Decision Support in Specialty Chemical Operations:

a hybrid simulation based multi-criteria multi-objective optimization system

Research Proposal

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Introduction

The operation of a bulk material handling system for a specialty chemical operation can be complex. The Pittsburg facility of Criterion Catalysts & Technologies, L.P. (Criterion) has six (6) powder silos and four (4) reground fines silos feeding three (3) processing units. Portions of the material handling system are shared by all units, and portions are dedicated to specific units. Each processing unit produces a different product on different production cycles. The individual units work in a semi-batch mode; receiving varying batch sizes of powder and then processing them in a continuous manner. This requires that the right amount of powder be available at a particular unit at specific times, delays affect production. The bulk material handling systems are pneumatic transport systems that also operate in part continuous and part batch mode. Planning and scheduling logistics and operations of this system is a complex endeavor. Utilization of a decision support system could improve operations.

Decision support systems (DSS) for planning and scheduling logistics and operations are a common procedure. Discrete event simulation (DES) for studying system performance is also a common procedure. The integration of the two, especially for complex systems is not well understood (Gooding, Sarjoughian, and Kempf (2007)). Many specialty chemical plants have processes (such as bulk material handling) that operate in both a discrete method and a continuous method at the same time. Kelton, Sadowski, and Sturrock. (2004) in Simulation with Arena stated that in a continuous model, the state of the system can change continuously over time and that in a discrete model, the change can occur only at separated points in time.

Developing a decision support system and a simulation model of an operating facility is a time consuming effort. Studies by the Government Accounting Off ice have shown that many are seldom used due to ease of use issues (Fosset, Harrison, Winthrop, and Gass (1991)).

General Background and Motivation

In the specialty chemical process industry the same plant can, and often does, make different products, some times concurrently. Because of this, a factor that can impact heavily on the effective plant production rate is when common facilities, such as the bulk material feed system, switches, on a short cycle, between different processes. In the case of a pneumatic transport system delivering powders, if different units are making different products, they will usually require different powders. But, the system can feed only one process unit at a time. Because of this, other process units may be waiting for powder causing operational delay. Competitive pressures have caused process industries to search for new tools for optimizing operations; in particular planning and scheduling of logistics and production. A particular tool for this is decision support system (DSS).

The powder handling system at Criterion Catalyst & Technologies Pittsburg Operation feeds up to six (6) types of alumina powder and four (4) types of reground fines by a pneumatic transport system to three (3) catalyst carrier extrusion units. Each unit normally produces different products on different operating cycles. In operation different groups have different informational needs and different objectives in studying the plant systems and thus different needs from a decision support system:

- Logistics/Supply chain needs to have the raw materials on hand when needed but not before there is room for them.
- Operations needs to verify that production rates can be achieved and that any changeovers from one product to another can be done expeditiously.
- Engineering needs to determine system bottlenecks and potential solutions.
- Maintenance needs to predict potential failures

The standard approach is to have each of these be a separate decision support system (DSS), using different optimization methods.

Combining the different informational needs of users with the complexity of a specialty chemical material handling system creates the need for a highly flexible decision support system.

Statement of the Problem

Application of DES/DSS in specialty chemical operations has been limited to design activities (Aguilar-Lasserre, et al. (2009), Balasubramanian and Grossmann (2004)) and studying system performance such as cycle time (Alexander (2006)). For planning and scheduling stochastic methods still predominate (Alexander (2006), Balasubramanian and Grossmann (2004), Dogan (2007), and Castillo and Roberts (2001)). The theoretical work of work of Byrne and Bakir (1999), Kim and Kim (2001), and Byrne and Hossain (2005) on hybrid systems has shown the applicability in general, no work has been identified in the specialty chemical industry.

Semini, Fauske, and Strandhagen (2006) in their literature review, found very few real world applications for multi-echelon supply chain decision-making. They also found only one recent (2002 through 2006) paper related to bulk material handling simulation.

Fioroni, et al. (2007) identified that bulk material handling systems are a mixture of discrete and continuous operations, and that the modeling of such a system is a challenge for model builders.

Hao and Shen (2008) mention that the material handling system is often over simplified, which can lead to production breakdowns, low efficiency, and low performance of a production system.

Studies by the Government Accounting Office (GAO) (Fosset, Harrison, Winthrop, and Gass, (1991)) identified that a large number of simulation models developed for the U. S. Government were never used. They attributed this to inflexible models that were not easy to use. Also, simulation models are usually built to analyze a particular problem and optimized for that use. A similar statement could be made for DSS's.

Godding, Sarjoughian, and Kempf (2007) state that:

> "(T)he science of how to rigorously integrate simulation and decision models is not well understood and becomes critically important as the complexity and scale of these models increase".

Perssone, et al. (2006) state that while multi-objective optimization is an active research area in their literature review they found "few attempts in the area of simulation-based multi-objective optimization." And that of this even less information was found on operation scheduling problems. They propose that future work should include incorporating the system into a DSS.

Zhu and Wilhelm (2005) review literature to 2005 on sequence dependent scheduling problems. Of the 128 references they reviewed only two used simulation methods for their primary approach (several used simulation to verify results) and none used a true hybrid approach.

From this a need has been identified for:

- A decision support system of a bulk material handling system.
- A decision support system of a multi-source, multi-destination bulk material handling system incorporating hybrid simulation.
- A decision support system incorporating alternative procedures for analysis.

- Work on a process scheduling application that takes into account the discrete/continuous nature of the system.

Research Goal

The primary contribution of this research will be to present a method for developing a decision support system (DSS) for multi-criteria, multi-objective optimization of a bulk material handling system. The DSS would be run from a common interface and allow alternative analytical methods to be run in a hybrid system with discrete event simulation model(s) (DES) of the system. For verification and validation a case study of a multi-source, multi-destination bulk material handling system in the specialty chemical process industry will be used.

Hypotheses

It is feasible to construct a user friendly, decision support system (DSS) for multi-criteria, multi-objective optimization, using a hybrid (combined analytical model portion and a discrete event simulation model) approach.

Research Approach

The concept would be to develop a decision support system consisting of a user interface, an analytical model portion and a discrete event simulation model of the system. Depending on the users requirements either a purely analytical analysis can be preformed, a purely discrete event simulation can be performed, or a hybrid analysis comprising the analytical and discrete event portions can be performed. Readily available and commonly available tools will be utilized to minimize the end users learning curve.

