

INTRODUCTION TO SIMIO

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ABSTRACT

This paper describes the Simio™ modeling system that is designed to simplify model building by promoting a modeling paradigm shift from the process orientation to an object orientation. Simio is a *simulation* modeling framework based on *intelligent objects*. The intelligent objects are built by modelers and then may be reused in multiple modeling projects. Although the Simio framework is focused on object-based modeling, it also supports a seamless use of multiple modeling paradigms including event, process, object, systems dynamics, agent-based modeling, and Risk-based Planning and scheduling (RPS).

1 THE SIMIO OBJECT PARADIGM

Simio is a *simulation* modeling framework based on *intelligent objects*. The intelligent objects are built by modelers and then may be reused in multiple modeling projects. Objects can 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 for use in building hierarchical models.

An 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. The model logic and animation is built as a single step. Further, you might typically work in 2D mode for ease of modeling, but the fully automatic compelling 3D animation is just a single keystroke away (Figure 1).

An object may be animated in 3D to reflect the changing state of the object. For example a forklift truck raises and lowers its lift, a robot opens and closes its gripper, and a battle tank turns its turret. The animated model provides a moving picture of the system in operation. Simio provides a direct link to Google Warehouse (a free massive online library of graphic symbols) for animating 3D objects (Figure 2).

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. There is no need to write programming code to create new objects.

The activity of building an object in Simio is identical to the activity of building a model – in fact there is no difference between an object and a model. This concept is referred to as the equivalence principle and is central to the design of Simio. Whenever you build a model it is by definition an object that can be instantiated into another model. For example, if you combine two machines and a robot into a model of a work cell, the work cell model is itself an object that can then be instantiated any number of times into other models. The work cell is an object just like the machines and robot are objects. In Simio there is no way to separate the idea of building a model from the concept of building an object. Every

model that is built in Simio is automatically a building block that can be used in building higher level models.

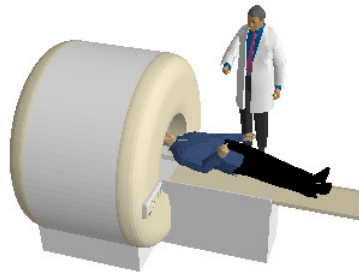
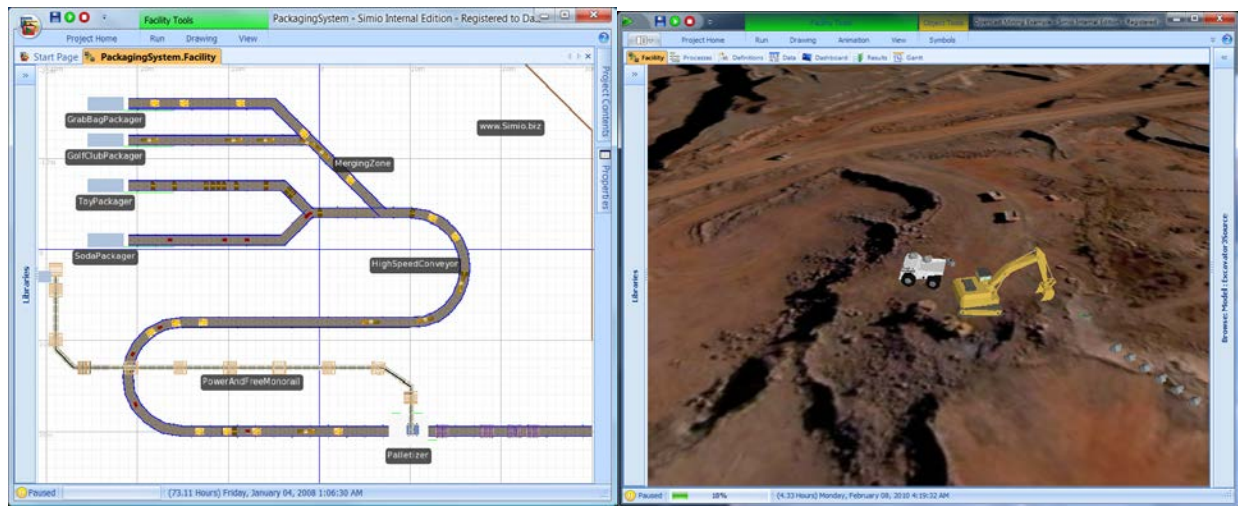


