An Integrated Optimization Tool with Applications in Mining Using a Discrete Rate Stochastic Model

by

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ABSTRACT

The simulation as a stand alone optimization tool of a complex system such as a vertical integrated mining operation, significantly over simplifies the actual picture of the system processes involved resulting in an unaccountable effort and resources being spent on optimizing Non Value Added (NA) processes.

This study purposed to develop a discrete stochastic simulation-optimization model to accurately capture the dynamics of the system and to provide a structured way to optimize the Value Added (VA) processes.

The mine operation model to be simulated for this study is designed as a hybrid level throughput model to identify the VA processes in a mining operation. This study also allows a better understanding of the impact of variation on the likelihood of achieving any given overall result.

The proposed discrete stochastic simulation- optimization model provides the ability for a process manager to gain realistic understanding of what a process can do if some factors constraining the process were to be optimized i.e. to conduct what-if analysis. Another benefit of this approached technique is to be able to estimate dependable and reasonable returns on a large optimization related expenditure.

The inputs into the model are the capability of the processes which are entered using various variables depending on how much information is available; simple inputs for least amount of information to detailed inputs for well known process to combinational inputs for somewhere in between. The process bottlenecks are identified and measured using the outputs of the model which include production output, severity of constraints, capacity constraints and cumulative bottleneck plots. Once a base case has been identified and documented then the inputs can be modified to represent the business initiatives and the outputs can be compared to the base case to evaluate the true value of the initiative.

LIST OF ABBREVIATIONS AND SYMBOLS USED

Symbols	Description
5M+E	Used to represent the six sources for process variation.
A	Used in scoring criteria as "Average"
ARENA	A simulation software by Rockwell Automation Inc.
CI	Confidence Interval
ExtendSIM	A simulation software by Imagine That Inc.
FGS	Faculty of Graduate Students
G	Used in scoring criteria as "Good"
LHD	Load-Haul-Dump underground mining vehicle
P	Used in scoring criteria as "Poor"
PERT	Performance Evaluation Review Technique
SIMUL8	A simulation software by SIMUL8 Corp.
SIPOC	Supplier-Input-Process-Output-Customer
Six Sigma	A business management strategy
TOC	Theory of Constraints

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CHAPTER 1: INTRODUCTION

1.1 Overview

This chapter gives the background and motivation of this thesis and specifically defines the problems that lead to the research. It presents the specific problems that were solved. It also outlines the objectives of the thesis and explains the methodology involved in building the tool used to achieve the objectives of this thesis. The methodology underlying the field testing of the tool is also given. The style, outline, organization and scope of the thesis are also discussed.

1.2 Background & Motivation

This research was motivated by the need to better evaluate and to develop better business cases intended to optimize mine production processes. In past and even today, many mine operations face the predicament of whether to implement an optimization initiative or not as most of the initiatives do not deliver on the promised optimization.

A tool is needed to first identify where the optimization efforts should be focused and then to adequately gauge the return that an optimization initiative will deliver.

1.3 Statement of the Problem

The main problem deals with spending capital/resources on non-optimum process initiatives. In other words, projects are undertaken to optimize processes which do not work towards achieving the goal (i.e. make money[1]). This problem can be related into three main issues:

Myths / beliefs about location and severity of bottleneck

Localized optimization
Various levels of optimization

1.3.1 Location and Severity of bottlenecks

This problem exists in many industry operations today[2]. Usually, operations chase the bottlenecks instead of identifying them. An optimization solution is generally implemented for the perceived issue; bottlenecks moves within the system and the end result is no net optimization.

1.3.2 Localized Optimization

This problem usually exists in an integrated operation. Usually a part of the integrated operation will conduct a local optimization without realizing the affect of this optimization on the rest of the system. Problem arises when a business initiative which promises to increase the throughput (money) fails to do so due to no understanding of the bottlenecks within the integrated system[3].

1.3.3 Discrepancy between Optimization Levels

This problem is very common in modeling industry today[4]. Problem occurs as various processes are modeled with different scientific methodologies. The problem is not in modeling itself but lies in the communication between various methodologies. It becomes very complex and time consuming to connect the model inputs/outputs built on different levels such as communication between models built with chemical parameters to a model built with thermodynamic parameters.

1.4 Objective of the thesis

The main objective of this research is to build a tool/model to identify the bottlenecks in an integrated mining operation. Following are the sub objectives intended to be attained by the tool develop in this research:

- Validate improvement initiatives to address process bottleneck
- Analyze the flow behavior of bottlenecks in the models by removing/optimizing the constraints.
- Provide the ability for a process manager to gain a realistic understanding of what a process is capable of producing by regulating the capacity and/or the variation in a certain area i.e. to conduct what-if analysis.
- Analyze the return of large throughput related capital expenditures.
- Provide a tool to evaluate the return of a business initiative in terms of a business goal.
- Observe the performance of throughput processes by regulating variability of the inputs
- The ability to identify the hot spots where further analysis is needed which can then be achieved by constructing more detailed models of the relative areas.
- To identify any process capacity waste in a system.

1.5 Methodology

1.5.1 General

The research objectives were achieved by a combination of (i) literature review of the principals behind the stated problems researched such as Process Variation and Theory of Constraints; (ii) discussions and consultation with six-sigma and continuous improvement experts on resolving these problems and modeling techniques; (iii) creation and utilization of discrete rate simulation modeling; and (iv) field testing of the model built. The research strategy investigated the fundamental principles underlying the difficulties faced by mining operations and techniques currently employed by industry experts. The specific methodologies are given in the following section.

1.5.2 Model

The model is designed as discrete rate flow model using ExtendSIM simulation software. Simulation is one of the most widely applied techniques of management science. Simulation tools can evaluate the efficiency and possible drawbacks of certain options before they are actually implemented in practice, thereby playing a crucial role in the evaluation process[5]. Today, a number of simulation models have been developed to optimize any aspect of mining related system activities. However, most of these models were developed either for specific applications or developed at various levels of design.

If the model is designed to optimize a specific activity or process then the effect of the optimized solution cannot be monitored throughout the whole system. For example, in a Mining Operation, there are various unit operations such as drilling, mucking and hoisting. If mucking operation was specifically modeled to be optimized then the optimized solution may result in hoisting operation to become a bottleneck or may cause a drilling operation to become a constraint as the capacity of drill area may not produce enough muck for the optimized operation to be utilized efficiently. This narrow focus optimization results in “Rolling Bottlenecks” with potential of effort, resources and money being spent on non bottleneck processes. This is waste because none or very little of the improvement makes it all the way to the final product.

Similarly, if a model is designed for the whole system but at different levels of designs then it becomes quite complex to link the various optimized solutions. For example, in a Milling & Smelting Operation, there are various unit operations such as Ore Recovery, Roasting, Casting etc. Now, if recovery model was designed chemically, roasting model was designed thermodynamically and casting model was designed mechanically then it will require tremendous amount of time and effort to link the optimized solution of each model.

Thus, to overcome these shortcomings of current practice of simulation models, this model is designed at the throughput level for the integrated mining operations. The important processes are identified in the entire plant or asset. Every process is treated according to SIPOC Model. Inputs into the processes and the capacity of processes are simulated stochastically using a distribution. Any factor which may affect the flow of the model can be entered into the model by linking it to the throughput.

1.5.3 Field Testing

The field testing started with mapping of the operation processes and collection of the data for the purpose of estimating historical process capability distributions. This field work was done at an integrated Nickel mining Vale Inco Limited operation. Field testing was conducted at an underground mine, a mill facility, a smelter facility, and a refinery facility.

Four separate models were built in such as way that they could either be utilized as standalone modules or as an integrated tool. Once the model was completed and validated for the flow of the processes, then further data was captured either through creation or utilization of an existing database to filter out the effect of misleading variation with the historical process data. This data was also collected through discussions with process experts if the collection of variation data was not plausible.

Next, the input distributions into the model were refined to reflect individual process variation. The model was re-validated against the historical data and significant production events. Once the model validation was adequately confirmed then the bottlenecks in every operation were individually identified. Next, various business initiatives were evaluated using this tool. The integrated Vale Inco mining operation has mandated the use of this tool for future throughput related business initiatives.

1.6 Style, Structure, and Scope of the thesis

1.6.1 Thesis Style and Format

Thesis style and format follows the Faculty of Graduate Students (FGS) thesis formatting guidelines[6]. Language format used is U.S. English. A style appropriate to subject matter is followed throughout the thesis. The thesis document is printed on one sided 21.5 × 28cm (8.5" × 11"), portrait orientation. Left hand side margins are 38mm (1.5") wide. All other marines are at least 25mm (1") wide. Text for main body of the thesis is in a standard 12pt, Times New Roman font. The title of the thesis and the title for all entries in Table of Contents are cased. The order of items in entire thesis follows the FGS guidelines.

1.6.2 Structure and Organization

The general structure and organization of the thesis consists of seven chapters. Chapter 1 is the introductory chapter which outlines the background and motivation of the research and defines specifically the problem statement that led to the research. It highlights the aims, objectives and the methods used to achieve the objective. Scope, structure and organization of the thesis are also presented.

Chapter 2 gives is based on the literature review of principles underlying the cause of process bottlenecks. Focused topics are process variation and theory of constraints (TOC). The significance of these principles to the thesis is also presented.

Chapter 3 gives a review of methods and techniques essential for building a bottleneck model. It elaborates on the exchange of information gathered through discussions and consultations with process optimization industry six sigma and continuous improvement experts.

Chapter 4 gives the detail of the simulation software assessment that was conducted during this research. Software evaluation criteria, scoring and then selection of the software are covered in this chapter.

Chapter 5 deals with the design of the throughput bottleneck model. It details the theory, logic and systems used in building of the model. Model components, inputs, outputs, and general usage are detailed in this chapter.

Chapter 6 gives an account of testing of the model in the field. Advantages and extent of the use of the model are also covered through case studies in this chapter.

Chapter 7; the last chapter discusses the robustness of the model and of possible pitfalls one must avoid when utilizing this model. Recommendations for further research and conclusions are also presented in this chapter.

Appendices give details about the purpose, the usage and options of various ExtendSIM blocks used in development of the bottleneck model.

1.6.3 Scope of the thesis

The thesis was initially limited to the identification of the bottlenecks in an integrated mining operation. However, due to TOC and complexity of process variation, it became pertinent to broaden the scope to investigate the movement of bottlenecks and to estimate the severity of bottlenecks on the output of an integrated mining operation. Once the model was completed and then tested, it became apparent that the model could not only be used for original scope but also to investigate other aspects of process optimization; such as Causal Modeling and Lean Optimization.

1.7 Optimization Literature Research

1.7.1 Introduction to Optimization

Optimization in its basic roots a mathematical term also referred as mathematical programming. The idea is to either minimize (usually cost) or maximize (usually profit) a mathematical function by logically analyzing the solution for all possible scenarios within a tolerable set. It is generally difficult to develop an optimized model that tackles all characteristics of the quandary and its surroundings. It is like trying to best fit a known analyzable geometrical shape into an unknown irregular shape. Thus there has been various different optimization techniques developed to best fit the real problem. However, it will be beneficial to first analyze a general optimization function then to get into various optimization techniques.

A general optimization model consists of three components: 1) the objective function, 2) the constraints, and 3) the variables. Objective function defines what is that needs to be optimized and whether is it to be maximized or minimized. Constraints define the limits for the optimization model. In other words, they set finite number of solutions that could be optimized. Variables allow us to define the aspects of a problem in mathematical terms. Thus, an optimization problem can be expressed in mathematical terms as follows.

Objective Function: $f = \{x\}$; $f(x0) \leq f(x)$ (minimization) or $f(x0) \geq f(x)$ (maximization)
Constraints: all values of a real set
Variable: x

So, problems that seek to maximize or minimize a mathematical function of a number of variables, subject to certain constraints, are known as optimization problems. Optimization problems may involve more than one objective function and are known as multi-objective optimization problems. Depending on the nature of the problem, the variables in the model may be real or a mixture. The optimization problem could be either constrained or unconstrained. In the constraint part of a mathematical model, the left-hand side of the constraint function is separated from the right-hand-side value by one of the following three eventualities: (1) equal to =, (2) less than or equal to ≤, or (3) greater than or equal to ≥.

1.7.2 History of Optimization

Clear evidence of optimization being employed can be observed as early as in 1900 when Gantt optimized scheduling jobs on machines using charts known as Gantt Charts. In

1915, Harris mathematically optimized inventory management by developing an ordering model from a vendor. Today, it is known as economic order quantity model. In 1917, Erland optimized the switchboard calling process. This optimization process is better known as queuing theory. During World War II, first British and then Americans optimized their limited resources to be used in battlefield. This is where “Operations Research” study was first classified.

After World War II, the operations research and more importantly optimization was introduced in day to day business operations. Optimization techniques have been available for more than a century. In 1947, Dantzig designed an optimization algorithm to solve complex linear programming problems. This algorithm is known as Simplex. Simplex allowed the complex problems to be solved using computers. As the computing technology improved so did the power of Simplex algorithm. In addition to many other conventional optimization techniques developed over the past half-a-century (as will be discussed later), the recent development of modern heuristic techniques such as simulated annealing, tabu search, genetic algorithms, neural computing, fuzzy logic, and ant colony optimization are providing practitioners with some sophisticated tools to address more complex situations.

1.7.3 Optimization Techniques

Use of mathematical optimization to solve real life problems can be divided into two major groups: (1) the classical optimization techniques and (2) the modern heuristic techniques. There are various mathematical programming techniques in use today:

Linear programming (LP) – problems involve the optimization of a linear objective function, subject to linear equality and inequality constraints.

Integer programming – similar to linear programming but the unknown variables are all required to be integers.

Quadratic programming – similar to linear programming solving techniques, however the solution is quadratic as the objective function is defined as a quadratic.

Nonlinear programming – process of solving a system of equalities and inequalities, collectively termed constraints, over a set of unknown real variables, along with an objective function to be maximized or minimized, where some of the constraints and/or the objective function are nonlinear.

Convex programming – the case when the objective function is convex and the constraints, if any, form a convex set. This can be viewed as a particular case of nonlinear programming or as generalization of linear or convex quadratic programming.

Stochastic programming – the case in which some of the constraints or parameters depend on random variables.

Robust programming – same as stochastic programming, however the uncertainty is introduced by deliberated inaccurate input data.

Combinatorial optimization – problems where the set of feasible solutions is discrete or can be reduced to a discrete one.

Infinite-dimensional optimization studies the case when the set of feasible solutions is a subset of an infinite-dimensional space, such as a space of functions.

Heuristic algorithms – an algorithm that ignores whether the solution to the problem can be proven to be correct, but which usually produces a good solution or solves a simpler problem that contains or intersects with the solution of the more complex problem.

Constraints satisfaction – the case in which the objective function f is constant. This is mostly reserved for automatic reasoning and is the basis behind Artificial Intelligence.

Disjunctive programming – the case where at least one constraint must be satisfied but not all. This is mostly used in schedule optimization.

Trajectory optimization – as the name suggest, it is used to optimize trajectories for air and space vehicles.
Calculus of variations – a part of dynamic optimization; an objective defined over many points in time, by considering how the objective function changes if there is a small change in the choice path. Optimal control optimization is generalization of this programming.

Dynamic programming – a method of solving problems where one needs to find the best decisions one after another.

1.7.4 Applications of Stochastic Optimization in Complex Integrated Mining Operations

There has been a lot of scholarly work done in the field of stochastic optimization when applied to mining such as one of the latest paper published by Raj[16]. However, almost all of this effort has been limited to optimizing single production mining operations. Stochastic optimization is also generally used in mining operations when conducting risk analysis or dealing with uncertainty[17]. Due to complexity of the integrated mining operations, there seems to be no single optimization technique or tool available today.

CHAPTER 2: REVIEW OF PRINCIPLES UNDERLYING PROCESS BOTTLENECKS

2.1 Overview

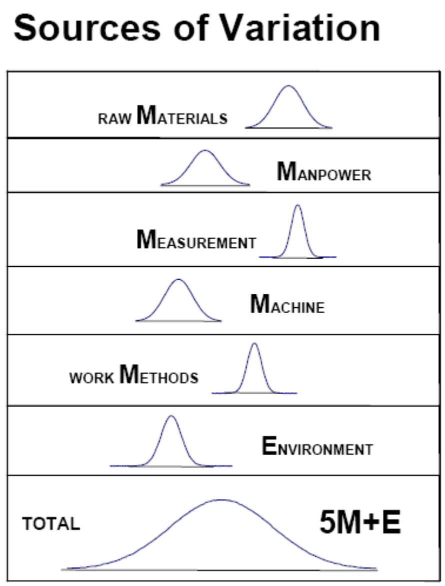
This chapter gives an overview of natural and unnatural variation that exists in every process. Sources and types of variations are also discusses. Finally, the significance of process variation to the tool developed in this research is also detailed.

This chapter also gives an overview of the theory of constraints (TOC) that applies to every system and specifically to a mining operation system. The section on TOC also elaborates on terms used in business improvement literature. Finally, the significance of TOC to the tool developed in this research is also detailed.

2.2 Process Variation

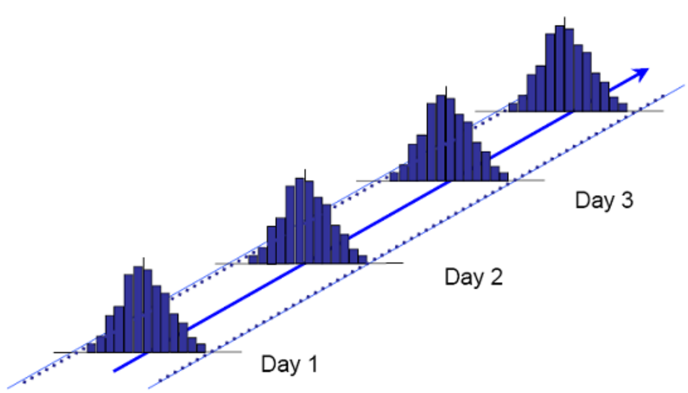
Variation is a natural phenomenon; it is everywhere[7]. All processes are subject to variation in performance and thus no two outputs will ever be exactly same. Variation is caused by sub-variations within the process (Figure 2.1) i.e. variation caused by:

Materials e.g. variation in ore grade
Manpower e.g. variation between different shifts for same process
Measurement e.g. variation in grade measurement of same concentrate by composite vs. series sampling
Machine e.g. variation in throughput or quality from two mills of similar specifications
Methods e.g. variation between two methods to achieve same out come such as ore grind size by rod and a ball mill
Environment e.g. variation in ore treatment caused by oxidation due to weather



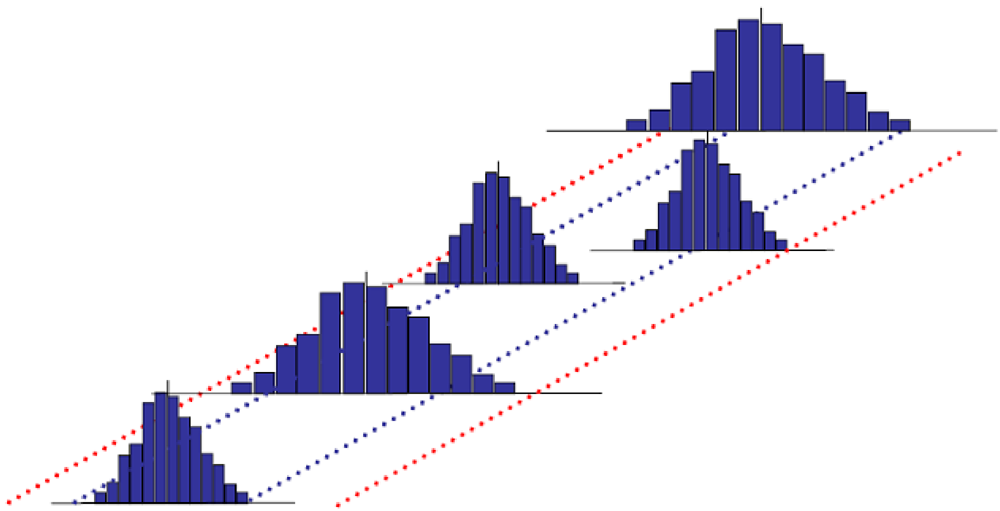
• Figure 2.1 - Souces of Variations present within any mining related process

There are two types of variations[8]; common cause and special (assignable cause). Common cause variation is an inherent part of the process (or system) design and execution; hour after hour, day after day and effect everyone in the process (Figure 2.2).



• Figure 2.2 – illustration of day to day common cause variation

The histogram or the distribution in (Figure 2.2) represents the common cause variation within a process. Assignable cause variation is not part of the process all of the time and do not affect it all of the time but arises out of specific circumstances e.g. breakdown of a machinery. The shift and the unpredictable spread of the histogram in (Figure 2.3) represent the special or assignable cause variation.



• Figure 2.3 – Effect of Special Cause Variation to a process outcome; within a day, and day to day

2.2.1 Significance of Process Variation to the objective of this research

From the understanding of the variation; it is correctly believed that reduction in variation will result in higher throughput and thus more money in sales. However, this gives birth to the common myth that if the work is done to reduce the variation in any process then there will be sufficient gain in the throughput. This is not entirely correct as if the process with reduced variation is not the bottleneck or the constrained process then the throughput gain will be mostly lost in the bottleneck as the constrained process is already running at full capacity and thus can neither receive more input nor provide more output i.e. cannot process anymore. The model developed through this research highlights this phenomenon as well as shows the improvement of reducing variation when conducted properly.

Process variation is a major contributor to the performance of any process and thus the model is designed with variation in mind. Inputs into the models are based on the distributions instead of averages to observe the affect of variation in the process. The use of averages instead of full variation significantly skews the full picture as a model built on averages at best predicts how the process will perform 50% of the time.

2.3 Theory of Constraints

Dr. Eliyahu M. Goldratt introduced the Theory of Constraints (TOC) in his 1984 book, The Goal[1]. Theory postulates that any system is restricted from achieving its goal by one or at most very few constraints at a given time. Thus, the philosophy is to identify the constraint (bottleneck), exploit it, redistribute all resources around it, elevate it, and then keep track of the constraint movement. Exploitation relates to the maximum utilization of the constraint, while elevations relates to the availability. Tracking of bottleneck movement is essential as if the bottleneck has moved then the process has to start over as the old constraint is not the bottleneck anymore.

Goal here is in basic terms is to “make money” now and in future. It is not high productivity, efficiency, utilization or even low cost, if in the end a company is not achieving the goal i.e. making money. Thus, the theory measures an organization with three parameters in terms of goal.

Throughput – higher the throughput, more money a company makes through sales.
Operating Expenses – It is the money spent to keep the company going.
Inventory – money invested by the company to sell its products. For example, the entire inventory created is to ensure that the product is produced as demanded by the customer.

Constraint here is not limited to just a mathematical term as in general optimization but is anything that is preventing the company from getting more throughput (money from sales) i.e. bottleneck.

2.2.1 Significance of TOC to the objective of this research

TOC applies directly to the main underlying problem behind this research. If a constraint is not identified the resources (time, money, people) are spent on working /improving something which in the end doesn't work to achieve the Goal. Another important fact that TOC highlights is that even though there is usually one or at most few bottlenecks are present at any given time but these bottlenecks can shift places or move within the system overtime. Thus, it becomes very important to know where this bottleneck might move to & how profound the impact will be.

CHAPTER 3: REVIEW OF METHODS & TECHNIQUES ESSENTIAL FOR BUILDING A BOTTLENECK MODEL

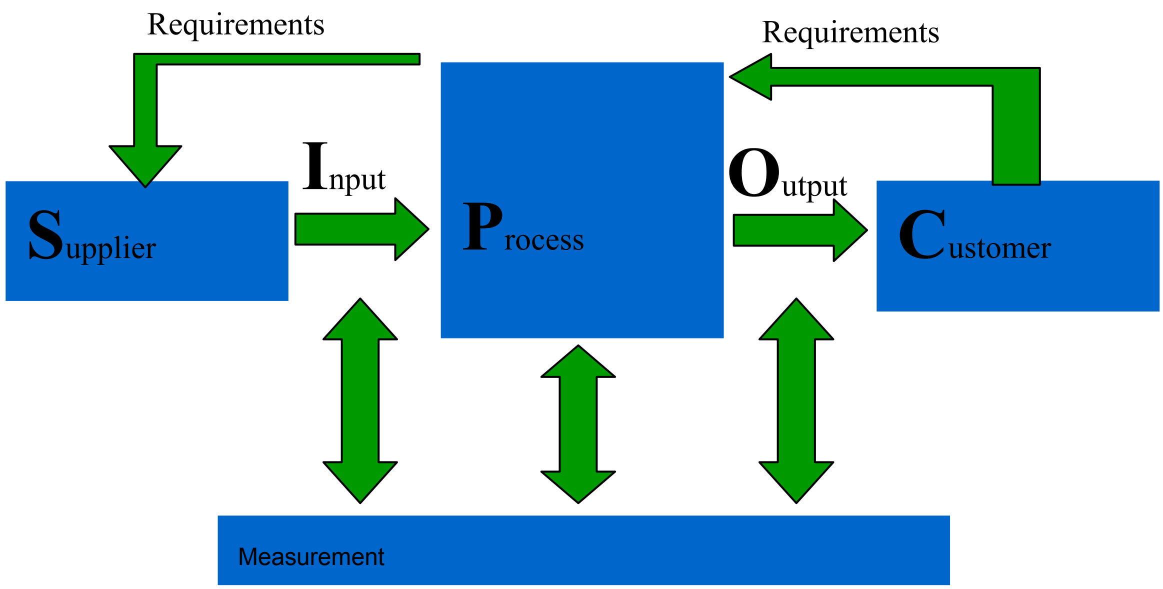
3.1 Overview

This chapter gives an overview of SIPOC modeling system. The origin of the system is also acknowledged. Finally, the significance of SIPOC application to the tool developed in this research is also detailed.

This chapter also gives an overview of the process mapping; a technique used by optimization industry experts. Utilization and types of process mapping are also discussed. Finally, the significance of mapping to the tool developed in this research is also detailed.

3.2 SIPOC

SIPOC; an acronym for Suppliers → Inputs → Process → Outputs → Customers, is a high level diagram of a process and a deduced version of a process map[9]. It helps in understanding the scope of a process (Figure 3.1).



• Figure 3.1 – Illustration of the components and flow of information within the SIPOC system

SIPOC is a business management (such as six-sigma) mapping technique which represents an organized set of connected parts or activities that take inputs and transform and/or transfer them to produce a set of outputs. The definition of each SIPOC components is given below:

Supplier – provide inputs to the process. These could be the customer of the previous process in the sequence.

Inputs – these are the inputs usually the material, service and/or information that are used by the process to produce the outputs.

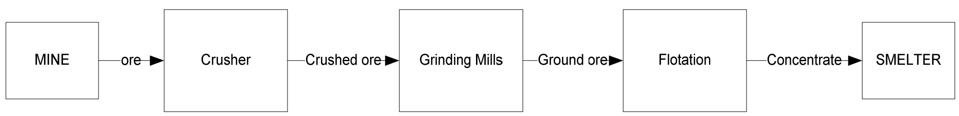
Process – sequence of activities, usually adds value to inputs to produce outputs for the customers.

Outputs – these are the outputs usually the products, services, and/or information that are valuable to the customers.

Customer – usually are the users of the outputs produced by the process. These in turn become the suppliers for the next process.

3.2.1 Significance of SIPOC to the objective of this research

The model built in the research employs the SIPOC principal for every process modeled. This can be best understood using an example elaborated in (Figure 3.2).



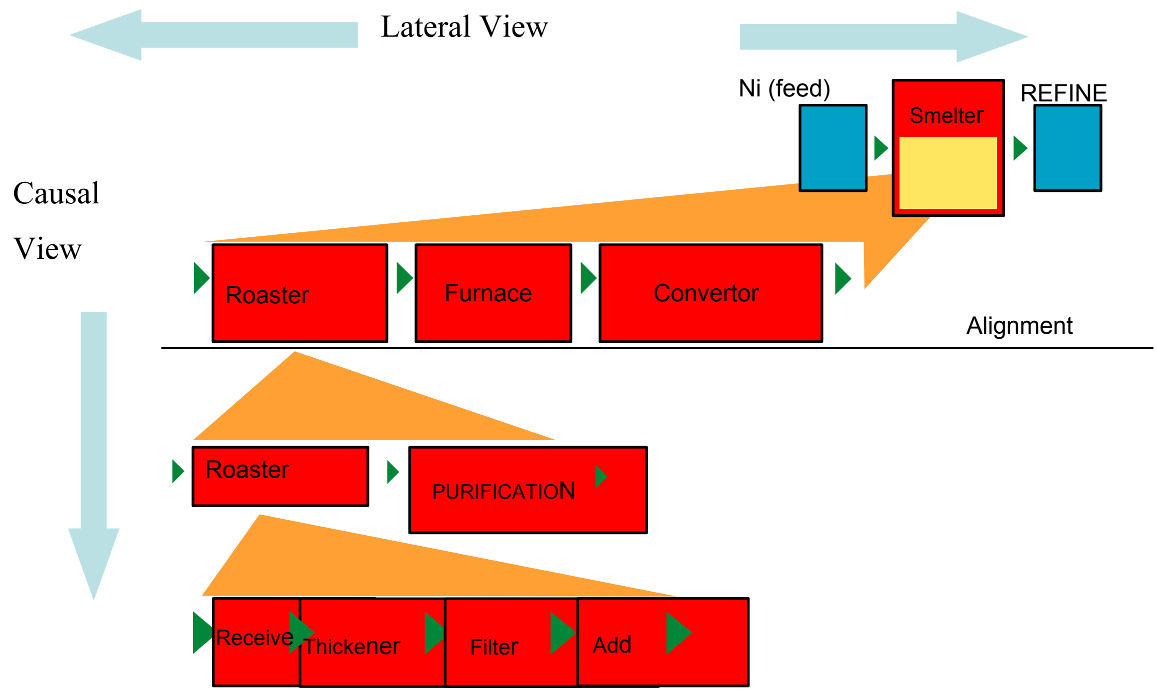
• Figure 3.2 – An example of modeling mining processes in series using SIPOC

In this example, we have three processes. Every process is represented as a supplier and as a customer in the model. When crusher is the process then mine is the supplier which supplies ore to the crusher which processes it and outputs the crushed ore to the customer i.e. grinding mills. Now, Grinding mills are the process and the crusher is the supplier which supplied crusher rock as an input to the process which in turn processes it and outputted the ground ore to the customer i.e. Flotation. So Flotation received the input from the supplier (Mills) and processed it and outputted the concentrate to its customer which is Smelter. It is essential to build the model on this principal as it allows not only in identifying which process is the bottleneck but also recognizes the actual component of the system which is becoming the constraint. Just to clarify, even though above example depicts processes in series, same SIPOC terminology can be applied to processes in parallel as the processes in parallel will still have inputs by suppliers and outputs to customers.

3.3 Process Mapping

It is a 6σ technique utilized to understand the organization and the performance of a process[9]. A mining operation is full of processes, not only technical processes such as mining, milling, smelting, refining, etc. but also administrative, marketing and managerial processes such as purchasing, warehousing, manpower, sales, handling orders.

A process map usually gives a 2 dimensional picture of a process[10]; lateral and causal. Lateral or alignment view elaborates the relative position of a process to other processes on the same level. It is usually used to describe the relationship between the described outputs of a process and the parameters that impact those outputs (Figure 3.3). Causal or analytical view elaborates the details of sub processes or productive units within the focused process. It is usually used to build a hypothesis for improving the performance of a process.



• Figure 3.3 – illustration of lateral and causal mapping of a smelter facility

Process mapping differs from a flowchart by creating a hypothesis describing the current best understanding of the relationship between the desired outputs of a process and parameter that impacts those outputs.

3.3.1 Significance of Process Mapping to the objective of this research

One of the steps in building the model researched in this thesis is to map the plant or the operation to identify the bottleneck(s). This is important as it gives a visual representation of the whole process and allows in achieving an appropriate balance with respect to the level of detail incorporated in the model. Too much detail unnecessarily consumes the analyst's time. It may also hamper the tractability of attaining a solution to the model or realizing extended analytical objectives such as mathematical optimization. Conversely, too little detail may result in a model that is an abstraction of little relevance to the problem at hand.

CHAPTER 4: SIMULATION SOFTWARE ASSESSMENT

4.1 Overview

This chapter gives an overview the simulation software assessment. The Evaluation criteria for software assessment are discussed. Finally, the scoring of the software assessed is also detailed.

4.2 Simulation Software

In the optimization world, simulation is a common tool used to understand how a process or system performs and would perform when modifications/changes are made, without the need to conduct expensive and time consuming trials. Unfortunately, size of many, if not most practical problems often make the use of simulation programming infeasible from computational perspective[11]. Commercial simulation & optimization framework software have emerged as alternative to help build simulation models. However, these software are designed as “one size fit all” situation simulation software and thus are not ideal for all industries. For the scope of this research, three software were assessed; ExtendSIM, SIMUL8, and ARENA. The evaluation criterion as described in a paper[12] from Purdue University was used for assessing the software but the scoring was done by keeping the scope of this research in mind (Table 4.1).

• Table 4.1 – Scoring of assessed Simulation Software according to the evaluation criteria

Evaluation Criteria	Extend SIM	SIMUL8	ARENA
Model Building Structure			
Hierarchical model	GOOD	GOOD	GOOD
Accessibility	AVERAGE	GOOD	GOOD
Reusability	GOOD	GOOD	AVERAGE
User Defined Elements			
Extensibility	GOOD	GOOD	AVERAGE
Design Facility	GOOD	GOOD	AVERAGE
Interaction with Applications			
Internal Database	GOOD	GOOD	GOOD
External Databases	GOOD	GOOD	GOOD
Dynamic Model Updating			
Optimization	GOOD	GOOD	GOOD
Updating on the fly	GOOD	POOR	AVERAGE
Routing	GOOD	AVERAGE	GOOD
Miscellaneous			
Multiple Simulations	AVERAGE	AVERAGE	AVERAGE
Animation	GOOD	GOOD	AVERAGE
Built-in items	AVERAGE	AVERAGE	AVERAGE
Statistical Ability	GOOD	GOOD	GOOD
Model Protection	GOOD	POOR	GOOD

4.3 Evaluation Criteria

Following criteria was selected from Purdue University's paper[12] as these factors were essential to the effective development of the model.

4.3.1 Hierarchical Model

This is the ability to capture various levels of details within a model. It is important to have this capability as it allows hiding unnecessary detail in a model when only conceptual design is required and conversely, allows showing the details when needed.

4.3.2 Accessibility

This is the capability of a model to link various items in a model. Good modeling software must allow connecting different items in the background to keep the model less clustered. However, it must also have the ability to directly link and communicate between items when required. Here, items could be various processes, statistical or data calculation blocks etc.

4.3.3 Reusability

It is the ability of using a model or item into another model.

4.3.4 Extensibility

It is the capability of changing the model state rules depending on occurrence of an event. In other words, it is the ability to run a model with different rules at different times.

4.3.5 Design Facility

It is the ease of designing in the modeling environment. Least amount of coding required is classified as best.

4.3.6 Internal Database

This criterion partly relates to the capability of creating spreadsheets or database within the modeling software and partly to the ease of capturing the data to the database.

4.3.7 External Database

This criterion partly relates to the capability of capturing data to spreadsheets or database outside the modeling software such as in Excel and partly to the ease of capturing the data to the database.

4.3.8 Optimization Programming

This relates to the accessibility and extent to various Operation Research optimization techniques such as Linear Programming, Queuing policies, etc.

4.3.9 Updating on the Fly

This relates to the capability of changing or modifying a model within the simulation run.

4.3.10 Routing

It is the ability to change the path of the flow in a model. In other words, it is the ability to define how the material flows through a system.

4.3.11 Multiple Simulation

It is the ability to run multiple simulations at the same time.

4.3.12 Animation

It is the ability to visualize how the material is flowing within the system and how the processes are behaving. A good model should be able to show some extent of animation within the simulation run.

4.3.13 Built-in Items

This relates to the resourcefulness of the items (processes, statistical blocks, mathematical blocks, variables) provided as default with a simulation software.

4.3.14 Statistical Ability

It is the ability to define various statistical distributions and the ability to capture various statistical trends.

4.3.15 Model Protection

It relates to the user content protection provided by the software.

4.4 Simulation Software Selected

As outlined in the table 4.1, ExtendSIM scores most "GOOD" rating in evaluated criteria. Even though ExtendSIM was chosen to be used for building the model in this research, it must be noted SIMUL8 and ARENA can be used to build similar models. ExtendSIM however allows the discrete rate simulation in addition to continuous and discrete event simulations. The discrete rate simulation allows better and much realistic simulation of mining processes.

CHAPTER 5: DESIGN OF THE THROUGHPUT BOTTLENECK MODEL

5.1 Overview

This chapter gives an overview of the theory behind the model developed for this research. Underlying system and mapping utilized in development of this tool are also discussed. Model logic, inputs and outputs are detailed. Construction and Simulation of the model is also detailed. Finally, the use and the scenario analysis are also covered in depth.

5.2 Theory

Simulation is one of the most widely applied techniques of management science. Simulation tools can evaluate the efficiency and possible drawbacks of certain options before they are actually implemented in practice, thereby playing a crucial role in the evaluation process[13]. Today, a number of simulation models have been developed to optimize any aspect of mining related system activities. However, most of these models were developed either for specific applications or developed at various levels of design.

If the model is designed to optimize a specific activity or process then the effect of the optimized solution cannot be monitored throughout the whole system. For example, in a Mining Operation, there are various unit operations such as drilling, mucking and hoisting. If mucking operation was specifically modeled to be optimized then the optimized solution may result in hoisting operation to become a bottleneck or may cause a drilling operation to become a constraint as the capacity of drill area may not produce enough muck for the optimized operation to be utilized efficiently. This narrow focus optimization results in "Rolling Bottlenecks" with potential of effort, resources and money being spent on non bottleneck processes. This is waste because none or very little of the improvement makes it all the way to the final product.

