations. Gantt charts made it easy to see the timing of processes, and to explore how changes in equipment or employees affect that timing.

Simio users such as BAE can run simulations whenever system downtime, employee availability, or other factors change, resulting in a "finger on the pulse" awareness that enables quick adjustments and aids confident decision-making. Simio Enterprise Edition software with scheduling functionality helped BAE Systems meet production deadlines. BAE now uses Simio to meet a variety of forecasting and scheduling challenges, including decreasing overtime, developing training goals, preparing proposals, and evaluating capital investments.

Simio has also been applied in manufacturing environments running Schneider Electric's Wonderware MES. Wonderware MES provides real time tracking of work in process and completed, providing operator visibility into the current and past state of the system. Simio's scheduling software projects the current state forward based on the planned work for the facility. By integrating directly with Wonderware the operators have visibility into the past, present, and future state and can view the planned schedule and feasible alternatives when the plan is no longer viable due to unexpected problems. The Simio solution also provides timely management feedback on production, scrap, and other status data to support appropriate and timely remedial action.

An example of Simio's scheduling application in transportation and logistics is the use of Simio by Shell Oil to schedule a fleet of vessels for delivering supplies to offshore rigs. The vessel fleet and related docks are an expensive resource to manage and the cost of material shortages to rigs is extremely high. In this environment it is essential that all material be delivered on time. However there are many variables, such as wind and wave height, that impact vessel travel times and add risks to the schedule. Simio's scheduling software and risk-based planning features are used by Shell to plan the allocation of vessels and generate schedules that account for the uncertainty in the system.

An example of Simio's scheduling application in healthcare is in the Capital Region of Denmark, where Herlev Hospital and Rigshospitalet chose CGI Denmark, Wonderware MES and Simio to support logistics flow, scheduling and material handling for their two new Central Sterile Services Departments and Distribution centers. The Sterile Services Departments and Distribution Centers will be highly automatic and equipped with robots and AGV's to reduce the manual work with the goods.

Rigshospitalet is the teaching hospital for medical students from Copenhagen University. It is the preferred choice for patients in need of highly specialized treatment. Herlev Hospital has 1,616 beds, employs 4,000 people and tends to 82,000 patients annually.

## 8 SUMMARY

The use of simulation for the day-to-day scheduling of complex systems is an important new and rapidly expanding application area for simulation. This new role for simulation extends the value of simulation beyond its traditional role of improving system design. With Simio the same model that was built for evaluating and improving the design of the system can be carried forward to provide an important business tool to improve the day to day operations. Applications include manufacturing, transportation/logistics, healthcare, and many other complex systems with expensive and competing resources.

There are a number of unique features required to successfully apply simulation to scheduling. These include data integration features for accessing enterprise data, detailed transaction logging, cloud-based deployment of detailed schedule results, and schedule risk analysis based on variability/uncertainty (RPS). Simio has been designed from the ground up to incorporate this functionality into its object-based architecture.

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