Figure 1: Ease of 2D modeling, with compelling 3D presentations

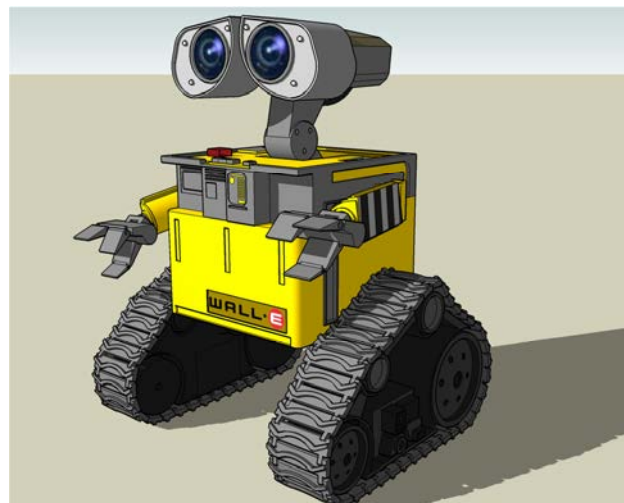


Figure 2: 3D object imported directly into Simio from Google Symbol Warehouse

2 THE OBJECT ORIENTED FOUNDATION

Many popular programming languages such as C++, C#, and Java are all built around the basic principles of object oriented programming (OOP). In this programming paradigm software is constructed as a col-

lection of cooperating *objects* that are instantiated from *classes*. These classes are designed using the core principles of *abstraction*, *encapsulation*, *polymorphism*, *inheritance*, and *composition*.

The *abstraction* principle can be summarized as focusing on the essential. The basic principle is to make the classes structure as simple as possible.

The *encapsulation* principle specifies that only the object can change its state. Encapsulation seals the implementation of the object class from the outside world.

Polymorphism provides a consistent method for messages to trigger object actions. Each object class decides how to respond to a specific message.

Inheritance is a key concept that allows new object classes to be derived from existing object classes: this is sometimes referred to as the “is-a” relationship. This is also referred to as *sub-classing* since we are creating a more specialized class of an object. Sub-classing typically allows the object behavior to be extended with new logic, and also modified by overriding some of the existing logic.

Composition allows new object classes to be built by combining existing object classes: this is sometimes referred to as the “has-a” relationship. Objects become building blocks for creating higher level objects.

Many people assume that object-oriented programming concepts were developed within the programming world; however this was not the case. These principles were developed for building simulation models, and then adopted by the programming world.

Although the simulation world created the original object-oriented concepts, until recently it had yet to produce an object-oriented modeling framework that practitioners have widely embraced. Although there have been a number of attempts to provide such a framework, in the end practitioners have for the most part stuck to their proven process orientation for modeling. One of the big reasons for this is that most object-oriented simulation tools still require the user to step back in time 25 years and code their models and/or objects in a programming language. Simio has a significantly better way.

3 THE SIMIO OBJECT FRAMEWORK

The Simio object framework is built on the same basic principles as object oriented programming languages; however these principles are applied within a modeling framework and not a programming framework. For example the Microsoft development team that designed C# applied these basic principles in the design of that programming language. Although these same principles drive the design of Simio, the result is not a programming language, but rather a graphical modeling system. This distinction is important in understanding the design of Simio.