Similarly, if a model is designed for the whole system but at different levels of designs then it becomes quite complex to link the various optimized solutions. For example, in a Milling & Smelting Operation, there are various unit operations such as Ore Recovery, Roasting, Casting etc. Now, if recovery model was designed chemically, roasting model was designed thermodynamically and casting model was designed mechanically then it will require tremendous amount of time and effort to link the optimized solution of each model.

Thus, to overcome these shortcomings of current practice of simulation models, this model is designed at the throughput level for the whole Thompson Operations, from Mining to Refinery. The important processes are identified in the entire plant or asset. Every process is treated according to SIPOC Model. Inputs into the processes and the capacity of processes are simulated stochastically using a distribution. Any factor which may affect the flow of the model can be entered into the model by linking it to the throughput.

5.3 System

Every process in the model is based on the SIPOC system. Every parameter is either directly modeled or converted back to a throughput unit. If a model is designed for the whole system but at different levels of designs then it becomes quite complex to link the various optimized solutions. For example, in a Milling & Smelting Operation, there are various unit operations such as Ore Recovery, Roasting, Casting etc. Now, if recovery model was designed chemically, roasting model was designed thermodynamically and casting model was designed mechanically then it will require tremendous amount of time and effort to link the optimized solution of each model.

Thus, to overcome these shortcomings of current practice of simulation models, this model is designed at the throughput level for the integrated mining operation. The important processes are identified in the entire plant or asset. Every process is treated according to SIPOC Model. Inputs into the processes and the capacity of processes are simulated stochastically using a distribution. Any factor which may affect the flow of the model can be entered into the model by linking it to the throughput.

Advantage of keeping every parameter reporting in the same unit is that any type of process can now be linked together based on SIPOC system principle. For example Flotation or recovery is a chemical process but performance of it can be measured in increase/decrease of throughput. Other example could be of a roasting process which is a thermodynamic process but an optimization in the process can still be reported in throughput processed by the roaster. By deducing everything back to throughput, all processes can now easily be placed in the SIPOC system.

5.4 Mapping

Every plant is process-mapped before building the model. This helps in identifying the level of detail needed for the scope of the model. For example, if the aim is to find where the bottleneck sits in an integrated mine operation then first the whole operation would be mapped as mine → mill → smelter → refinery etc. Then, mine could be causally mapped into drill → blast → muck → crush → hoist etc. Next, the model can be run to identify the process which is the major bottleneck and then can be further causally mapped e.g. if the bottleneck is the mucking process then map could look like shovels (LHDs) → truck (trams) → conveyor → bins etc. This is the advantage of mapping the process laterally and causally before building the model as it allows getting results with minimum amount of effort and time.

5.5 Logic

Model is designed to simulate one day at a time over duration of one year (365 days). This was necessary as the objective was to capture day to day movement and quantity of the bottlenecks. There is a simulated stockpile with infinite capacity present behind every process to capture bottlenecks with exception of where a real stockpile (e.g. ore pass/bins etc.) may be present. This was designed so no constrained process may slow down a process behind it. It is important to note here that total flow through all processes will still be same if these simulated stockpiles were not present.

Simulated stockpiles are essential part of the model in identification of bottlenecks and in visualizing the impact of de-bottlenecking on the final product. Without these stockpiles, the user may be able to see that an initiative may not result in an improvement in the final product but would not be able to see what process(es) stopped that improvement. Hence, the simulated stockpiles play an important role in identifying which processes to optimize.

5.6 Inputs

Inputs are entered randomly but according to a distribution. In other words, the inputs are generated rationally not just randomly. Rational Random inputs as pure randomness will not represent the actual variation of the processes. Stochastic inputs add confidence in the optimized solutions and this can be achieved as probability distributions are either known or can be estimated. There are three main types of inputs entered in this model usually based on the distribution.

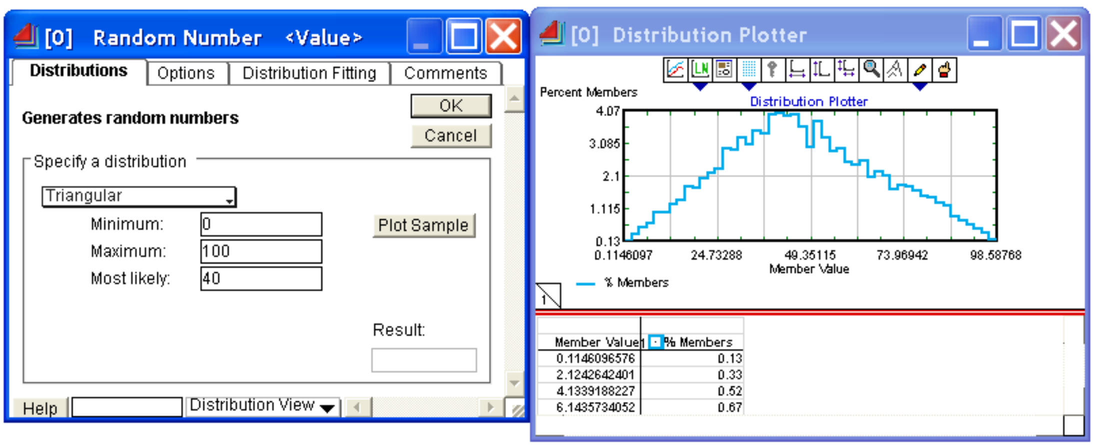
Amorphous

Defined

Empirical

5.6.1 Amorphous

Triangular distribution is generally used for this type of input as least amount of information is known about a process which occurs usually at the beginning of the model database building[15]. Triangular distribution is based on PERT (Performance Evaluation Review Technique). Figure 5.1 depicts the only three values needed for these inputs which are Minimum (pessimistic), Maximum (optimistic), and Most likely (mean).

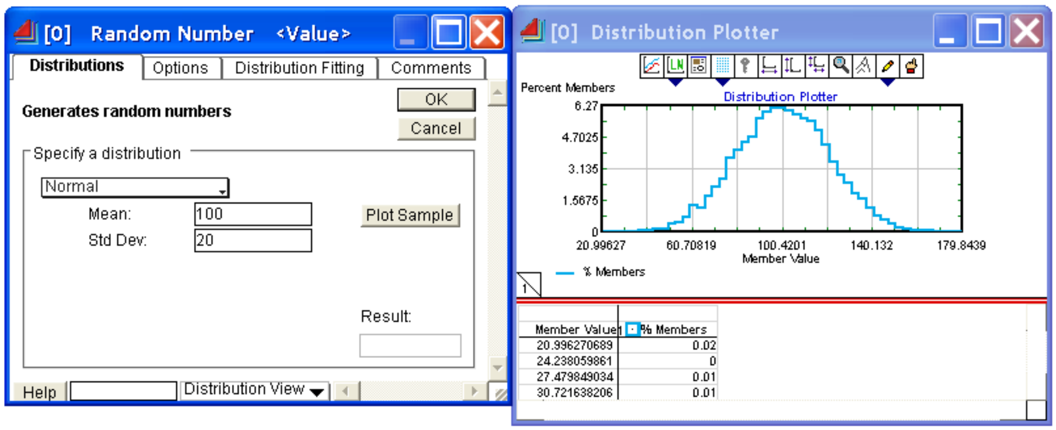


• Figure 5.1 – Illustration of Amorphous inputs into the model

Distribution Plotter window can be accessed by pressing the "Plot Sample" button on Random Number window. Plotter illustrates the rational stochastic distribution.

5.6.2 Defined

This type of input is used when some data already exist about a process behavior. In some cases, these input distributions are used as the output from the previous process is observed to be behaving as well defined process distributions. Figure 5.2 depicts the only two values needed for these inputs for a normal distribution, which are Mean (average) and Std Dev (standard deviation). Refer to Section 2 for instructions on how to enter this input.

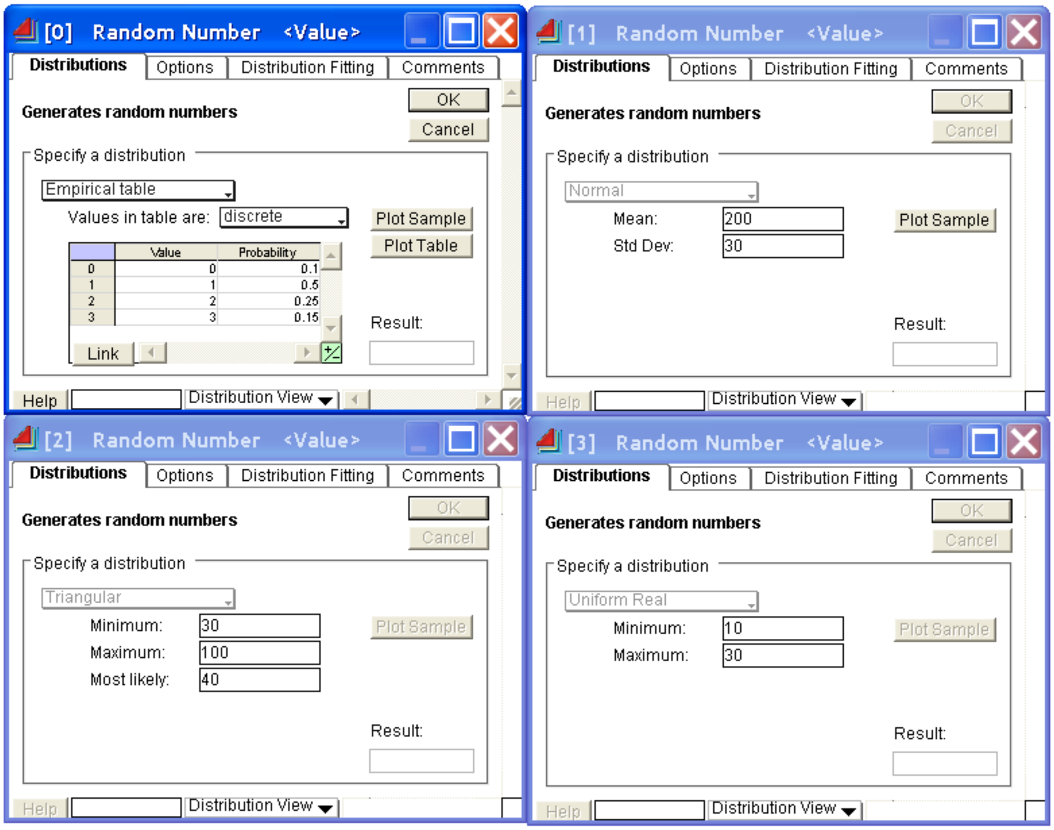


• Figure 5.2 – An illustration of Defined inputs into the model

Distribution Plotter window can be accessed by pressing the "Plot Sample" button on Random Number window. Plotter illustrates the rational stochastic distribution.

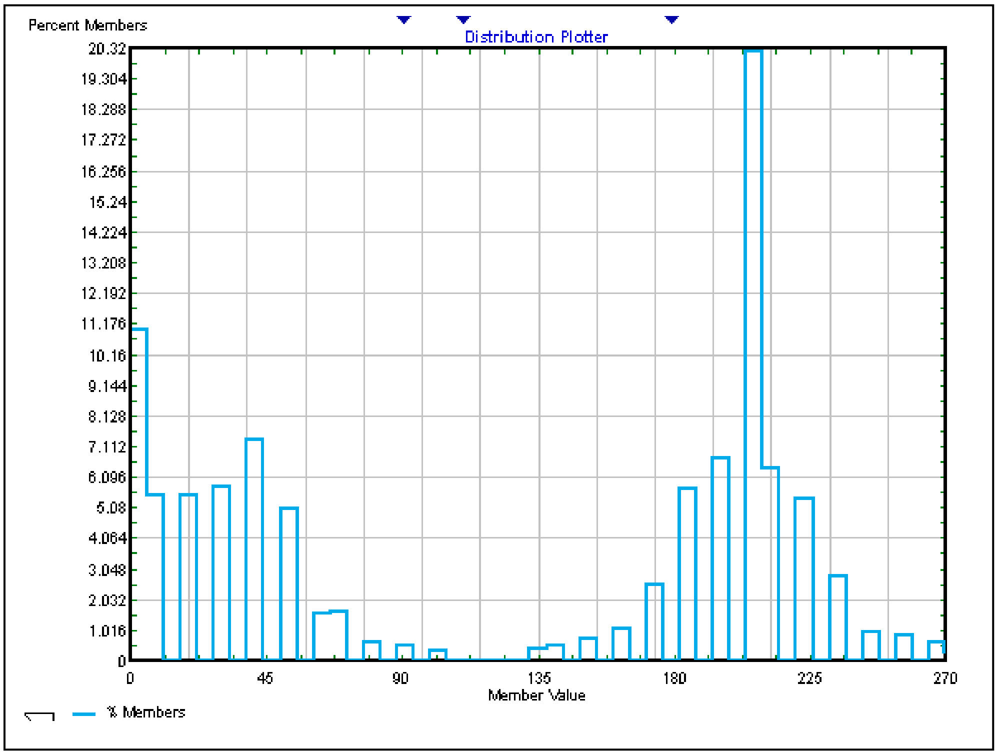
5.6.3 Empirical

Empirical inputs are used when no known distribution will adequately fit the whole span of data and PERT distribution will significantly over or underestimate the probability density (Figure 5.3). An example will be when a process has a multi-model distribution. In this case, the data will be split into several bins of occurrences and then a frequency of occurrences will be calculated. From these bins and frequencies of occurrences an empirical table is inputted into model. Figure 5.3 depicts an empirical input capture from a model.



• Figure 5.3 – An illustration of Empirical inputs into the model

In the case depicted in Figure 5.3, the inputs will be entered using various distributions at a given time. In this case, 10% of the time input will be 0, 50% of the time input will be represented by normal distribution as represented in Window 1, 25% of the time input will be represented by triangular distribution as represented in Window 2, and 15% of the time input will be represented by uniform distribution as represented in Window 3. The advantage of using this type of input is that it can be used for any kind of distribution. The process depicted in Figure 5.4 has multiple distributions; one when the process is running optimally from 135 st to 270 st, and second when process is running at a slow rate due to slowdowns and shut downs as shown from 0 st to 105 st.



• Figure 5.4 – An illustration of multi model distribution

5.7 Outputs

There are several outputs which are generated from the simulating the model:

Production Output

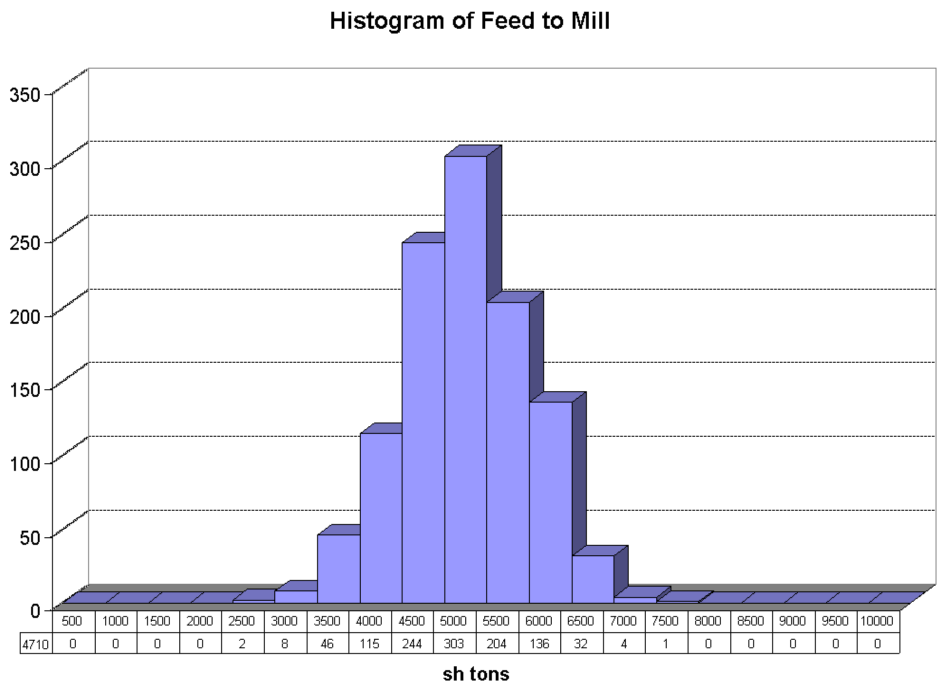
Severity of Constraints

Capacity Constraints

Cumulative Bottleneck Plots

5.7.1 Production Output

This output illustrates a day to day production at the end of a model in a form of a histogram. The production output histogram allows a user to observe the distribution of produced result and aids in defining the input of sequential module. Histogram is also helpful in comparing the results of the model to historical actual production results. Figure 5.5 depicts a histogram of ore feed skipped to mill captured by a mine model.



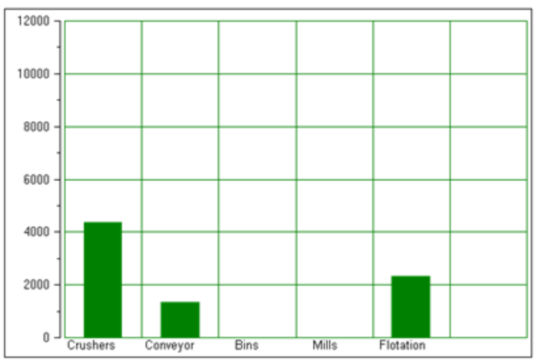
• Figure 5.5 – Production Output: a histogram depicting sh. tons skipped to a mill

5.7.2 Severity of Constraints

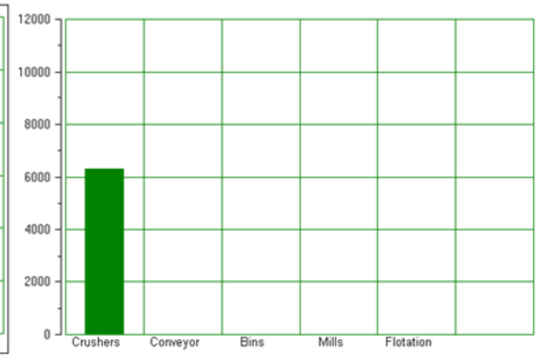
This output allows a user to identify which processes became a constraint on a day to day basis and the severity of those constraints over a year. There are three types of plots that generated through simulating the model. They are:

5.7.2.1 Bar Chart

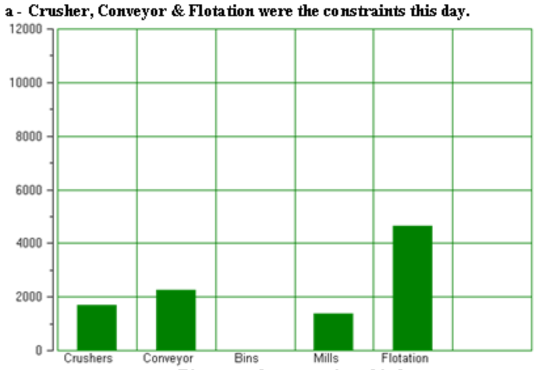
This plot is updated on day to day basis and is available while the simulation is running. This plot helps the user identify what process or combination of processes are the constraints for a given day. Also, it allows the user to observe the severity of the constraint in reference to the units of the model (e.g. sh. tons). Figure 5.6 depicts an example of this chart.



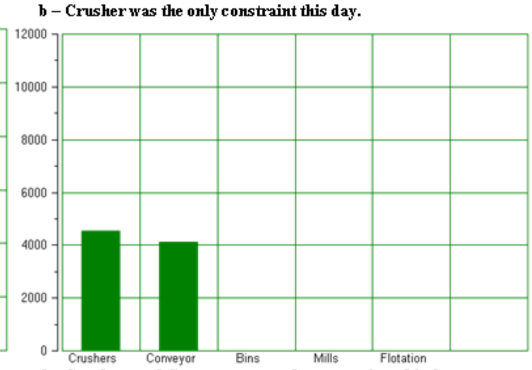
a - Crusher, Conveyor & Flotation were the constraints this day.



b – Crusher was the only constraint this day.



c - every process except Bins were the constraints this day.

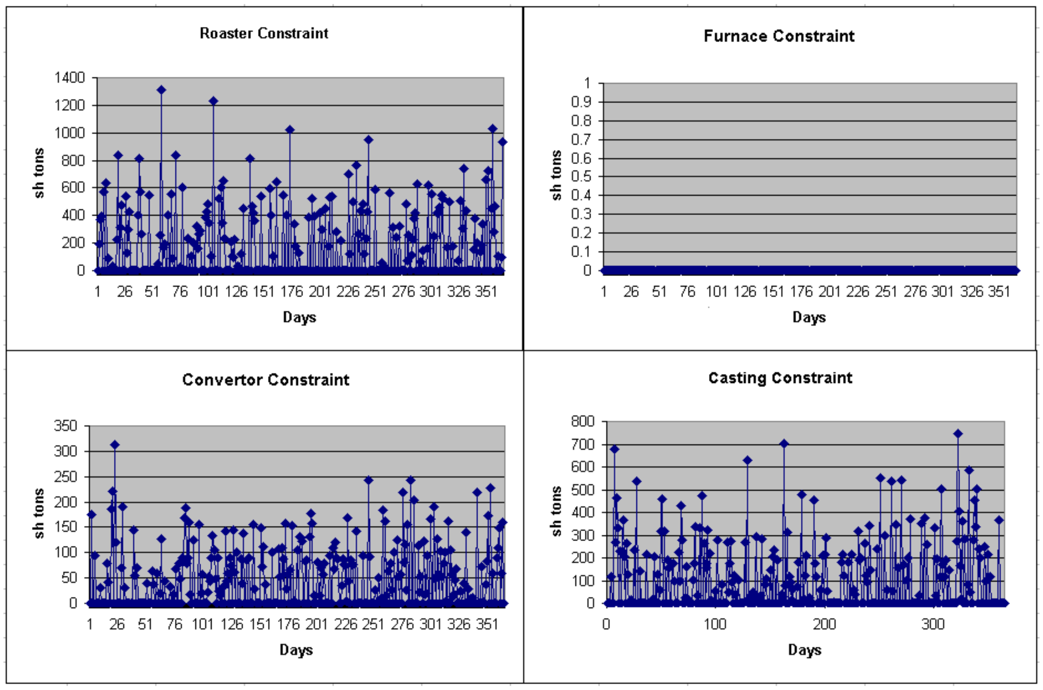


d – Crushers and Conveyors were the constraints this day.

• Figure 5.6 – Bar Chart Output: an illustration of day to day constraint of various processes.

5.7.2.2 Scatter Chart

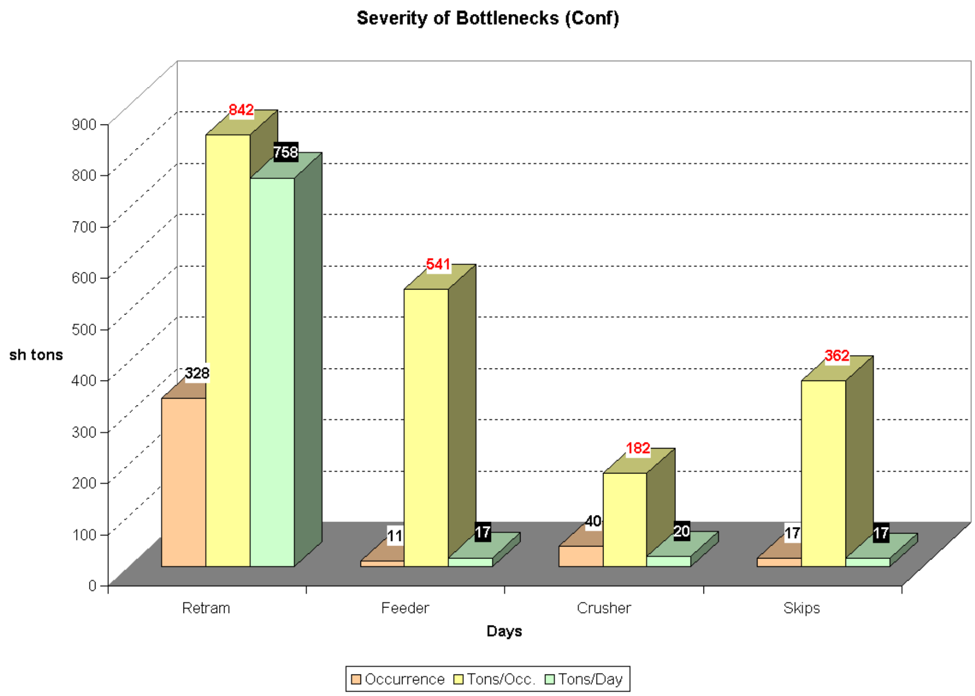
This plot is generated to identify the severity of each process for each day in a year. This plot is available at the end of simulation. Figure 5.7 depicts an example of this chart.



• Figure 5.7 – Scatter Chart Output: an illustration of sh. tons constrained by various process over a duration of 1 year (365 days).

5.7.2.3 COLUMN CHART

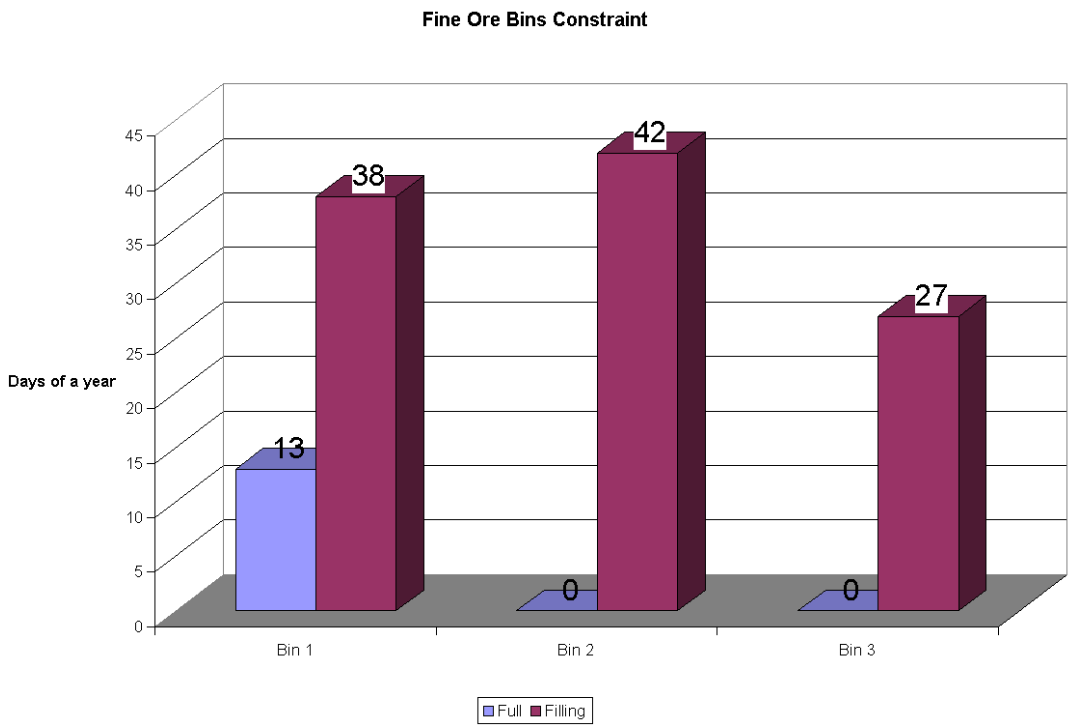
This plot is available at the end of the simulation. Out of the three this plot gives the user the most information. There are two column charts generated; one at the end of each run and one for multiple runs (Monte Carlo). There are three columns for each process; first illustrates the number of days a process became a constraint during the simulation year, second illustrates the average sh. tons that were constrained by a process when the process became a constraint, and third illustrates the average sh. tons per day constrained by a process. Figure 5.8 depicts an example of this chart.



• Figure 5.8 – Column Chart Output: an illustration of the severity of the constrained processes.

5.7.3 Capacity Constraint

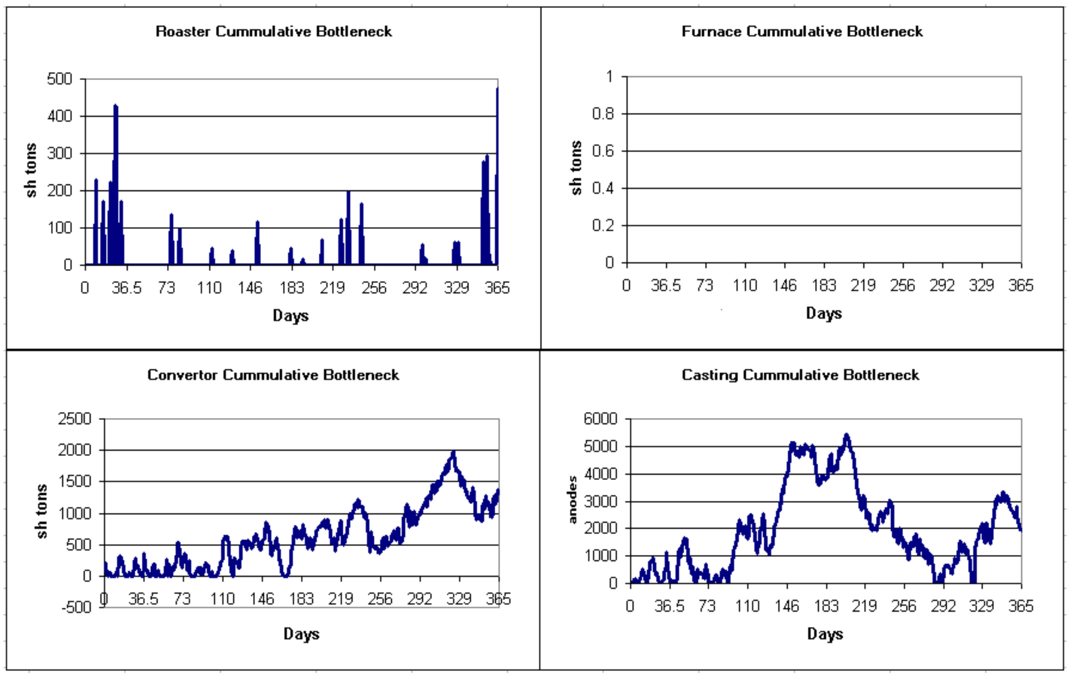
This plot is generated at the end of the simulation. This output is helpful in observing the number of days a physical capacity (e.g. Ore Bins, Ore Passes, Convertor Shell) was either full or filling (backing up). Figure 5.9 depicts an example of this output.



• Figure 5.9 – Capacity Constraint Output: an illustration of ore bins backing up representing process in front being a constraint.

5.7.4 Cumulative Bottleneck Plots

This output helps a user visualize which process is growing bottleneck and which one is not. This output adds value as it shows the increase and decrease in the flow constrained by a process. Figure 5.10 depicts an example of this output.



• Figure 5.10 – Cumulative Bottleneck Output: a fictional illustration of cumulative bottlenecks of various processes.

This output is beneficial in visual interpretation of the severity of the bottlenecks. Figure 5.10 illustrates three processes which become the bottleneck over the span of a year (365 days). Roaster occasionally becomes the bottleneck but usually have enough capacity in following days to process the constrained throughput. Casting though is not a constant accumulating bottleneck but when it does become a bottleneck it could take most of the year for it to process the constrained throughput. Convertor is the primary bottleneck as it never catches up to the constrained throughput.

5.8 Construction and Simulation of the Bottleneck Model

The plant/operation is first process-mapped using the SIPOC system. Second, the inputs are defined using rational stochastic distributions; these include the SIPOC inputs and process capabilities. Final setup step entails defining the simulated stockpiles to capture the constraint information (Figure 5.11). Next, the model is simulated and the outputs are captured. First output is the day to day bar severity chart which shows what combination of process are becoming bottlenecks and the severity of these day to day bottlenecks is captured. Second output is the severity column charts which help identify the magnitude of severity of bottlenecks over the simulation time e.g. over a year. From the simulation results, the cumulating bottleneck charts are generated which provide the overall picture of all process bottlenecks. Final output is a histogram of throughput produced. Once the base case is established through multiple runs then, the inputs can be changed according to established business cases and initiatives and the model is re-simulated. All the outputs are again captured. Improvement if any is clearly established in the throughput histogram output. If there is no improvement then the severity column charts clearly show where the improved/freed throughput was lost and in turn confirms if the initiative was actually improving the major bottleneck.

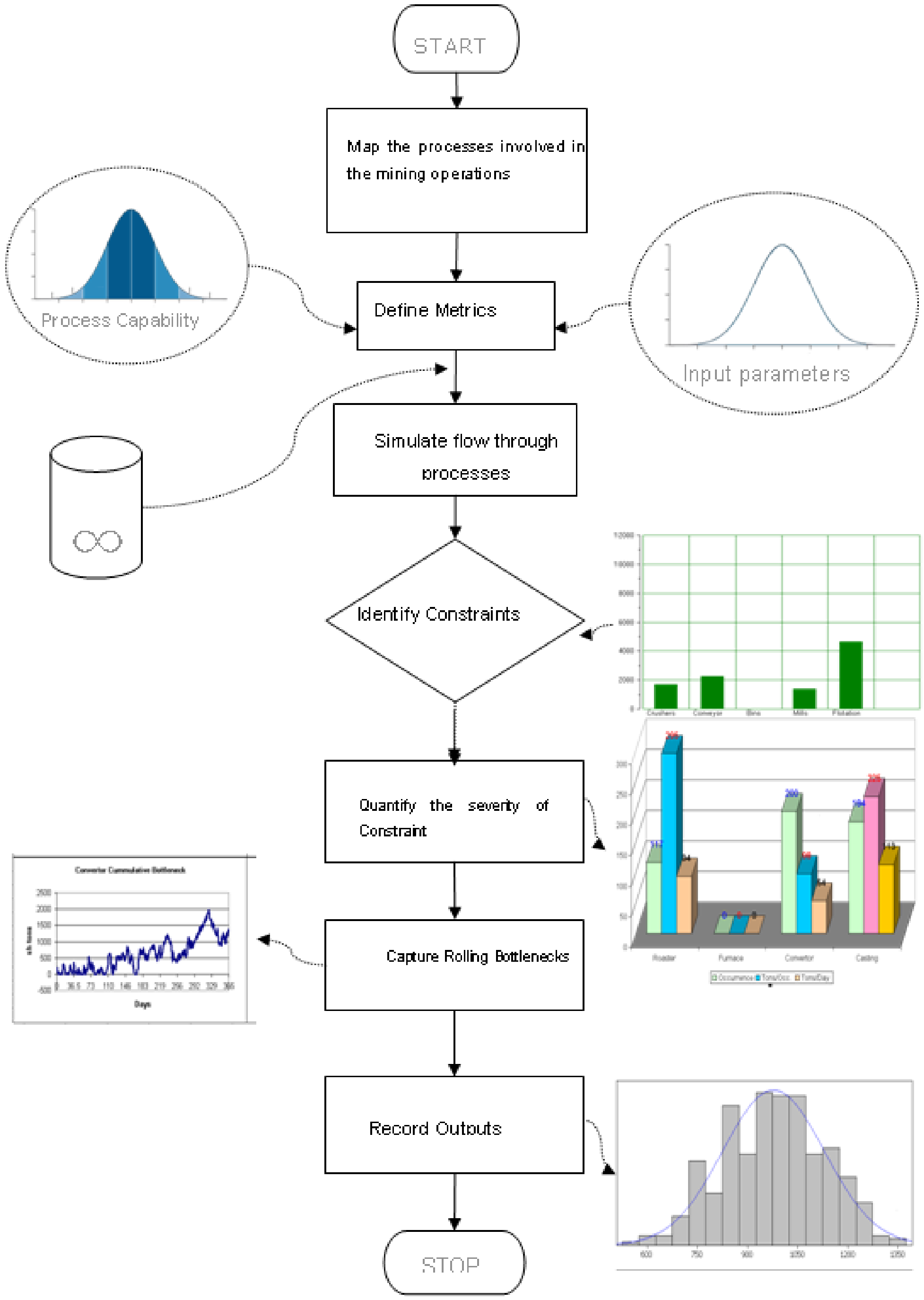
5.8.1 Structure of the Model

Processes can be defined into a model either by using built-in blocks within ExtendSIM or by creating custom blocks. Custom blocks can be created by using a Mod-L, ExtendSIM programming language. The models built for this thesis utilizes both methods. Multiple custom Blocks were built as needed to properly simulate some complex processes. A sample of customized code written in Mod-L programming language is included in Appendix J.

5.8.2 Data Capture and Filtering

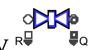
This step during the creation of the model is most essential and time consuming. Due to process variation principal, any database of actual data from a production facility will include distorted and shifted data. If this data is used in the throughput model then the results obtained would also be distorted. Issue lies with the effect of variation on all processes and thus the capacity of each process being affected by extremities of each other process.

To resolve this issue, a database must be created to capture slowdown and shutdowns of each process included in the scope of a model. This in turn then allows filtering out the minimums from each process which are in the database due to process variation. MiniTab was used to accomplish data filtering for models built in this thesis. This filtering can be achieved in MS Excel too but MiniTab not only provides data manipulation functions for prompt data filtering but also allows running real-time statistical test to ensure statistical confidence in filtered data distributions.