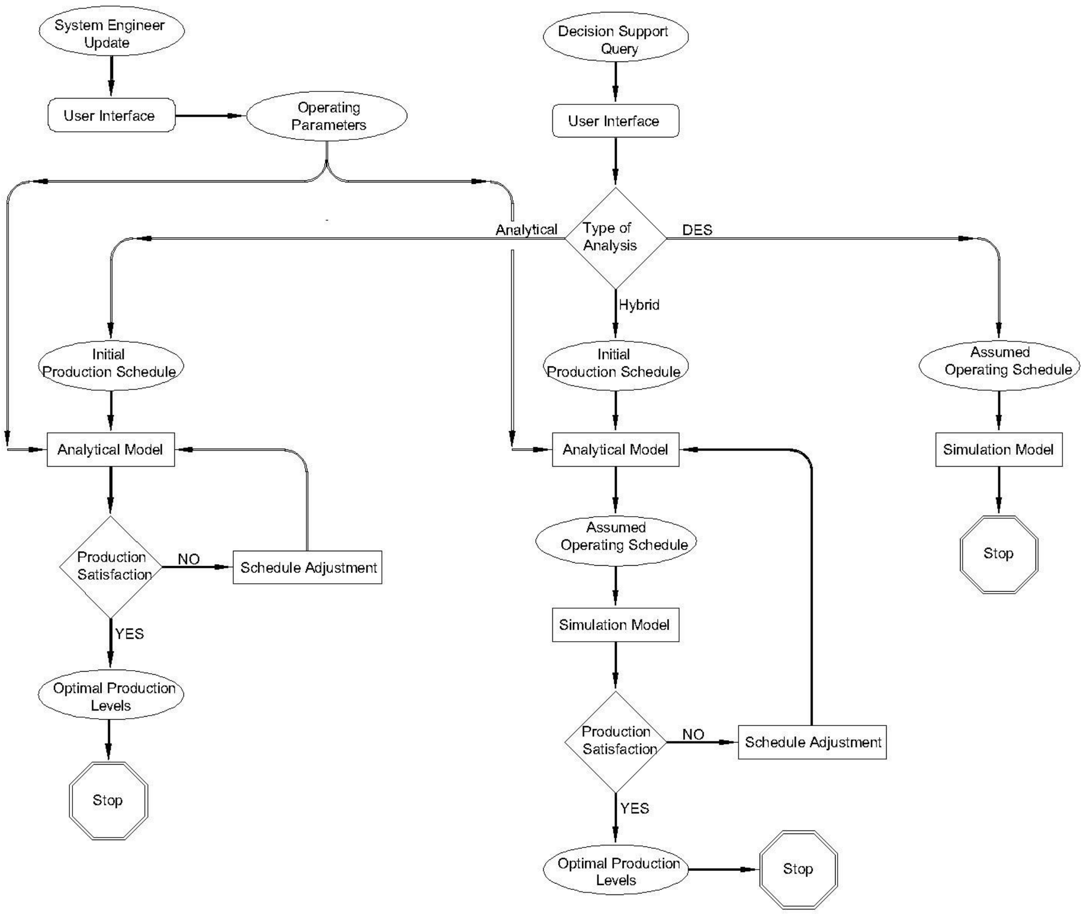


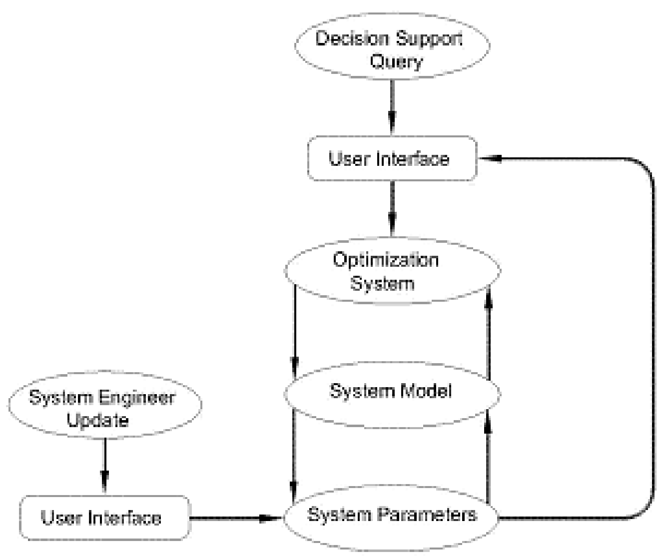
Figure 1 Proposed Decision Support System

Literature Review

Decision Support

Labadie (2004) presented t that a DSS consists of a data base management system (DBMS), a user interface, and an analysis and modeling component.

The goal in the development of DSS is to create an expert system to guide the user into making the proper decisions. From Labadie (2004), an expert system, also known as a knowledge network, is usually a computer program that contains some of the subject-specific knowledge, and contains the knowledge and analytical skills of one or more human experts.



After Labadie (2004)

Figure 2: Generic Expert System

The expert system is made up of a set of rules that analyze information supplied by the user of the system or through some data acquisition system (Fonseca and Knapp (2000)). The system will have the ability to provide mathematical analysis of the problem(s), and, depending upon their design, recommend a course of user action in order to implement corrections. It is a system that utilizes what appear to be reasoning capabilities to reach conclusions.

DES in Decision Support

DES has been used in DSS applications, but is still not an everyday use (Johansson and Kaiser (2002)). A typical approach was used by Balasubramanian and Grossmann (2004) where they solve a scheduling problem for a chemical batch plant using mixed integers and two-stage approach. Castillo and Roberts, (2001) presents using DES and search algorithms to optimize batch chemical plant operation. They provide an example using timed Petri Nets. Chen, Lee and Selikson (2000) describe the development of a semi-hybrid model of a chemical processing facility. The system modeled is the storage and shipping side (from plant to storage to shipment), emPlant was used, with a unit size of 2 tonnes to provide a semi-continuous system. Experiments were conducted using different numbers and sizes of silos. Joines, et al. (2003) describe the application of Virtual Factory for a scheduling simulation. López-Mellado, Villanueva-Paredes and Almeyda-Canepa (2005) describe the use of Petri Nets for modelling a batch system. They provide a case study showing using Petri Nets in a chemical batch process plant. Sims (1997) presents an overview of using DES for scheduling with examples from manufacturing and service industries. Vaidyanathan, Miller, and Park, (1998) examines a coffee roasting and packaging operation using SIMAN. They look at alternative schedules for each of the operating stages using DES, with the goal to improve utilization while meeting delivery requirements. Williams and Narayanaswamy, (1997) use AutoMOD to develop a scheduling and planning tool for a heavy industrial operation. Three different crane choices were evaluated to determine which could meet the desired schedule. Production rate, material delivery, and delivery sequence were studied.

Schruben (2008) presents that simulation and modeling research has gone in two separate directions. Much of the work on DES languages and packages is oriented towards improved animation, while the analysis portion has tended to ignore the actual model as an after thought. Schruben then shows how the DES model structure can impact the system performance and thus the results.

In constructing a DES the choice of the tools used can have a big impact. A general purpose DES can improve operability. Because, different users can find that different analytical methods are more appropriate for their use. In normal practice this would lead to individual DSS's, but, as with simulation models, this can be time consuming. Being able to select the analytical method at the time of running the analysis can have advantages.

Integrated DES/DSS

Molina (2005) describe the use of a knowledge management system (KSM) with a system (CONCEL) to create an ontological level description of a model. And then using a conversion system (LINK) to create the actual model. He presents an integrated DSS using real world data connected to a knowledge base, they verify results using a simulation feature to predict future results. The system starts at high levels and by the use of reconstructed subtasks works down through the knowledge levels to create an operational system.

Buchholtz (2000) presents a combination of DES and mathematical programming. Instead of using the MP for higher level analysis it is used for stochastic purposes. The application is shown using servers and queues. The DES is used for calculation of the interarrival function and continuous time Markov chains (MTMC) are used for the service function. The DES simulation keeps the queue populated while the CTMC handles the actual server function.

Godding, Sarjoughian, and Kempf (2007) state that:

> "(T)he science of how to rigorously integrate simulation and decision models is not well understood and becomes critically important as the complexity and scale of these models increase".

Hybrid Simulation

In manufacturing, simulation problems often have both a discrete and a continuous component. Tasks commonly thought of as discrete events (such as discharging a bin) have a continuous component (bin discharge takes a finite and varying period of time (angle of tipping can change rate of discharge, etc.)).

Both analytical models and DES have advantages and disadvantages in modeling a system (Byrne and Bakir (1999)). A purely analytical method can have issues when dealing with queues and alternating production rates. At the same time DES has an inherent limitation in handling continuous events (Cellier (1979) and Hitt (1998)). Recognizing this limitation, work towards a hybrid system, has been an area of development.