Simio is not simply a simulation modeling tool that is programmed in an OOP language (although it is programmed in C#). Likewise it is not simply a set of classes available in an OOP language such as Java or C++ that are useful for building simulation models. Simio is a graphical modeling framework to support the construction of simulation models that is designed around the basic object oriented principles. For example when you create an object such as a “machine” in Simio, the principle of inheritance allows you to create a new class of machines that inherits the base behavior of a “machine”, but this behavior can be modified (overridden) and extended. Whereas in a programming language we extend or override behavior by writing methods in a programming language, in Simio we extend or override behavior by adding and overriding graphically defined process models.

This distinction between object oriented modeling and object oriented programming is crucial. With Simio the skills required to define and add new objects to the system are modeling skills, not programming skills.

4 THE ANATOMY OF AN OBJECT (MODEL)

When you create a model in Simio, you are creating an object class from which multiple instances can be created. This process is referred to as instantiation.

When you instantiate an object into a model, you may specify *properties* of the object that govern the behavior of this specific instance of this object. For example the properties for a machine might include the setup, processing, and teardown time, along with a bill of materials and an operator required during the setup. The creator of the object decides on the number and the meaning of the properties. The properties in Simio are strongly typed and can represent numeric values, Booleans, strings, object references, dates and times, etc. Since any model that you build is by definition an object, you have the opportunity to parameterize your model through properties as well.

In addition to properties, objects also have *states*. States are also strongly typed but always map to a numeric value. For example the Booleans true and false map to 1 and 0, and an enumerated list of state names map to the list index position (0, 1, ..., N) in the list. A state changes as a result of the execution of the logic inside the object. Properties can be thought of as inputs to an object, and states can be thought of as output responses that change throughout the execution of the object logic. A state might represent a count of completed parts, the status of a machine selected from an enumerated state list, the temperature of an ingot heating in a furnace, the level of oil in a ship being filled, or the accumulation level on a conveyor belt.

There are two basic types of states: discrete and continuous. A discrete state is a value that only changes at event times (customer arrival, machine breakdown, etc.) A continuous state (e.g. tank level, position of a cart, etc.) has a value that changes continuously over time.

5 THREE OBJECT TIERS

One of the important and unique internal design features of Simio is the use of a three tier object structure that separates an object into an object definition, object instance, and object realization. The object definition specifies the object behavior and it is shared by all instances of the object. An object instance is simply an instance of that object within a parent object definition (e.g., a lathe machine instance is placed inside a work cell definition). The object instance defines the property values for each individual instance of the object and this instance data is in turn shared by all object realizations.

The object realization is used to represent a specific realization of an instance within an expanded model hierarchy. For example, each time a new work cell instance is placed in a parent object definition (e.g., a production line) it creates the need for a new realization for the embedded lathe. Although the work cell definition is built from a single lathe instance, this single lathe instance cannot hold the state values corresponding to multiple lathe realizations that result from multiple instances of the work cell. The object realizations provide the mechanism for holding this hierarchical state information in a very compact form. The object realizations are only created during model execution and hold only the model state variables and a reference to their parent object instance. This is a highly efficient structure that is crucial for large scale applications such as agent-based models that can have many thousands of object realizations.

6 THREE WAYS TO BUILD OBJECT DEFINITIONS

The previous example in which we defined a new object definition (work cell) by combining other objects (machines and a robot) is one example of how we can create object definitions in Simio. This type of object is called a *composed object* because we create this object by combining two or more *component* objects. This object building approach is fully hierarchical, i.e., a composed object can be used as a component object in building higher level objects. This is only one way of building objects in Simio - there are two other important methods.

The most basic method for creating objects in Simio is by defining the logical processes that alter their state in response to events. For example, a machine object might be built by defining the processes that alter the machine state as events occur such as part arrival, tool breakdown, etc. This type of model-

ing is similar to the process modeling done in traditional modeling systems in use today such as Arena or GPSS. A base object can in turn be used as a component object for building higher level objects.