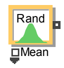


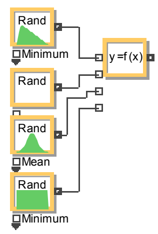
• Figure 5.11 – A flowchart of steps involved in building and simulating the model

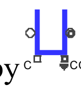
5.9 Model Buildup and Operation

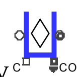
In ExtendSIM discrete rate flow model, every main process is treated as a flow valve which is represented by 

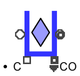
. Every input into the process is represented by either 

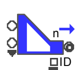
for triangular distribution, or 

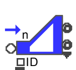
for normal distribution or combination of random variable and equation blocks 

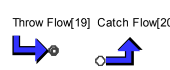
for multi model distribution. The actual stockpiles such as bins, passes, etc. with physical capacity are represented by 

. The simulated stockpiles present with infinite capacity for identifying severity of bottlenecks are represented by 

. There is one more type of tank blocks which are generally present at the beginning of a model; 

, they represent the infinite supply source of material. 

is used to represent merging of two or more flow streams into one. 

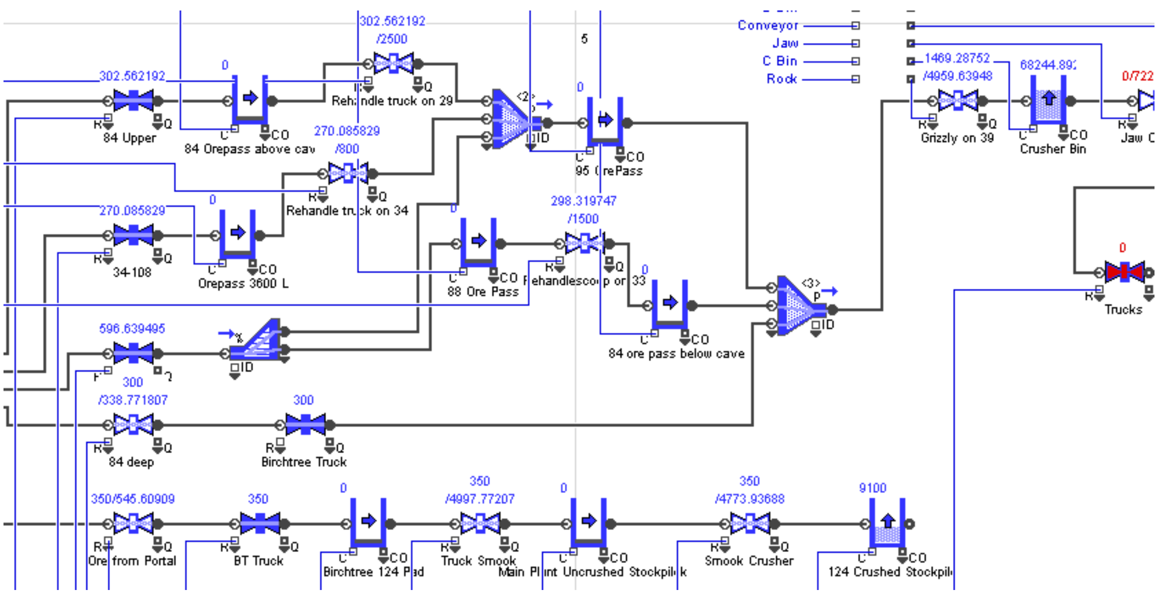
is used for diverging one flow stream into many. 

are used to throw and catch flow i.e. to direct flow without actually connecting the blocks, generally used to make model less clustered.  is used to increase or decrease the amount of flow by a factor. It can also be used to change the units of flow e.g. tons of convertor matte to anodes. Refer to Appendices for detailed description and usage of these ExtendSIM blocks[14].

5.9.1 Simulation of a Model

Flow was simulated as required by programming the governing mechanism in the executive block of each model. Every integrated mining process is represented by the valve block as it allows programming the constraints using the random input blocks. Each physical capacity in a mining operation such as ore passes, bins, and stockpiles are represented by tank block as they allows controlling the inventories. Merge and Diver Blocks are used to represent the splitting and joining of flow streams.

Each block will show the information about the activity if simulation is run with animation. Animation can be quite useful in getting live information about the processes as the simulation is run. It is also essential when trying to understand how the model works and if the model logic is accurate. Figure 5.12 is a snapshot of a mine model with animation on.



• Figure 5.12 - Simulation Model in ExtendSIM with Animation On

There are several pieces of information that can be gained from this figure such as a process “84 deep” ore stope is being constrained. This is observed by looking at the information displayed on top of “84 deep” block; first number is the amount of flow that is passing through the block and second is the amount of flow that could have passed through the block if the process was not constrained by the process ahead. For “84 deep” ore stope, there is 300 st of ore being mined while the capacity was there to mine an approximate total of 378 st of ore that day. Following the same stream of flow, next process is “Birchtree Truck” which has only one number displayed on top of the block. This represents that this process is one of the bottlenecks for the day. In this case Birchtree truck can haul 300 st a day from the 84 deep stop and hence, causing the 84 deep stope to be constrained.

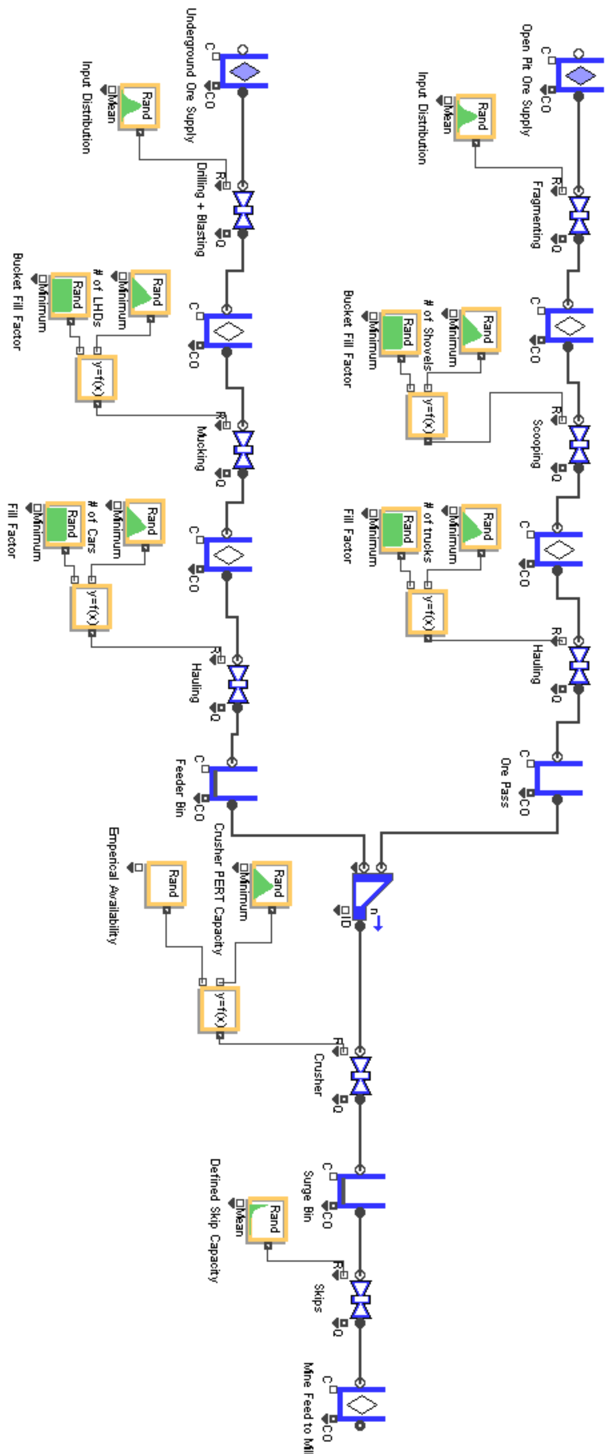
Other information that can be obtained from Figure 5.12 is the various level of physical capacity. One example can be noted in the “Birchtree 124 Pad” block where the ore pad is completely empty, the other is the “124 Crushed Stockpile” block which is being constrained by the Truck in front as the truck seems to be down (zero flow). This information can still be captured by exporting the data to excel at the end of the run but Animation allows us to capture same information while the model is simulating.

5.10 Use of the model & Scenario Analysis

The full extent of the model can be observed through a use of a fictional case study of a mine operation. Assume a mine which has the following unit operations as process-mapped in Figure 5.12 using ExtendSIM.

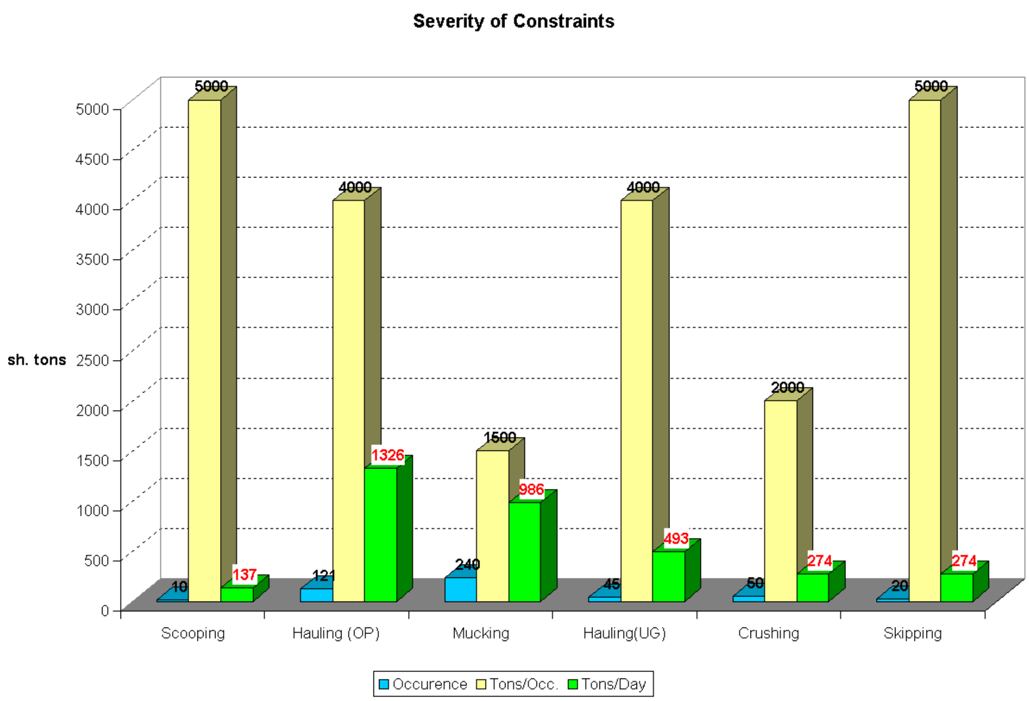
In this case study, a mine has two sections; open pit and underground. The main processes involved in open pit operation are: fragmenting, scooping, and hauling. The main processes involved in underground operation are: drilling & blasting, mucking, and hauling. Both ore supplies are then fed to a crusher via ore pass and a feeder bin. Crushed material is stored in a surge bin which is then skipped to mill.

Data entered and simulated results for this fictional case study can be found in Appendix K.

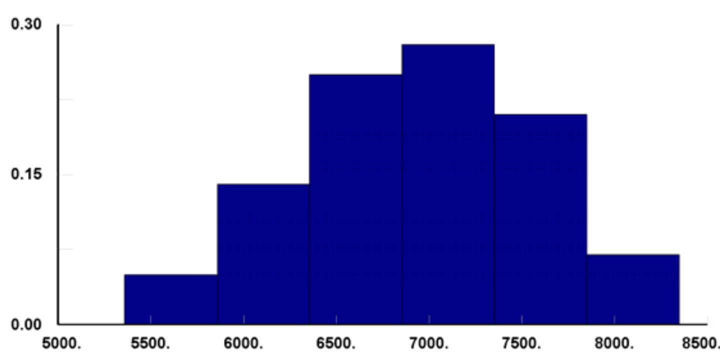


• Figure 5.13 – Fictional Mine Model - an illustration of a mine operation designed in ExtendSIM.

The model was simulated and outputs were captured. Figure 5.13 and 5.14 show the severity of constraints and tons of material produced respectively captured as outputs for the base case scenario. From severity output, it can be observed that hauling is a major constraint in open pit flow stream and mucking is a major constraint is underground flow stream as these processes constrain the major flow per day on average.



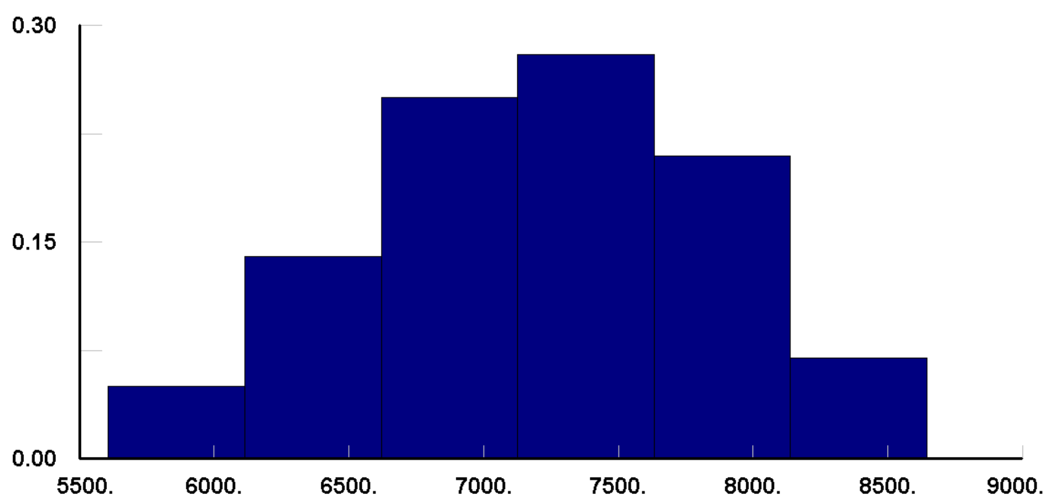
• Figure 5.14 – Fictional Case Study: severity of constraints (Base Case).



• Figure 5.14(a) – Fictional Case Study: Production histogram (Base Case).

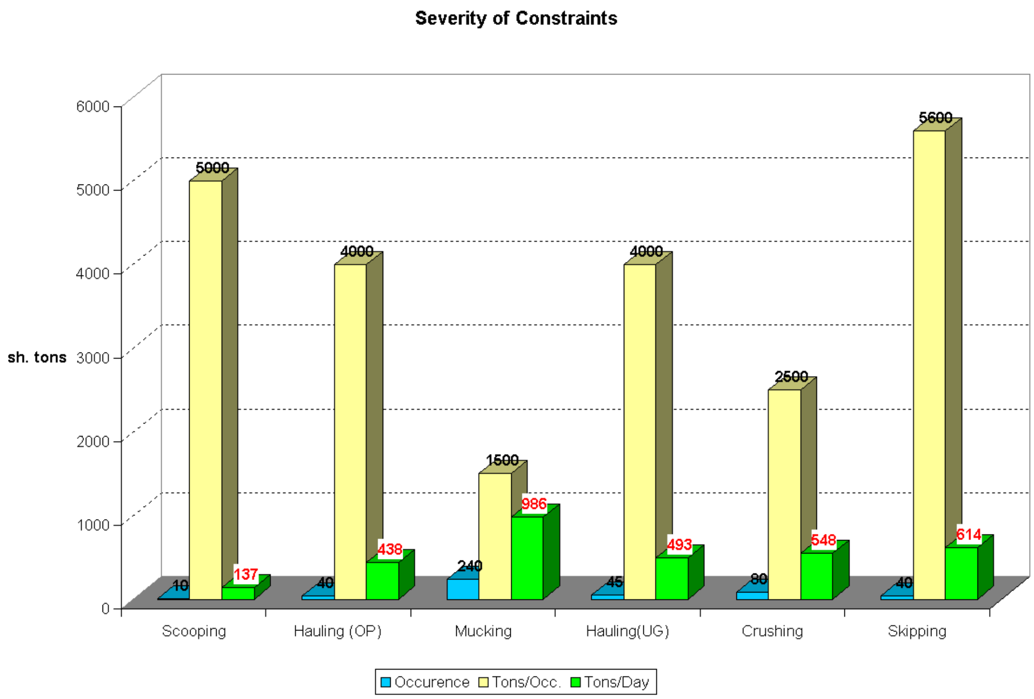
From production output it was observed that that the ore feed skipped to mill was on average 7000 sh. tons per day.

There were three business cases considered. The **First initiative** was to work on debottlenecking the hauling process for open pit ore stream. According to the business case, 5 additional trucks will increase the hauling process capacity by 10% and thus should result in extra 1000 sh. tons ore skipped to mill. The input values of open pit hauling process were increased by 10% and then the model was re simulated. Figure 5.15 and 5.16 show tons of material produced and the severity of constraints respectively captured as outputs for this initiative.



• Figure 5.15 – Fictional Case Study: Production histogram (Initiative 1).

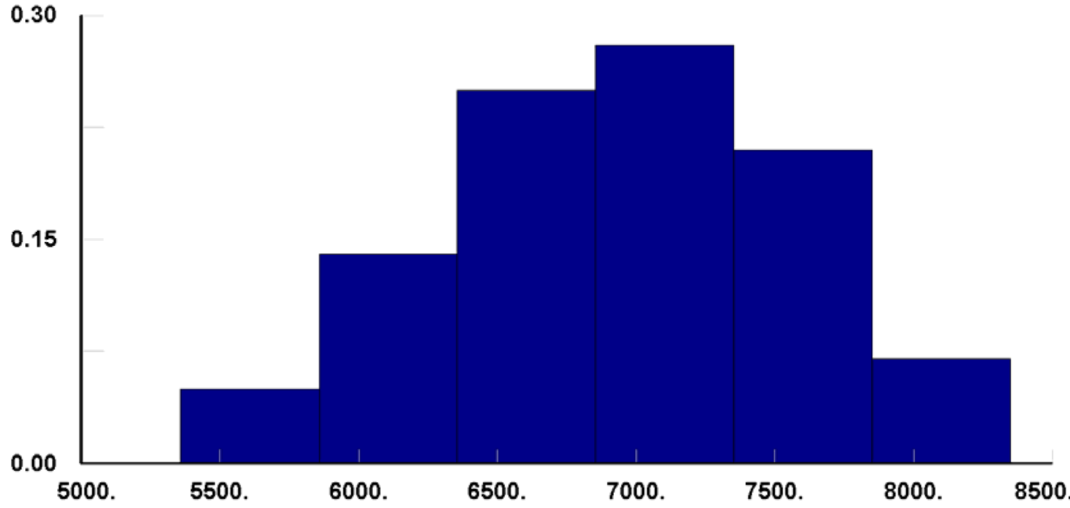
From production output it was observed that that the ore feed skipped to mill was increased to 7274 sh. tons per day. That is an increase of 7274 – 7000 = 274 sh. tons per day. However, it was also observed from severity chart output that there was a total of approx. 888 sh. tons = (1326 – 438) freed from this initiative which were less then the projected output of the business case due to variation in hauling process.



• Figure 5.16 – Fictional Case Study: severity of constraints (Initiative 1).

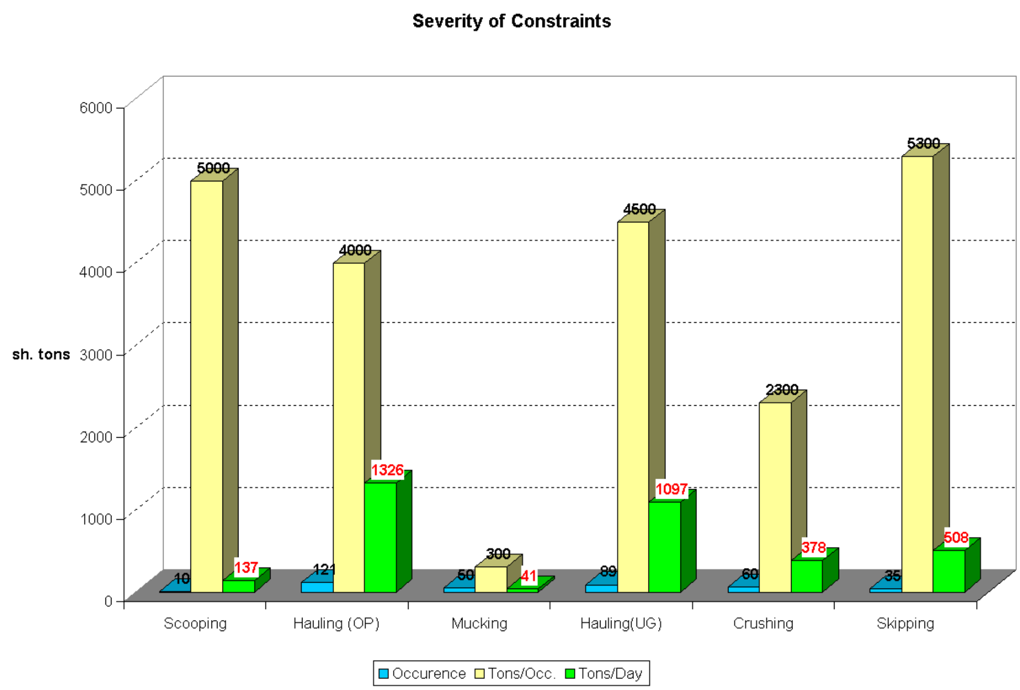
However, that is a return of 274 ÷ 888 = 31%. So, what happened to the rest of 69% of the freed flow from this initiative? Answer can be found by closely observing Figures 5.13 and 5.16. From Figure 5.16, it is obvious that 69% of the freed material actually was constrained by crushing and skipping processes. Thus, the true value of this initiative can be estimated using only 31% return.

The **Second initiative** was to work on debottlenecking the mucking process for underground ore stream. This business case states that if were to increase the number of LHDs we can get 10% improvement in the output of the mine. The input values of underground mucking process were increased by 10% and then the model was re simulated. Figure 5.17 and 5.18 show tons of material produced and the severity of constraints respectively captured as outputs for this initiative.



• Figure 5.17 – Fictional Case Study: Production histogram (Initiative 2).

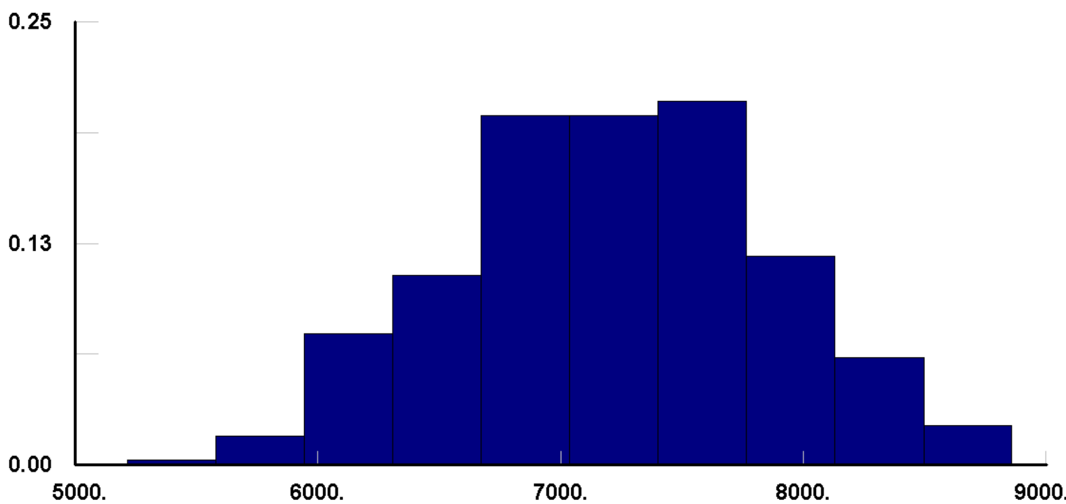
From production output it was observed that that the ore feed skipped to mill stayed at 7000 sh. tons per day. But that would mean a 0% return. Let's examine Figure 5.18.



• Figure 5.18– Fictional Case Study: severity of constraints (Initiative 2).

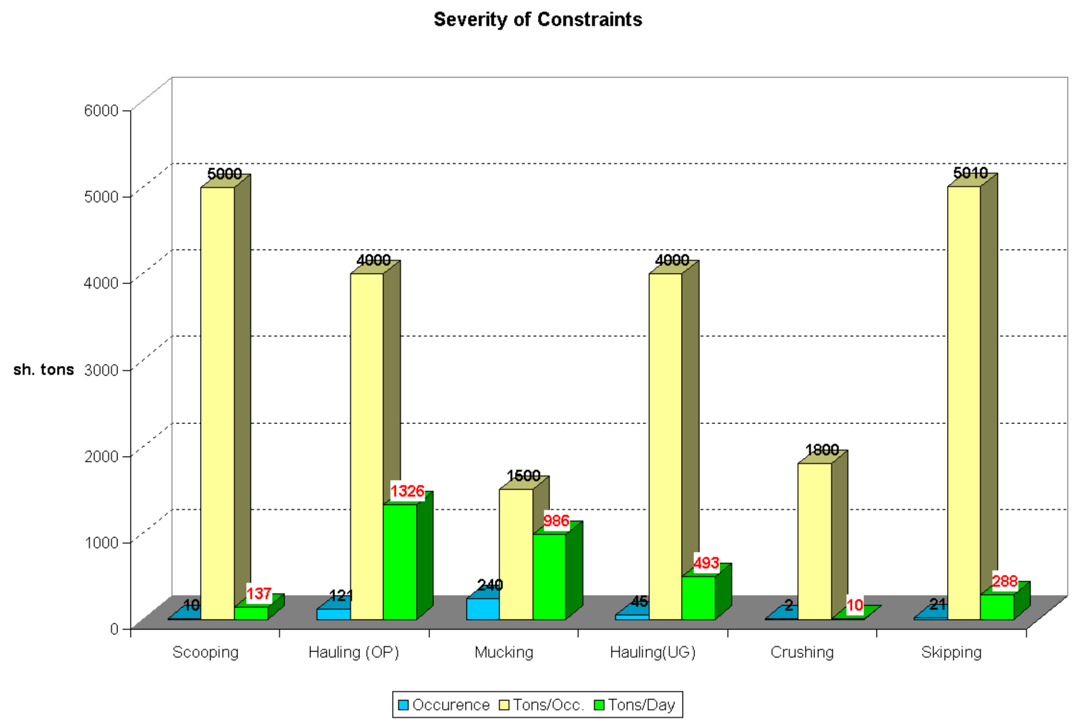
Here, there was actually 986 – 41 = 945 sh. tons per day of material was freed but all of the freed material was constrained by hauling, crushing and skipping processes. Thus, the true value of this initiative can be estimated 0% return.

The **Third initiative** was to work on debottlenecking the crushing process by increasing the utilization of the crusher. Again, the input values of crushing process were increased by 10% and then the model was re simulated. Figure 5.19 and 5.20 show tons of material produced and the severity of constraints respectively captured as outputs for this initiative.



• Figure 5.19 – Fictional Case Study: Production histogram (Initiative 3).

From production output it was observed that that the ore feed skipped to mill was increased to 7250 sh. tons per day. That is an increase of 7250 – 7000 = 250 sh. tons per day. It was also observed from severity chart output that there was a total of approx. 264 sh. tons = (274 – 10) freed from this initiative.



• Figure 5.20 – Fictional Case Study: severity of constraints (Initiative 3).

Thus, the true value of this initiative can be estimated at 250 ÷ 264 = 95% return.

Hence, using this case study, first we were able to identify the major bottlenecks in the system. Second, we were able to identify the areas of interest where to improve processes. Thirdly, we were able to estimate a return on three purposed initiatives. Here, it is important to note that though the physical return (tons) of initiative 1 is little more than initiative 3. The effort and resources that might be needed to increase the process capacity in initiative 1 will probably outweigh the effort and resources required to achieve the improvement from initiative 3. And that is one of the reason we should compare the return % as well as the physical return when comparing initiatives.

CHAPTER 6: FIELD TESTING AND DISCUSSIONS

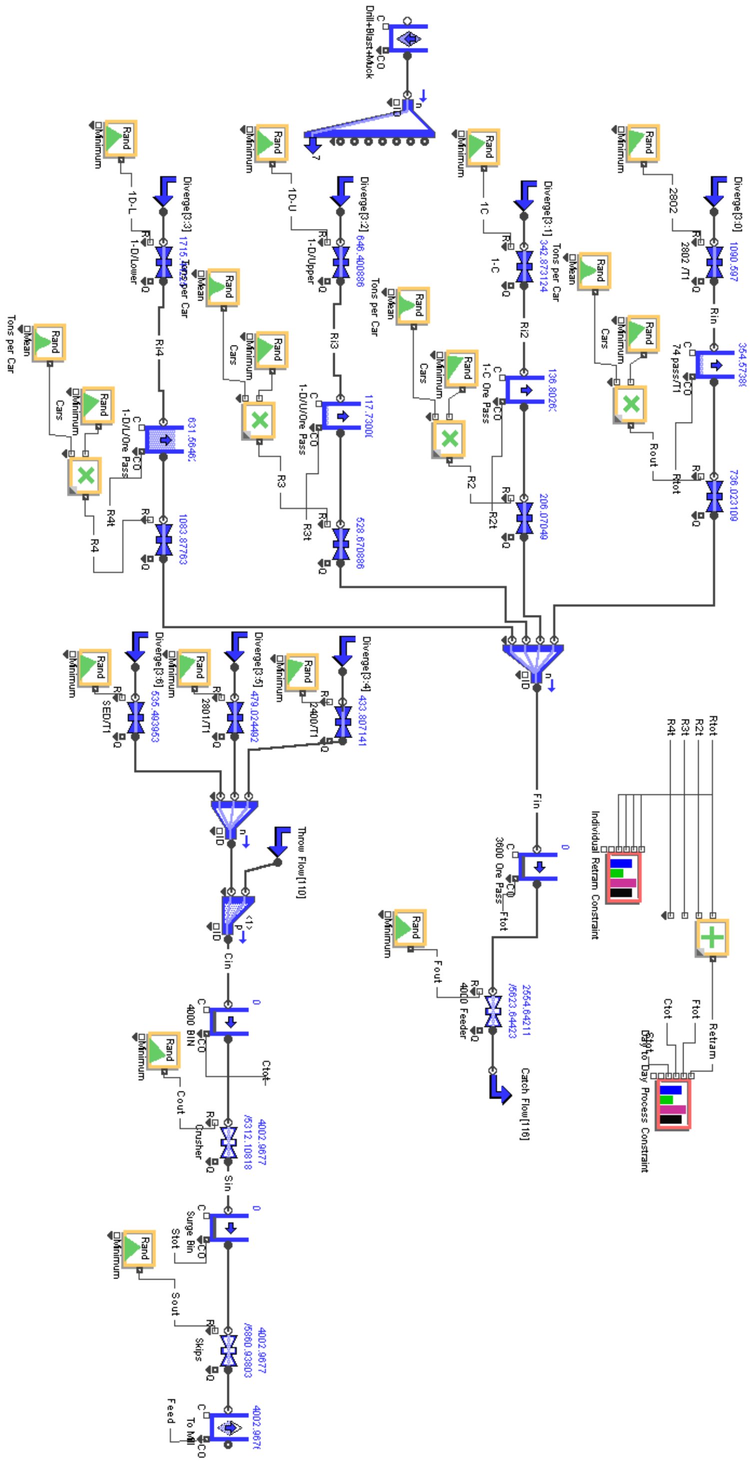
6.1 Overview

All the field testing was conducted at one of Vale Inco Limited integrated Nickel Mining Operation. There were four facilities where various business initiatives were tested using the model developed through this research. There are six distinct advantages of using this tool which were field tested and the results are detailed in six case studies.

6.2 Case Study 1 – Bottleneck Identification

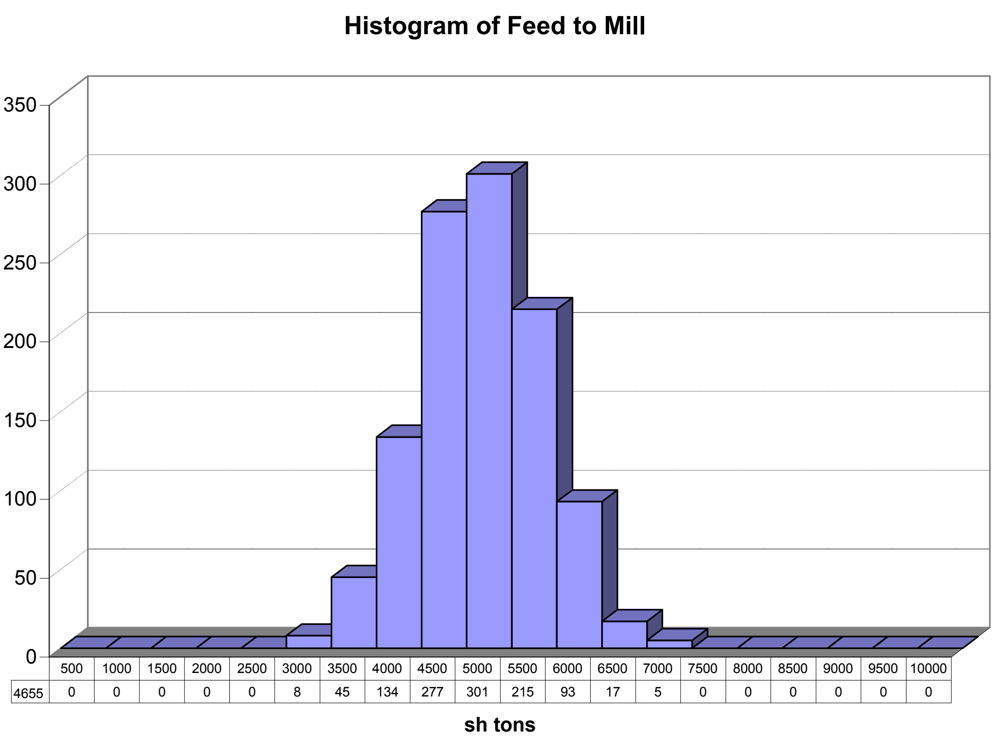
This study was done at a mine operated by Vale Inco. The common belief is that mine is capable of producing much more then it currently does, however for one reason or the other it always seem to be constrained by a process within the mine. Drilling and blasting process always seem to keep up with the planned throughput and hence the constraint seems to be in front of the ore bins. The mine process was mapped using ExtendSIM as depicted in Figure 6.1.

The major processes modeled were mucking/hauling, feeder, crusher and skips to surface. Hauling process which consists of a Tram train pulling blasted ore from the bins at different levels dumps the ore in an ore pass. Ore pass opens into a feeder which dumps ore into a crusher bin which also receives ore from other ore passes from various levels. Then this ore is crushed and moved to a surge bin. Surge bins feed the skips which hoist the ore to surface to be fed to mill.

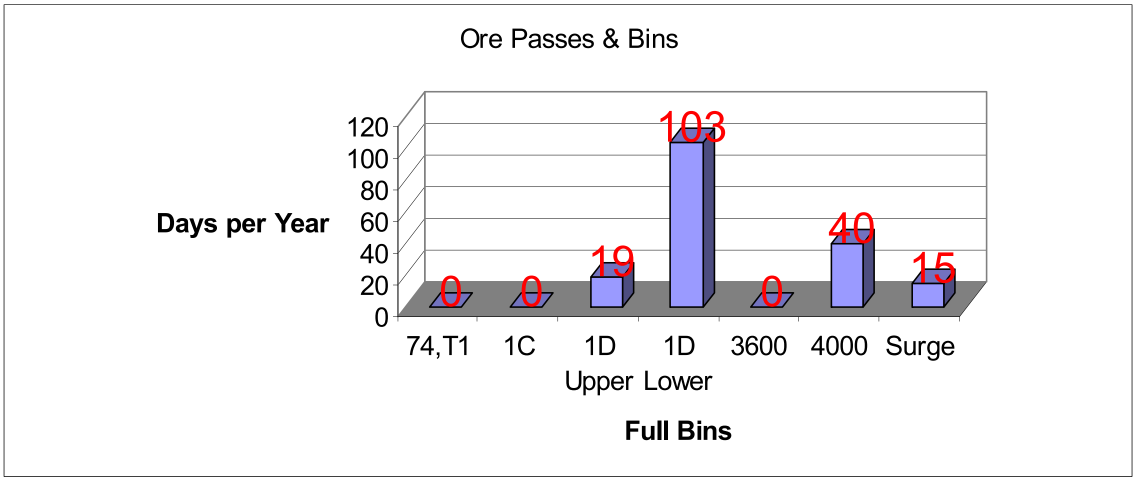


• Figure 6.1 – Process Map of a Vale Inco Mine Facility

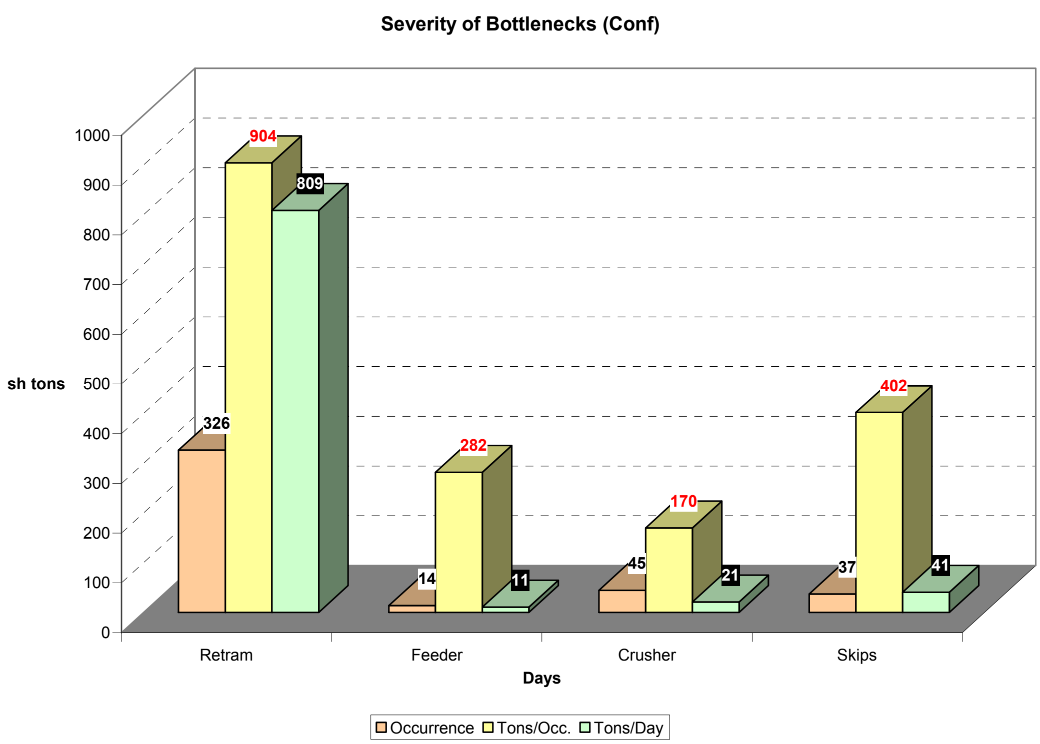
Model was completed and simulated; following results were captured. Figure 6.2 shows the distribution or ore skipped to mill i.e. throughput of the mine. Figure 6.3 illustrate number of days in a simulation year (365 days), the ore bins and passes were full. Figure 6.4 shows the severity of the bottlenecks thru main processes. Finally Figure 6.5 shows the visual representation of the bottlenecks.