Ang and Sivakumar (2007) present a hybrid simulation system using a simulation-based genetic algorithm with desirability function (SIMGAD) for determining the weights to schedule an ion-implanter subjected to multiple conflicting objectives and sequence-dependent setups in semiconductor manufacturing.

Bachelet and Yon (2007) propose using simulation as a stage in optimization to improve efficiency. They present that using purely mathematical models may require extensive simplifications in system operation, which while theoretically good have problems in practice. But, using pure DES requires extensive modeling time, which pure mathematical models can solve quickly.

Hybrid Simulation has several different meanings depending on who is using the term.

Duse (1994) in his dissertation defined the term as a combination of standard DES and a Fast simulation where Fast means a model that does not maintain an events list. Again this is treated as a standard DES for this review.

The Defense Modeling and Simulation Office (DMSO) defines Hybrid Simulation as simulation with live and virtual components. While differing from creating a DES model and running it under varying conditions, this can be considered more of a game approach, and is not specifically treated in this review.

In the early days of DES, most SPL's had the ability to handle discrete events only. Y events occurred at X time intervals, but today most packages allow for the events to occur at random intervals, using alternative frequency distributions. But as most DES SPL's and packages are capable of stochastic event conditions this is not separated out from general DES in this analysis.

Shanthikumar and Sargent (1983) examined the use of both analytical and discrete components in a common system. Venkateswaran and Son (2005) have also used this approach, which is a combined discrete event/stochastic approach. For this work a combined discrete event/stochastic approach is followed.

Using a stochastic system to generate input is often a Decision Support System approach. Incorporating continuous functions in a DES can lead to a hybrid system. Going beyond a simple hybrid system can then lead to more advanced concepts with simulation into complex systems and knowledge networks.

For this review the definition as proposed by Shanthikumar and Sargent (1983) is used:
"Hybrid systems are systems that evolve with both discrete and continuous behaviors".

They went on to describe four (4) types of hybrid systems combining analytical portions and simulation portions.

> I: Results are obtained by alternating between independent analytical and simulation models; after the solution for each is derived the solutions are then combined for an overall solution.
>
> II: An analytical and simulation model operate in parallel and their output is compared together.
>
> III: A simulation model is used to feed an analytical model.
>
> IV: An analytical model is used to feed a simulation model.

The majority of the work in discrete/continuous simulation has involved types III and IV.

A major reason for the use analytical models is that they can be lower in development cost then simulations and are usually low in cost to run once developed. Simulation models, though, give more detail and are usually more realistic. Combining them in to discrete/continuous systems can give strong benefits of both. Type I or II are used if the time dependent nature of the system can be broken out, with type I being used if the time dependent nature can be completely separated and type II if their is some interdependency. These types are also used when the simulation model is used for validating the analytical models output. Type III is used when a simulation of system or subsystem is used to determine some or all of the values used in the analytical model. Type IV is used when an analytical model is used to determine some or all of the inputs for the simulation.

Petropoulakis and Giacomini (1998) present a system for modeling a manufacturing process using both continuous and discrete model components. They present that few manufacturing systems are purely discrete or continuous, but rather a combination of both. They propose a combined discrete and continuous system. Their system uses Simple++ as the DES component and

SAM for the continuous portion. The DES is top level system which calls the continuous portion as needed. This would compare to a type IV system as described by Shanthikumar and Sargent (1983).

By inference a fifth type (type V) exits that is a combined analytical DES model. In this an analytical model feeds a simulation, which is then fed to an analytical model. This gets even closer to true artificial intelligence.

A Combined Analytical DES Model

Some of the earliest work on a combined (hybrid) system was by Cellier (1979). Cellier (1979) in his dissertation, describes techniques for simulating systems with complex structures by use of a digital computer, as well as the requirements of tools (simulation languages) to cope with the problem in a user-friendly way.

He describes three (3) classes of simulation problems

(i) continuous time systems described by ordinary differential equations
(ii) continuous time systems described by partial differential equations
(iii) discrete time systems described by difference equations, sequence of time events or by mixtures of both

For type i and ii, modeling languages have been available for some time, but (at the time of this paper) type ii models are still difficult, he comments that many problems are truly combined i & iii. He then proposes a structure of an SPL to handle combined type i & iii.

(a) a discrete part consisting of elements from known discrete event simulation
(b) a continuous part consisting of elements from known continuous system simulation

(c) an interface part describing the conditions when to switch from (a) to (b) and vice-versa

Cellier then describes the conditions and characteristics for part (c). His proposed system is essentially an executive program that manages the activities of a DES and a continuous simulator and keeps track of which one should function next.

The work of Byrne and Bakir (1999), Kim and Kim (2001), and Byrne and Hossain (2005) examined the use of combined system where a linear programming model fed a simulation which was used to update the LP mode. The three papers examined a multi-period multi product (MPMP) production scheduling problem, based on a three (3) product, three (3) period case. The system had four (4) processing areas (Machine Centers) each with one (1) production unit. Each unit has a maximum capacity of 2400 minutes (40 hours) per period.

Perssone, et al. (2006) present an approach similar to Byrne and Bakir (1999), Kim and Kim (2001), and Byrne and Hossain (2005) using an iterative approach with an analytical and simulation component of the Swedish postal systems sorting stage. They state that while multi-objective optimization is an active research area in their literature review they found “few attempts in the area of simulation-based multi-objective optimization.” And that of this even less information was found on operation scheduling problems. They propose that future work should include incorporating the system into a DSS.

Willis and Jones (2008) describe a system that uses a heuristic search algorithm with a simulation model coupled to a database. Their initial description and figures indicate an iterative process, but their flowchart seems to show only one pass through the simulation model. Hao and Shen (2008) claim their system is a hybrid system, but the description appears to be more a high level DES with continuous components.

Lee, et Al. (2007) present a simulation optimization system that uses an evolutionary algorithm with simulation.

Zeng, and Yang (2009) present the use of a hybrid system for scheduling loading operations in container terminals. They use genetic algorithm and a simulation model (developed in Arena). As with many other examples (Schruben (2008)) the majority of their article is related to the GA with only four paragraphs on the simulation model, and no discussion of the actual model. The actual hybrid concept is fairly standard with an internal and external iterative loop. As with Byrne and Bakir (1999), Kim and Kim (2001), and Byrne and Hossain (2005) the hybrid solution produced good results.

Batch Specialty Chemical Process

While much of the chemical process industry operates in a continuous mode, these are primarily large processes such as petroleum refining. For specialty chemicals the use of batch and semi-batch processes are prevalent (Aguilar-Lasserre, et al. (2009), Alexander (2006), Balasubramanian and Grossmann (2004), Dogan (2007), and Castillo and Roberts (2001)). In a batch process, a fixed amount of material is turned into a product over a fixed period of time, and then another batch is processed. Semi-batch processes have batch components and continuous components that work in series or in parallel. These plants often make more than one product at a time (López-Mellado, Villanueva-Paredes and Almeyda-Canepa (2005); and Roberts, Dessouky, and Dessouky (1999)).

Other industries also work in this same mode, such as coffee roasting (Vaidyanathan, Miller, and Park, (1998)), consumer products (bottling) (Siprelle and Phelps (1997)), and other manufacturing and service industries (Sims (1997)).

The use of DES in specialty chemical operations has been generally limited to design activities (Balasubramanian and Grossmann (2004)) and studying system performance such as cycle time (Alexander (2006)). For planning and scheduling stochastic methods still predominate (Alexander (2006), Balasubramanian and Grossmann (2004), Dogan (2007), and Castillo and Roberts (2001)).