The final method for building objects in Simio is based on the concept of inheritance. In this case we create an object from an existing object by overriding (i.e., replacing) one or more processes within the object, or adding additional processes to extend its behavior. In other words we start with an object that is almost what we want, and then we modify and extend it as necessary to make it serve our own purpose. For example, we might build a specialized drill object from a generalized machine object by adding additional processes to handle the failure and replacement of the drill bit. An object that is built in this way is referred to as a *derived object* because it is sub-classed from an existing object.

Regardless which method is used to create an object, once created it is used in exactly the same way. An object can be instantiated any number of times into a model. You simply select the object of interest and place it (instantiate it) into your model.

7 OBJECT CLASS

There are six basic classes of objects in Simio (Figure 3). These six classes of objects provide a starting point for creating intelligent objects within Simio. By default, all six of these classes of objects have very little native intelligence, but all have the ability to gain intelligence. You build intelligent versions of these objects by modeling their behavior as a collection of event driven processes. The Standard Library included with Simio provides a rich and customizable set of objects that are derived from these six basic classes of objects.

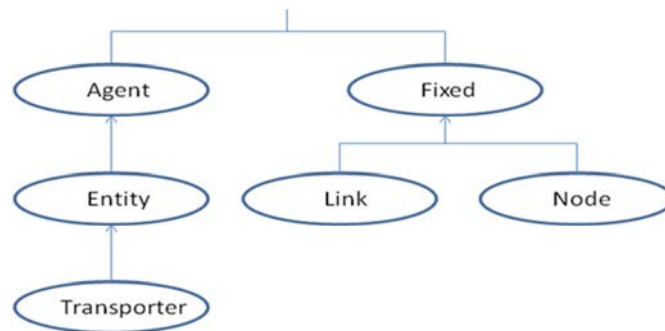


Figure 3: Basic Simio object classes

The first class is the *fixed object*. This object has a fixed location in the model and is used to represent the things in your system that do not move from one location to another. Fixed objects are used to represent stationary equipment such as machines, fueling stations, etc. The Simio Standard Library contains a number of fixed objects, such as the Source, Sink, Server, Workstation, Resource, Combiner and Separator.

Agents are objects that can freely move through 3-dimensional space. Agents are also typically used for developing agent-based models. This modeling view is useful for studying systems that are composed of many independently acting intelligent objects that interact with each other and in so doing create the overall system behavior. Examples of applications include market acceptance of a new product or service, or population growth of competing species within an environment.

An *entity* is sub-classed from the Agent class and has one important added behavior. Entities can move through the system from object to object over a network of links and nodes. Examples of entities include customers in a service system, work pieces in a manufacturing system, ships in a transportation system, tanks in a combat system, and doctors, nurses, and patients in a health delivery system.

Note that in traditional modeling systems the entities are passive and are acted upon by the model processes. However in Simio the entities can have intelligence and control their own behavior.

Link and **node** objects are used to build networks over which entities may flow. A link defines a pathway for entity movement between objects. A node defines a starting or ending point for a link. Links and nodes can be combined together into complex networks. Although the base link has little intelligence we can add behavior to allow it to model unconstrained flow, congested traffic flow, or complex material handling systems such as accumulating conveyors or power and free systems. The Standard Library contains four link objects and two node objects. The Connector, Path, TimePath and Conveyor are derived from the Link object and the Basic Node and the Transfer Node are derived from the Node object. The final class of object is a **transporter** and is sub-classed from the entity class. A transporter is an entity that has the added capability to pickup, carry, and drop off one or more other entities. By default transporters have none of this behavior, but by adding model logic to this class we can create a wide range of transporter behaviors. A transporter can model a taxi cab, bus, AGV, subway car, forklift truck, or any other object that has the ability to carry other entities from one location to another. The Standard Library contains a Vehicle object and a Worker object, both of which are derived from a Transporter object.