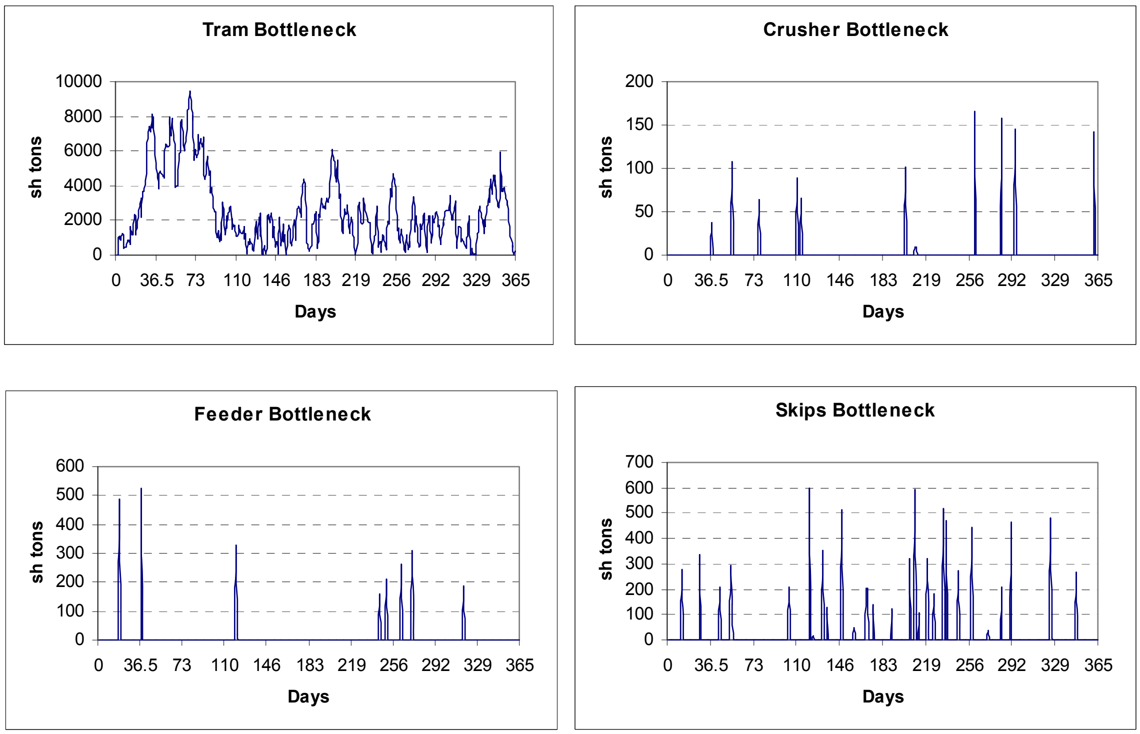
• Figure 6.2 – Histogram of Mine throughput to Mill (Base Case)



• Figure 6.3 – Frequency of Ore Bins & Passes being Full



• Figure 6.4 – Severity of Bottlenecks as identified by the model (Base Case)

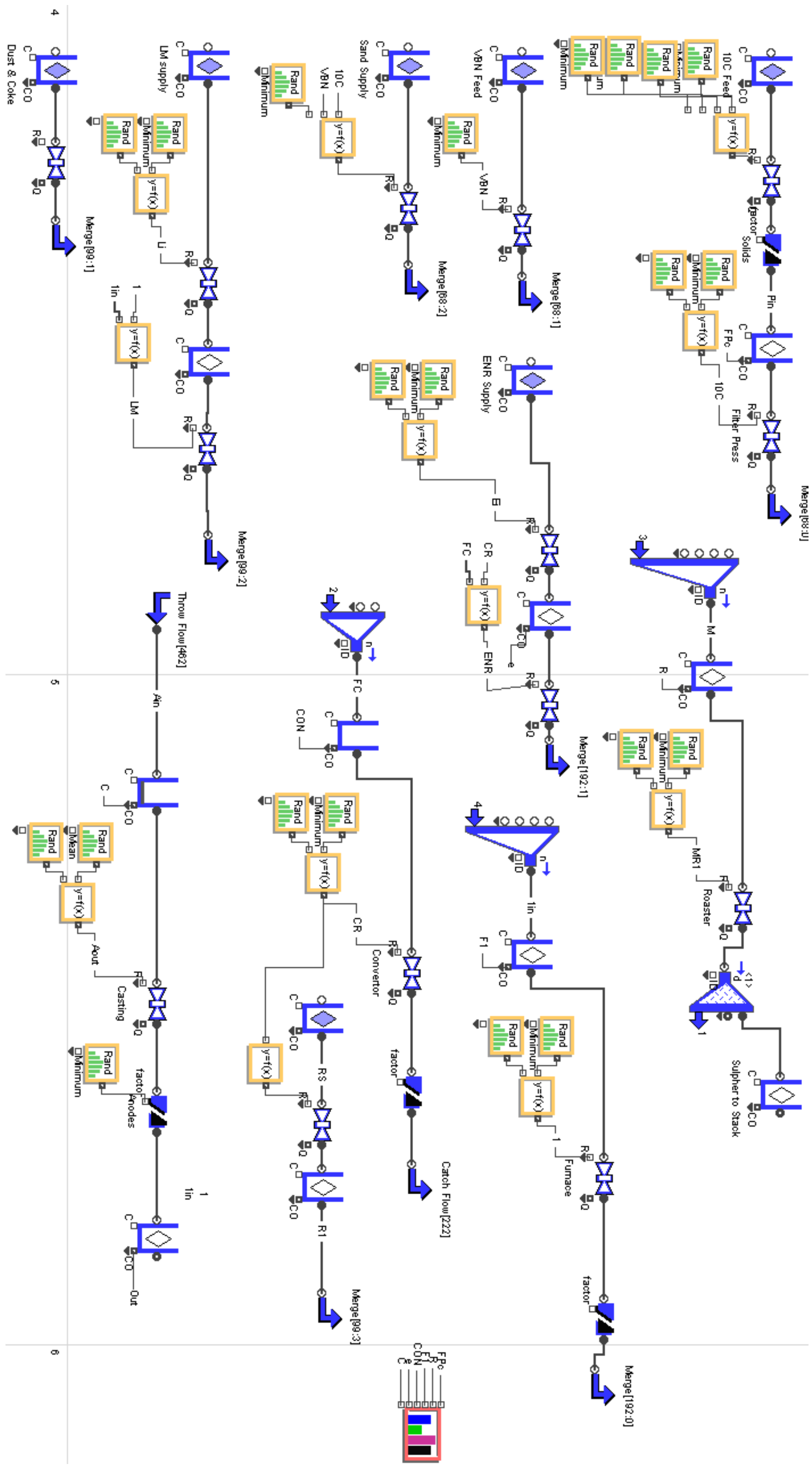


• Figure 6.5 – Visualization of Bottlenecks as identified by the model (Base Case)

It is evident from Figure 6.5; Tram process is the major accumulating bottleneck. Figure 6.4 highlights the severity of this bottleneck as there is approx. 800 sh. tons of ore being constrained by this process every day.

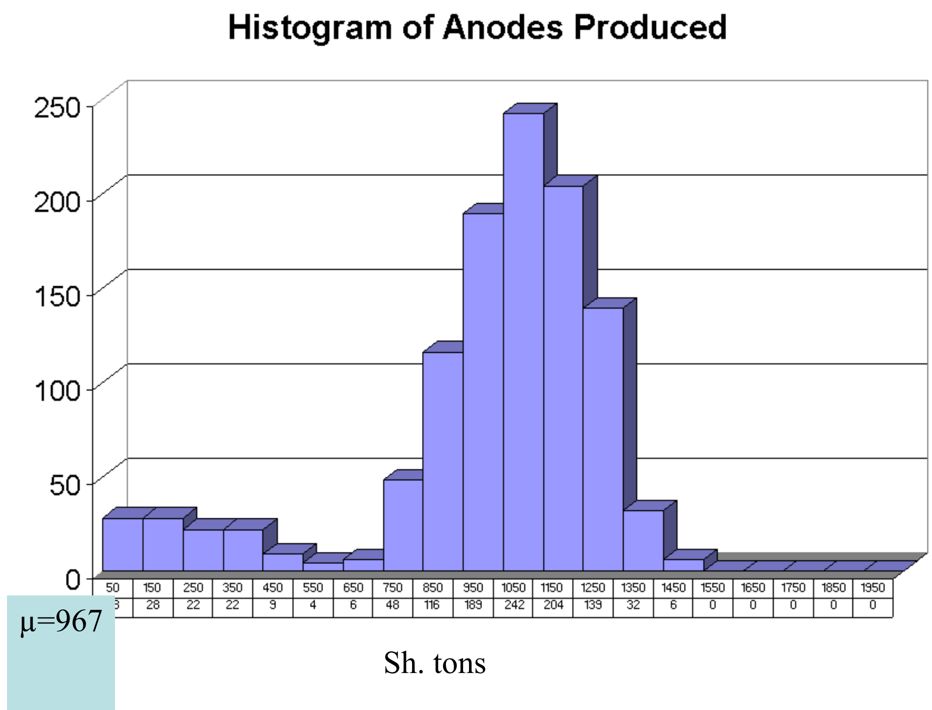
6.3 Case Study 2 – Perceived Bottleneck

This study was done at a smelter facility operated by Vale Inco. Over many years in past Vale Inco Limited has spent enormous amount of resources in improving the throughput of this smelter facility but all the initiatives have resulted in minimum to limited improvements. During conducting research on this facility, it was observed that many process experts had different opinions about perceived bottleneck in the smelter facility. However, the majority of experts believed it to be the roaster process as it seemed to be down most of the time. The process map of the smelter facility as modeled in ExtendSIM is illustrated in Figure 6.6.

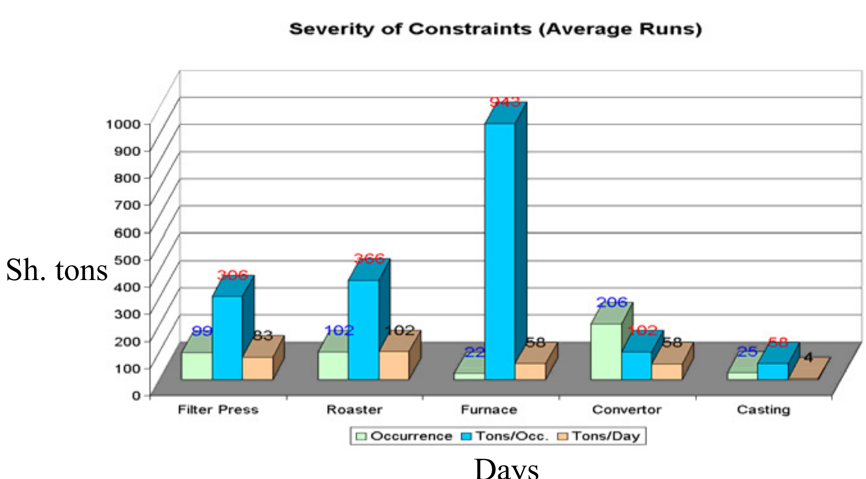


• Figure 6.6 – Process Map of a Vale Inco Smelter Facility

The outputs of the model simulations were captured as depicted in Figure 6.7 & Figure 6.8. Histogram in Figure 6.7 shows the anodes produced per day simulated from the Smelter model.



• Figure 6.7 – Histogram of Anodes produced; throughput output of the model (Base Case)



• Figure 6.8 – Severity of bottlenecks within the smelter facility (Base Case)

From Figure 6.8, it can be observed that, 102 days out of a simulated year (365 days), roaster was a constraint. And when it became a constraint, there was approx. 366 sh. tons of material constrained by it and thus it is constraining about 100 tons of material every day.

So, to test the popular theory of roaster being the major bottleneck in the smelter facility, the capacity of the roaster process was increased by 10% in the model and then model was re-simulated. Now, if this initiative was actually implemented then the cost of this initiative will be around $2 Million. But the business case will project an improvement of 20 more anodes a day which will be (20×365) =7300 anodes a year. At approximately $2000 per anode that will generate a revenue of $14.6 Million. On paper, this business case looks very solid as the payback is within months. The results of this 10% increase in the roaster capacity as simulated by the model are depicted in Figure 6.9 & Figure 6.10.

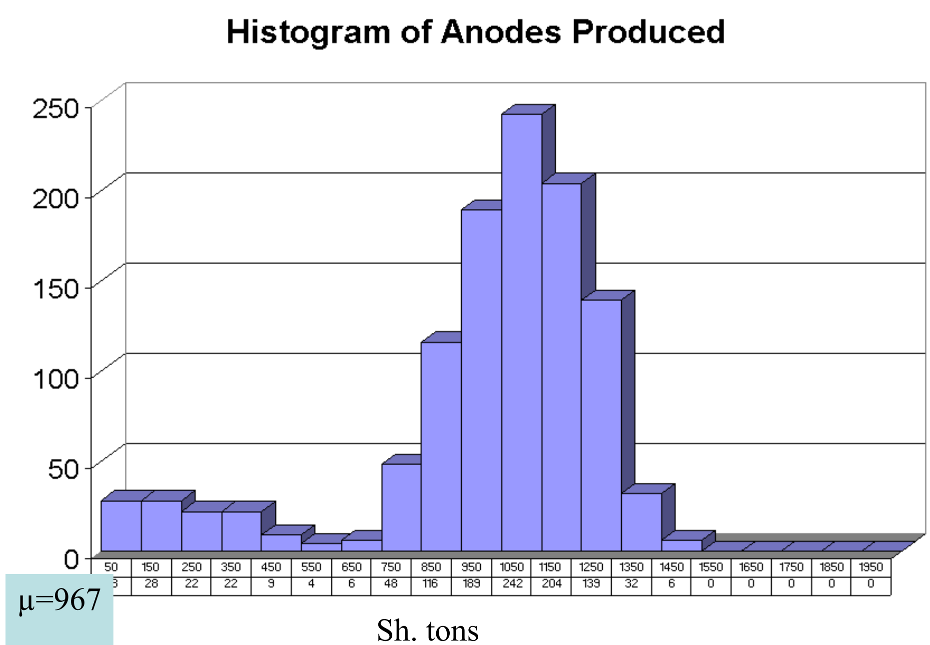
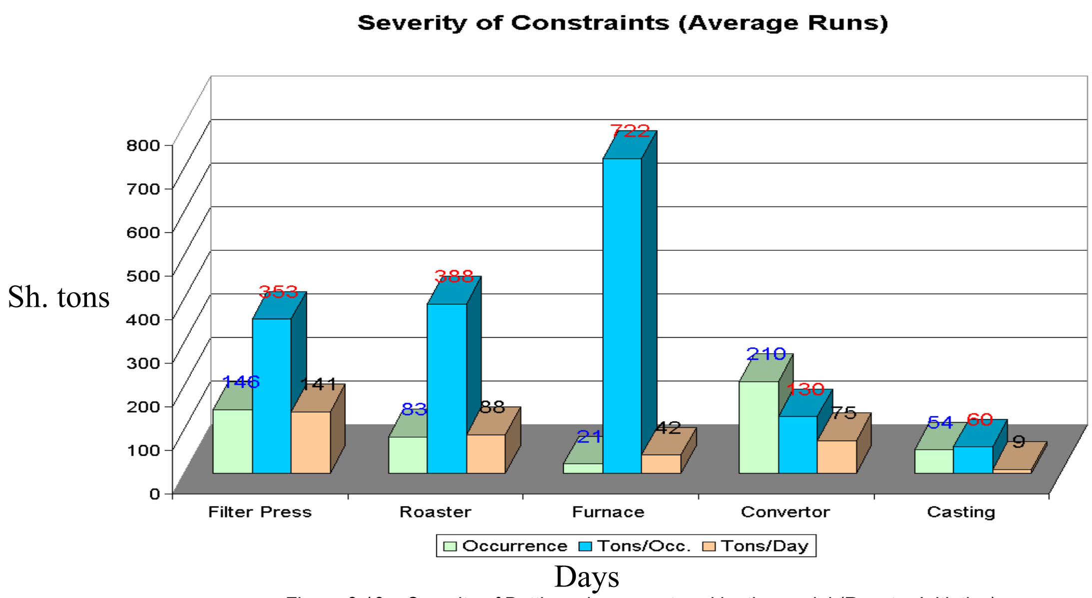


Figure 6.9 – Throughput of Smelter Facility after Roaster initiative (capacity increase by 10%)



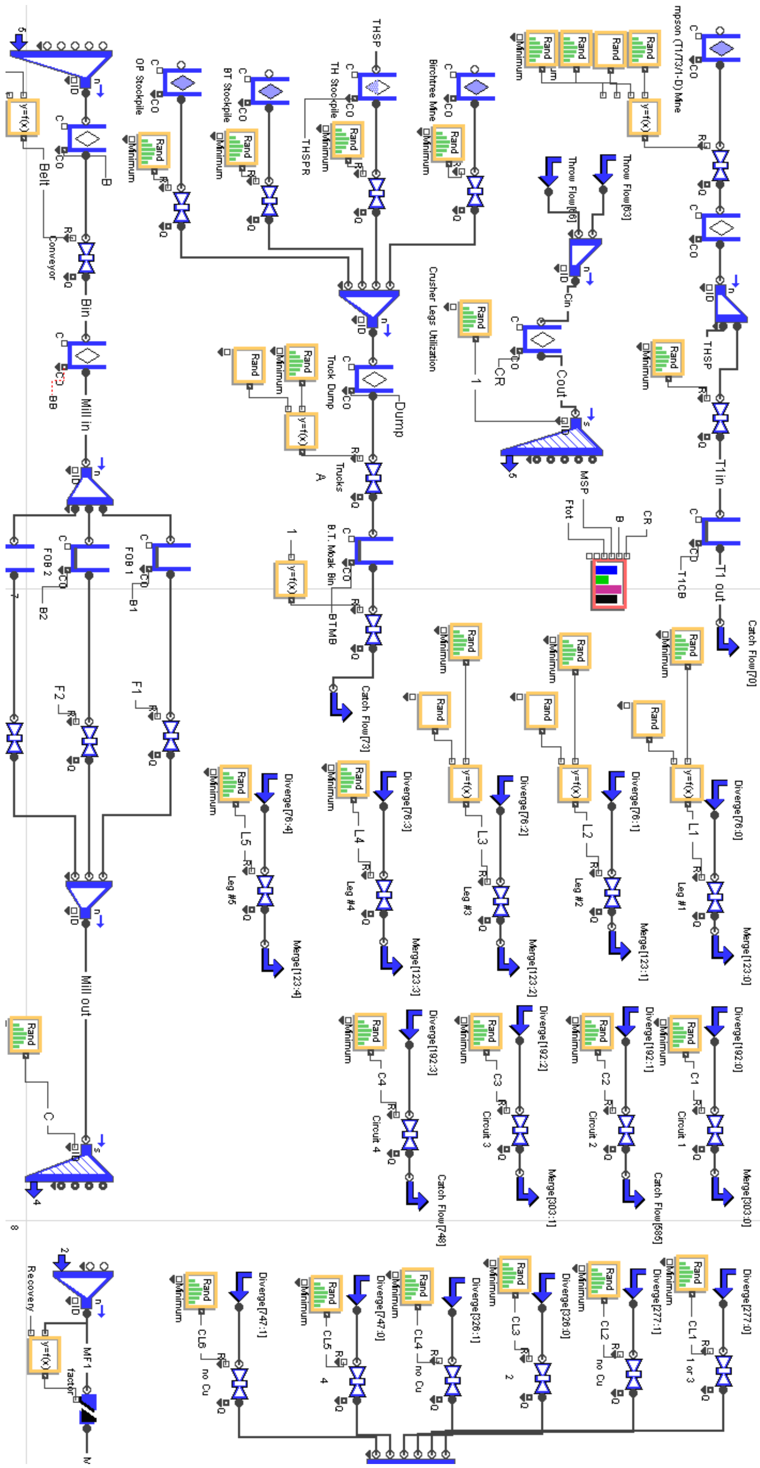
• Figure 6.10 – Severity of Bottlenecks as captured by the model (Roaster Initiative)

From analysis of Figure 6.8 & Figure 6.10, it can be observed that yes there was material freed from the roaster (102 – 88), but all of this material was lost in convertor and casting processes. Thus the total gain in anodes from this initiative is 0 as evident in Figure 6.9. In other words, $2 Million down the drain. Even though scope of this case study was to show the result of an initiative done without identifying the bottleneck first, the tool was used to actually identify the primary bottleneck, which is the convertor process. Methodology described in case study 1 was used to identify the bottleneck

6.4 Case Study 3 – Variation Reduction

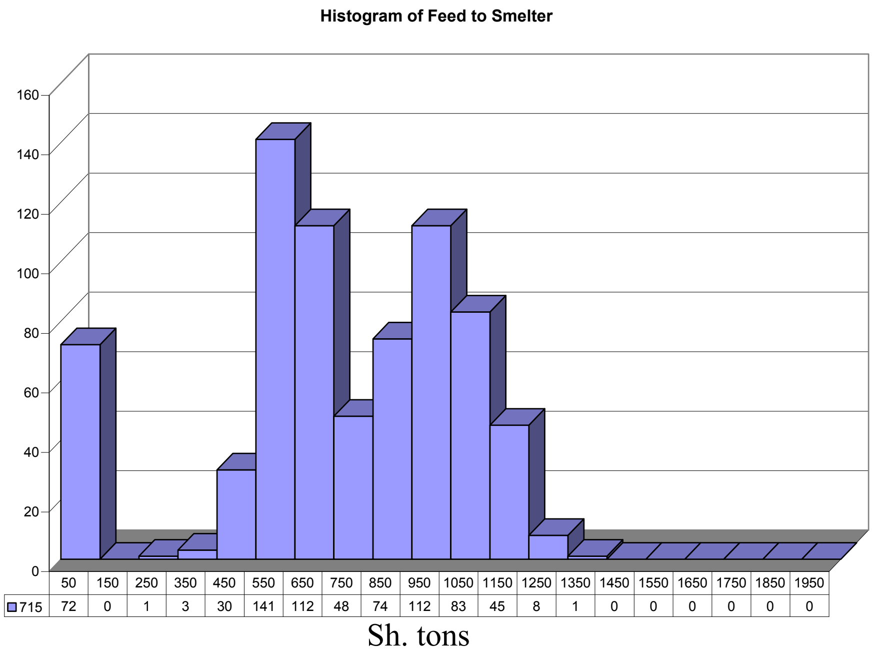
This study was done at a mill facility operated by Vale Inco. This case study was undertaken to better understand the effect of variation reduction on the performance of the facility. The mill facility was mapped using ExtendSIM as shown in Figure 6.11.

To better illustrate the point of identifying the bottleneck first, this study was done in two parts. First the variation of the crusher process was reduced by 20% and the mean was shifted as to reflect the reduction of the minimums of process capability distribution. Crusher process was chosen as it has the widest variation when compared to other mill processes.

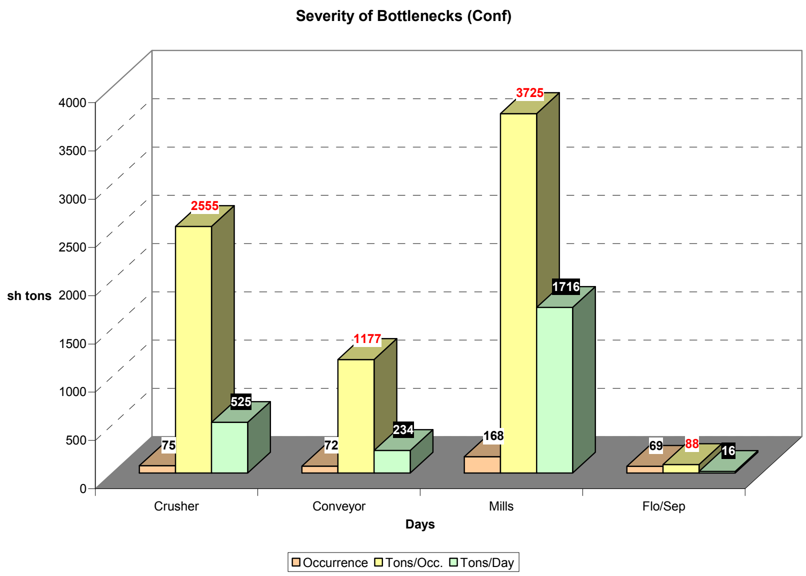


• Figure 6.11 – Process Map of a Vale Inco Mill Facility

Figure 6.12 and Figure 6.13 show the throughput produced by the mill and the severity of process constraints for the base case before the variation reduction in crusher. Figure 6.12 shows the histogram of tons of concentrate produced from the Mill model.

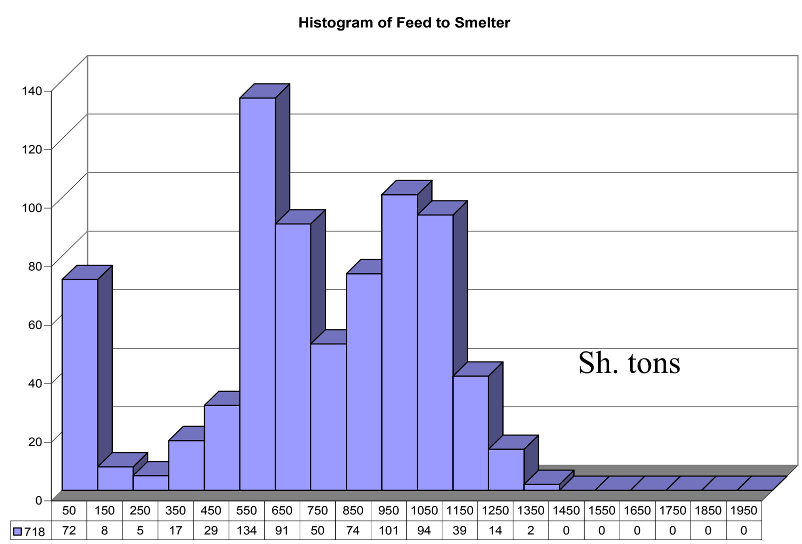


• Figure 6.12 – Throughput Histogram of Mill (Base Case)

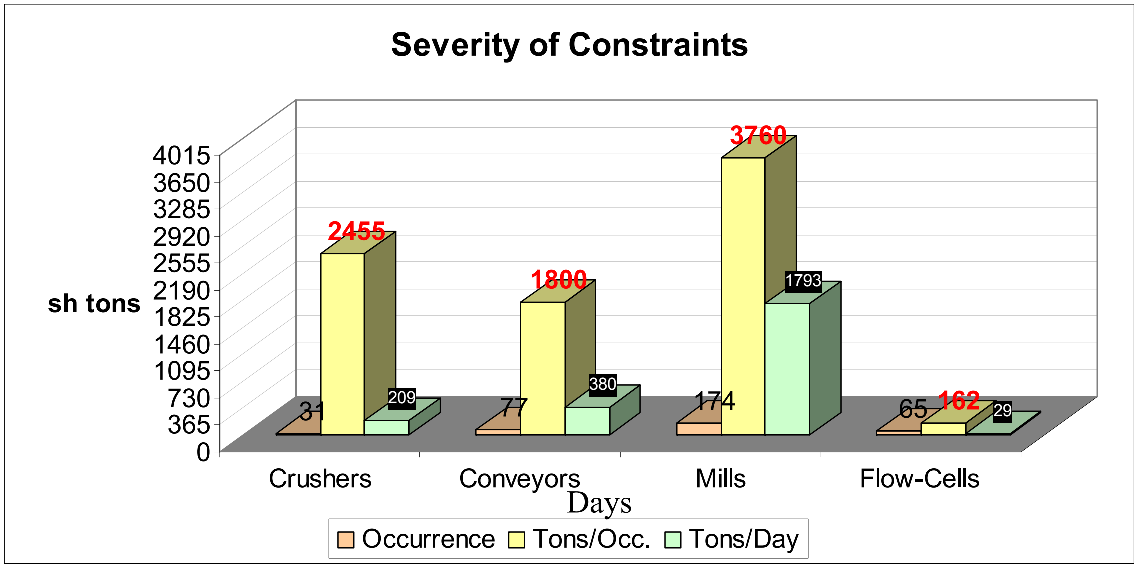


• Figure 6.13 – Severity of Bottlenecks in the Mill (Base Case)

Figure 6.14 and Figure 6.15 show the throughput produced by the mill and the severity of process constraints for the simulation case with the variation reduction in crusher.



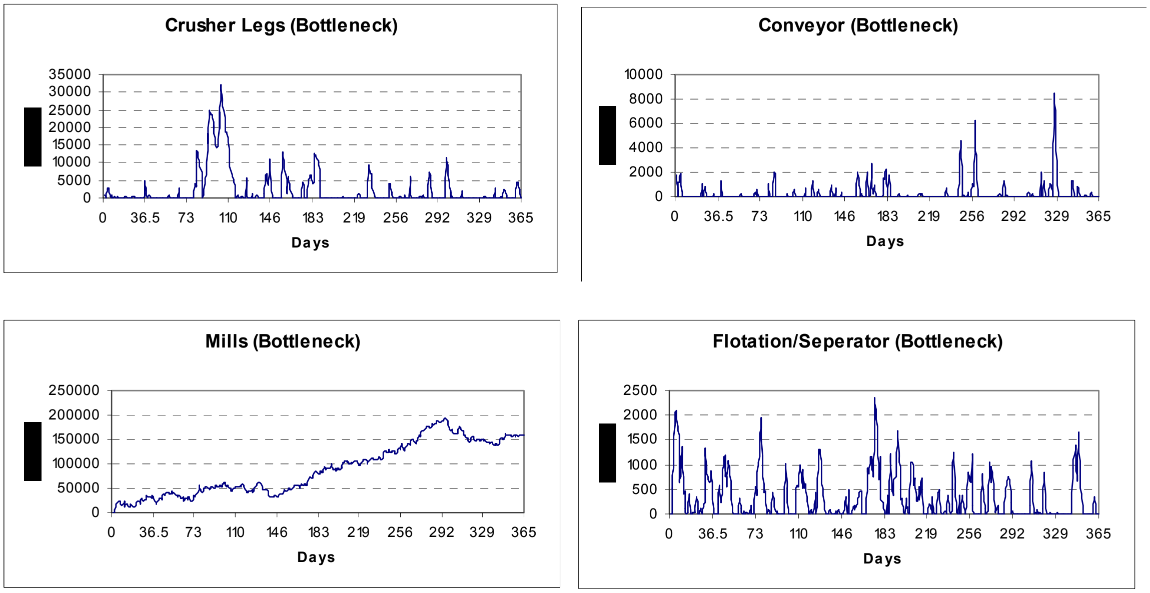
• Figure 6.14 – Throughput Histogram of the Mill (Crusher Initiative)



• Figure 6.15 – Severity of bottlenecks within the mill (Crusher Initiative)

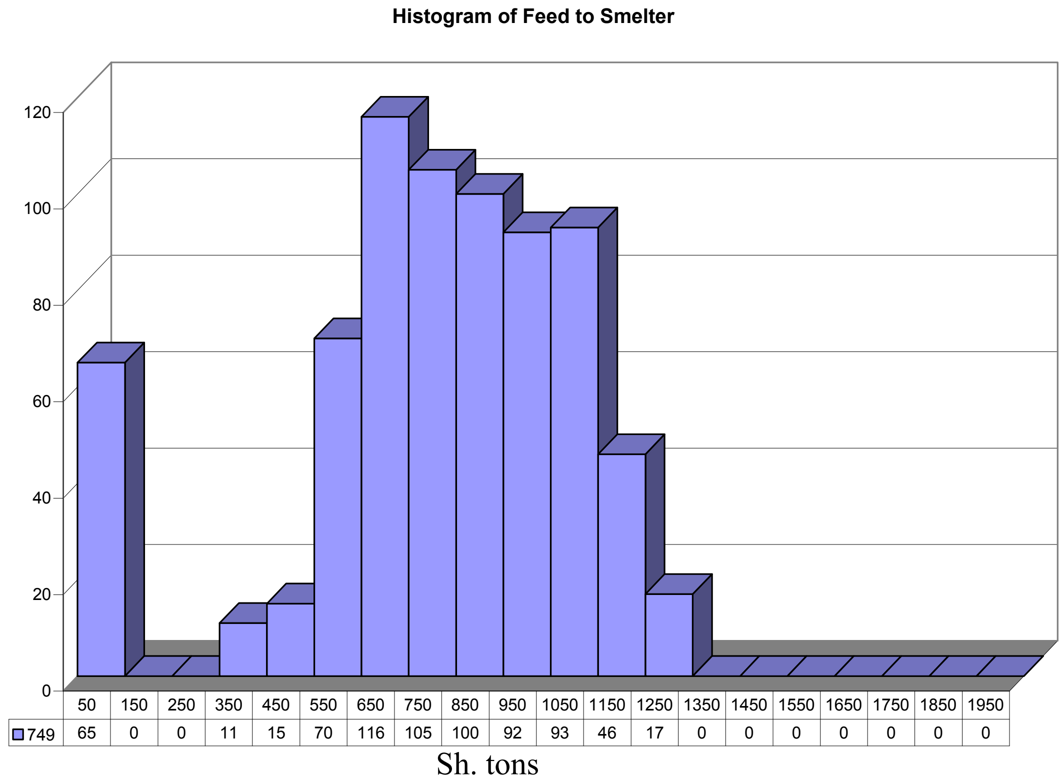
Thus, it can be observed from the Figure 6.15 that even though severity of crusher constraint lowered but the freed material was consumed by the following processes. Important thing to note here is there was no statistically significant gain in throughput by reducing the variation in crusher process distribution.

The second part of this case study was to first identify the bottleneck and then reduce the variation of the bottlenecked process to see the effect of reducing variation. Grinding Mills were identified as the major bottleneck of the mill facility from Figure 6.16

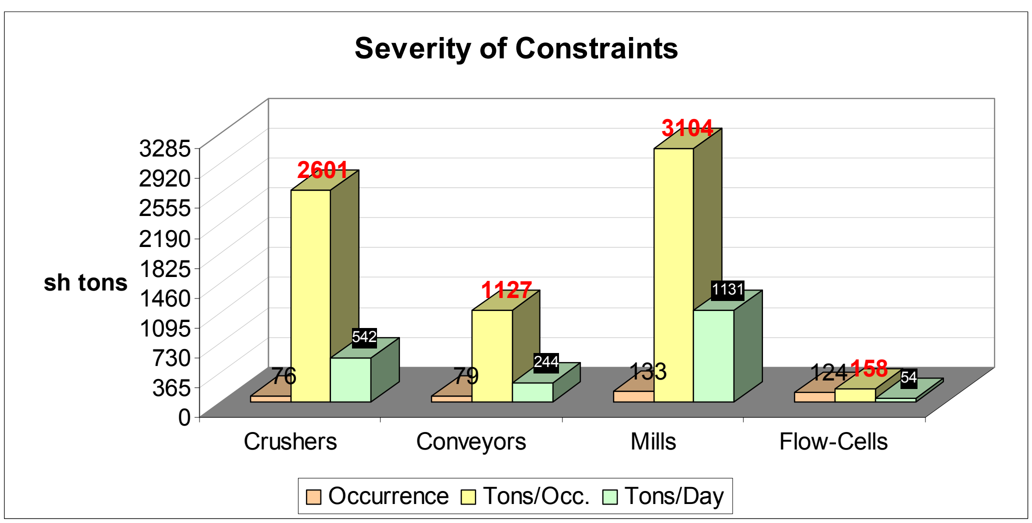


• Figure 6.16 –Cumulative Bottlenecks output as identified by the model (Base Case)

Next the variation in grinding mills was reduced by 20% in such a way that the minimum were lowered and mean was shifted for the grinding mills distribution. Model was re-run and the outputs were captured. Figure 6.17 and Figure 6.18 show the throughput produced by the mill and the severity of process constraints for the case with the variation reduction in mills.