Aguilar-Lasserre, et al. (2009) present an optimization method for multi-criteria batch plant design in specialty chemicals, food products and pharmaceutical industries under imprecise demand. They use the analytic hierarchy process to improve on the non-denominated results from a genetic algorithm approach to optimization.

While the theoretical work of Byrne and Bakir (1999), Kim and Kim (2001), and Byrne and Hossain (2005) on hybrid systems has shown the applicability in general, no work has been identified using this approach in the specialty chemical industry.

Material Handling Simulation

Simulation of material handling has been well studied in general manufacturing. In reviewing books on the topic of simulation, the predominate reference to material handling is to moving parts around a work shop, or in pulling parts or packages from inventory (Banks, et al. (2004) and Kelton, et al. (2004)). In specialty chemical operations this type of material handling is used, but in the actual system bulk material handling is also used. The simulation of bulk material handling is a key component for a specialty chemical DSS. A literature search by Semini, Fauske, and Strandhagen found only one recent (2002 through 2006) paper related to bulk material handling simulation. One of the factors can be related to the nature of bulk material handling. Fioroni, et al. (2007) identified that bulk material handling systems are a mixture of discrete and continuous operations, and that the modeling of such a system is a challenge for model builders.

Many of the published works on the use of DES in bulk material handling modeling comes from the mining industry (Albrecht (2005); Giacaman, Medel, and Tabilo (2002)). Both of these looked at large belt conveyor systems. In both cases work arounds of small packets were used for handling the continuous aspect of large conveyor systems. Other work was in recycling (Mellor, et al. (2002)), and component selection (Sharp, et al. (2001)).

For pneumatic transport system simulation and modeling references are on the particle flow characteristics (Lim, Wang, and Yu (2005)) unusually related to discrete *element* modeling (dealing with flow characteristics), but not on the system as a material handling system.

Material Handling DSS

Dahal, et al. (2005) present a decision support system that combines an expert system (using GA's) with a discrete event model. The study is based on an bulk material handling port system. The DES models the port and material handling system, with the GA component evaluating the results to select optimization points.

Hao and Shen (2008) describe a system for modeling a Kanban based material handling system. While claiming it to be a hybrid system, the description appears to be more a high level DES with continuous components. They present their description stressing the system dynamics approach. They mention that material handling system is often over simplified but can lead to production breakdowns, low efficiency, and low performance of a production system.

Fonseca, Uppal, and Greene (2004) present a DSS for selecting conveyor equipment. The system is oriented towards system selection based on general criteria. They identify that the traditional method has been to leave the selection to process engineers, who may or may not have specific experience in the required type of conveying application. They identified eight (8) previous efforts to automate the conveying system selection. Their system combines most of these with additional preference based criteria. Initially they separate the selection by general type; unit conveying, bulk material handling, or sorting conveyors. Each of these has specific selection criteria to further define the system. The output ranks the recommendations based on derived suitability scores.

System Analysis

The manufacturing industry has been a major user of simulation to reduce in process storage and surge capacity, with the goal of increasing throughput without increasing facility size. Benjaafar (2002) describes the use of a process oriented DES (ARENA) to study congestion in manufacturing material processing systems. For similar reasons this topic has been looked at by several mining operations.

Giacaman, Medel, and Tabilo (2002) describe the impact on capacity of changes in truck and loader size. Brunner, Yazici and Baiden (1999) used Automod to evaluate the capacity and life of a mine under varying conditions and to evaluate the impact of changing system details (size and capacity) on the total mine life and throughput.

Al-Aomar (2006) proposes using DES as part of Lean Six sigma approach to process design, particularly in relation to a lean service system. He modifies the standard DFSS-IDOV approach to better suit a lean service organization. Primary use of DES is in the verification stage. He shows how to use other tools (QFD, P-diagram, etc) and interface them with the DFSS-IDOV concept. He also shows how DES in a Lean Six Sigma approach can be used with both an existing and a new operation.

Specific DES work related to engineering, maintenance and operations activities includes:

Engineering

DES has gained use in solving process design constraints. Work by Castillo and Roberts (2001) present using DES (Timed Petri Nets (TPN)) to optimize batch chemical plant operation. Based on a typical plant circuit and typical plant scheduling (from literature) they motivate an algorithm and present an example using TPN to identify system bottlenecks and constraint points. Albrecht (2005) presents the use of DES (Sigma) in the sizing of a mining material handling system. By simulating the actual operation versus using traditional rule of thumb measures, the system size could be reduced. Martinez and Castagna (2003) compare two alternative ways to size a time constrained plant

- spectral algebraic approach
- DES using Arena

Results are complementary, with the DES being simpler to apply and understand

Logistics/Supply chain

The use of DES and DSS in logistics/supply chain work has included work by Chen, Lee and Selikson (2000) who used DES to look at the logistics in chemical plant, and Dogan (2007) who looked at alternative algorithms for batch multi-period, multi-product processing facilities. Other work has been aimed at parts handling in assembly operations (Lee et al. (2002), Lee, et Al. (2007), and Venkateswaran (2005)). Pathak's (2005) in his dissertation looked at how supply chains (he uses Supply Networks (network of firms transforming raw material into finished products)) grow and emerge. April, et al. (2004) provide a general overview of using simulation for optimization in supply chain using DES for verification. Glover, Kelly and Laguna (1999) present examples of using an integrated set of methods, including Tabu Search, Scatter Search, Mixed Integer Programming, and Neural Networks, combined with simulation.

Semini, Fauske, and Strandhagen (2006) present a survey of recent WSC papers dealing with DES for manufacturing logistics DSS. They report on 52 papers of which several reported on the combination of DES with optimization. The major industries reporting on the use of DES in logistics were semiconductor (13) and automotive (10). Arena (13) and Automod (11) were the two most used SMP. Five papers described a combined simulation and optimization methods. Two dealt with using DES to calculate objective function values in heuristic algorithms (Shanthikumar and Sargent (1983) Type III); one estimated queuing times and slack repeatedly in an iterative scheduling algorithm (Type I); one identify bottlenecks in a bottleneck-based scheduling algorithm (Type II); and one used DES to assess the performance of a flow shop schedule created by a scheduling heuristic (not truly hybrid). Four of these were short term planning and scheduling. They conclude that optimization has a greater potential to support DES in operational planning processes rather than strategic decision-making.

Maintenance

Use of DES in maintenance work has also gained use. Contreras, et al. (2002) provide a case study of using simulation for reliability. They present the use of a DES for evaluating alternative maintenance practices for a garment distribution facility in New Mexico. Data was collected and analyzed to determine the reliability of motors on the conveyor system. Two models developed one using existing practice (preventative maintenance) and one using a predictive maintenance (simulation) approach. Predictive Maintenance produced better results. They used ARENA to develop the models with failure modes. Fonseca (1998) and Fonseca and Knapp (2000) propose a reliability centered maintenace (RCM) system that reads real-time operating data via Aspen Tech and ouputs an

RCM list for evaluation. Current data is compared to the rule base to generate the RCM documents.

Operations

Operations use of DES has included the work by Dassisti and Galantucci (2005) where they present the use of standard DES (EM-Plant) to perform fuzzy simulations in an on-line environment. Goal was to use the DES for on-line control of a flexible manufacturing system (FMS). They use two sets of numbers in both a correlted (both sets the same) and an un-correlated (each different) manne. A tranmission assembly operation was used as a test case. Part of the input to the simulator is a factor called machine efficiency facotr that was set as a fuzzy set and modified for each of 10 replicate runs at each point. When in the uncorrelated mode, the number of runs needed grew large. Garcia (2000) presents a study of nuclear spent fuel processing facility using a DES. He describes the facility and how the simulation model was developed. He discusses some of the results of the analysis, but does not state what DES was used.