A key feature of Simio is the ability to create a wide range of object behaviors from these six basic classes. The Simio modeling framework is application domain neutral – i.e., these six basic classes are not specific to manufacturing, service systems, healthcare, military, etc. However it is easy to build application focused libraries comprised of intelligent objects from these six classes designed for specific application. For example it is relatively simple to build an object (in this case a link) that represents a complex accumulating conveyor for use in manufacturing applications. The design philosophy of Simio directs that this type of domain specific logic belongs in the objects that are built by users, and not programmed into the core system.

The flexibility provided by this architecture is unprecedented. For example, consider the problem of modeling multiple cranes on a common runway. This has traditionally been a rather tough application to model because of the interference between cranes and the wide possibility of interactions. Add movement in 3 dimensions and acceleration/deceleration to this and it's a problem that most products solve poorly if at all. Now consider the new style of underhung cranes that ALSO allow crane cabs to move from bridge to bridge and even between buildings – a dramatic new level of flexibility, but also modeling complexity. The Simio transporter object was extended to completely model these new types of cranes entirely in process logic WITH NO CODING! Since it is part of the object instead of the Simio engine, users can examine and even change this logic using graphical processes.

8 CREATING INTELLIGENT OBJECTS WITH PROCESSES

Modeling in Simio begins with base objects – it is the foundation on which higher level objects are built. A base object in Simio is a fixed object, agent, entity, link, node, or transporter that has intelligence added by one or more processes. Processes give an object its intelligence by defining the logic that is executed in response to events.

Each process is a sequence of process steps that is triggered by an event and is executed by a *token*. A token is released at the start of the process and is simply a thread of execution (similar to entities in Arena). A token may have properties (input parameters) and states (runtime changeable values) that control the execution of the process steps. You can define your own classes of tokens that have different combinations of properties and states.

The modeling power of Simio comes from the set of events that are automatically triggered for the six basic classes of objects, along with the process steps that are available to model state changes that occur in response to these events. Fully mastering the art of building intelligent objects involves learning the events and the collection of available process steps, along with the knowledge and experience of how to combine these steps to represent complex logic.

Each step in Simio models a simple process such as holding the token for a time delay, seizing/releasing of a resource, waiting for an event to occur, assigning a new value to a state, or deciding between alternate flow paths (Figure 4). Some steps (e.g., *Delay*) are general purpose steps that are useful in modeling objects, links, entities, transporters, agents, and groups. Other steps are only useful for spe-

cific objects. For example, the *Pickup* and *Dropoff* steps are only useful for adding intelligence to transporters and the *Engage* and *Disengage* steps are only useful in adding intelligence to Links.

Each object class has its own set of events. For example, a link provides events that fire when entities enter and leave the link, merge fully onto the link, collide with or separate from other entities that reside on the link, move within a specified range of another entity, etc. By providing model logic to respond to these events we can completely control the movement of entities across the link. For example, to add accumulation logic to the link we simply write a small process that its triggered when an entity collides with the entity it is following, and reassigns the speed of the entity to match the speed of the entity that it is following.