• Figure 6.17 – Throughput Histogram of the Mill (Grinding Mills Initiative)



• Figure 6.18 – Severity of Bottlenecks within the mill as identified by the model (Grinding mills initiative)

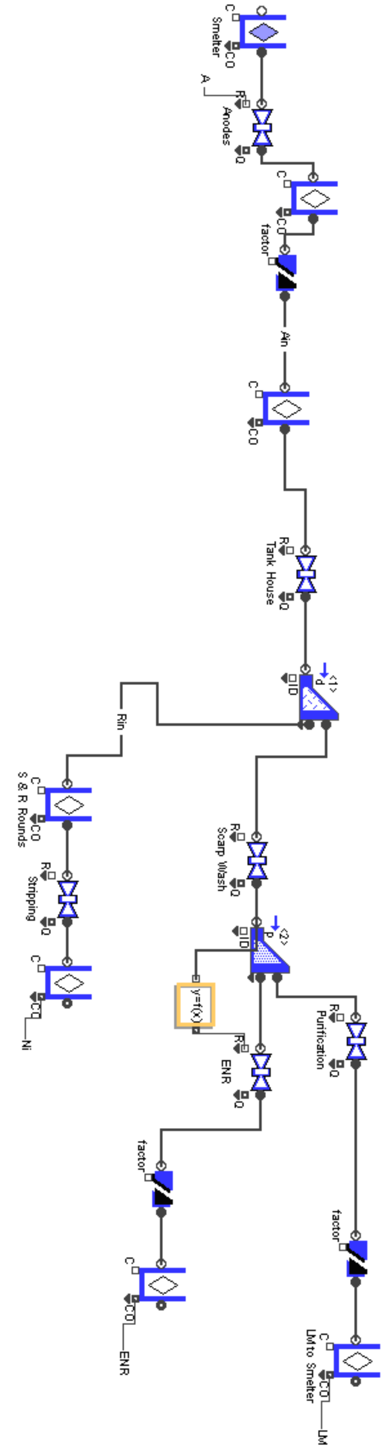
The throughput was increased on average from 715 to 749 sh. tons per day i.e. approx. 35 sh. tons per day. The severity output in Figure 6.18 illustrates that variation reduction in grinding mills freed more material (1793-1131) which should have resulted in a net gain of 60 sh. tons of concentrate if all of it passed through the rest of the system but it can be observed in Figure 6.18 that some of the freed material was constrained by the flotation & Separation process which confirms the results in Figure 6.17 as flotation though is not the major bottleneck but is the 2nd biggest bottleneck in the mill facility. Thus, the total gain thru this variation reduction initiative is about 58%.

The aim of this study was to show that yes, reducing the variation helps in improving the performance of a process but the bottleneck of the system should first be identified or there is a risk of no to very low gain.

6.5 Case Study 4 – Lean Optimization

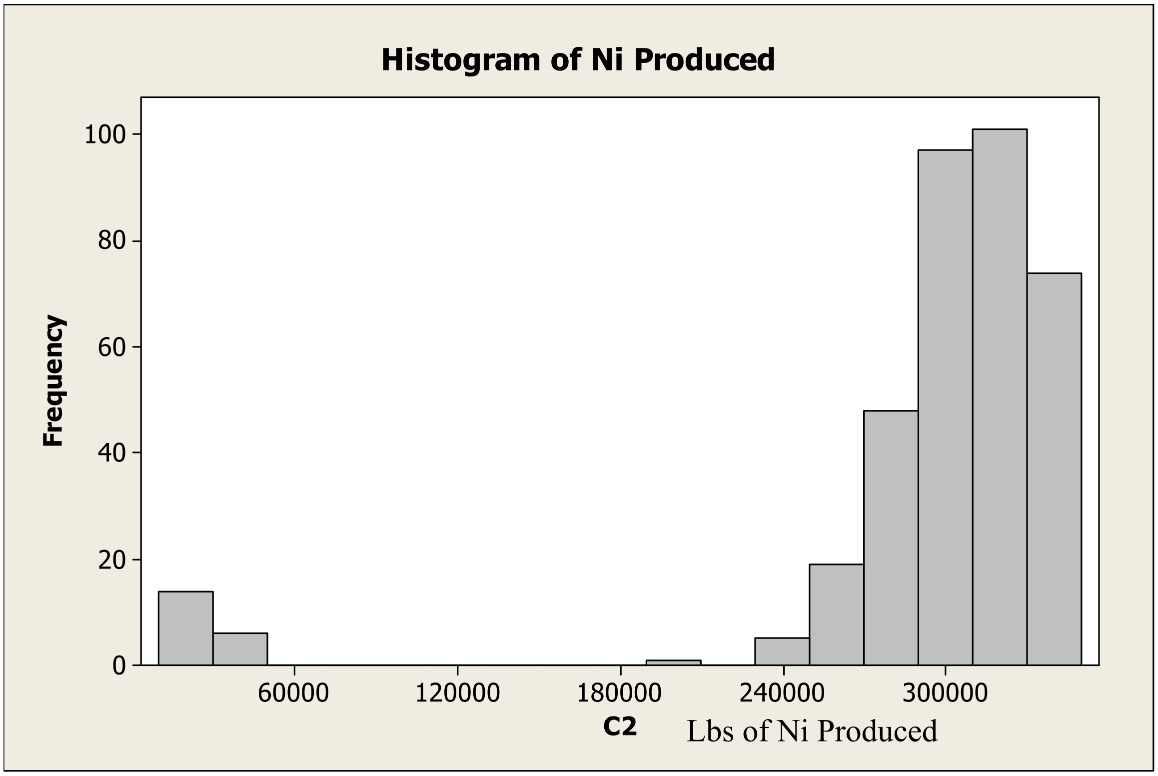
This study was done at a refinery facility operated by Vale Inco. This case study was undertaken to see if any waste can be identified using this tool. The idea behind lean optimization is to identify any waste and eliminate it. For the scope of this research, waste would be any capacity of a process which is not being used and then can be eliminated to keep the throughput the same. Here it is important to note that to utilize this model, the base case will be established as outline earlier and then the range will be calculated using power test in such a way as to test if two systems are same and not different. Again, as before the power test will only prove that the processes are the same and cannot prove that the processes are different. In other words, if two cases fail to satisfy power test, it does not mean that they are different but that there is not enough proof for them to be similar.

Process map of the refinery facility drawn in ExtendSIM is illustrated in Figure 6.19.



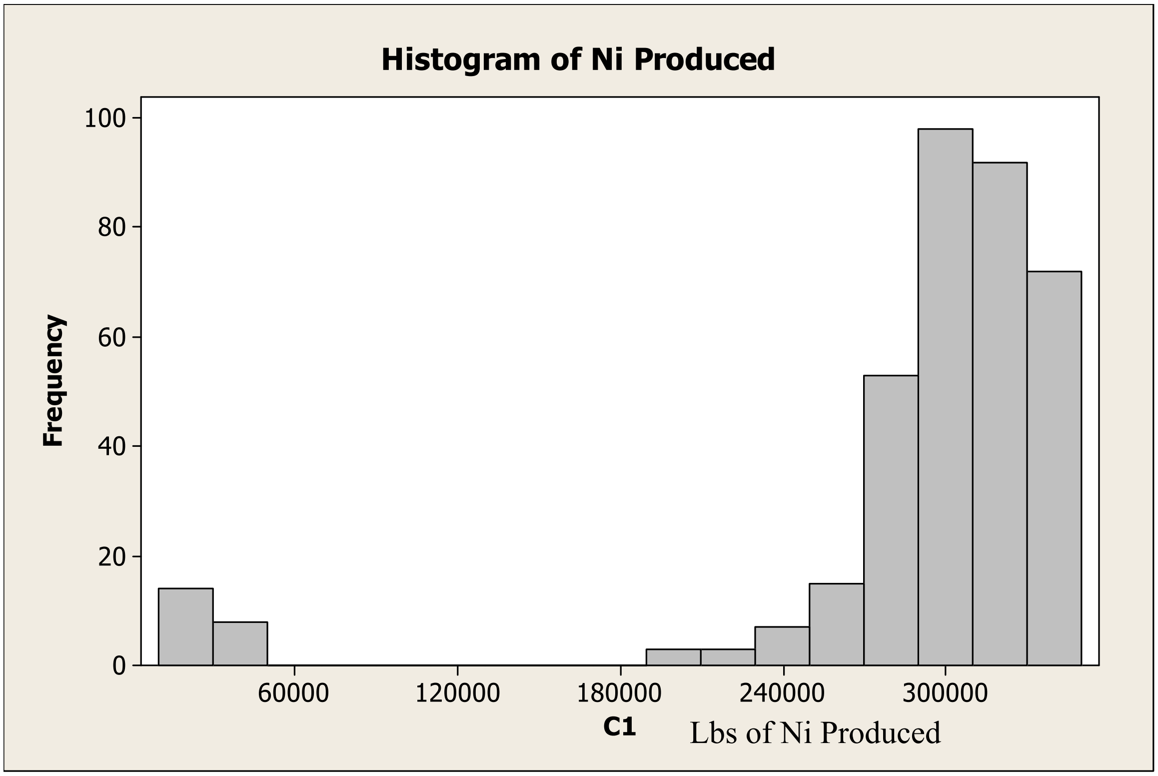
• Figure 6.19 – Process Map of a Vale Inco Refinery Facility

The output throughput histogram (lbs of Ni produced per day with a mean of 293515) from base case simulation are illustrated in Figure 6.20.



• Figure 6.20 – Throughput Histogram of the Refinery (Base Case)

For this case study, tank house capacity was reduced by 5% as the common belief is that tank house process is never fully utilized. The output throughput histogram (lbs of Ni produced per day with a mean of 293485) from base case simulation are illustrated in Figure 6.21. The difference falls within the test range to classify two processes as the same with a 95% CI. This was shown to be true by utilization the T-Test.

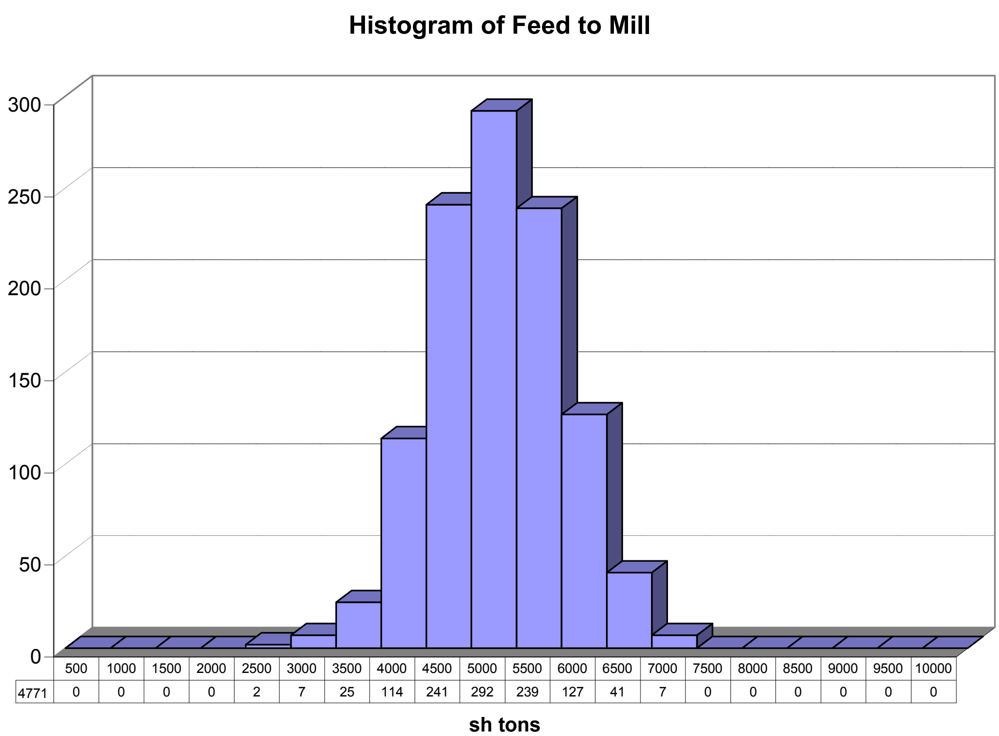


• Figure 6.21 – Throughput Histogram of the Refinery (Tank house Lean initiative)

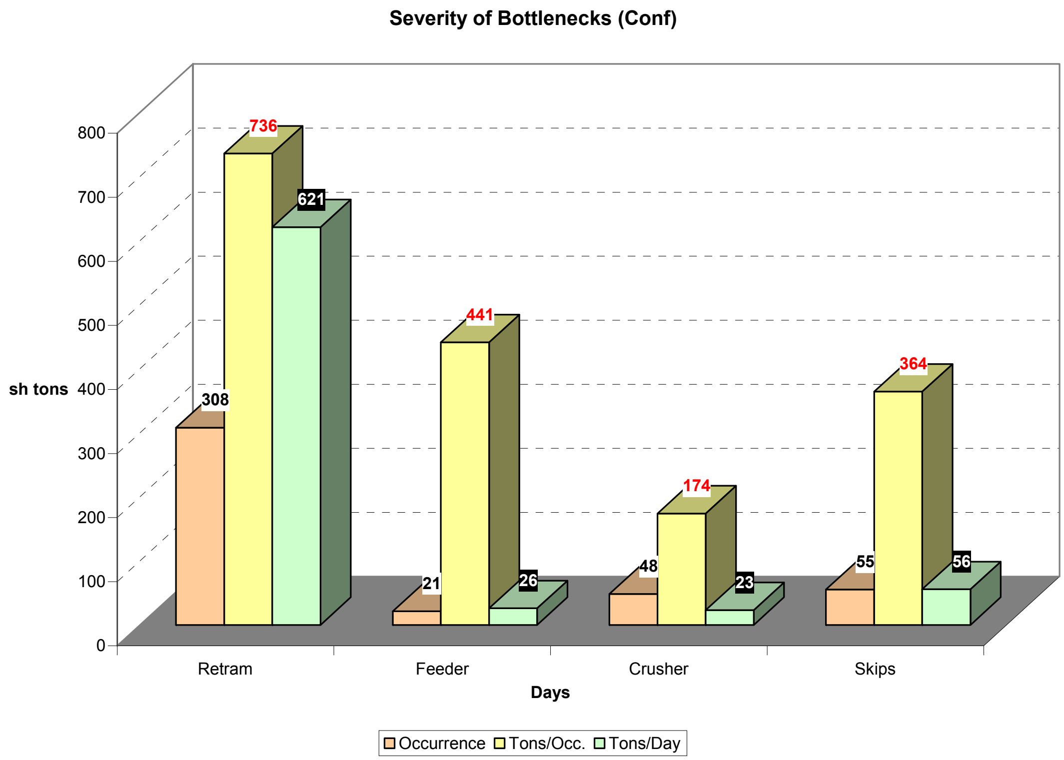
Thus, it is concluded that the tool developed in this research can be used for lean optimization (identification of waste capacity).

6.6 Case Study 5 – Un-Localized Optimization

This case study was conducted to illustrate the fact that in an integrated mining operation, an initiative must be judged on the merit of producing an optimized outcome for the whole operation. This cases study was conducted at a Vale Inco integrated mining operation with a scope enveloping mine, mill and smelter facilities. The initiative was to increase the bottleneck capacity identified in Case Study 1 i.e. the capacity of Tram process. Thus, for this case study, the capacity of Tram was increased by 10% and the mine model was re-simulated. The outputs for mine throughput and the bottleneck severity were captured as displayed in Figure 6.22 and Figure 6.23 respectively.

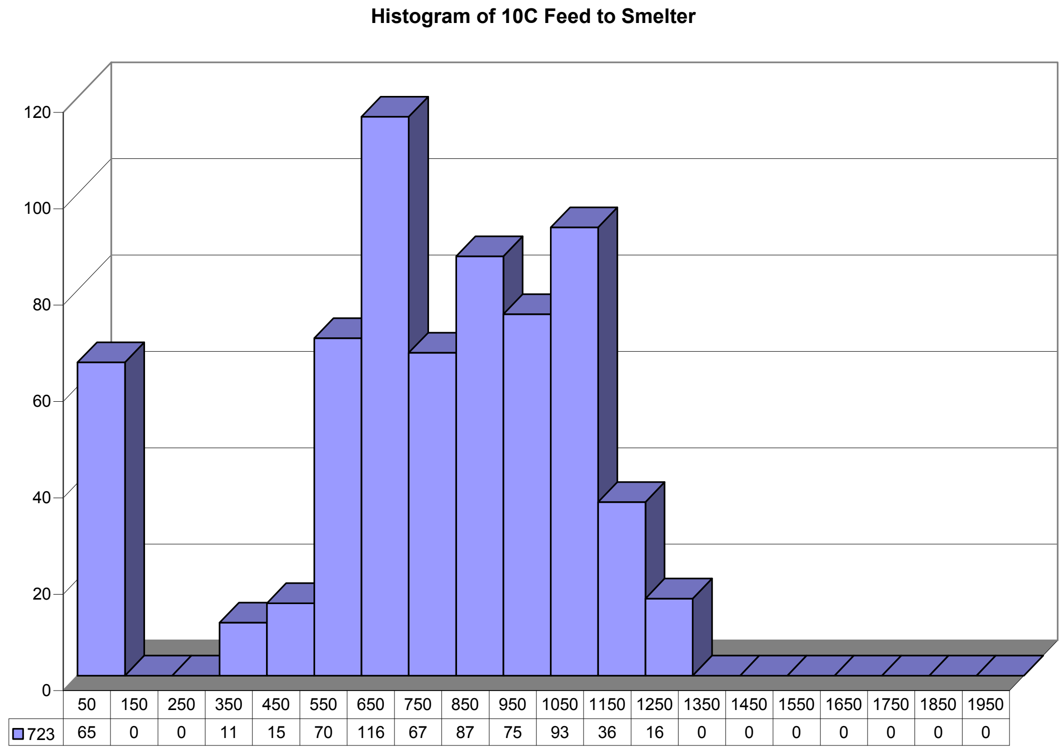


• Figure 6.22 – Throughput Histogram of Mine (Tram initiative)



• Figure 6.23 – Severity of bottlenecks within the mine (Tram initiative)

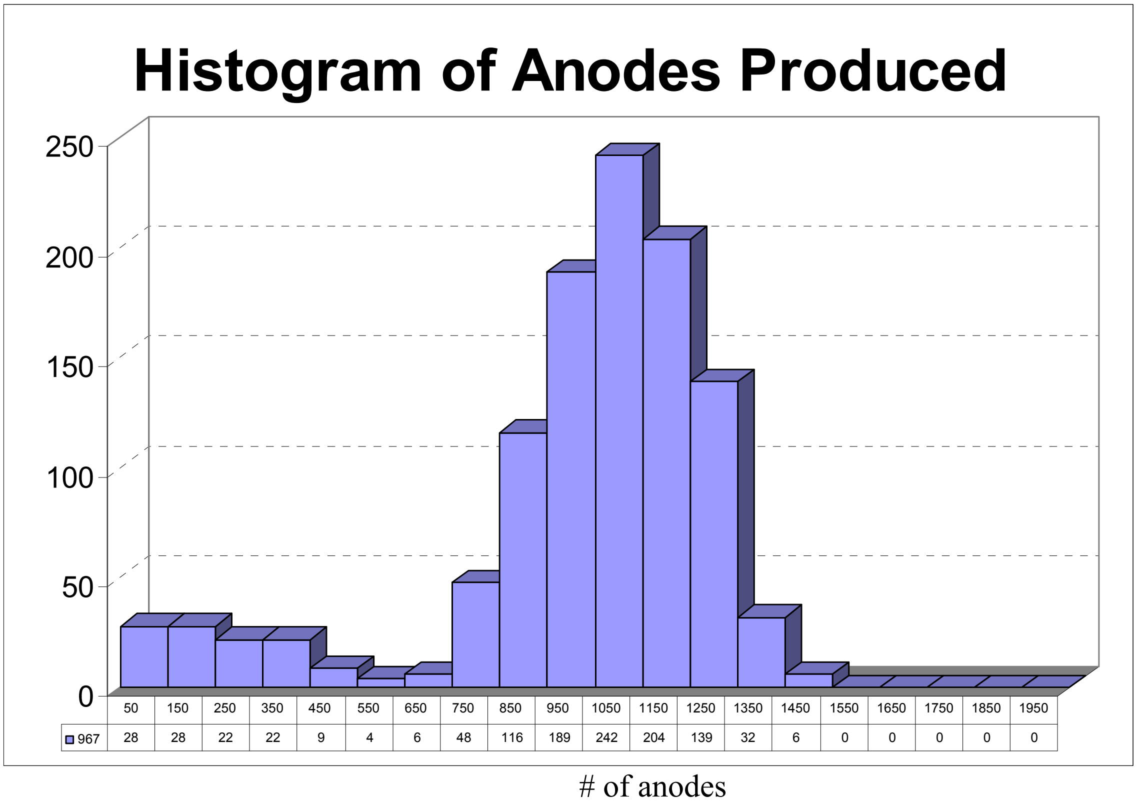
Comparing throughputs from Figure6.2 and Figure 6.22, it is concluded that this initiative for increasing the tram (mine bottleneck) will increase the throughput of mine by approx. 100 sh. tons per day which in monetary terms will equate to $32000 per day at a price of $8/lb and a grade of 2%. A very solid business case if the mine was a business by itself. But at this Vale Inco's mining operation, the mine ore throughput is fed to the mill which in turn feeds concentrate to the smelter. So, the next step is to examine how the throughput of the mill is affected by this increase in mine throughput. The increased mine throughput distribution was modified into the mill model and then the mill throughput results were captured as shown in Figure 6.24.



sh. tons

• Figure 6.24 – Throughput Histogram of the Mill (Tram initiative)

Comparing this to the base case mill throughput as illustrated in Figure 6.12 under Case Study 3; it can be concluded that the increase in Tram capacity of 10% would increase the mill concentrate throughput by approx. 8 sh. tons with a monetary value of $19200 per day at a price of $8/lb and a concentrate grade of 15%. That is about a decrease of 40% in business case return. In other words, 40% of the mine throughput increased through the Tram initiative is lost in the mill bottlenecks. However, it is still a good business case if the mine & mill was the business by itself. Next step was to modify this concentrate throughput increase into the Smelter model. The smelter model was re-simulated with the modification of mill throughput increase and the smelter throughput output was captured as illustrated in Figure 6.25.

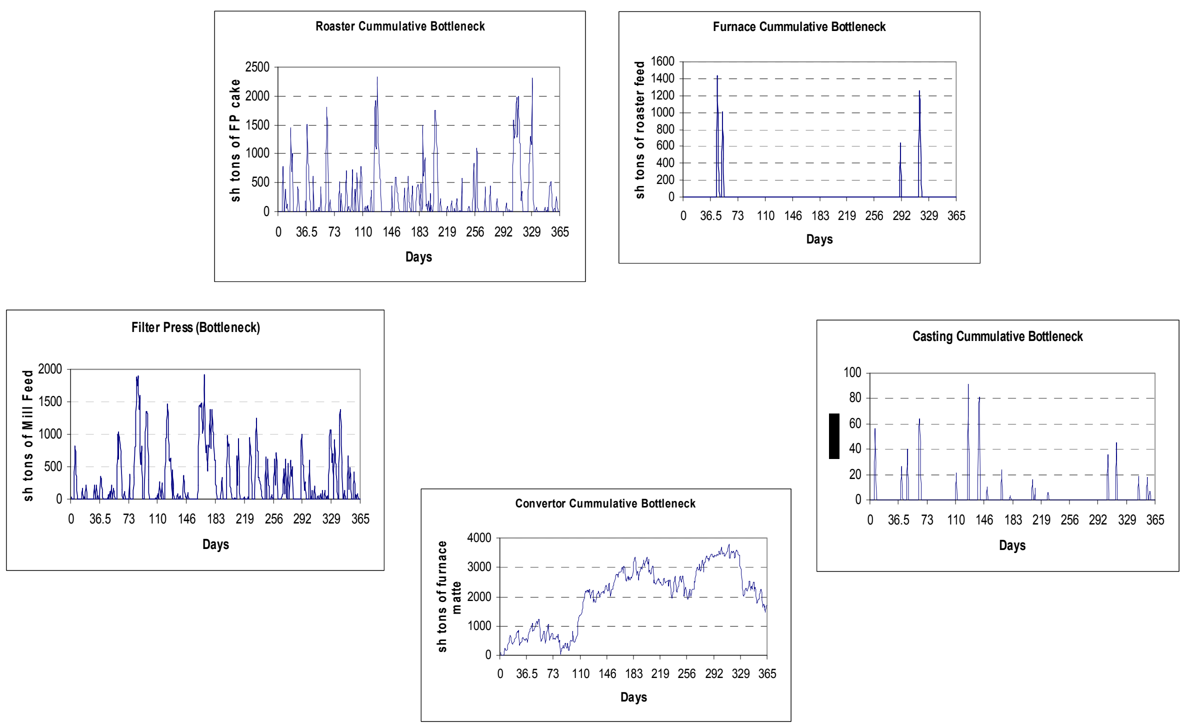


• Figure 6.25 – Throughput Histogram of the Smelter (Tram initiative)

Comparing this result to the smelter base throughput result in Figure 6.7, it can be observed that the throughput remained unchanged. In other words, the increase in mill throughput caused by Tram initiative was completely constrained by the smelter bottlenecks. The lesson learned through this case study is that a business case should not only look at the local optimization but at the end of the system optimization. Hence, this model through the identification of bottlenecks and simulation could be utilized as integrated planning tool for evaluating business cases.

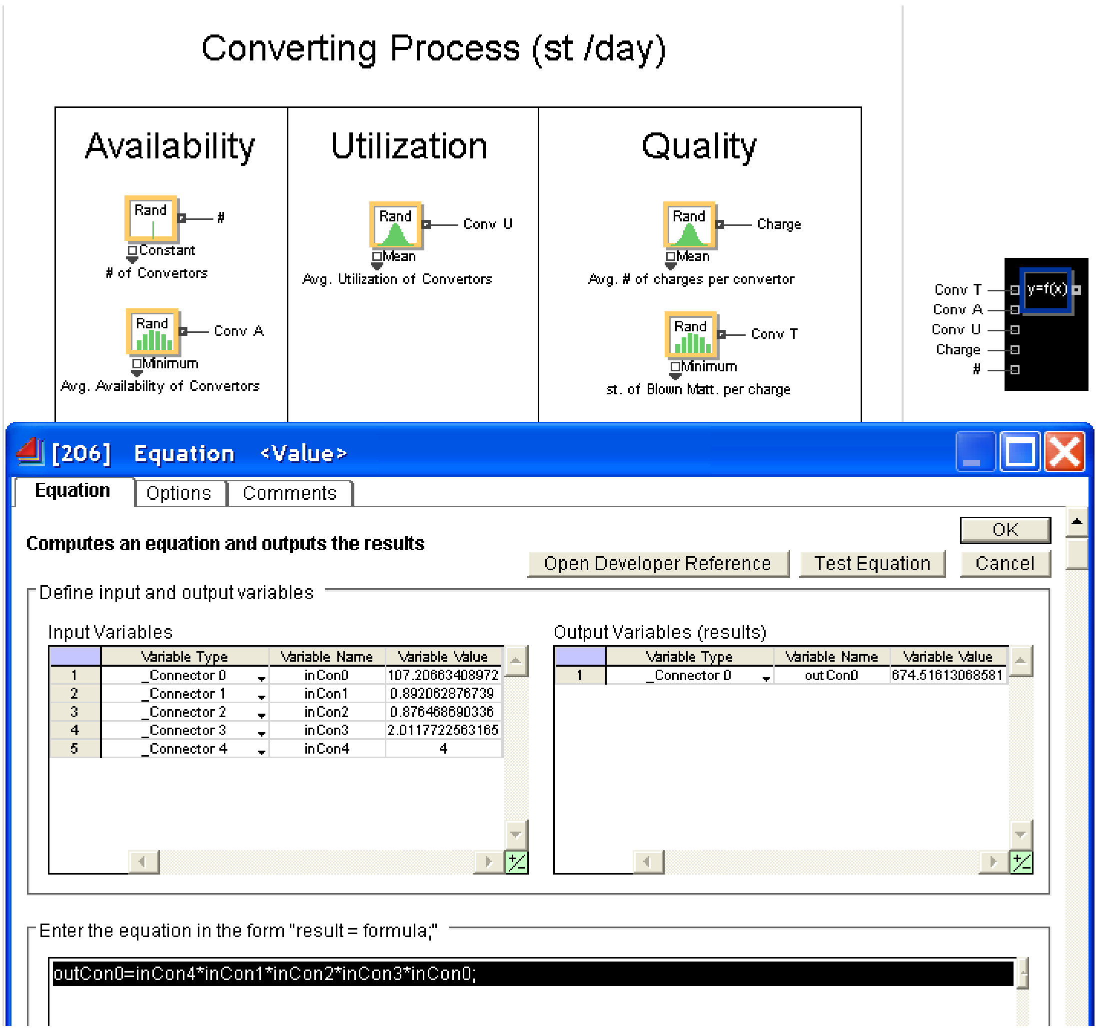
6.7 Case Study 6 – Further Casual Mapping/Modeling

This case study was conducted to achieve one of the objectives of this research; to identify bottleneck area and then further casual map the process and model the constraint to understand the impact of sub-processes/factors within the constrained process. This case study was completed at a Vale Inco Smelter facility as highlighted in Case Study 2. First the base case was simulated and the bottleneck output was captured as in Figure 6.26. From this output, convertor process was identified to be the major bottleneck in the facility.



• Figure 6.26 – Cumulative Bottlenecks within Smelter as identified by the model (Base Case)

The convertor process distribution was further mapped into three categories; availability, utilization, and quality Figure 6.27. Availability was mapped as a product of number of convertors to average availability of convertors. Utilization was mapped as the average utilization of the convertors and the quality was mapped as a product of number of charges per convertor to the sh. tons of material throughput per charge.



• Figure 6.27 – A snapshot of casual mapping of convertor process in ExtendSIM

By further causal mapping of the constraint process (convertor), various scenarios now can be evaluated within the convertor process to optimize the total throughput of the smelter facility. Average number of charge per convertor was identified as the most optimum factor and returned the most improvement out of all individual identified causes in Figure 6.27. Scenarios were evaluated using the methodology described in case study 2.

CHAPTER 7: CONCLUSIONS

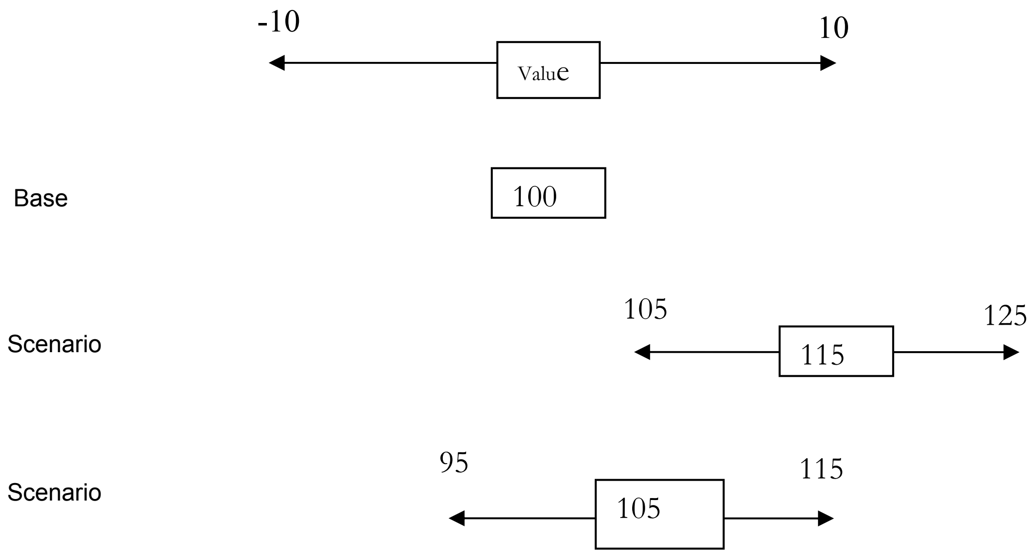
7.1 Overview

In this chapter, summary of the tool, the robustness and the comparison of various business initiatives through the model are provided. Also, the importance of using the proper input data is detailed. Finally, the recommendation and conclusion are also covered.

7.2 Robustness of the Model

This model is simulated using rational stochastic discrete optimization which functions on the basis of Monte Carlo technique. Due to randomness in data through every input, it is essential to simulate a given scenario at least thirty times to lock in the base case model values as the population values. Once the base case is established then using the statistical t-test we can determine the range of values for a given Confidence interval (CI) by which an initiative can be compared and judged to be statistically different or inconclusive. It is important to note here that by definition a t-test can only prove that two given cases are different and not same. If two cases fail to satisfy t-test, it does not mean that they are similar but that there is not enough proof for them to be different.

Let's consider a case with a base throughput value of 100 tons. Through t-test it was determined that for an initiative to be different with CI of 95% the value will have to be ±20 tons. Thus if a initiative shows an improvement of 10 tons or more then t-test will conclude that the initiative has improved the process Figure 7.1.



• Figure 7.1 - An example of Scenario Analysis and Robustness of the model

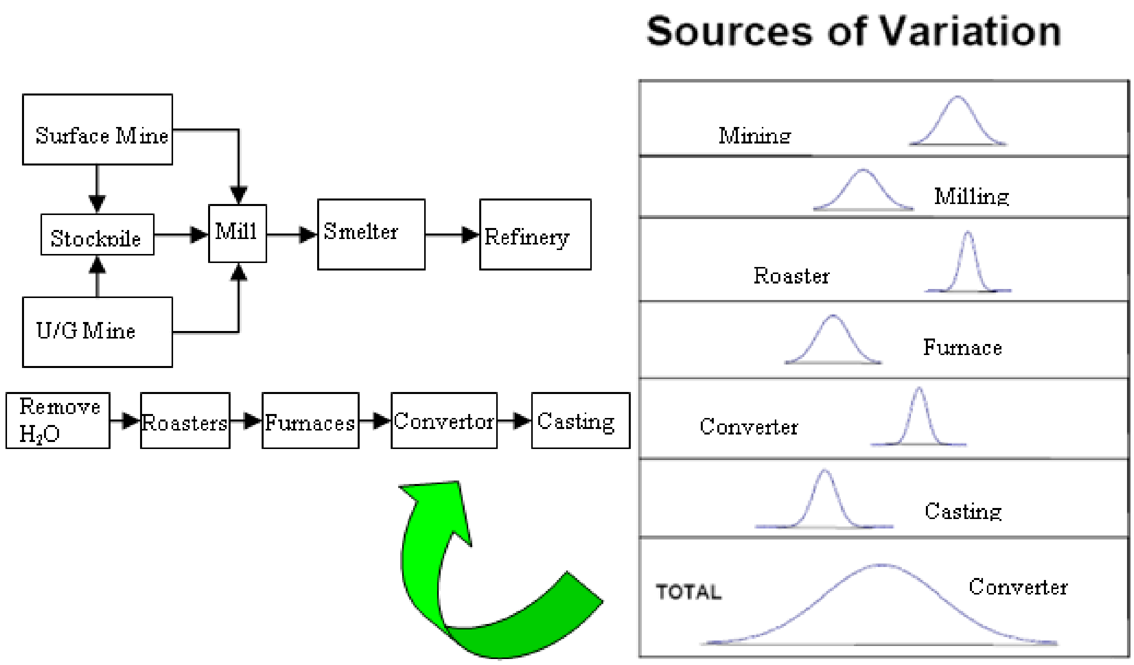
It is very probable for the example depicted in Figure 7.1 that scenario 1 yields a positive impact, as even the minimum value is greater than 10 units off the base case. Although, the generated value of scenario 2 (105) is greater than of the base (100), the overlap is significant and therefore statistically insignificant. In other words, the return in the improvement is unsure.

7.3 Data Analysis

It is important for this tool to function effectively that the data entered in this model for the process capacities is filtered properly and is not just actual historical data. Filtering of data for a given process is essential as the historical data is actually affected by the variation in processes before and after the given process as depicted in Figure 7.2.

If data is entered into the model with built-in variation then the model will execute the flow through the each process using built-in variation. Each individual process would behave with a spread out throughput distribution resulting in total flow being affected over and over as the flow is simulated through each process.

Filtering of data can be conducted by creating a database of all shutdown and production reductions in a given operation and then conducting a Pareto Analysis. If the database is not available and time is of the essence then same information can be obtained through informal discussion with the given process experts.



• Figure 7.2 – Filtering of Data: an illustration of before & after variation affecting actual performance of a process.

In Figure 7.2, the variation of captured historical production data of a convertor is showed. This convertor process is located in a sequence of processes inside a smelter facility. The historical production data for convertor will show the variation not only cause by convertor process but all processes before and after it i.e. sum of variation caused by mining, milling, dewatering, roasting, melting, casting, and refining processes. If this accumulated variation is entered in the model instead of actual process variation then the results of the model will be much skewed to the low side and will not show the actual picture of the bottlenecks.

Data Analysis stage in building of a throughput model takes the most time and effort. Data such as tonnage, flow, capacity and delays are observed through a live system such as PI. Then, the data is analyzed and tagged for actual minimums. Next, distributions are filter using tagged processes and then data is reanalyzed to create new throughput distributions.

7.4 Conclusions

- An optimization tool has been developed and tested
- The objective proposed to develop and test an integrated optimization tool for a complex integrated mining operation has been achieved
- Results were validated and field tested at multiple Vale Mine Operations
- Integration Optimization Tool developed in this research has been adopted and is being used by Vale Base Metals to optimize and evaluate large capital expenditures

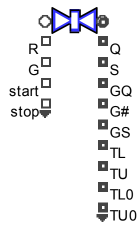
7.5 Recommendations for Further Research

There were six unique cases for utilization of this tool to conduct proper optimizations which were tested at four integrated mining facilities; mine, mill, smelter and refinery.
This research revealed the following areas in bottleneck discrete rate simulation modeling that needs to be studied further.

Through the field testing of the tool, it was observed that though the model is exceptional in identifying the bottlenecks and capturing the severity of these constraints, it does not magnify the severity of the lost capacities of the processes which are being constrained by the bottleneck. The use of this advantage of capturing this information should be further researched.

Exporting of the data from the model causes a significant waste in an analyst's time. Further investigation and researched is needed into advanced programming of a direct entry from a model into an external database.