Optimization

For analysis of alternative options (“what if analysis)” the common approach is to use analytical methods, especially for multi-criteria decision analysis and multi-objective optimization problems. Different users can find that different analytical methods are more appropriate for their use.

In optimization problems for manufacturing systems a standard approach is to use an analytical hierarchy process, goal programming methods, or other nondominated solution methods (Labadie (2004)). Often in manufacturing the goals are not discrete (if nothing else produce product x up to amount y). In cases where the rules are not “hard” and may be violated, other methods have application. These include Stochastic Programming, Fuzzy Rule-Based Systems, Genetic Algorithms, or Artificial Neural Networks.

Allaoui and Artiba (2004) present a methodology for approaching a hybrid simulation of a shop. They describe a hybrid flow shop, and explain methods for the analysis. They use heuristics and simulated annealing, and then show how to integrate into a hybrid. They provide a simplified example

Alrefaei and Alawneh (2004) analyze how to select the optimal system by stochastic methods. They describe a statistical approach for simulation optimization and recommend performing parallel DES (PDES) runs as an alternative to massive runs. This is applicability to PDES and in hybrid optimization.

April, et al. (2004) provide a general overview of using simulation for optimization. They describe general optimization methods and how simulation can be used with them. Their approach is an iterative approach where the analytical phase is used to feed the simulation and to analyze the results. They use Tabu Search, Scatter Search, Mixed Integer Programming, and Neural Networks for their optimization. Note: paper is general in nature an primarily selling OptiQuest, it is also a reprise of April, et al. (2001). For the portfolio analysis they use Monte Carlo simulation, and for the supply chain example they use some unnamed DES which they do not describe.

Bachelet and Yon (2007) propose using simulation as a stage in optimization to improve efficiency. They present that using purely mathematical models may require extensive simplifications in system operation, which while theoretically good have problems in practice. But, using pure DES requires extensive modeling time, which pure mathematical models can solve quickly.

Boesel (1999) presents the application of a modified GA with DES to provide optimization during simulation. He uses GA to search during replicate runs, the GA adjusts the number of replicates to maintain desired error control. After the runs a separate heuristic approach is used to select optimal results from replicates. Provides comments on problems using GA’s over a highly varying solution space (stochastic) versus deterministic spaces, and methods used to control this. During the final best selection the system may recycle into simulation mode to evaluate some promising, but unevaluated areas.

Byrne and Bakir (1999) used an LP approach in a hybride system to analiyze production constraints. Balasubramanian and Grossmann (2004) presented a case in solving a scheduling problem for a chemical batch plant using mixed integers and two-stage approach. Chen, Lee and Selikson (2000) describe the development of a semi-hybrid model of a chemical processing facility. The system modeled is the storage and shipping side (from plant to storage to shipment). Byrne and Bakir (1999), Kim and Kim (2001), and Byrne and Hossain (2005) examine a multi-period multi product (MPMP) production scheduling problem using linear programming and unnamed DES routines.

Cavalieri and Gaiardelli, (1998) present the application of hybrid adaptive GA's for scheduling. The GA's are combined with a DES to determine the results. The GA feeds the simulation and analyzes the results. One version also includes a dispatching rule between the GA and the DES input. They compare the two GA approaches with earlier non-adaptive approaches and report that their approach worked better.

Dogan (2007)) in his dissertation, presents the use of mixed integer linear programming (MILP) models for solving the planning and scheduling of batch multi-period, multi-product processing facilities. He also analyzes multi-product continuous facilities in a similar manner.

Evans and Alexander (2007) present the use of an analytical approach (Shanthikumar and Sargent (1983) Type III (a simulation model is used to feed an analytical model)) to solving multi-criteria problems for lean manufacturing support. They describe how to select the factors for the analytical portion and how to evaluate them. They apply their concept to an example of distribution system for a manufacturer. They state that this method conforms to basic lean principles and by using this a hybrid approach can be attained.

Hitt (1998) in her dissertation presents the use of artificial neural networks (ANN) in simulation models. She presents the application of an object oriented C++ system, based on GPSS that can be combined with artificial neural network components to achieve a hybrid system.

Lacksonen (2001) presented a method of using algorithms for optimization with a DES. He proposes that if a easy to use robust algorithm can be determined it will make the use of DES for system optimization easier. Four alternative algorithms are used with four simple simulation models and the results compared to determine which produced the most optimal solutions.

- pattern search
- simplex
- simulated annealing (SA)
- genetic algorithm (GA)

Genetic algorithm performed best, followed by pattern search, simulated annealing, and simplex last. He discussed why each performed better or orse than others.

Perrone, Zinno, and La Diega (2001) present an application of fuzzy concepts to DES. In agile manufacturing, there may not be enough lead time to collect adequate data for standard modeling procedures, this leads to the use of fuzzy logic which can cause problems in DES. They describe three areas where fuzzy logic impacts upon DES; event selection, simulation clock updating, and activity selection. Of these, the second (clock time) is relatively straight forward, and can be considered as part of the normal delay time activity of clock updating. The other two are more problematic, and can lead to a time paradox where the clock actually needs to back up to cover the actual events in proper sequence. Their solution is to iterate through to achieve a minimal time paradox.

Selecting a Simulation and Modeling Language

In conducting a simulation modeling study one or more software tools are needed. There are many (84+) packages available for discrete event simulation alone. Selecting the appropriate language or package can be a study of its own. Tools for this selection are generally scarce. Several sources have proposed methods and or frameworks for evaluating these tools.

- Page (1994) in his dissertation on developing the next generation modeling framework presented a series of criteria for evaluating that framework. His criteria were quantifiable and could be adapted to simulation package evaluation.
- Hlupic, Irani, and Paul (1999) presented an evaluation framework for simulation software that was fairly cumbersome and the analysis was not quantifiable.
- Banks and Gibson (1997) also presented some qualitative features to consider.
- Ahmed, Hall, and Wernick (2003) provided more guidelines.

It was felt that a more user friendly approach could be developed. By combining the work of Ahmed, Hall, and Wernick (2003); Banks and Gibson (1997); Hlupic, Irani, and Paul (1999); and Page (1994) a Modeling Package Evaluation Procedure was developed (Albrecht (2007)).

The procedure covered seven (7) major areas.

- Modeling Environment
- Model Documentation and Structure

- Verification & Validation
- Experimentation facilities
- Statistical facilities
- User support
- Financial and technical features

To show use of this method, five (5) simulation packages are evaluated.

- Arena
- Extend
- Sigma
- Viskit
- Ptolemy II

Arena is by Rockwell Software (http://www.arenasimulation.com/) that is based on the older SPL SIMAN. It is an integrated package with an academic version often used in simulation course when it is bundled with Simulation with Arena (Kelton, Sadowski, and Sturrock, 2004). Arena is often distributed as part of course textbook (Kelton, Sadowski, and Sturrock, 2004) providing excellent basic documentation. Other information is available from literature reviews and Internet searches. The academic use of Arena is cultivated by Rockwell (supplier). Advanced training, portability and conversion to other systems are weak. Having Arena distributed with a textbook reduces the total cost for the basic package, but commercial versions are significantly more expensive. Being Windows (tm) based samples the hardware requirements, but updates are not often, and can be expensive.

Extend is a DES SMT by Imagine That, Inc. (http://www.imaginethatinc.com/) that is an extensible program with add-ons from several sources. It can be used to model continuous, discrete event or discrete rate processes. Extend is primarily a commercial tool with some academic support. General support is adequate, particularly if you work with one of the Extend add-on sources.