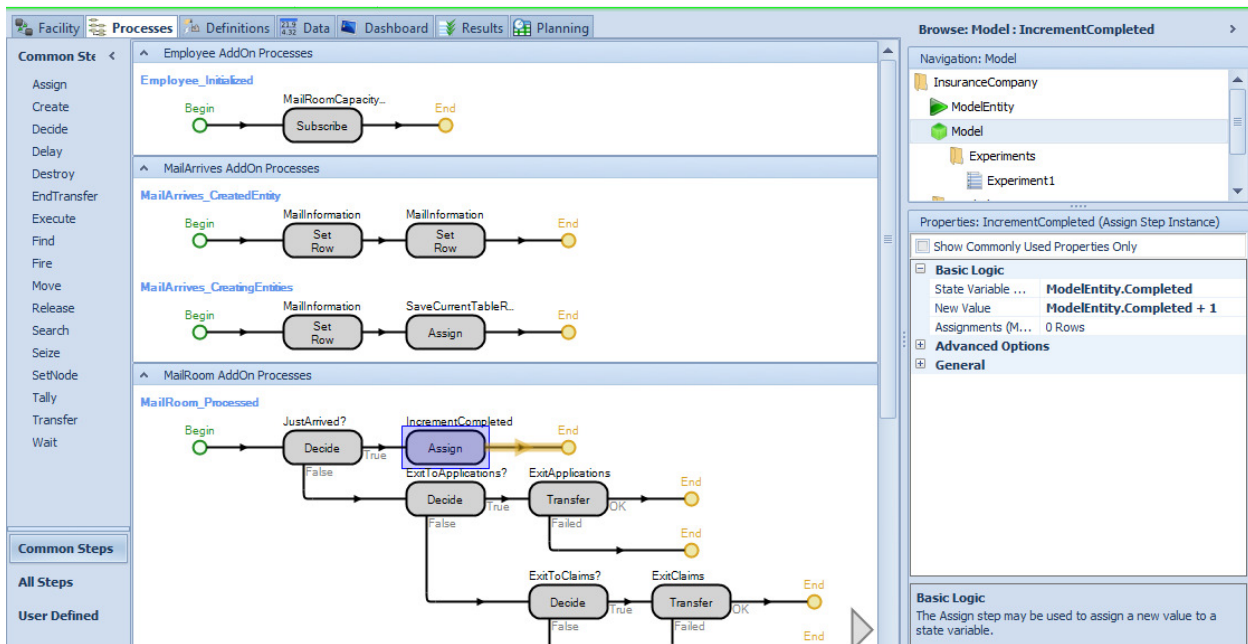


Figure 4: Graphical Process Definition

The process steps that are used to define the underlying logic for an object are stateless – i.e., they have properties (input parameters) but no states (output responses). This is important because this means that a single copy of the process can be held by the object class definition, and shared by an arbitrary number of object instances. If the process logic is changed, this fact is automatically reflected by all instances of the object.

9 RISK-BASED PLANNING AND SCHEDULING (RPS)

Although simulation has traditionally been applied to the design problem, it can also be used on an operational basis to generate production schedules for the factory floor. When used in this mode, simulation is a Finite Capacity Scheduler (FCS) and provides an alternative to other FCS methods such as optimization algorithms and job-at-a-time sequencers. However simulation-based FCS has a number of important advantages (e.g., speed of execution and flexible scheduling logic) that make it a powerful solution for scheduling applications. Simio not only provides extensive support for FCS (described just below) but also provides the unique capability of Risk-based Planning and Scheduling (described at the end of this section).

Simulation provides a simple yet flexible method for generating a finite capacity schedule for the factory floor. The basic approach with simulation-based scheduling is to run the factory model using the

starting state of the factory and the set of planned orders to be produced. Decision rules are incorporated into the model to make job selection, resource selection, and routing decisions. The simulation constructs a schedule by simulating the flow of work through the facility and making “smart” decisions based on the scheduling rules specified. The simulation results are typically displayed as jobs loaded on interactive Gantt chart that can be further manipulated by the user. There are a large number of rules that can be applied within a simulation model to generate different types of schedules focused on measures such as maximizing throughput, maintaining high utilization on a bottleneck, minimizing changeovers, or meeting specified due dates.

Because of the special requirements imposed by scheduling applications (e.g., the need for specialized decision rules and the need to view the results in the form of an interactive Gantt chart), simulation-based scheduling applications have typically employed specialized simulators specifically designed for this application area. The problem with this approach is that the specialized simulators have built-in, data-driven factory models that cannot be altered or changed to fit the application. In many cases this built-in model is an overly simplified view of the complexities of the production floor. This *one model fits all* approach severely limits the range of applications for these tools. Some production processes can be adequately represented by this fixed model, but many others cannot.

Simio takes a different approach by allowing the factory model to be defined using the full general-purpose modeling power of the tool. Hence the range of applications is no longer restricted by a fixed built-in model that cannot be altered or changed between applications. The complexities of the production process can be fully captured by the user-built Simio model. This not only includes the logic within each work center, but also the material handling required to move jobs between work centers.