APPENDIX A – EXTENDSIM VALVE BLOCK

Symbol: 

Purpose:

Controls, monitors, and transfers flow. This block places an upper bound on the rate at which flow is allowed to pass through. The block's maximum rate can be controlled by the Maximum rate field on the Valve tab, the R input, or the Goal and Hysteresis options found on the Flow Control tab.

Connecters:

Value input connectors: (Listed in the order they appear on the connector.)

R: Maximum rate. This overrides the Maximum rate field in the dialog.

G: Goal. This connector is used to specify the size of a new goal (either in terms of flow volume or units of time). In some configurations it can also be used to start a new goal.

start: This connector is used to start hysteresis and under some configuration goals as well.

stop: This connector is used to stop hysteresis.

Value output connectors: (Listed in the order they appear on the connector.)

Q: The cumulative quantity of flow that has passed through this block.

S: Valve status. The status of the Valve can cycle between any of the following four states: limiting (0), starved (1), blocked (2), starved & blocked (4). If the checkbox "Valve animates and reports blocking and starving information" found in the Executive on the Discrete Rate tab has been checked, this field reports all four states. However, if the checkbox is unchecked, only the limiting (0) and non-limiting (1) states are reported.

GQ/GD: This connector reports the amount of progress that has been made towards a goal in terms of flow quantity or time depending on whether a quantity goaled or duration goal has been selected.

G#: This result reports the number of goals the block has pursued. For example, if the Valve has completed 2 goals and is currently in the middle of a third, the number reported is 3.

GS: Goal status reports: none (0), start (1), in progress (2), end (3), interrupt (4).

TL: Time limiting reports the amount of simulation time this block spent limiting the effective rate of flow.

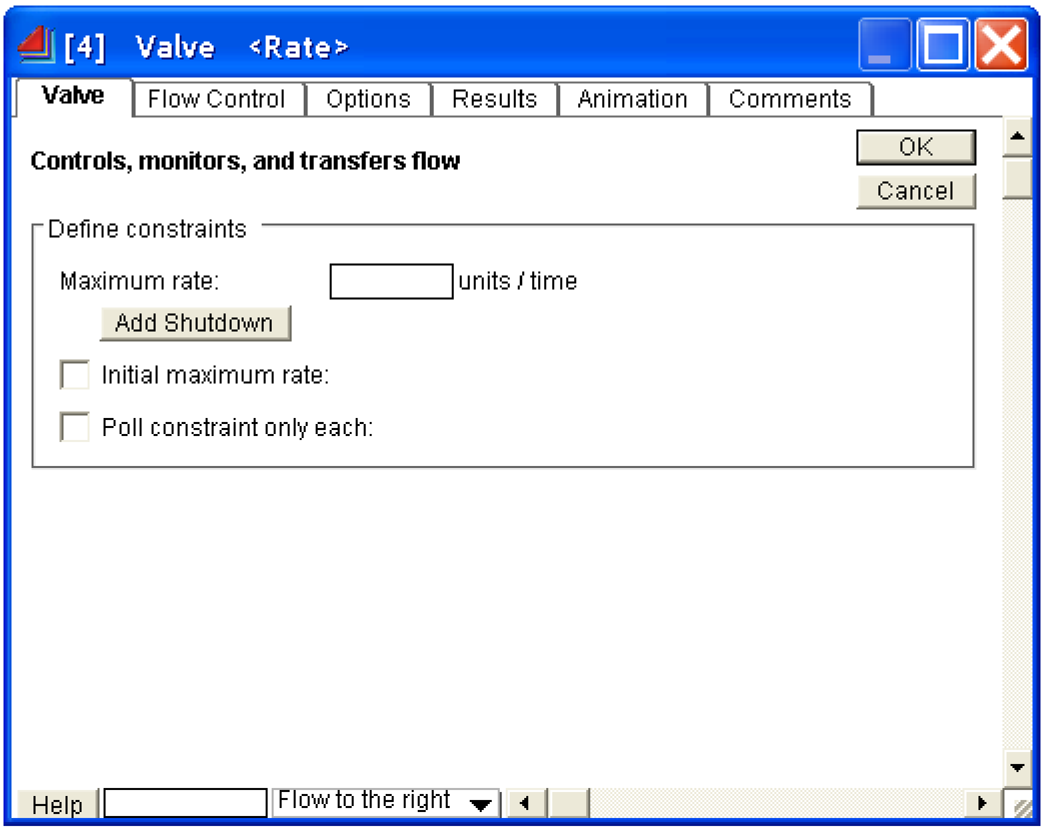
TU: Time unlimiting reports the amount of simulation time this block spent not limiting the effective rate of flow.

TLO: Time limiting zero reports the amount of simulation time this Valve blocked flow while being shutdown.

TUO: Time unlimiting zero reports the amount of simulation time this Valve did not block flow while being shutdown.

Tabs:

Valve Tab



Maximum rate: The current maximum rate is displayed here as the maximum number of flow units per time which can flow in this section of the model.

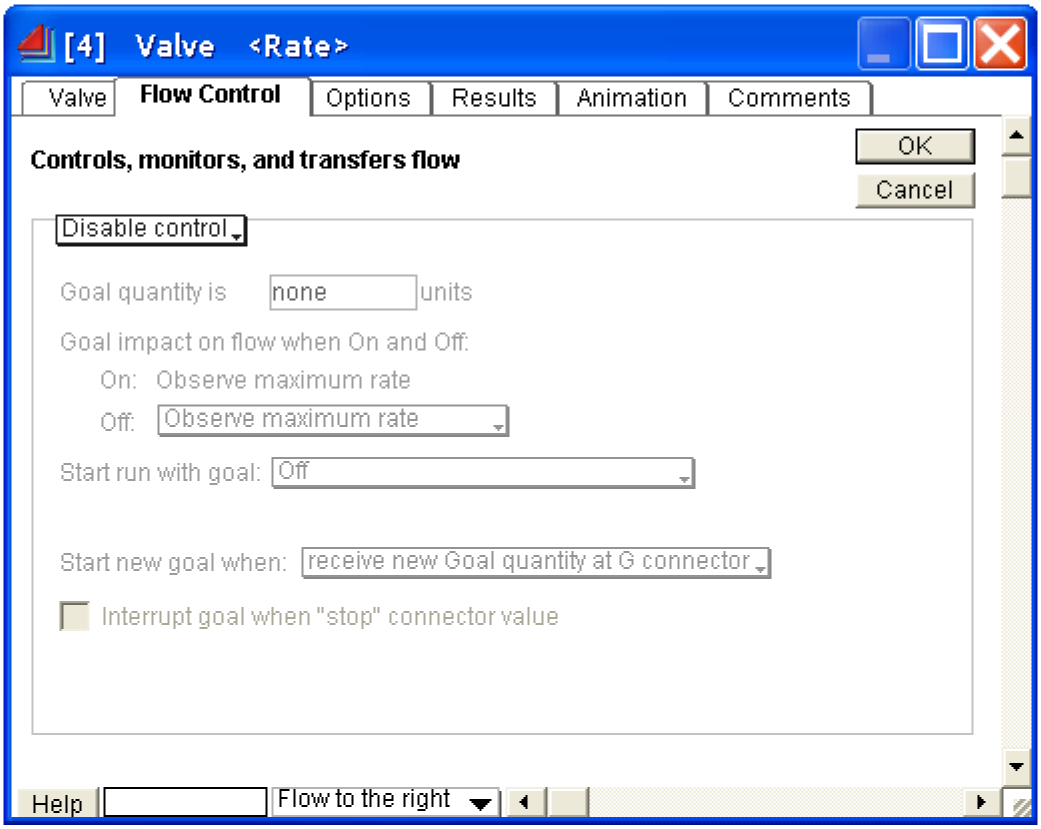
Maximum rate at R: If the R connector is connected, the maximum rate field will have this title.

Add Shutdown: Clicking this button causes a Shutdown block to be added to your model and automatically connected to the R connector.

Initial maximum rate: The initial maximum rate the Valve will have at the start of the simulation. This feature is useful if the R connector is connected.

Poll constraint only each: When this option is turned on, the Valve will query the block connected to its R connector for a new value at fixed intervals. If the Maximum rate changes between two intervals the new maximum rate will be taken into account only at the end of the interval. This option is useful when the R input is connected to a passive block like the Random number block.

Flow Control Tab



Disable control: This popup option turns off flow control.

Goal: There are two types of goals: quantity and duration. Irrespective of which type is chosen, a Valve's maximum rate is observed while the goal is On. While the goal is off, you have the option to choose whether the maximum rate is observed or ignored (i.e., the maximum rate is set to infinity). A duration goal switches states by monitoring the passage of time. A quantity goal switches states by monitoring the quantity of flow that has passed through. When a legitimate value is received at the start connector, the goal switches to On and remains that way until the goal has been achieved or interrupted.

Goal quantity: With this option chosen, specify a fixed goal quantity that does not change during the simulation run.

Goal quantity at G: If the G connector is connected, the Goal quantity field will have this title. The value at the G connector is used to specify the goal quantity and may change during the simulation run.

Goal duration: With this option chosen, specify a fixed goal duration that does not change during the simulation run.

Goal duration at G: If the G connector is connected, the Goal duration field will have this title. The value at the G connector is used to specify the goal duration and may change during the simulation run.

Goal impact on flow when off: There are three options that control how the Valve behaves when the goal is off. Stop flow shuts the valve down. Ignore maximum rate sets the maximum rate to infinity, thereby removing any influence the Valve can have on the movement of flow. Observe maximum rate uses the rate specified on the Valve tab to limit the flow.

Start Run with goal: Three options are available for controlling how the goal is initialized at the beginning of each run. Off specifies that the goal is off at the start of the simulation. On specifies that the goal is on at the beginning of the simulation. If the Start new goal when start connector value and the Start run with goal defined by "start" connector value options have both been selected, then the start connector value at the beginning of the run determines Valve's initial on/off goal status. On the other hand, if the Start new goal when receive new goal at G connector and the Start run with goal defined by G connector value options have been both selected, then the G connector value at the beginning of the run determines Valve's initial on/off goal status (the goal is on if G connector value is greater than 0 and not BLANK).

Initial goal quantity or Initial goal duration appears only if the option Start Run with goal on or Start Run with goal defined by "start" connector value are selected. If this checkbox is checked, a field appears allowing you to specify an initial goal at the start of the simulation, this number has to be greater than 0.

Start new goal when: Three options are available for controlling how a new goal is initiated. Start connector value allows you to define which values at the start connector will be used to start a new goal. Note in order to start a new goal with this option, not only does the start connector have to have a legitimate start value, but a message must also be received at the start connector. Receive new goal at G connector will start a new goal when a message is received. Previous goal finishes initiates a new goal as soon as the previous one has finished.

Interrupt goal when "stop" connector value: With this optional checkbox, the current goal may be interrupted if a legitimate stop value and associated message are received at the stop connector.

If a new goal arrives before the previous one is finished: There are four options available for handling the arrival of a new goal before the current goal has completed. Ignore new goal ignores any new goal that may arrive while the block is currently pursuing an existing goal. Start over using new goal will start a new goal by interrupting the current one. Continue progress using new goal use the progress that has been made towards the current goal and apply it to the new goal that has arrived prematurely. For example, if progress of 50 flow units has been made towards the current goal and a new goal of 75 arrives, then only 25 more flow units will need to be passed through before this new goal has been achieved. Use new goal after the previous goal has finished will finish up the current goal and remember the new goal was submitted prematurely.

Hysteresis: Hysteresis is a property of systems that causes them to not react instantly to a change. The purpose of adding hysteresis in a model is to introduce a delay in the time it takes some part of the system to switch from one state to another. Hysteresis allows you to insert a lag or delay in a Valve's response to system requirements. It is used to avoid oscillations or "system nervousness" in order to achieve better control over flow movement. This is accomplished by using model conditions to explicitly control both when a Valve's maximum rate is observed and when it is ignored. Unlike the quantity and duration goals where the conditions for applying the Valve's maximum rate are entered in the dialog, hysteresis must always get its control information from outside the block through the start and stop connectors. The hysteresis option always relies on the Valve's start input to control when the Valve's maximum rate will be observed and its stop input to control when the maximum rate will be ignored. When the maximum rate is ignored, the Valve's dialog provides a popup menu for choosing if the flow stops or if the Valve does not constrain the flow.

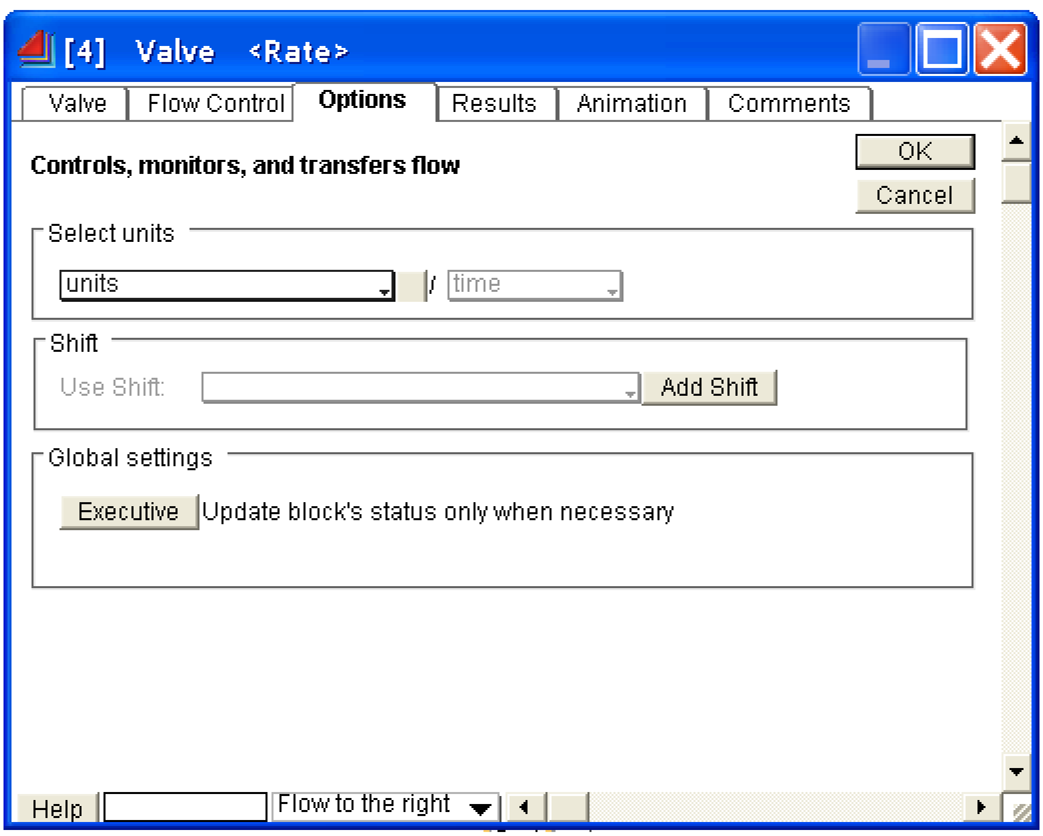
Observe Maximum rate when "start" connector: This field allows you to specify the conditions under which the start connector will cause the Maximum rate to be observed.

Ignore Maximum rate when "stop" connector: This field allows you to specify the conditions under which the stop connector will cause something other than the Maximum rate to be observed.

When Ignoring: There are two actions that can be taken when hysteresis is in the ignoring state; the flow may be stopped, or the maximum rate may be ignored (i.e., the maximum rate is unbounded).

Start run with hysteresis: Three options are available for controlling if the Hysteresis is ignored or observed at the beginning of the run. Ignored the hysteresis is ignored when the simulation starts. Observed the hysteresis is observed when the simulation starts. Defined by "start" connector value at the start of the simulation, the hysteresis ignored or observed depends on the value at the start connector.

Options Tab



Select units: In the "Select units" frame, the first popup allows the user to choose the flow units for all the blocks residing in this block's unit group by either selecting an existing flow unit category or by creating a new one. A unit group is a collection of blocks connected together through flow connections and sharing the same flow unit. Notice that once you've made your selection, not only will the "flow units / time unit" for the Maximum rate field on the Valve tab reflect that change, but the flow units for all blocks in this unit group will have changed as well. When the square button to the right of this popup menu is pressed, all blocks included within this block's unit group are selected. The second popup allows the user to define the time units for this particular Valve block.

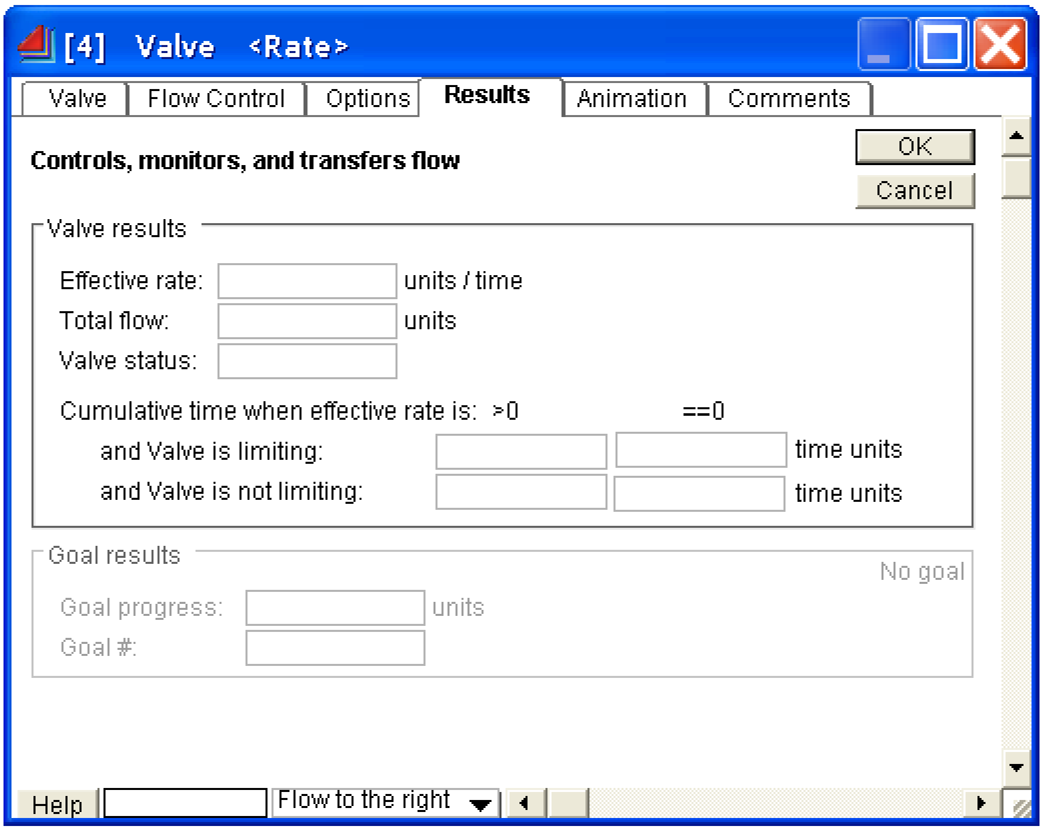
Use Shift: The popup menu in this frame allows you to select from a list of existing shift blocks to control the Maximum rate to be 0 when the shift is off. If the selected shift is an On/Off shift, the Valve will shut down when off shift and come back online with the original value in the Maximum rate field when the shift is On. Blocks from the Rate library are not compatible with Numeric shifts.

Add Shift: This button allows you to automatically add Shift blocks to the model.

Executive: This button will open the Executive block to the Discrete Rate tab where you can define how often Rate blocks in the model update their status. For more information on this feature, please consult the Executive's help text.

Update animation and results at each event: This checkbox allows you to update the block's icon animation at every event during the model run. In order for this checkbox to be enabled, the Blocks update flow status: each block defines how often setting must be selected on the Discrete Rate table in the Executive.

Results Tab



Effective rate: The current effective rate at which flow is moving through the block.

Total flow: The total amount of flow having passed through the block.

Valve status: The status of the Valve can cycle between any of the following four states: limiting (0), starved (1), blocked (2), starved & blocked (4). If the checkbox "Valve animates and reports blocking and starving information" found in the Executive on the

Discrete Rate tab has been checked, this field reports all four states. However, if the checkbox is unchecked, only the limiting (0) and non-limiting (1) states are reported.

Cumulative time when effective rate is > 0 and Valve is limiting: The total amount of time during which flow passed through and the Valve was limiting the effective rate.

Cumulative time when effective rate is > 0 and Valve is not limiting: The total amount of time during which flow passed through and the Valve was not limiting the effective rate.

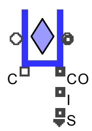
Cumulative time when effective rate is = 0 and Valve is limiting: The total amount of time during which flow did not pass through because the Valve's Maximum rate was set to zero.

Cumulative time when effective rate is = 0 and Valve is not limiting: The total amount of time during which flow did not pass through even though the Valve's Maximum rate was not set to zero.

Goal progress: This result reports the amount of progress that has been made towards a goal in terms of amount of flow for a quantity goal and amount of time for a duration goal.

Goal #: This result reports the number of goals the block has pursued. For example, if the Valve has completed 2 goals and is currently in the middle of a third, the number reported is 3.

APPENDIX B – EXTENDSIM TANK BLOCK

Symbol: 

Purpose:

Acts as source, intermediate storage, or sink. As a residence type block the Tank has the capacity to hold defined amounts of flow as time advances. Contents may be 1) received from an upstream source of flow or 2) an initial quantity in the tank. If a Tank has no outflow connection, by definition it is being used as a sink. Conversely, if a tank has no inflow connection, by definition it is being used as a source.

Connecters:

Value input connectors:

C: Capacity. This overrides the Capacity field on the Tank tab.

Value output connectors: (Listed in the order they appear on the connector.)

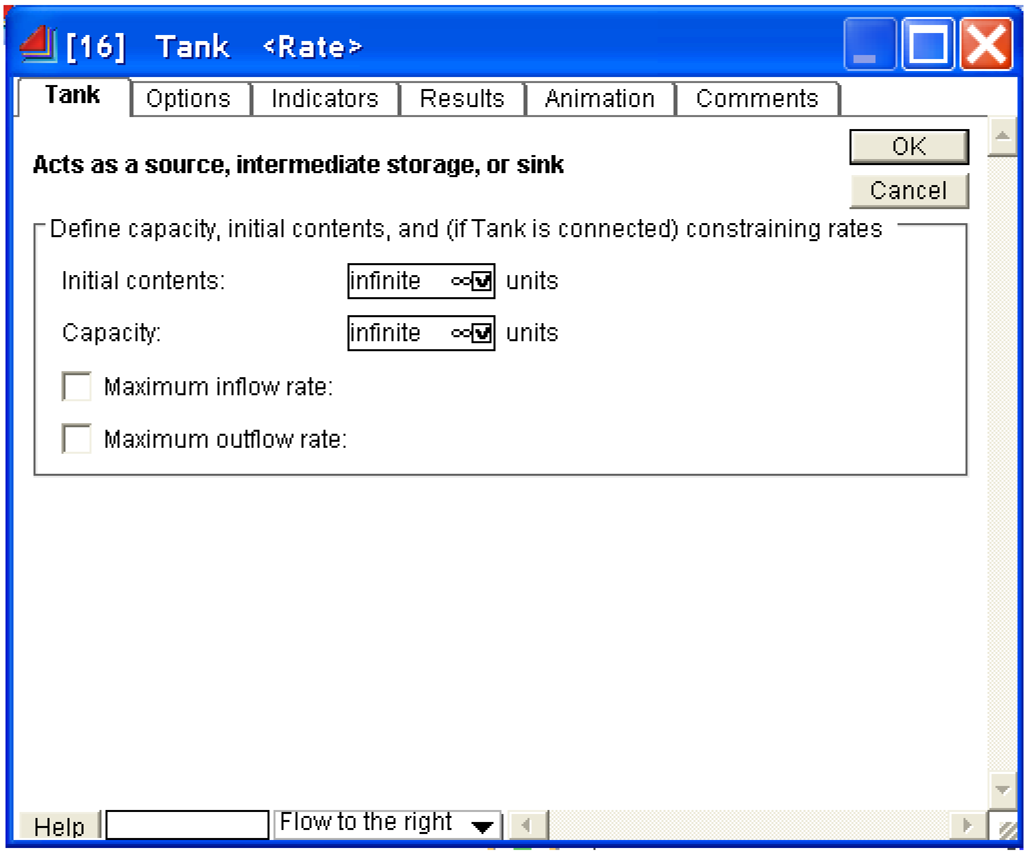
CO: Contents; Reports the current flow level.

I: Indicator; Reports the current indicator level as defined by the table on the Indicator tab.

S: Status. Reports whether the level of flow in the Tank is currently going up (1), stable (0), or down (-1).

Tabs:

Tank Tab



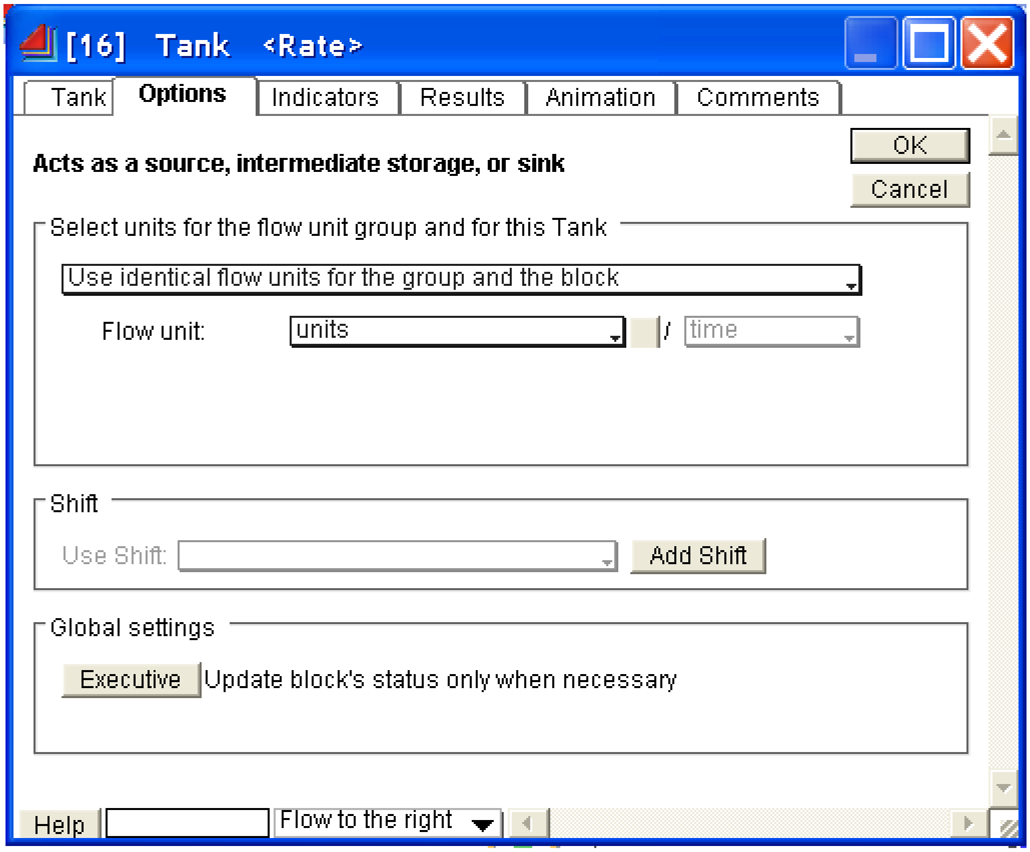
Initial contents: This field allows you to initialize the starting contents of the tank to the desired flow level. There is the option to set this field to infinity. Note: if Initial contents are set to infinity, Capacity is automatically set to infinity also.

Capacity: This field allows you to set the tank's capacity for holding flow. A Tank's capacity can be infinite, a finite but non-zero number, or zero. If the tank's contents exceed capacity (can be the case when capacity is changed dynamically) the tank will not receive any new product until the flow level falls below capacity.

Maximum inflow rate: This option allows you to set an upper limit on the maximum inflow rate. Its behavior is similar to placing a Valve block upstream of the inflow connector. Using this feature is optional.

Maximum outflow rate: This option allows you to set an upper limit on the maximum outflow rate. Its behavior is similar to placing a Valve block downstream of the outflow connector. Using this feature is optional.

Options Tab



Use identical flow units for the group and the block: With this option chosen, there is no difference between the flow and block units.

Define a flow unit for the group and a block unit for the block: With this option chosen, flow units are different from block units as defined by the Unit factor field. Block units are used to calculate the level of flow, capacity, indicators, etc. For example, if flow units are defined as boxes and block units as tons, the inflow and outflow will be expressed in boxes and the capacity and contents for the tank will express in tons.

Flow unit: The first popup menu in this field allows the user to choose the flow units for all the blocks residing in this block's unit group by either selecting an existing flow unit category or by creating a new one. A unit group is a collection of blocks connected together through flow connections and sharing the same flow unit. Notice that once you've made your selection here, the flow units for all blocks in this unit group will have changed. When the square button to the right of this popup menu is pressed, all blocks included within this block's unit group are selected. The second popup menu in this field allows the user to define the time units for this particular Tank block.

Block unit: This popup menu allows you to change the block units for this Tank. Block units are an internal unit of volume specific to the Tank. If you desire a block unit that differs from the flow units that come into and out of this block, you must enter a unit factor. The unit factor represents the ratio of the block unit to the flow unit. This internal representation of volume is specific to this Tank only.

Unit factor: This is the field where the conversion factor between flow and block units is defined.

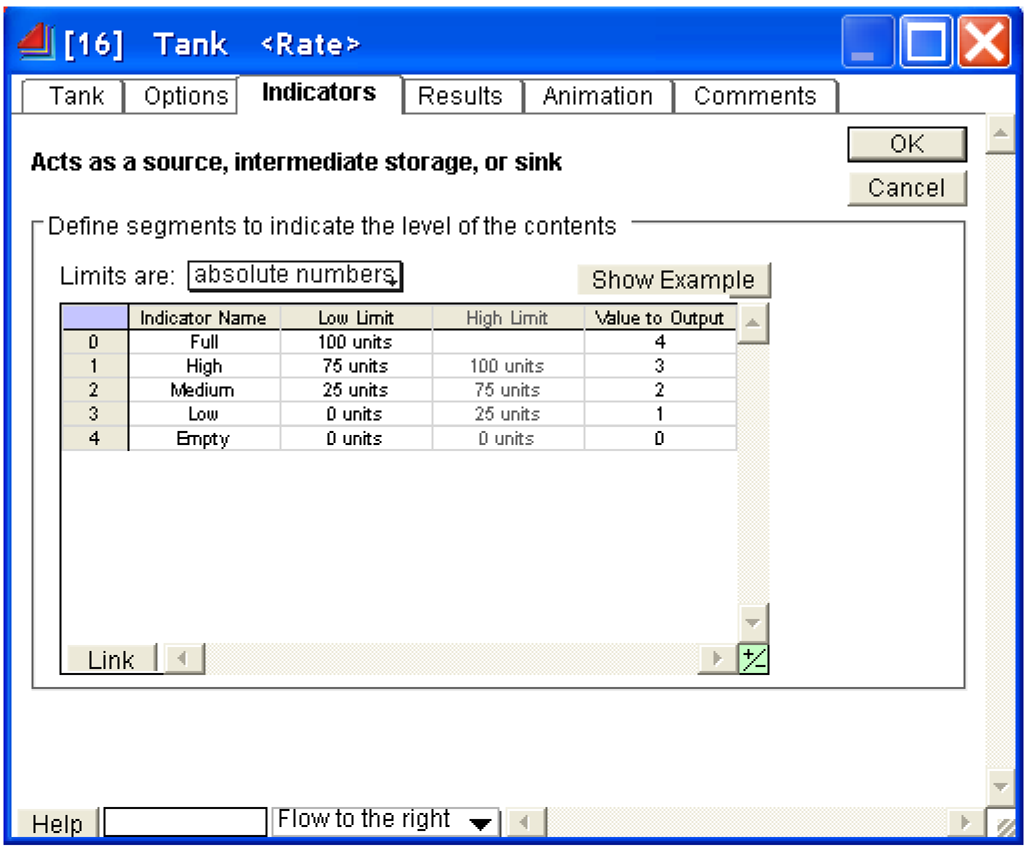
Use Shift: The popup menu in this frame allows you to select from a list of existing shift blocks to control the Maximum inflow rate and Maximum outflow rate to be 0 when the shift is off. If the selected shift is an On/Off shift, flow will not be allowed to either enter or exit the block while the shift is off. Blocks from the Rate library are not compatible with Numeric shifts.

Add Shift: This button allows you to automatically add Shift blocks to the model.

Executive: This button will open the Executive block to the Discrete Rate tab where you can define how often Rate blocks in the model update their status. For more information on this feature, please consult the Executive's help text.

Update animation and results at each event: This checkbox allows you to update the block's icon animation at every event during the model run. In order for this checkbox to be enabled, the Blocks update flow status: each block defines how often setting must be selected on the Discrete Rate table in the Executive.

Indicators Tab



As the simulation runs, the level of flow in the Tank will vary over time. You might want an indication when the flow level is within a certain range of values. This is common when monitoring the tank to determine if its contents are approaching or have reached one or more important benchmarks. For instance, some emergency procedures might need to take place if a Tank's level reaches the "high" range; they can be discontinued when the contents return to a “normal” range. Indicators are a method of reporting what category or range the current level of flow falls into. With this feature, each range is assigned a name, a lower limit, and an upper limit. When the level of flow reaches a value that falls within a different range, the block reports the change on its I (indicator) value output connector and alerts any connected blocks to the change in status.

Limits are absolute numbers: The numbers you type in the "Low Limit" column (the second column) will be interpreted as absolute numbers.

Limits are percentages: The numbers you type in the "Low Limit" column (the second column) will be interpreted as percentages.

Show Example: This button will fill out the Indicators table with an example of a typical set of indicators Note, the levels defined in the table must be placed in descending order, that is, the first level in row 0 must be the highest level in the Tank while the last level in the bottom row of the table must be the lowest level in the Tank.

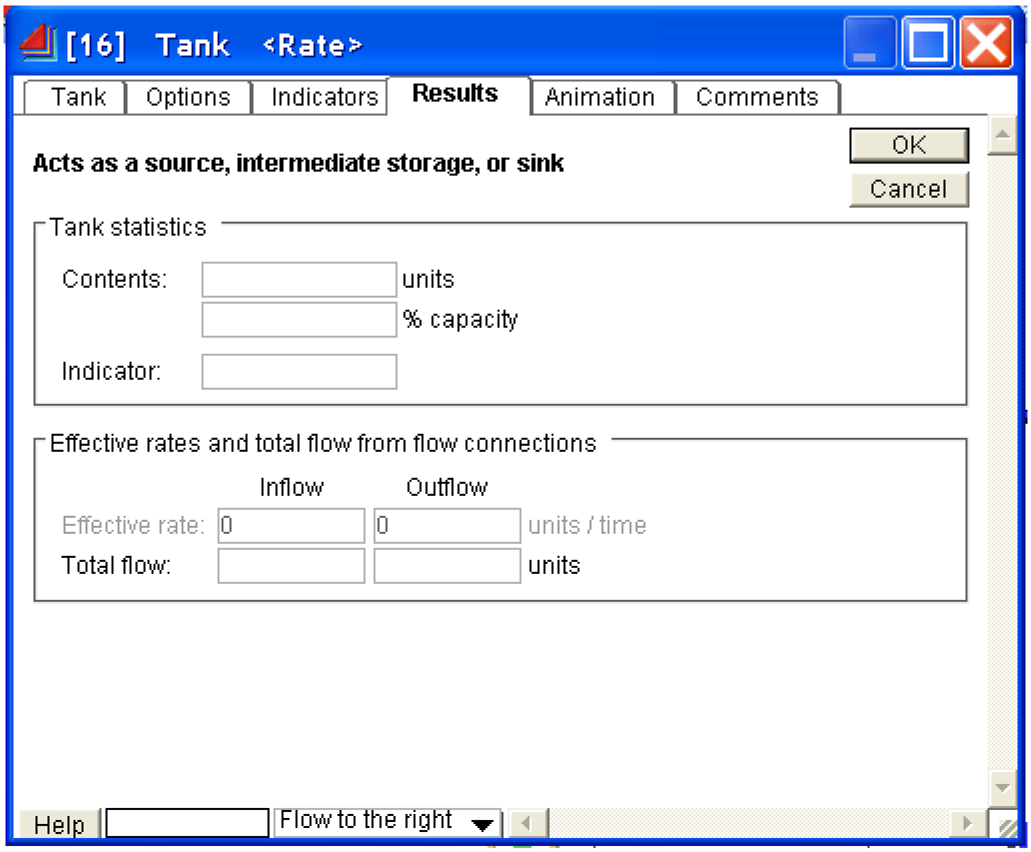
Table column 1 (Indicator Name): This is the column where you give each level a name or label. Again, your levels must be defined in descending order.

Table column 2 (Low limit): This is the column where you type the lower limit for a particular level. Again, your levels must be defined in descending order.

Table column 3 (High Limit): This column is filled for you automatically.

Table column 4 (Value to Output): The numbers in this column are used to report the current level out the I (indicator) connectors.

Results Tab



Contents (units): Reports the current flow level.

Contents (% capacity): Reports the percentage of capacity occupied by the current level of flow.

Indicator: If Indicators are being used, this field reports which indicator the level of flow currently occupies.

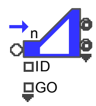
Effective Rate (Inflow): Reports the current inflow effective rate.

Effective Rate (Outflow): Reports the current outflow effective rate.

Total flow (Inflow): Reports the total amount of flow that has entered this Tank.

Total flow (Outflow): Reports the total amount of flow that has exited this Tank.