Advanced training, portability and conversion to other systems are weak. Extend's academic version is reasonably priced, but if more power is needed the price goes up quickly. Being Windows (tm) based simplifies the hardware requirements, but updates are not often, and can be expensive.

Ptolemy II is a DES/Continuous SMT developed by the Center for Hybrid and Embedded Software Systems (CHESS), at the Department of Electrical Engineering and Computer Sciences, University of California at Berkeley (http://ptolemy.eecs.berkeley.edu/). Ptolemy II is a software framework developed as part of the Ptolemy Project. It is a Java-based component assembly framework with a graphical user interface called Vergil. Vergil itself is a component assembly defined in Ptolemy II. Ptolemy II is a development environment and is not a commercial package. There is a large amount of documentation and several demonstration models. But the tutorial is rather difficult to follow and is not geared for general users, but rather for developers.

SIGMA is a DES SMT by Custom Simulations (http://www.customsimulations.com/) based on event graphs. It is also used in many simulation courses as it is relatively easy to learn. Sigma is often used as an introductory simulation teaching tool and is available with a course textbook (Graphical Simulation Modeling and Analysis Using Sigma for Windows (Schruben, 1995)) providing excellent basic documentation. Very little other information is available. Advanced training, portability and conversion to other systems are weak. Commercial versions are significantly more expensive. Being Windows (tm) based samples the hardware requirements, but updates are not often, and can be expensive.

Viskit is a DES SMT by is a visual editing verison of Simkit developed by Arnold Buss of the Naval Postgraduate School http://diana.nps.edu/Viskit/ and http://diana.nps.edu/Simkit/) based on event graphs. It is similar to Sigma but with a different interface and also being open source. Viskit (and its non-graphical version Simkit) is used as a simulation teaching tool at the Naval

Postgraduate School. Basic documentation is minimal, but being similar to Sigma the basic concepts that relate to event graphs is useful. . Very little other information is available. Advanced training is weak, but portability and conversion to other systems are good. A commercial version is not available. Being Java based simplifies the hardware requirements, and updates are fairly often.

Of these simulation packages, Ptolemy II is the most flexible and offers the most features. But, since Ptolemy II is primarily a test bed, it has few standard features, although it has a true open source system to allow development of features. Arena and Extend, being commercial packages, offer the most comprehensive tools ready to use. They also hide more of the underpinnings. Sigma is used as teaching tool, is some what developed, Viskit is the least developed of the five, but is low cost (free) and is open source.

A topic not discussed by of Ahmed, Hall, and Wernick (2003); Banks and Gibson (1997); Hlupic, Irani, and Paul (1999); Page (1994) and Albrecht (2007) is the ability of the DES to adequately model a system. Savage, Schruben, and Yücesan (2005) present that event graphs are capable of modeling any type of system because they can model a Turing machine and thus pass Church's thesis. They present an example of an event graphs simulating a Turing machine. They claim that all modeling languages do not meet the requirements of true generality, but that event graphs do, and thus can model any system, in particular system dynamics. In Schruben (2008) he presents that event graphs are a very good general purpose simulation modeling language.

Literature Review Conclusion

Based on this search the following conclusions can be drawn.

- There has been no prior documented work on a decision support system of a bulk material handling system.

- There has been no prior documented work on a decision support system of a multi-source, multi-destination bulk material handling system incorporating hybrid simulation.
- There has been no prior documented work on a decision support system incorporating alternative procedures for analysis.
- There has been no prior documented work on process scheduling applications that took into account the discrete/continuous nature of the system.

Case Study for Verification & Validation

For this research it is proposed to study the bulk powder storage system at the Pittsburg Operation of Criterion Catalysts & Technologies, L.P. The system feeds alumina powder and reground fines to three (3) catalyst carrier extrusion units. These units produce the base catalyst pellets.

Petroleum refining catalyst is a small pellet, made from aluminum trioxide (Al2O3) (alumina) that is impregnated with various amounts of other metals. Production is a two (2) stage process where first the pellets are produced and then impregnated with the other metals. At Pittsburg three units are dedicated to making the carrier pellets for subsequent impregnation both onsite and at other operations. The bulk storage system feeds these three (3) units. Pittsburg operates 24 hours a day, seven (7) days a week, with periodic shutdowns for product change over and maintenance.

Two (2) basic factors define the carrier; the recipe and the pellet size. Pellet size is determined by inserts in the extrusion equipment. The recipe defines the specific product, and consists of (among other factors) the type and amount of powder and fines to be used. Pittsburg uses up to six (6) different types of alumina that vary based on particle size, density, and pore characteristic.

To reduce waste and recover otherwise lost metals off specification catalyst are collected in bulk bags, transported to the warehouse grinder area and ground to micron size. The fines are then fed back into the system as part of the recipe for new catalyst. At any one time Pittsburg has up to four (4) different fines, usually designated by some basic characteristic.

During the first quarter 2008 Pittsburg used 13 of a possible 16 different recipes for 36 different production runs. Production runs varied from 9,000 to 1,400,000 pounds of carrier. The shortest product run was less than 24 hours, and the longest was 25 days. Each catalyst recipes takes a different time to produce. In addition the physical layout requires a different amount of time to pneumatically transport the powder and the fines to each unit.

Optimizing the schedule and even determining what unit to use is a continuing effort, with conflicting goals.

System Description

The system has three main components that work together; the "A" system, powder silos, and the fines system.

"A" System

The "A" system receives powder from 100 ton (nominal) hopper bottom rail cars. The powder is first transported by a dilute phase pneumatic transport system to the "A" system receiver. From here it is transported by a dense phase pneumatic transport system to one of six (6) silos depending on powder type. Pittsburg normally stocks four (4) different powders at any one time.

Providing powder to the silos is heavily constrained by the railroad and corporate logistics activities. While shown for clarity, this project will assume that the powder is available as needed in the silos and the "A" system will not be modeled or included in the DSS.

Powder Silos

The main powder system ("B" and "C" systems) draws powder from the silos on demand from the units and pneumatically conveys the powder to the unit. The "B" system feeds either unit "1" or unit "2", and the "C" system feeds unit "3". The capacity of unit "3" is equal to the combined capacity of units "1" and "2". Any particular powder draw can be a combination of two or more silos to give a particular powder blend. The powder is conveyed by separate dilute phase transport systems to either the "B" system receiver or the "C" system receiver.

From the individual receivers the powder is transported by a dense phase pneumatic transport system to one of three (3) operating units.

Fines system

The fines system consists of a manual loading station where bulk bags (1000-1800 lbs each) are dumped into the receiving hopper. From the receiving hopper a screw conveyor feeds the grinder station. The ground material is pneumatically conveyed (dilute phase system) to one of three silos. In addition a fourth silo is normally dedicated to molybdenum oxide. Each silo holds a different type of ground material. A rotary airlock that then feeds a pneumatic transporter controls the silo discharge. The material in the pneumatic transporter is then fed to one of three (3) operating units or recycled to the silos, or transferred to a bag out station by a dense phase transport system.

The off-spec material fed to the grinder is stored in the warehouse and is normally available as needed. For this project it will be considered available as needed, as will the grinder/unloading operator. A fixed feed and transport rate to the silos will be used (material is available in the fines silos as needed).

The DSS will consider silo feed rates, transport rates to the units, and demand variations from the units. The main components of the study system are shown below.

The powder system is shown below.