The specialized requirements for FCS applications are addressed by incorporating features into Simio to specifically support the needs of FCS. These features include the support for externally defined job data sets along with very flexible modeling of resources and materials. Although these features are specifically designed to unleash the full modeling power of Simio for FCS applications, they are also useful in general modeling applications.

A Simio job data set allows a list of jobs to be externally defined for processing by the simulation model. The jobs are defined in a data set containing one or more tables, with relations defined between table columns. The specific schema for holding the job data is arbitrary and can be user defined to match the data schema for the manufacturing data (e.g., an ERP system). The job data typically includes release and due date, job routings, setup and processing times, material requirements, as well as other properties that are relevant to the system of interest. The objects in Simio can directly reference values specified in the job data set (e.g., processing time) without knowing the schema that was implemented to store the data.

Any object in Simio can serve as a capacitated resource and can have its own independent behavior. Resources can be selected from a list based on flexible rules such as minimum changeover time or longest idle time. Resources also support very flexible rules (earliest due date, least remaining slack, critical ratio, etc.) for selecting between competing jobs that are waiting to seize the resource. Finally the job usage history for resources can be displayed on an interactive Gantt chart (Figure 5).

The Materials element in Simio provides direct support to model things that can be consumed and produced during the execution of the model. Materials can also be defined hierarchically to model a traditional Bill of Materials (BOM) for manufacturing applications. Hence a manufacturing step can be modeled as the consumption of a specific list of materials within the hierarchical BOM.

A critical problem with the traditional APS approach is that it requires that all the data be fully known and deterministic. For example all processing times must be fixed and there can be no unexpected events or delays. Hence the resulting schedule with APS is by nature optimistic, and is typically very different from what occurs in the real facility. It is common that what starts off as a feasible schedule turns infeasible over time as variation and unplanned events degrade performance. It is normal to have large discrepancies between predicted schedules and actual performance. To protect against delays the scheduler must buffer with some combination of extra time, inventory, or capacity; all adding cost to the system. Risk-

based Planning and Scheduling (RPS) extends traditional APS to fully account for the variation that is present in nearly any production system, and provides the necessary information to the scheduler to allow the upfront mitigation of risk and uncertainty. Simio provides a family of products that let you