APPENDIX C – EXTENDSIM DIVERGE BLOCK

Symbol: 

Purpose:

Distributes the input flow to two or more outputs. The systems modeled using discrete rate technology frequently have one flow stream that needs to be split (or diverged) into multiple streams (referred to as branches). The Diverge block has been designed specifically to model this type of routing behavior. It has seven different rule-based options that define how the inflow will be distributed across the outputs.

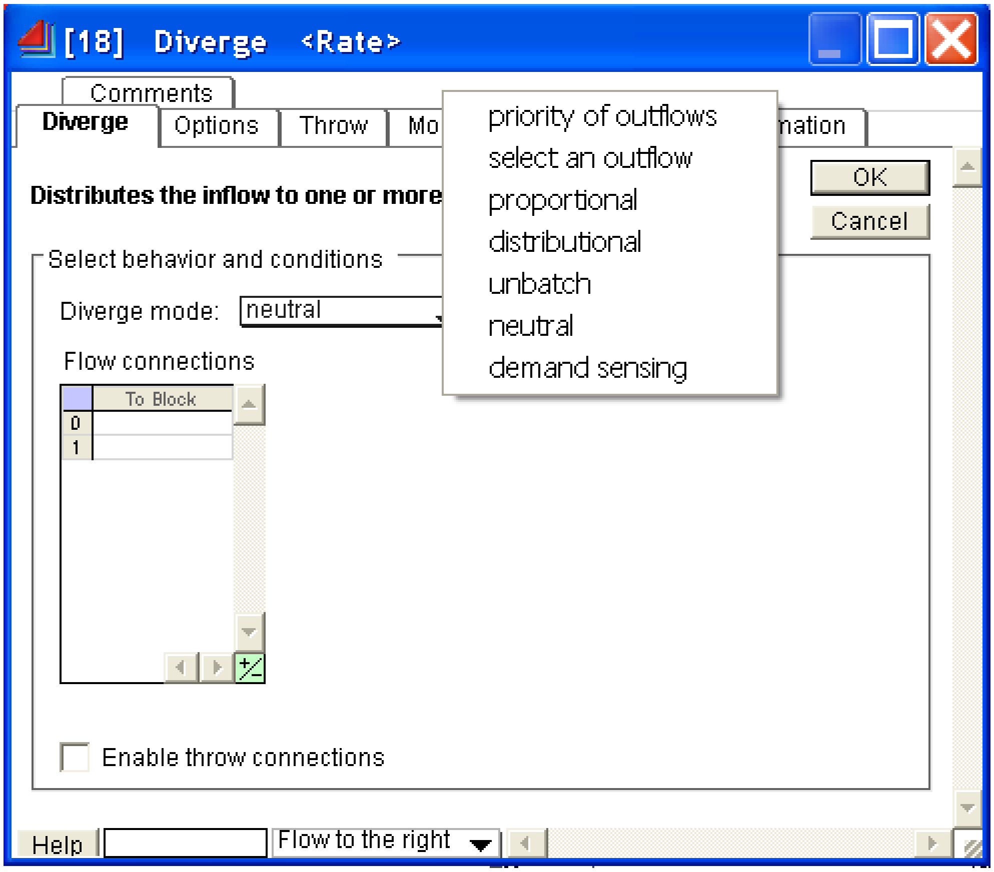
Connecters:

ID: This connector is only used when the Diverge block is in Select an outflow mode to specify which branch should currently be open.

Go: Any dynamic changes to the merge parameters found in the Flow connections table will be ignored until a TRUE value has been received at the GO connector.

Tabs:

Diverge Tab



Diverge mode: This popup menu allows you to select from one of 7 diverge modes.

priority of outflows: The Priority mode allows you to attach priorities to the outflow branches of the Diverge block. Given the maximum rate of flow which can go through the block, the Flow will be directed in preference to the higher priority outflow branches. Note, in Priority mode, if you enter the same Priority number for more than one outflow branch, those specific outflows will behave the same as if they were in Distributional mode with identical proportions. Also note, if the priority for a particular branch has been set to blank, the effective rate for that branch will be zero and flow will stop for that branch.

select an outflow: When the Diverge block is in Select mode, only one selected branch at a time is open. The Flow connections table allows you to assign a unique ID number to each outflow branch (the ID number cannot be blank). The ID connector on the block's icon is then used to select which branch to open. The ID value field displays the current value at the ID connector. The Invalid value at ID popup provides options for handling values at the ID input that don't match any of the branch IDs listed in the table: 1.) Choose top connection, 2.) Choose bottom connection, 3.) Stop flow, 4.) Generate error. A blank value received at the ID connector always stops the flow until the connector receives a valid input.

proportional: With the Proportional mode, you define in the Flow connections table what the proportion of flow through each branch will be. The proportion for each branch is defined in the table relative to each of the other branches. For instance, assume you have a Diverge block with two outflow branches. A value of 2 for the top outflow branch and 4 for the bottom outflow branch would indicate that the bottom branch should send twice the amount of flow as the top branch. If a particular branch's proportion has been defined to be blank or <= 0, the effective rate for that branch is set to 0 and the flow is stopped for that branch. This mode uses a fixed flow rule where the effective rate at each branch is required to meet the proportion defined by the table. Consequently, if the flow through one or more of the branches is blocked or starved, the effective rates for all branches will be set to zero and all flow through the block is halted. Note the Sum of proportions displays the total sum of the proportions that have been entered in the table.

distributional: Similar to Proportional mode, the Distributional mode allows you to define a desired set of proportions for each branch. However, unlike the Proportional mode (but similar to Priority mode), these proportions serve as the decision rule for assigning effective rates to the branches only when discrepancies arise between the upstream flow supply and the downstream flow demand. When the upstream supply is greater than or equal to the downstream demand, the block passes as much flow through each branch as the downstream demand will allow and the proportions are ignored. However, when downstream demand exceeds upstream supply, the proportions assigned to each branch are used as preferences to determine how the limited supply should be distributed across the outflow branches. Note the Sum of proportions displays the total sum of the proportions that have been entered in the table.

unbatch: In this mode, the effective rate for the inflow connector is required to be equal to the effective rates for each outflow connector. Consequently, every unit of inflow is unbatched into one unit of flow for each outflow branch. This means the total amount of inflow is different from the total amount of outflow. The Diverge block's behavior in this mode, then, is similar to that of the Unbatch block (Item library). Note, the Unbatch mode is different from all the other diverge modes because the amount of total inflow is never equal to the amount of total outflow.

neutral: Unlike any of the modes discussed previously, the Neutral mode does not allow you to control the effective rates for the branches. This is a passive mode where no branch has a throughput advantage; the branch that gets chosen cannot be predicted. It is used when the system does not need to control how the flow is routed. When the upstream supply is greater than or equal to the downstream demand, the block passes as much flow through each branch as downstream demand will allow. However, when downstream demand exceeds upstream supply, the distribution of flow across each branch cannot be predicted.

demand sensing: Similar to the Proportional mode, the Demand Sensing mode uses proportions to calculate the effective rates for the branches. However, unlike the Proportional mode where you directly enter or control the proportions for each branch, the proportions for the Sensing modes are derived dynamically from the model as it runs. Proportions for the outflow branches are calculated as a function of the potential downstream demand. For instance, the downstream demand placed on a particular outflow branch becomes the proportion for that branch. In the Sensing mode, you must define the maximum possible rate of flow through each branch in the Flow connections table. This upper bound is used as a way to limit throughput so that proportions can be determined when the upstream supply and downstream demand are infinite.

Flow connections table grow button: Use the green +/- grow button from this table to define the desired number of outflow connectors.

Flow connections table column 1 (To Block): Displays the block label and global block number of the block connected to this particular outflow branch.

Flow connections table column 2 (Parameter): The different meanings of this column are described above as its interpretation is dependant upon which diverge mode has been selected.

Flow connections table column 3 (Initialize): When the Use value in initialize column to initialize parameters checkbox is checked, this column will appear for those diverge modes whose branch requirements can be changed dynamically through input value connections. The modes where this column has meaning include: priority of outflows, proportional, distributional, and demand sensing. This option to initialize is useful when branch requirements change during the run, and you want the starting conditions to always be the same.

Throw connections table grow button: Use the green +/- grow button from this table to define the desired number of throw connections. Note, this can also be done on the Throw tab.

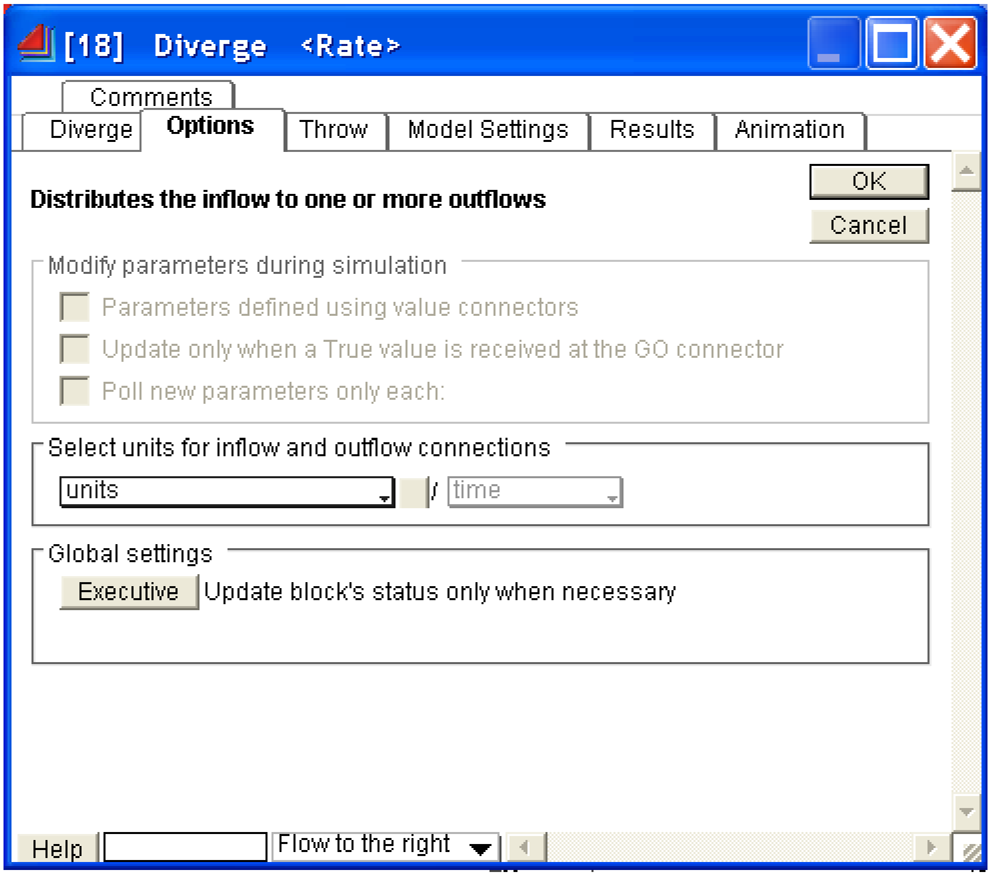
Throw connections table column 1 (Parameter): The Throw connections table and first column appear for most of diverge modes when the Enable throw connections checkbox has been checked. It is merely an extension of Flow connections table column 2 for the throw branches.

Throw connections table column 2 (Initialize): This column is just an extension of Flow connections table column 3 for the throw branches.

Use value in initialize column to initialize parameters: When this checkbox is checked, a third column for initializing will appear in the Flow connections table for those diverge modes whose branch requirements can be changed dynamically through input value connections. The modes where this column has meaning include: priority of outflows, proportional, distributional, and demand sensing. This option to initialize is useful when branch requirements change during the run, but you want the starting conditions to always be the same. (Note, if throwing has been enabled a second column for initializing will appear in the Throw connections table as well.)

Enable throw connections: When this checkbox is checked, the Diverge block's throwing capabilities are enabled. For the modes that require a Flow connections table (including priority of outflows, select an outflow, proportional, distributional, and demand sensing), an additional and analogous throw connections table will also appear. This new table requires the same type of diverging information needed by the Flow connections table so that flow may be distributed correctly across all the branches.

Options Tab



Parameter defined using value connectors: The parameters that get defined in the Flow connections table can also be defined dynamically through a separate set of input value connections when this checkbox is checked

Update only when a True value is received at the GO connector: With this checkbox checked, any dynamic changes to the diverge parameters found in the Flow connections table will be ignored until a TRUE value has been received at the GO connector.

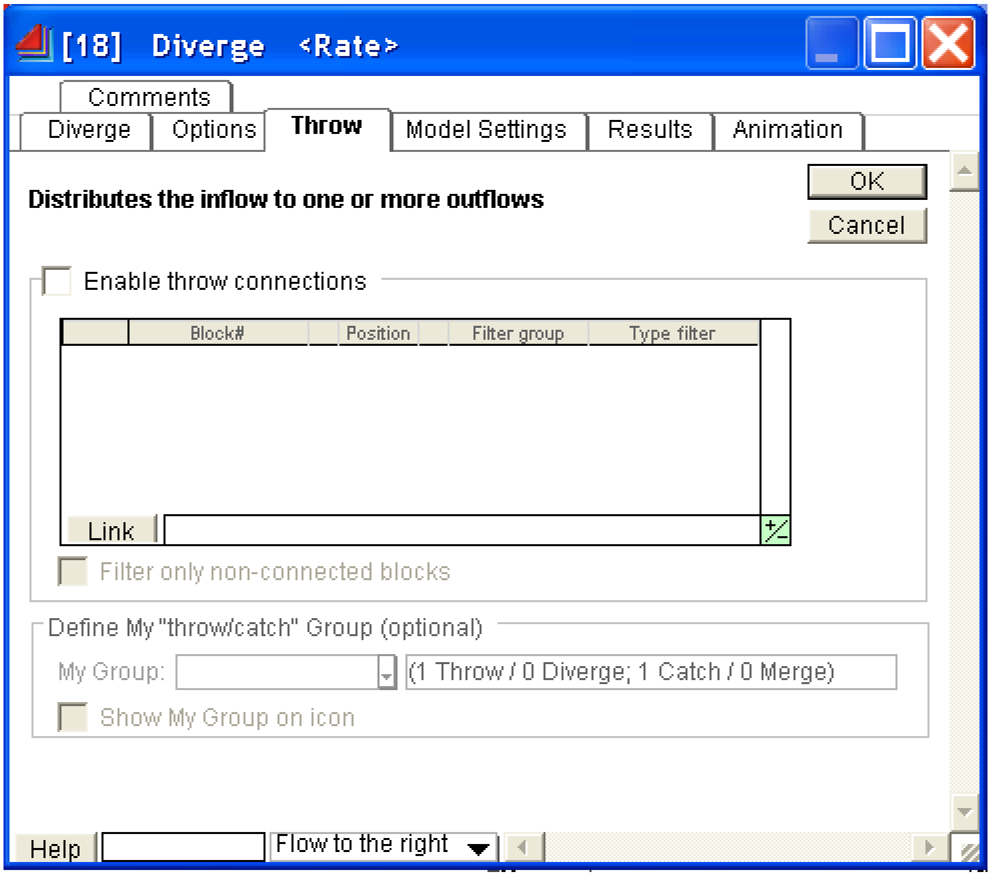
Poll new parameters only each: If this checkbox is checked, then requests for new parametric values for the Flow connections table will be made by this block at dedicated time intervals. This may make sense if the Flow connections table is linked to a database table or if the Parameter defined using value connectors checkbox is checked. In other words you may want to consider using this option if the decision rule for distributing the flow can change dynamically.

Select units: In the "Select units" frame, the first popup allows the user to choose the flow units for all the blocks residing in this block's unit group by either selecting an existing flow unit category or by creating a new one. A unit group is a collection of blocks connected together through flow connections and sharing the same flow unit. Notice that once you've made your selection here, the flow units for all blocks in this unit group will have changed. When the square button to the right of this popup menu is pressed, all blocks included within this block's unit group are selected. The second popup allows the user to define the time units for this particular Bias block.

Executive: This button will open the Executive block to the Discrete Rate tab where you can define how often Rate blocks in the model update their status. For more information on this feature, please consult the Executive's help text.

Update animation and results at each event: This checkbox allows you to update the block's icon animation at every event during the model run. In order for this checkbox to be enabled, the Blocks update flow status: each block defines how often setting must be selected on the Discrete Rate table in the Executive.

Throw Tab



Enable throw connections: This checkbox enables the Diverge block's throwing capabilities.

Table column 1 (Block#): Enter the catch type block you want the associated "throw branch" to throw to (you also can select block# in the list of available blocks into the next column).

Table column 1' : Using the popup for this column, select the catch type block you want the associated "throw branch" to throw to.

Table column 2 (Position): Enter the "catch branch" you want to throw to. Note, this option only makes sense if you are throwing to a Merge block.

Table column 2' : Using the popup for this column, select the "catch branch" you want to throw to. Note, this option only makes sense if you are throwing to a Merge block.

Table column 3 (Filter group): This column allows you to control which group of catch type blocks you would like to see when you click on a popup from column 1'.

Table column 4 (Type filter): This column allows you to control what type of catch type blocks (Catch, Merger or both) you would like to see when you click on a popup from column 1'.

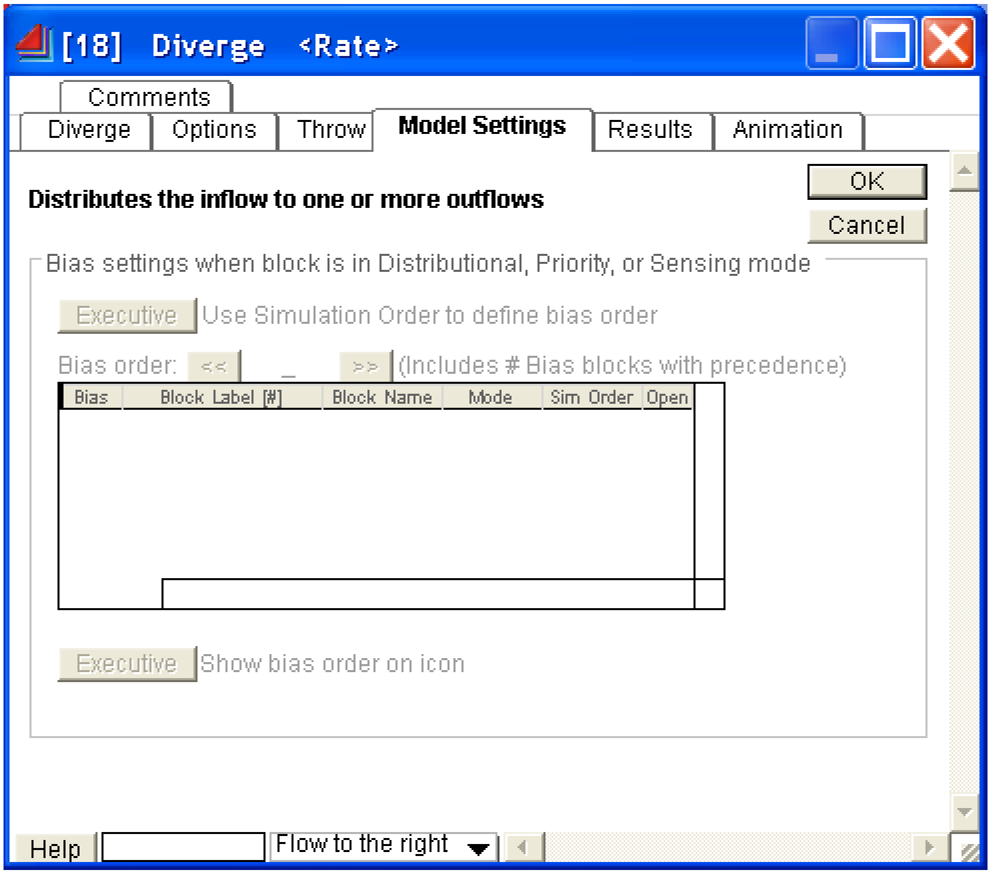
Table column 5 (Open): This column allows you to open the Catch (or Merge) block associated with a particular outflow branch from this block.

Filter only non-connected blocks: This checkbox allows you to show only the "free" catch type blocks (those not already assigned to a throw) when you click on a popup menu from column 1' .

My Group: This popup allows you to choose which "throw/catch" group you want this block to be associated with.

Show My Group on icon: When this checkbox is checked, the "throw/catch" group this block belongs to is displayed on the icon.

Model Settings Tab



Executive: Clicking on this button will open the Executive block's dialog to the Discrete Rate tab. Once there you can choose from two bias order control options: defined by simulation order or each block chooses its own.

Bias order: If each block chooses its own bias order (as defined by the Bias order popup in the Executive), then the bias order table will be enabled. Clicking the << or >> buttons will let you change the bias value on the selected row in the table.

Bias order table column 1 (Bias): Lists the bias value for the block associated with this row of the table.

Bias order table column 2 (Block Label[#}): Shows the block label plus the global block number for the block associated with this Bias value.

Bias order table column 3 (Block Name): Shows the Block Name associated with this Bias value.

Bias order table column 4 (Mode): Shows the selected mode of the block associated with this row of the table.

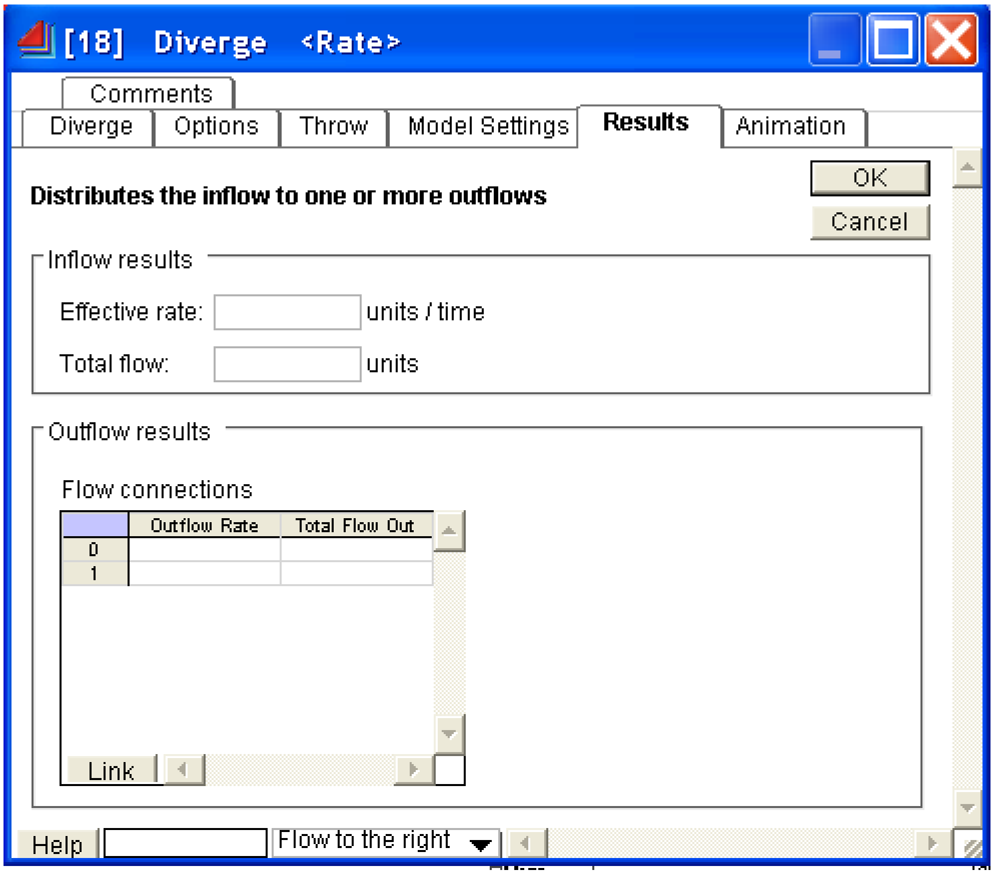
Bias order table column 5 (Sim Order): Shows the simulation order of the block associated with this row of the table.

Bias order table column 6 (Open): Allows you to open the dialogs of any blocks shown in this list.

Executive: Clicking on this button will open the Executive block's dialog to the Model Setting tab. From here you can choose from one of three options: show bias order on icon, don't show bias order on block icons, each block decides whether to show bias order on icon. If show bias order on icon is chosen, the bias order will be displayed under bracket <#> on the icon of the block.

Show bias order on icon: If the option "each block decides whether to show bias order on icon" has been chosen in the Discrete Rate tab of the Executive, then the Show bias order on icon checkbox will appear. If it is checked, the bias order will be displayed under bracket <#> on the icon of the block.

Results Tab



Effective rate: This field displays the current effective inflow rate.

Total flow: This field displays the total amount of flow that has entered the block.

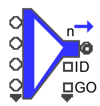
Flow connections table column 1 (Outflow Rate): The effective outflow rate for each out flowing connection branch.

Flow connections table column 2 (Total Flow Out): The total amount of flow that has exited each out flowing connection branch.

Throw connections table column 1 (Outflow Rate): The effective outflow rate for each out flowing throw branch.

Throw connections table column 2 (Total Flow Out): The total amount of flow that has exited each out flowing throw branch.

APPENDIX D – EXTENDSIM MERGE BLOCK

Symbol: 

Purpose:

Merges flows from multiple inputs into one output. The systems modeled using discrete rate technology frequently have multiple flow streams (referred to as branches) that need to be merged into one stream. The Merge block has been designed specifically to model this type of routing behavior. It has seven different rule-based options that define how the inflow will be merged from all inputs.

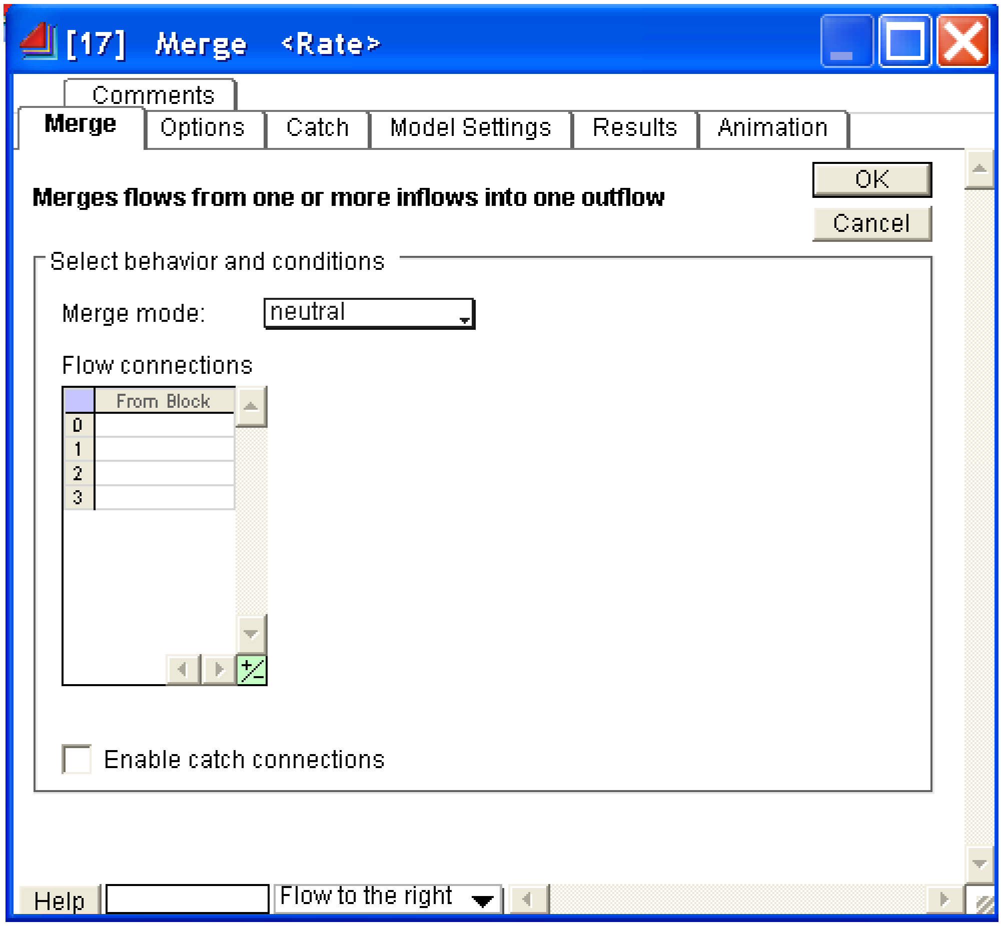
Connecters:

ID: This connector is only used when the Merge block is in Select an inflow mode to specify which branch should currently be open.

Go: Any dynamic changes to the merge parameters found in the Flow connections table will be ignored until a TRUE value has been received at the GO connector.

Tabs:

Merge Tab



Merge mode: This popup menu allows you to select from one of 7 diverge modes.

priority of inflows: The Priority mode allows you to attach priorities to the inflow branches of the Merge block. Given the maximum rate of flow which can go through the block, the Flow will be taken in preference from the higher priority inflow branches.. Note, in Priority mode, if you enter the same Priority number for more than one inflow branch, those specific inflowss will behave the same as if they were in Distributional mode with identic proportons. Also note, if the priority for a particular branch has been set to blank, the effective rate for that branch will be zero and flow will stop for that branch.

select an inflow: When the Merge block is in Select mode, only one selected branch at a time is open. The Flow connections table allows you to assign a unique ID number to each inflow branch (the ID number cannot be blank). The ID connector on the block's icon is then used to select which branch to open. The ID value field displays the current value at the ID connector. The Invalid value at ID popup provides options for handling values at the ID input that don't match any of the branch IDs listed in the table: 1.) Choose top connection, 2.) Choose bottom connection, 3.) Stop flow, 4.) Generate error. A blank value received at the ID connector always stops the flow until the connector receives a valid input.

proportional: With the Proportional mode, you define in the Flow connections table what the proportion of flow through each branch will be. The proportion for each branch is defined in the table relative to each of the other branches. For instance, assume you have a Merge block with two inflow branches. A value of 2 for the top inflow branch and 4 for the bottom inflow branch would indicate that the bottom branch should receive twice the amount of flow as the top branch. If a particular branch's proportion has been defined to be blank or <= 0, the effective rate for that branch is set to 0 and the flow is stopped for that branch. This mode uses a fixed flow rule where the effective rate at each branch is required to meet the proportion defined by the table. Consequently, if the flow through one or more of the branches is blocked or starved, the effective rates for all branches will be set to zero and all flow through the block is halted. Note the Sum of proportions displays the total sum of the proportions that have been entered in the table.

distributional: Similar to Proportional mode, the Distributional mode allows you to define a desired set of proportions for each branch. However, unlike the Proportional mode (but similar to Priority mode), these proportions serve as the decision rule for assigning effective rates to the branches only when discrepancies arise between the upstream flow supply and the downstream flow demand. When the downstream demand is greater than or equal to the upstream supply, the block passes as much flow through each branch as the downstream demand will allow and the proportions are ignored. However, when upstream supply exceeds downstream demand, the proportions assigned to each branch are used to determine how the excess supply should be distributed across the outflow branches. Note the Sum of proportions displays the total sum of the proportions that have been entered in the table.

batch: In this mode, the effective rate for each inflow connector is required to be equal to the effective rate for the outflow connector. Consequently, one unit of flow from each inflow brandh is batched into one unit of flow for the outflow branch. This means the total amount of inflow is different from the total amount of outflow. The Merge block's behavior in this mode, then, is similar to that of the Batch block (Item library). Note, the Batch mode is different from all the other merge modes because the amount of total inflow is never equal to the amount of total outflow.

neutral: Unlike any of the modes discussed previously, the Neutral mode does not allow you to control the effective rates for the branches. This is a passive mode where no branch has a throughput advantage; the branch that gets chosen cannot be predicted. It is used when the system does not need to control how the flow is routed. When the downstream demand is greater than or equal to the upstream supply, the block passes as much flow through each branch as upstream supply can provide. However, when upstream supply exceeds downstream demand, the distribution of flow across each branch cannot be predicted.

supply sensing: Similar to the Proportional mode, the Supply Sensing mode uses proportions to calculate the effective rates for the branches. However, unlike the Proportional mode where you directly enter or control the proportions for each branch, the proportions for the Sensing modes are derived dynamically from the model as it runs. Proportions for the inflow branches are calculated as a function of the potential upstream supply. For instance, the upstream supply placed on a particular inflow branch becomes the proportion for that branch. In the Sensing mode, the you must define the maximum possible rate of flow through each branch in the Flow connections table. This upper bound is used as a way to limit throughput so that proportions can be determined when the upstream supply and downstream demand are infinite.

Flow connections table grow button: Use the green +/- grow button from this table to define the desired number of inflow connectors.

Flow connections table column 1 (From Block): Displays the block label and global block number of the block connected to this particular inflow branch.

Flow connections table column 2 (Parameter): The different meanings of this column are described above as its interpretation is dependant upon which merge mode has been selected.

Flow connections table column 3 (Initialize): When the Use value in initialize column to initialize parameters checkbox is checked, this column will appear for those merge modes whose branch requirements can be changed dynamically through input value connections. The modes where this column has meaning include: priority of inflows, proportional, distributional, and supply sensing. This option to initialize is useful when branch requirements change during the run, and you want the starting conditions to always be the same.

Catch connections table grow button: Use the green +/- grow button from this table to define the desired number of catch connections. Note, this can also be done on the Catch tab.

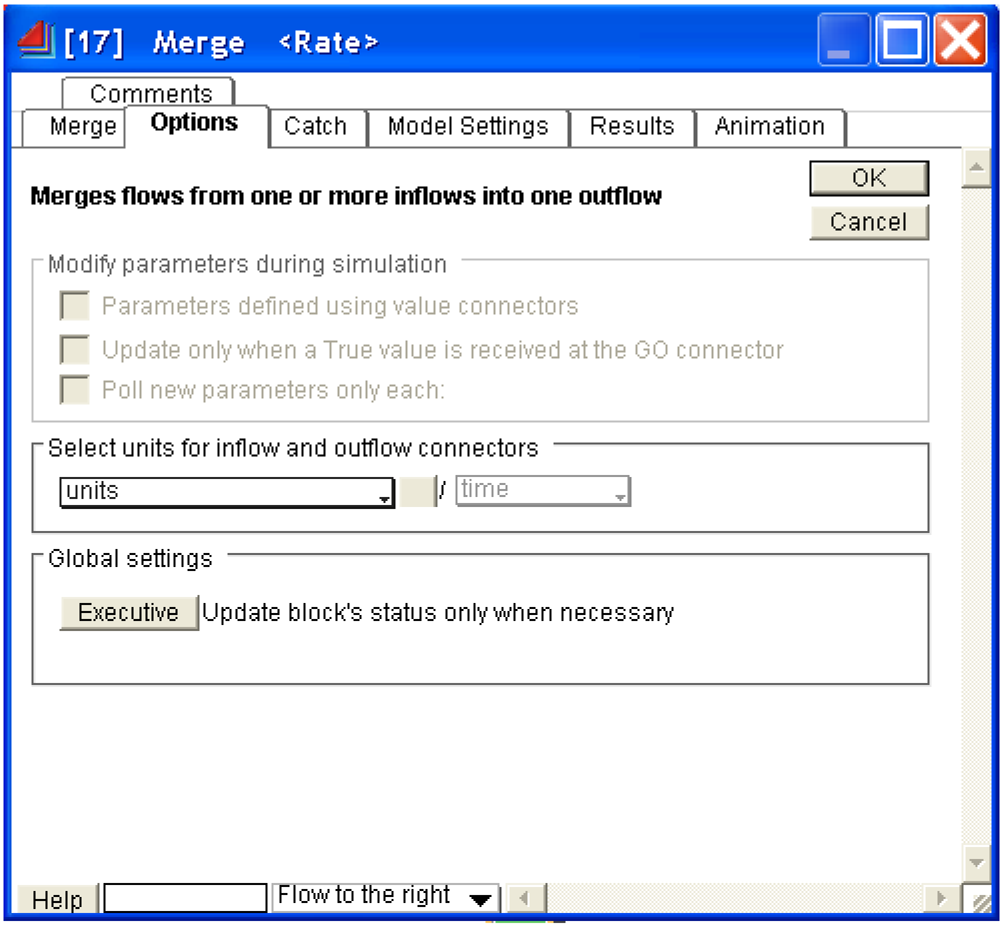
Catch connections table column 1 (Parameter): The Catch connections table and first column appear for most of the merge modes when the Enable throw connections checkbox has been checked. It is merely an extension of Flow connections table column 2 for the catch branches.

Catch connections table column 2 (Initialize): This column is just an extension of Flow connections table column 3 for the catch branches.

Use value in initialize column to initialize parameters: When this checkbox is checked, a third column for initializing will appear in the Flow connections table for those merge modes whose branch requirements can be changed dynamically through input value connections. The modes where this column has meaning include: priority of outflows, proportional, distributional, and supply sensing. This option to initialize is useful when branch requirements change during the run, but you want the starting conditions to always be the same. (Note, if throwing has been enabled a second column for initializing will appear in the Thow connections table as well.)

Enable catch connections: When this checkbox is checked, the Merge block's catching capabilities are enabled. For the modes that require a Flow connections table (including priority of outflows, select an outflow, proportional, distributional, and supply sensing), an additional and analogous Catch connections table will also appear. This new table requires the same type of merging information needed by the Flow connections table so that flow may be combined correctly across all the branches.

Options Tab



Parameter defined using value connectors: The parameters that get defined in the Flow connections table can also be defined dynamically through a separate set of input value connections when this checkbox is checked

Update only when a True value is received at the GO connector: With this checkbox checked, any dynamic changes to the merge parameters found in the Flow connections table will be ignored until a TRUE value has been received at the GO connector.