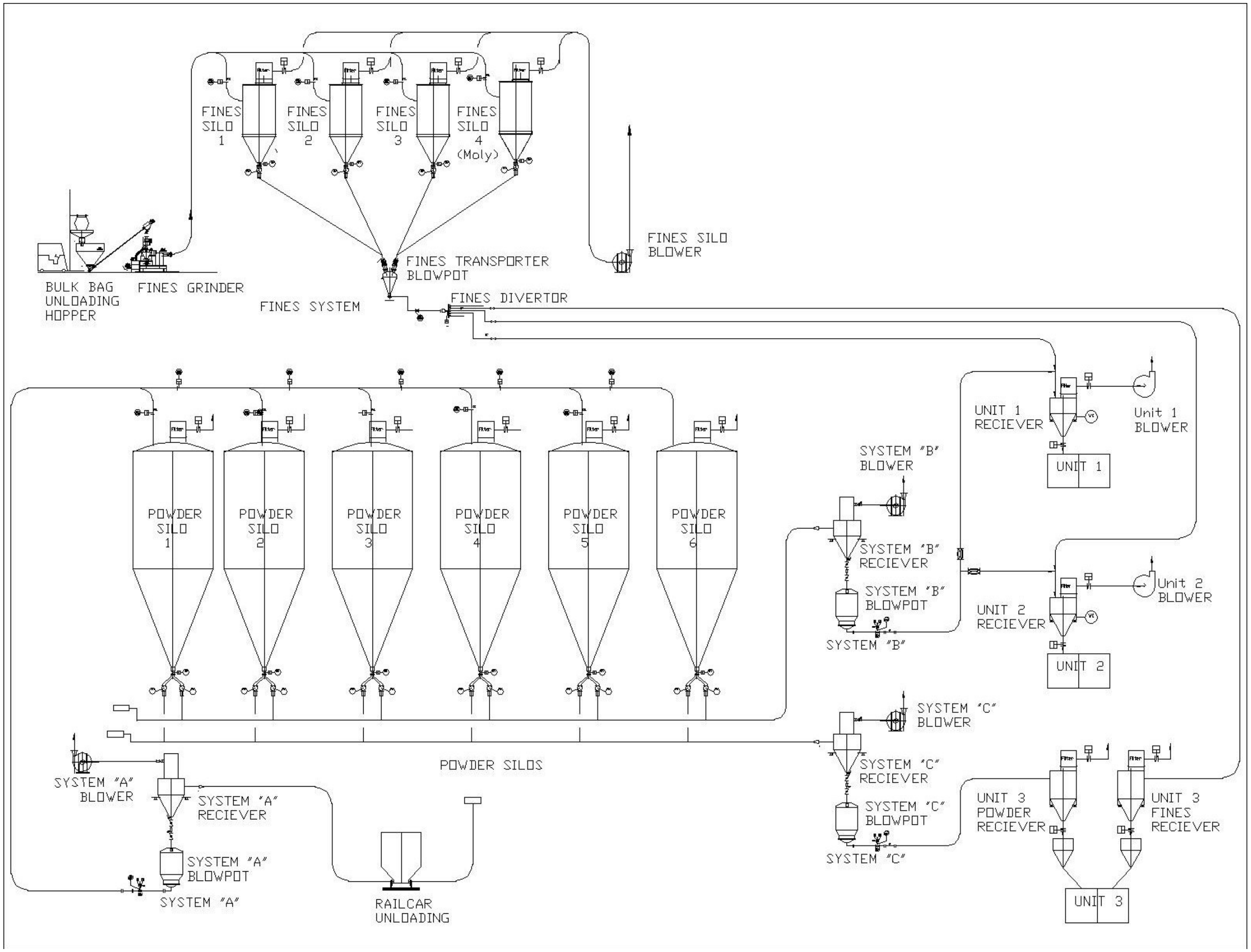


Figure 3: Powder System Flow

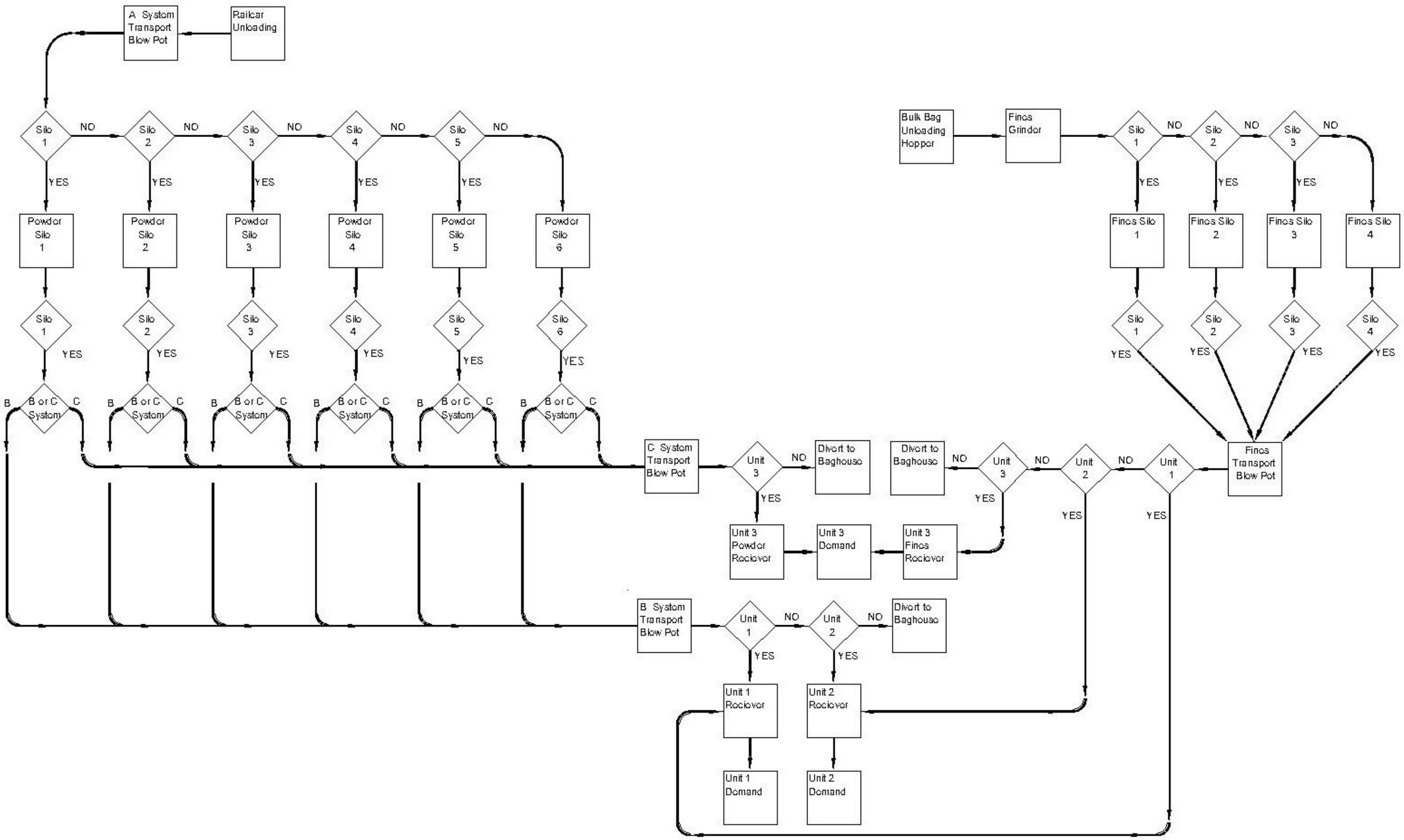


Figure 4: Study System

Approach to the problem

To achieve the stated goals, the main steps in this project will be:

- Develop a simulation model of the bulk material handling system that will take into account the discrete/continuous nature of the system.
- Develop alternative multi-criteria objective analysis options.
- Create an interface to allow a user to select:
  - An analytical approach using alternative stochastic methods.
  - A simulation run using the system model.
  - Or a hybrid approach using a combined analytical and simulation approach.
- Verify and validate the system.