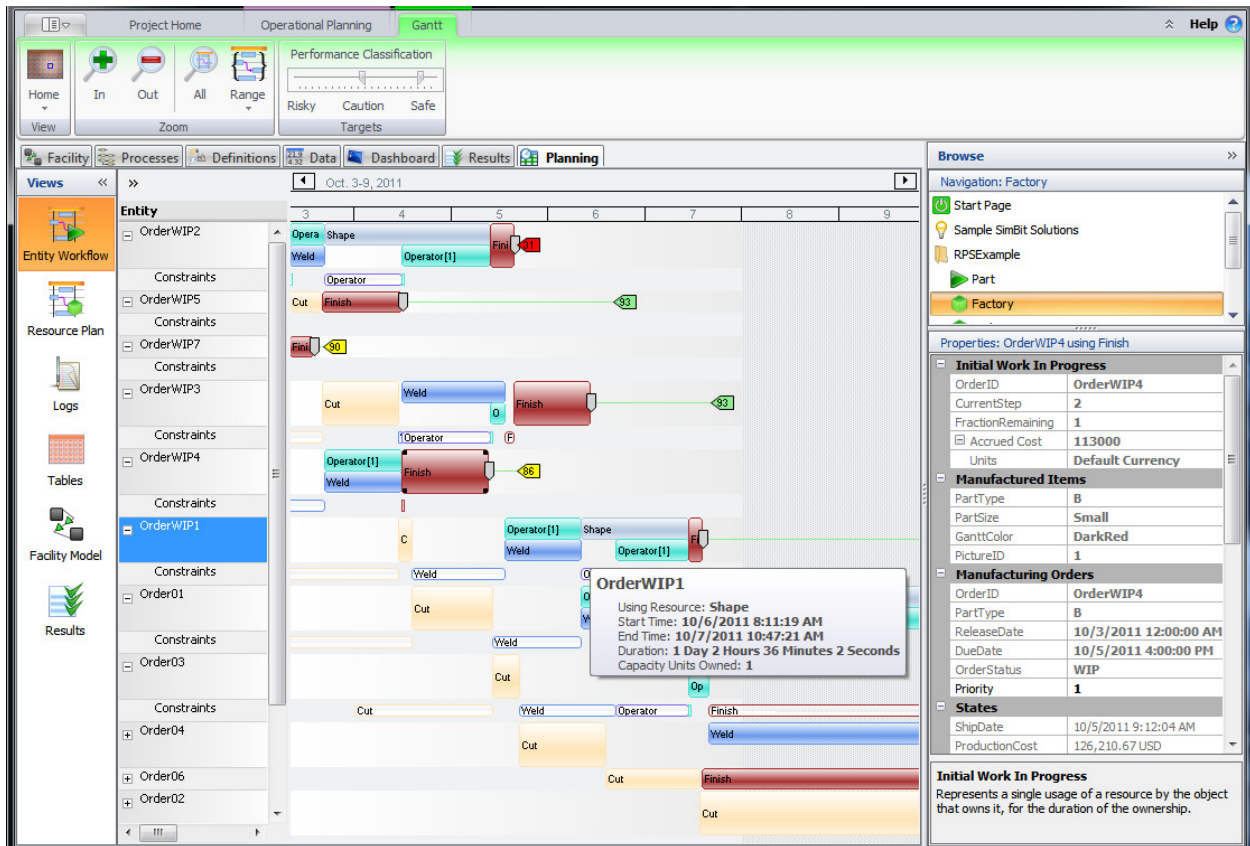


Figure 5: Sample Gantt Chart in Simio Enterprise Edition

leverage your existing investment in planning systems, such as SAP's APO, to finally close the gap between master planning and detailed production scheduling, thereby driving more revenues and greater customer satisfaction at reduced cost with existing assets.

Simio's family of RPS products (patent pending) allows for flexible scheduling strategies to support your key production objectives and lets you quickly reschedule in response to unplanned events. You can accurately model your complex production processes to capture all critical constraints so that the resulting schedules reflect the reality of your systems. You can display schedules in a wide range of outputs, including interactive Gantt charts that display individual waiting times at critical resources as well the root causes for non-value added time in the system. Simio products also integrate a 3D animation of your planned schedule to provide a unique and insightful preview of your facility operations. Simio's RPS solution is built on the Simio simulation engine and can be flexibly applied across a wide range of industries.

10 SUMMARY

Simio is a new modeling framework based on the core principles of object oriented modeling. It is unique in the following ways:

- The Simio framework is a graphical object-oriented modeling framework as opposed to simply a set of classes in an object-oriented programming language that are useful for simulation modeling. The

graphical modeling framework of Simio fully supports the core principles of object oriented modeling without requiring programming skills to add new objects to the system.

- Simio supports 3D animation as a natural part of the modeling process. Simio provides a direct interface to Google Warehouse to make it easy to incorporate realistic 3D symbols into your model.
- The Simio framework is domain neutral, and allows objects to be built that support many different application areas. The process modeling features in Simio make it possible to create new objects with complex behavior without programming (no C#, Java or custom language use is required).
- The Simio framework supports multiple modeling paradigms. The framework supports the modeling of both discrete and continuous systems, and supports an event, process, object, systems dynamics, and agent modeling views.
- The Simio framework provides specialized features to directly support applications in emulation and finite capacity scheduling that fully leverage the general modeling capabilities of Simio.
- Risk-based Planning and Scheduling (RPS) extends traditional APS to fully account for the variation that is present in nearly any production system, and provides the necessary information to the scheduler to allow the upfront mitigation of risk and uncertainty.

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