Simulation Model

Develop a simulation model of the bulk material handling system that will take into account the discrete/continuous nature of the system. Based on the results from the literature review (above) it is planned that an event graph simulation language willed be used (either Sigma or Viskit).

From a given production schedule (that will provide the individual product orders, the desired target delivery date, and the order priority) the operating parameters are defined by the recipe and the current operating information.

The simulation model will return a simulated schedule, with the predicted production amount, the predicted start date, and the predicted delivery date. As variations in random conditions can cause different results replicate runs (30+) will be performed. The average results of the replicates will be used. The terms and definition of the proposed variables are shown in Appendix A.

The model will be validated against known operational conditions.

Utilizing object oriented concepts the user will be able to select alternative levels of abstraction at run time.

Changes in the recorded variables can be used to determine:

- Unit delay waiting for powder or fines.
- System delay waiting for powder draw.
- Unit idle time (no production scheduled).
- Powder and fines consumption rates.

Following basic model verification, alterative run time models will be used to analyze these factors.

Alternative Multi-criteria Objective Analysis Options

Include alternative multi-criteria objective analysis options in the hybrid system.

In this system there are conflicting requirements where the goal may be to produce product x or y up to amount z1 or z2 respectively if no other product is being produced in unit 1. Or product x can be produced in units 1, 2, or 3. In cases where the rules are not “hard” and may be violated other methods have application. The user will be able to select between numerical programming, Fuzzy Rule-Based Systems, Genetic Algorithms, or Artificial Neural Networks.

Hybrid Simulation

Incorporate the simulation model in a user interface with a selectable stochastic component to perform a hybrid analysis. The initial system will be based on a linear programming model for the analytical portion.

The hybrid system will be organized as shown in figure x, below

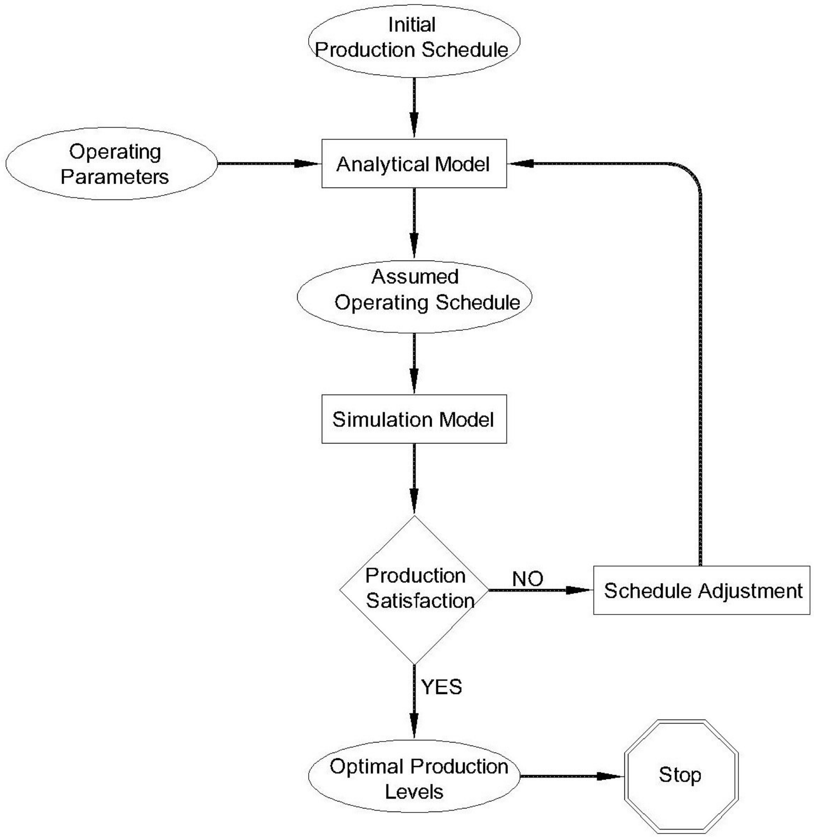


Figure 5: Hybrid Simulation system

The user will input the initial production schedule (S_p) as described above, and the operating conditions (O_c). The system will iterate until convergence on the output schedule ($S_p \approx S_a$).

User Interface

The target users for this DSS will be operations, maintenance, and supply chain personnel. Many of the proposed end users for this DSS will not be knowledgeable or interested in model development or program development. They will be interested in ease of use, and being able to get the output results in a format they can understand. For these reasons it is proposed to use MS Excel for the interface.

The ability to create programs in visual basic and then run them, as macros will be utilized. In addition the output of Excel program can be made compatible with other systems already in place.

Appendix A: Model Terms

Given:

$i = \{1,2,3\}$	: Number of operating units
$j = \{1,2,...,6\}$	: Number of powder sources
$k = \{1,2,3,4\}$	: Number of fines sources
$l = \{1,2,...,16\}$	: Number of possible recipes
$x = \{1,2,...,n\}$	: Number of orders

Where

$S_p = \{O_x, d_x, \pi_x\}$	: Production schedule
$O_x = \{R_l, Tp_x\}$	: Actual orders in current schedule
d_x	: Delivery date (order to be complete)
$\pi_x = \{1,2,...,n\}$	: Priority of order
$R_l = \{p_j, f_k, M_l, W_l\}$	: Recipe for that product
Tp_x	: Target production (pounds)
p_j	: % Powder *j* in recipe *l*
f_k	: % Fines *K* in recipe *l*
M_l	: Process time required for recipe *l*
W_l	: Target batch weight for recipe *l*
$O_c = \{P_j, F_k\}$	: Current operating information
P_j	: Type of powder in powder silo *j*
F_k	: Type of fines in fines bin *k*

Output (basic)

$S_a = \{Ta_x, ds_x, de_x\}$	: Output production schedule
Ta_x	: Output production (pounds)
ds_x	: Start date for order *x*
de_x	: Delivery date for order *x*

The production schedule ($S_p = \{O_x, d_x, \pi_x\}$) provides the orders ($O_x$), the target delivery date (d_x), and the order priority (π_x). The order ($O_x = \{R_l, Tp_x\}$) has the product type (defined by the recipe (R_l)), and the target production (pounds (Tp_x)).

Using the production schedule (S_p), for each order (O_x) the operating parameters are defined by the recipe (R_l) and the current operating information (O_c).

For a particular recipe $R_l = \{p_j, f_k, M_l, W_l\}$, the factors ($p_j, f_k, M_l, W_l$) can have an allowable variation based on operating conditions. Three (p_j, f_k, W_l) will be kept to the target levels during simulation runs. The process time (M_l) can vary due to downstream issues beyond the scope of this study (equipment malfunctions, operator error, and such). The recipe (R_l) guidelines give a range for base process time (M_l) from 20 minutes to 120 minutes, depending on particular recipe and operating unit.

For this study M_l will be modeled by a triangular distribution based on minimum, average, and maximum allowable mix times as defined by the recipe (R_l).

The operating conditions ($O_c = \{P_j, F_k\}$) is defined by the current distribution of powder and fines in storage.

The simulation model will return an actual schedule ($S_a = \{Ta_x, ds_x, de_x\}$), with the actual production amount (Ta_x), the actual start date (ds_x), and the actual delivery date (de_x).

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