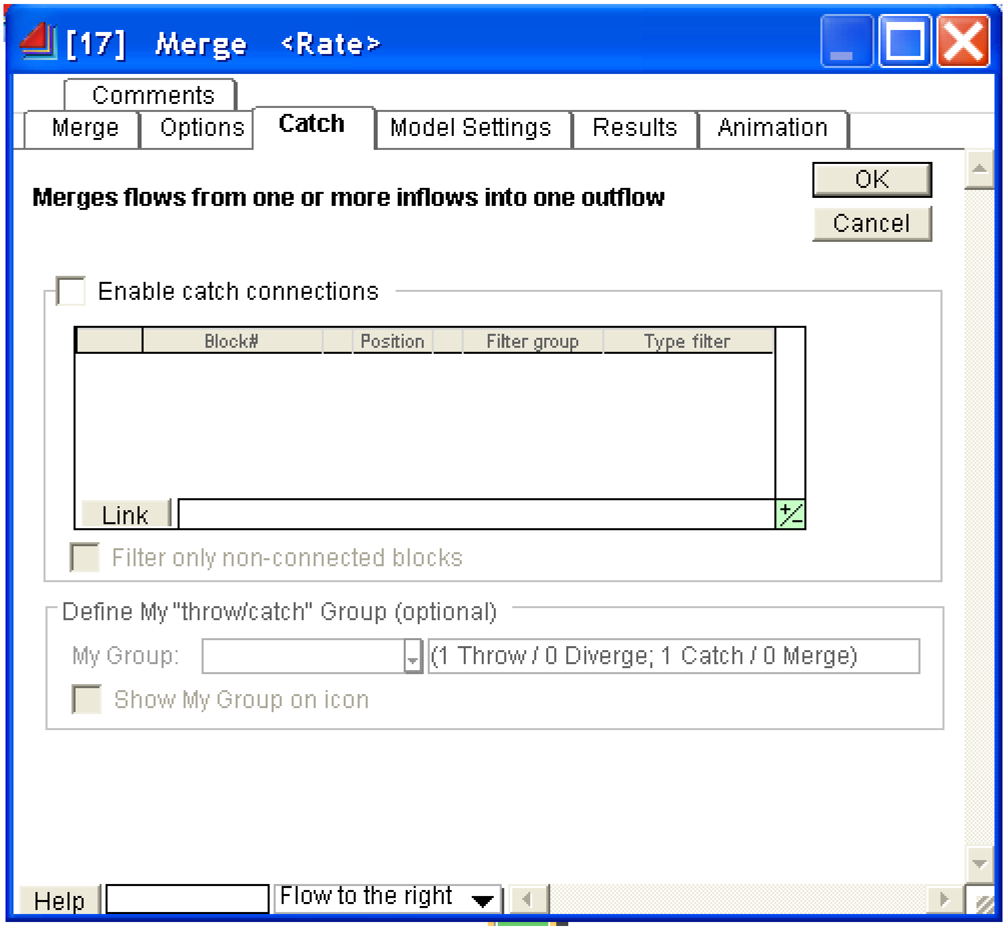
Poll new parameters only each: If this checkbox is checked, then requests for new parametric values for the Flow connections table will be made by this block at dedicated time intervals. This may make sense if the Flow connections table is linked to a database table or if the Parameter defined using value connectors checkbox is checked. In other words you may want to consider using this option if the decision rule for distributing the flow can change dynamically.

Select units: In the "Select units" frame, the first popup allows the user to choose the flow units for all the blocks residing in this block's unit group by either selecting an existing flow unit category or by creating a new one. A unit group is a collection of blocks connected together through flow connections and sharing the same flow unit. Notice that once you've made your selection here, the flow units for all blocks in this unit group will have changed. When the square button to the right of this popup menu is pressed, all blocks included within this block's unit group are selected. The second popup allows the user to define the time units for this particular Bias block.

Executive: This button will open the Executive block to the Discrete Rate tab where you can define how often Rate blocks in the model update their status. For more information on this feature, please consult the Executive's help text.

Update animation and results at each event: This checkbox allows you to update the block's icon animation at every event during the model run. In order for this checkbox to be enabled, the Blocks update flow status: each block defnes how often setting must be selected on the Discrete Rate tabl in the Executive.

Catch Tab



Enable catch connections: This checkbox enables the Merge block's catching capabilities.

Table column 1 (Block#): Enter the Throw type block you want the associated "catch branch" to catch from (you also can select block# in the list of available blocks into the next column).

Table column 1' : Using the popup for this column, select the throw type block you want the associated "catch branch" to catch from.

Table column 2 (Position): Enter the "throw branch" you want to catch from. Note, this option only makes sense if you are catching from a Diverge block.
Table column 2' : Using the popup for this column, select the "throw branch" you want to catch from. Note, this option only makes sense if you are catching from a Diverge block.

Table column 3 (Filter group): This column allows you to control which group of throw type blocks you would like to see when you click on a popup from column 1'.

Table column 4 (Type filter): This column allows you to control what type of throw type blocks (Catch, Merger or both) you would like to see when you click on a popup from column 1'.

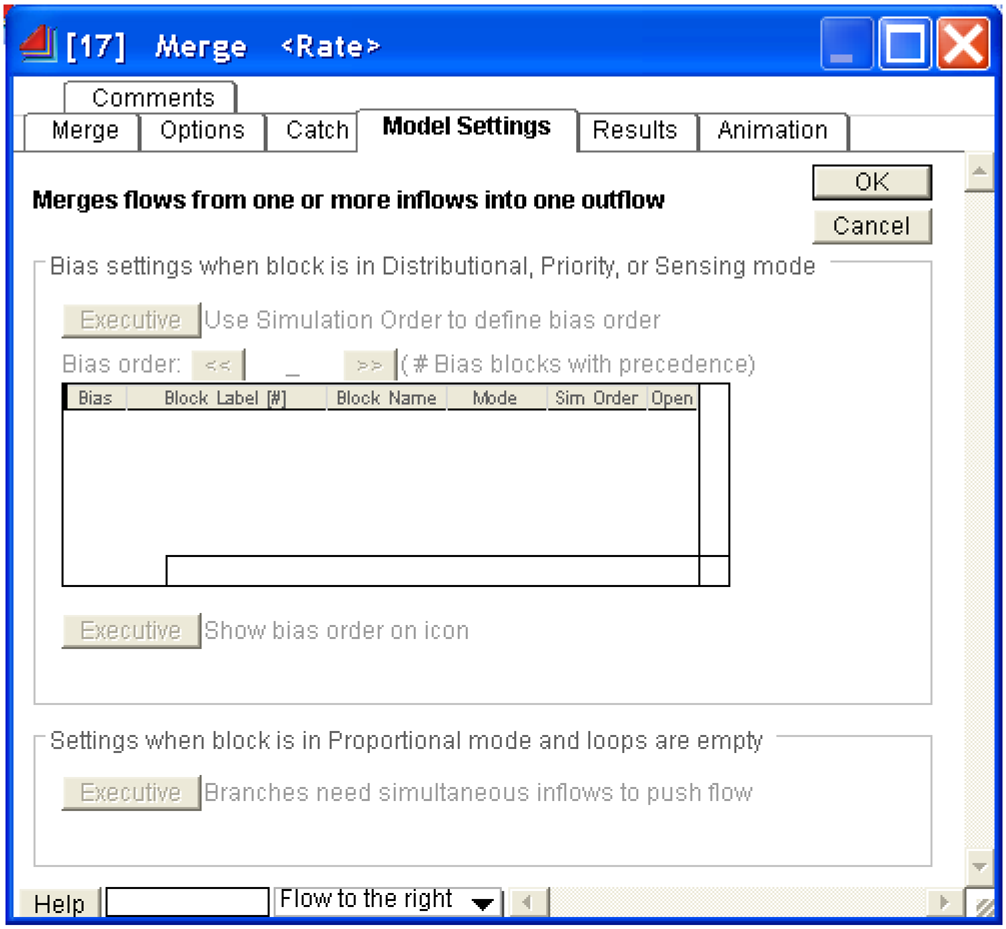
Table column 5 (Open): This column allows you to open the Throw (or Diverge) block associated with a particular inflow branch from this block.

Filter only non-connected blocks: This checkbox allows you to show only the "free" throw type blocks (those not already assigned to a catch) when you click on a popup menu from column 1' .

My Group: This popup allows you to choose which "throw/catch" group you want this block to be associated with.

Show My Group on icon: When this checkbox is checked, the "throw/catch" group this block belongs to is displayed on the icon.

Model Settings Tab



Executive: Clicking on this button will open the Executive block's dialog to the Discrete Rate tab. Once there you can choose from two bias order control options: defined by simulation order or each block chooses its own.

Bias order: If each block chooses its own bias order (as defined by the the Bias order popup in the Executive), then the bias order table will be enabled. Clicking the << or >> buttons will let you change the bias value on the selected row in the table.

Bias order table column 1 (Bias): Lists the bias value for the block associated with this row of the table.

Bias order table column 2 (Block Label[#}): Shows the block label plus the global block number for the block associated with this Bias value.

Bias order table column 3 (Block Name): Shows the Block Name associated with this Bias value.

Bias order table column 4 (Mode): Shows the selected mode of the block associated with this row of the table.

Bias order table column 5 (Sim Order): Shows the simulation order of the block associated with this row of the table.

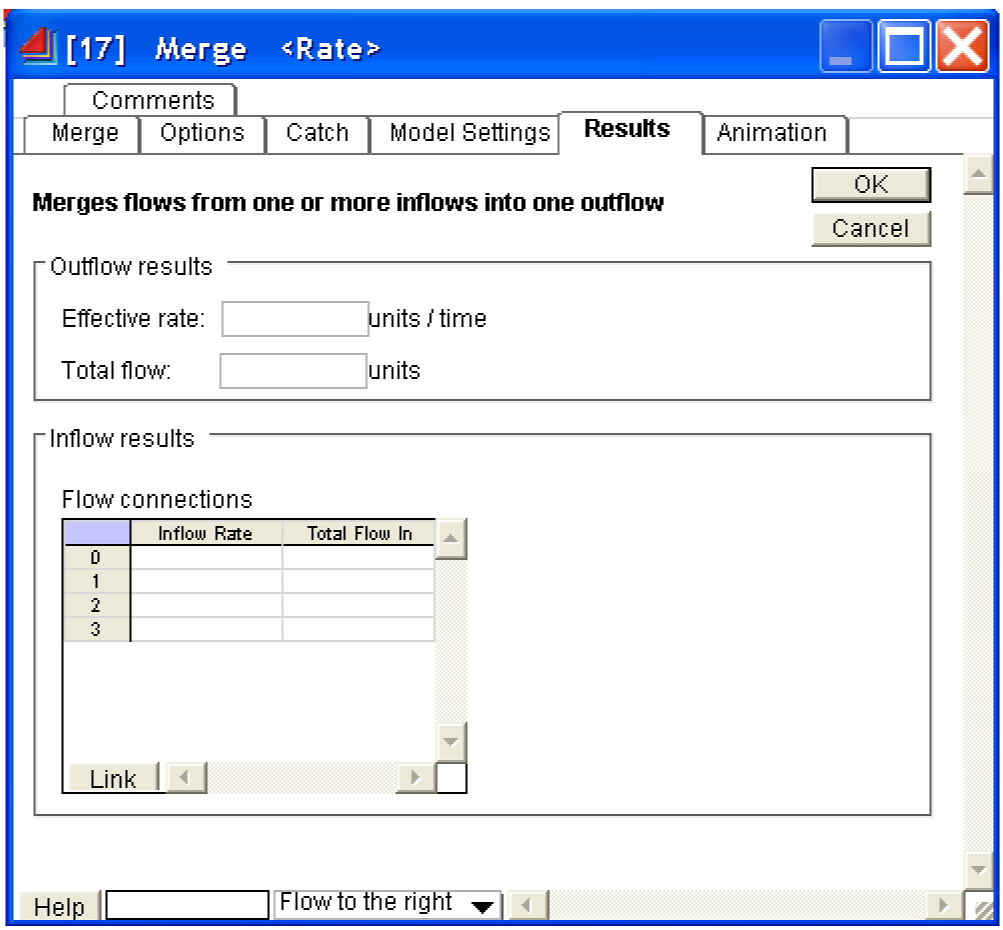
Bias order table column 6 (Open): Allows you to open the dialogs of any blocks shown in this list.

Executive: Clicking on this button will open the Executive block's dialog to the Model Setting tab. From here you can choose from one of three options: show bias order on icon, don't show bias order on block icons, each block decides whether to show bias order on icon. If show bias order on icon is chosen, the bias order will be displayed under bracket <#> on the icon of the block.

Show bias order on icon: If the option "each block decides whether to show bias order on icon" has been chosen in the Discrete Rate tab of the Executive, then the Show bias order on icon checkbox will appear. If it is checked, the bias order will be displayed under bracket <#> on the icon of the block.

Executive: Clicking on this button will open the Executive block's dialog to the Discrete Rate tab. Once there you can choose from three options when a Merge block is in Proportional mode and loops are empty: branches need simultaneous inflows to push flow, blocks push flow even in empty loops, and each block defines how it will push flow.

Results Tab



Effective rate: This field displays the current effective outflow rate.

Total flow: This field displays the total amount of flow that has exited the block.

Flow connections table column 1 (Outflow Rate): The effective inflow rate for each inflowing connection branch.

Flow connections table column 2 (Total Flow Out): The total amount of flow that has entered each inflowing connection branch.

Catch connections table column 1 (Outflow Rate): The effective inflow rate for each inflowing catch branch.

Catch connections table column 2 (Total Flow Out): The total amount of flow that has entered each inflowing catch branch.

APPENDIX E – EXTENDSIM UNITS BLOCK

Symbol: 

Purpose:

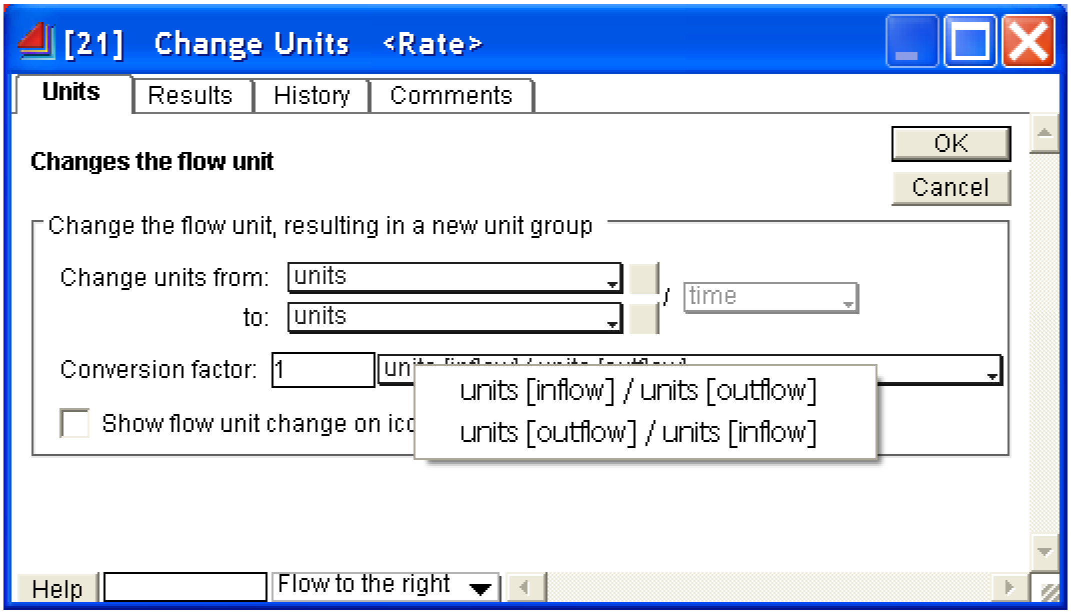
Changes the flow unit of measurement. Flow units describe what is flowing from one Rate library block to another. Blocks that are connected together through flow connections and share the same flow unit are called a unit group. The Change Units block uses the conversion factor to create a new unit group. This causes the blocks downstream of the Change Units block to be in a unit group different from its upstream blocks.

Connecters:

factor: This input overrides The factor is field on the Units tab.

Tabs:

Units Tab



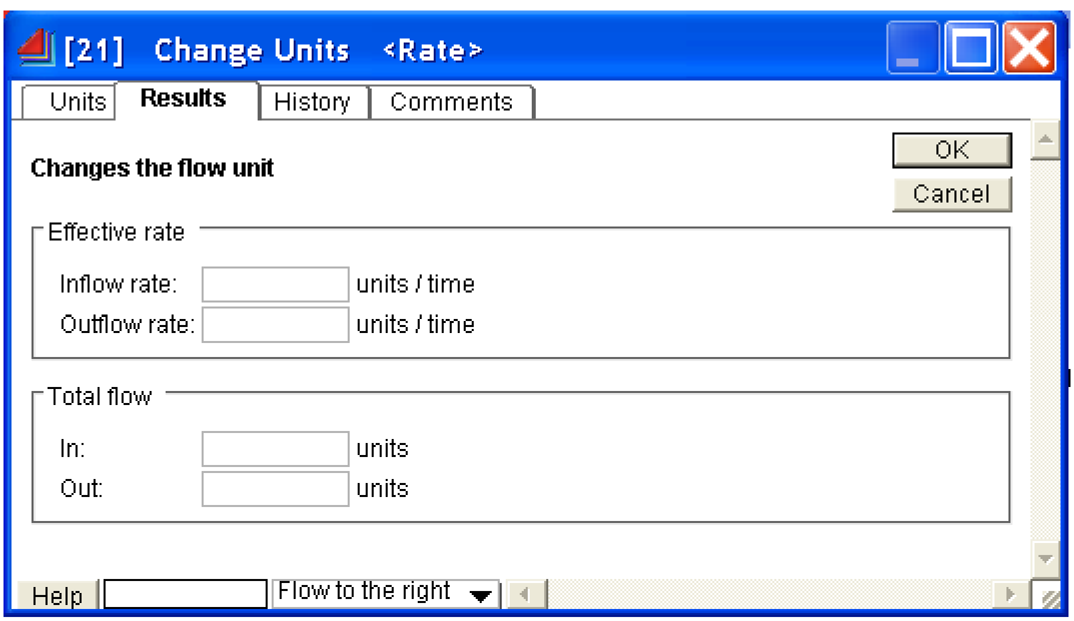
Change units from: These are the flow units coming into the block. The popup allows you to choose the flow units for all the blocks residing in this block's upstream unit goup by either selecting an existing flow unit category or by creating a new one. A unit group is a collection of blocks connected together through flow connections and sharing the same flow unit. Notice that once you've made your selection here, the flow units for all the upstream blocks in this unit group will have changed. When the square button to the right of this popup menu is pressed, all blocks included within this block's upstream unit group are selected.

to: These are the flow units exiting from the block. The popup allows you to choose the flow units for all the blocks residing in this block's downstream unit goup by either selecting an existing flow unit category or by creating a new one. A unit group is a collection of blocks connected together through flow connections and sharing the same flow unit. Notice that once you've made your selection here, the flow units for all the downstream blocks in this unit group will have changed. When the square button to the right of this popup menu is pressed, all blocks included within this block's downstream unit group are selected.

The factor is: This field is used to define a constant conversion factor. The popup to the left of this field allows you to define the conversion factor in terms of inflow units per outflow units or vice versa. Negative, zero or blank conversion factors are invald.

Show flow unit change on icon: With this checkbox checked, the "from / to" flow units will be displayed on the Change Units block icon.

Results Tab



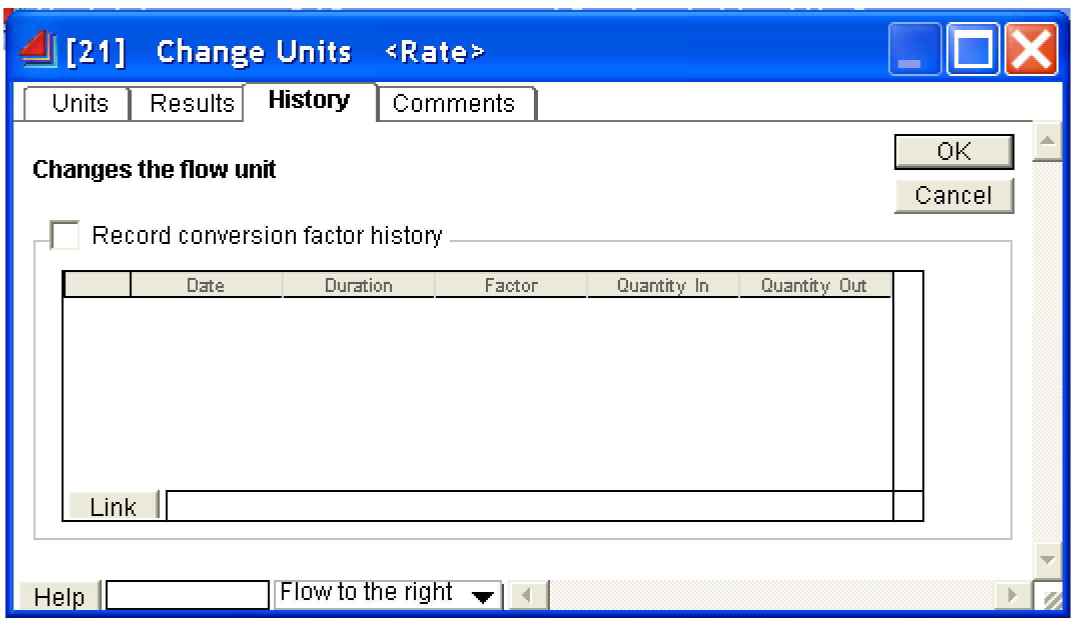
Inflow rate: This field reports the effective rate of flow entering the block.

Outflow rate: This field reports the effective rate of flow leaving the block.

In: This field reports the total amount of flow having entered the block.

Out: This field reports the total amount of flow having left the block.

History Tab



Record conversion factor history:

Table column 1 (Date): This column reports what time the associated factor was first introduced.

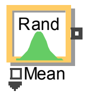
Table column 2 (Duration): This column reports the amount of time the associated conversion factor was used.

Table column 3 (Factor): This column reports the conversion factor.

Table column 4 (Quantity In): This column reports how much flow entered the block while the associated conversion factor was in use.

Table column 5 (Quantity Out): This column reports how much flow exited the block while the associated conversion factor was in use.

APPENDIX F – EXTENDSIM RANDOM NUMBER BLOCK

Symbol: 

Purpose:

Generates random integers or real numbers based on the selected distribution. You can use the dialog or the three inputs, 1, 2, and 3 to specify arguments for the distributions. You can select the type of distribution: Uniform (integer or real), Beta, Binomial, Cauchy, Chi Squared, Constant, Erlang, Exponential, Extreme Value type 1a, Extreme Value type 1b, Gamma, Geometric, HyperExponential, HyperGeometric, Inverse Gaussian, Inverse Weibull, Johnson SB, Johnson SU, Laplace, Logarithmic, Logistic, Log-Logistic, LogNormal, Negative Binomial, Normal, Pareto, Pearson type V, Pearson type VI, Poisson, Power Function, Rayleigh, Triangular, Weibull, or Empirical Table.

The Empirical distribution uses a table to generate a discrete, stepped, or interpolated empirical distribution. To change the number of rows in the table, click on the resize button on the table (the green +- icon in the lower right hand corner of the table). This button will allow you to resize the table to whatever size you wish. You will also be asked to resize the table when your first select the Empirical distribution.

Where it occurs, the location parameter shifts the entire distribution by the location value. This has the same effect as adding a constant to the output of the block.

Connecters:

1: Value of argument 1. If connected, this overrides the (1) dialog parameter.

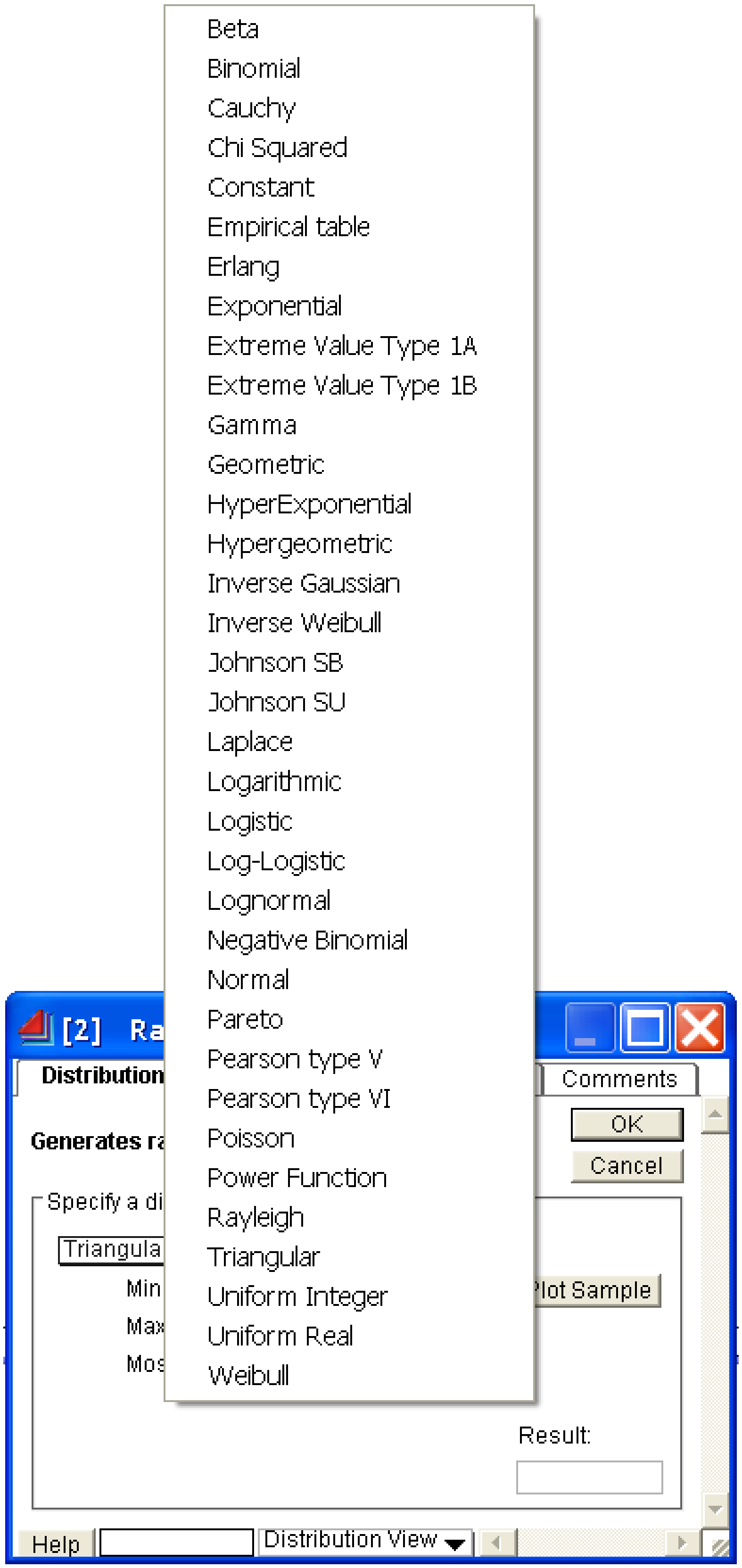
2: Value of argument 2. If connected, this overrides the (2) dialog parameter.

3: Value of argument 3. If connected, this overrides the (3) dialog parameter.

The output is the random value.

Tabs:

Distributions Tab


Beta
Binomial
Cauchy
Chi Squared
Constant
Empirical table
Erlang
Exponential
Extreme Value Type 1A
Extreme Value Type 1B
Gamma
Geometric
HyperExponential
Hypergeometric
Inverse Gaussian
Inverse Weibull
Johnson SB
Johnson SU
Laplace
Logarithmic
Logistic
Log-Logistic
Lognormal
Negative Binomial
Normal
Pareto
Pearson type V
Pearson type VI
Poisson
Power Function
Rayleigh
Triangular
Uniform Integer
Uniform Real
Weibull
[2]
Distribution
Comments
OK
Cancel
Min
Result:
Help
Distribution View

(1): The first argument for the selected distribution. This variable changes depending on the type of distribution.

(2): The second argument for the selected distribution. This variable changes depending on the type of distribution; it is sometimes unused.

(3): The third argument for the selected distribution. This variable changes depending on the type of distribution; it is sometimes unused.

Beta: A continuous distribution with finite upper and lower bounds. The two shape parameters can be used to generate a wide variety of density patterns within the two bounds. The lower bound is the location parameter; the upper bound is the maximum added to the location parameter. This distribution is often used as a rough estimate in the absence of data, a distribution of a random proportion, or the time to complete a task. The uniform distribution is a special case of the beta distribution (both shape parameters are equal to one).

Binomial: Outputs a value which is the number of successes (argument (1) - Probability) in a fixed number of independent trials (argument (2) - N). Probability is a real number and N is an integer. For example, this distribution is used to show the number of defective items in a batch of size N, the probability of error in the transmission of a message consisting of a specific number of bits, or the probability that a specified number of people will recover from a rare blood disease.

Cauchy: The Cauchy distribution is an unbounded continuous distribution that has a sharp central peak but significantly broad tails. The tails are much heavier than the tails of the Normal distribution. Lambda is a scaling parameter.

Chi Squared: The Chi Squared distribution is a continuous distribution bounded on the left side. Note that the Chi Squared distribution is a subset of the Gamma distribution with beta = 2 and alpha = nu/2. Nu is a shape parameter.

Constant: Outputs a constant value.

Discrete: For the Empirical distribution only. The data table will be used as discrete probabilities of the values given in the "Value" column. This means that the values listed in the value column are the exact numbers that the block will output.

Empirical table: Enter values in the first column and enter the probability of that value occurring in 100 cases in the second column. The value column contains the various values that will be output; Probability describes the chance that value will occur. The probabilities need only have the proper values relative to each other, since ExtendSim scales them automatically. You may type the values in directly or import the values to the data table through the Clipboard using the commands in the Edit menu.

Erlang: Outputs a value varying around the given (1) mean, with a wide range of outcomes depending on the value of the second argument, "k". This distribution is used in telephone traffic and queuing theory when an activity or service time is considered to occur in phases with each phase being exponentially distributed. It is common to use the Erlang distribution as a service time when you want to simplify a model by combining several similar steps into one representative step. The value of "k" should be an integer. Like the Wiebull, the curve approximates other distributions depending on the value of its Mean and especially the value of "k". A "k" of 1 resembles the exponential distribution while larger values tend to a normal distribution.

Exponential: A distribution shaped like a decaying exponential. This choice outputs a value varying around the (1) Mean, where the Mean is a non-negative real number.

However, the distribution is positively skewed (longer tail on the right), so it is more likely that the values will be between 0 and the Mean than between the Mean and two times the Mean. This distribution is the one most often used in science, business processes, and queuing theory. Use it to represent the length of a telephone conversation, the expected lives of electronic components, the time between failures for equipment, or any other situation where the events are completely independent of each other. It is generally not appropriate for modeling delay or processing times.

Extreme Value Type 1A: The Extreme Value IA distribution is an unbounded continuous distribution. It is also called the Gumbel distribution. The Extreme Value 1A distribution describes the limiting distribution of the greatest values of many types of samples. Beta is a scale parameter.

Extreme Value Type 1B: The Extreme Value IB distribution is an unbounded continuous distribution. The Extreme Value IB distribution describes the limiting distribution of the least values of many types of samples. Beta is a scale parameter.

Gamma: A continuous distribution bounded by zero at the left and unbounded on the right. The exponential and Erlang are special cases of the gamma distribution. Because of its flexibility, the gamma distribution can be used for a wide variety of purposes including: interarrival times, time to complete a task, or lifetimes.

Geometric: A discrete distribution bounded by zero on the left and unbounded on the right. It can be defined as the number of failures before the first success in a series of trials. In shape, it is similar to the exponential distribution. Traditional uses include inventory demand and the number of items inspected before the first defective item is found.

HyperExponential: A distribution used in telephone traffic and queuing theory given its Mean. It perturbs the Exponential distribution in an opposite way to the Erlang. The second argument, "s", ranges from 0 to 0.5 with 0.5 giving an Exponential distribution.

Hypergeometric: The Hypergeometric distribution is a discrete distribution bounded by [0,s]. It describes the number of defects, x, in a sample of size s from a population of size N which has m total defects.

Interpolated: For the Empirical distribution only. The probability distribution will be interpolated between the data points. The value that is output will be the values in the table and the values between those values. The probability of any value being output is also adjusted.

Inverse Gaussian: The Inverse Gaussian distribution is a continuous distribution with a bound on the lower side. It is uniquely zero at the minimum x and always positively skewed. The Inverse Gaussian distribution is also known as the Wald distribution. Alpha is a shape parameter. Beta is a mixture of shape and scale.

Inverse Weibull: The Inverse Weibull distribution is a continuous distribution with a bound on the lower side. It is uniquely zero at the minimum x, and always positively skewed. In general, the Inverse Weibull distribution fits bounded, but very peaked, data with a long positive tail. Alpha is a shape parameter. Beta is a mixture of shape and scale.

Johnson SB: the Johnson SB distribution is a continuous distribution that has both upper and lower finite bounds, similar to the Beta distribution. The Johnson SB distribution, together with the Lognormal and the Johnson SU distributions are transformations of the Normal distribution and can be used to describe most naturally occurring unimodal sets of data. Lambda is the range of X above the minimum. Gamma is a skewness parameter. Delta is a shape parameter.

Johnson SU: The Johnson SU distribution is an unbounded continuous distribution. The Johnson SU distribution, together with the Lognormal and the Johnson SB distributions are transformations of the Normal distribution and can be used to describe most naturally occurring unimodal sets of data. Lambda is the range of X above the minimum. Gamma is a skewness parameter. Delta is a shape parameter.

Laplace: The Laplace distribution, sometimes called the double exponential distribution, is an unbounded continuous distribution that has a very sharp central peak, located at theta. The distribution scales with phi.

Location: Some distributions have a fixed origin of 0. For these distributions, the location parameter will appear. This parameter can be used as an offset to the distribution so that it can have any fixed origin value. A value is generated from the distribution and then the location parameter is added to the result. This is identical to adding a value to the output of the Input Random Number block.

Logarithmic: The Logarithmic distribution is a discrete distribution bounded by [1,...]. Typically, if the data is bounded by [0, ...], then translating the data before fitting is required. Theta is related to the sample size and the mean.

Logistic: The Logistic distribution is an unbounded continuous distribution which is symmetrical about its mean. The shape of the Logistic distribution is very much like the Normal distribution, except that the Logistic distribution has broader tails. Alpha is a shift parameter. Beta is a scale parameter.

Log-Logistic: For Shape = 1, it resembles the Exponential distribution. For Shape < 1, it tends to infinity at Location, and decreases with increasing X. For Shape > 1, it is zero at Location, and then peaks and decreases.

Lognormal: Natural log of the variable that follows the Gaussian or bell curve with the given (1) Mean and (2) Std Dev (standard deviation). This distribution outputs a value > 0, skewed so that most of the values occur near the minimum value (positive skew). Lognormal is often appropriate for multiplying processes, while the Normal is best for additive processes. This distribution is widely used in business for security or property valuation, such as the rate of return on stock or real estate returns.

Negative Binomial: Number of failures before Sth success. P specifies the probability of success.

Normal: Gaussian or bell curve with the given (1) Mean and (2) Std Dev (standard deviation). This choice outputs a value approximately equal to the Mean every time unit, where the value is as likely to be from 0 to the Mean as to be from the Mean to two times the mean. The Mean is specified as a real number and the standard deviation is specified as a non-negative real number. The larger the standard deviation is, the wider the spread of values around the mean. For example, given a mean of 6 and the expectation that 68% of the numbers will occur at ±4 (that is, that 68% of the values fall between 2 and 10), you would enter a STD Dev of 4. This is calculated as 4/1, where 1 represents 1 standard deviation width of values (68%). However, if you expect that 96% of the numbers, or 2 standard deviations, will fall within that same range, enter a STD Dev of 2. This is calculated as 4/2.

Pareto: The Pareto distribution is a continuous distribution bounded on the lower side. It has a finite value at the minimum x and decreases monotonically for increasing x. A Pareto random variable is the exponential of an Exponential random variable, and possesses many of the same characteristics. Minimum is the minimum value for X. Alpha is a scale parameter.

Pearson type V: A distribution typically used to represent the time required to complete some task. A continuous distribution bounded by zero on the left and unbounded on the right. The density takes on shapes similar to lognormal, but can have a larger "spike" close to $x = 0$.

Pearson type VI: A distribution typically used to represent the time required to complete some task. A continuous distribution bounded by zero on the left and unbounded on the right.

Plot Sample: Plots a sample from the selected distribution in a histogram. Note: this plot is for the distributions on the left only; the Empirical distribution has its own "Plot Table" button.

Plot Table: Plots the outline of the Empirical distribution specified in the data table.

Poisson: Describes the number of events that occur in a given interval based on the given rate or (1) Mean. The variance equals the mean, so the larger the mean the wider the spread from the mean. This distribution is used to represent the number of telephone calls per minute, the number of errors per page, or the number of arrivals to a system.

Power function: A continuous distribution with both upper and lower finite bounds. It is a special case of the Beta distribution with $q = 1$. The Uniform distribution is a special case of the Power Function distribution with $p = 1$. Minimum is the minimum value, Maximum is the maximum value. Alpha is a shape parameter.

Rayleigh: The Rayleigh distribution is a continuous distribution bounded on the lower side. This distribution is frequently used to represent lifetimes because its hazard rate increases linearly with time, e.g. the lifetime of vacuum tubes. This distribution also finds application in noise problems in communications. Sigma is a scale parameter.

Stepped: For the Empirical distribution only. The data table will be used as probabilities of ranges of data. The lowest value in the Value column defines the low end of the bin while the next range value defines the upper end. This choice requires that the last set of points define the upper end of the distribution. For this reason the probability level of the last and next to last points must be equal. If this is not in the data table, an additional point will be added onto the data.

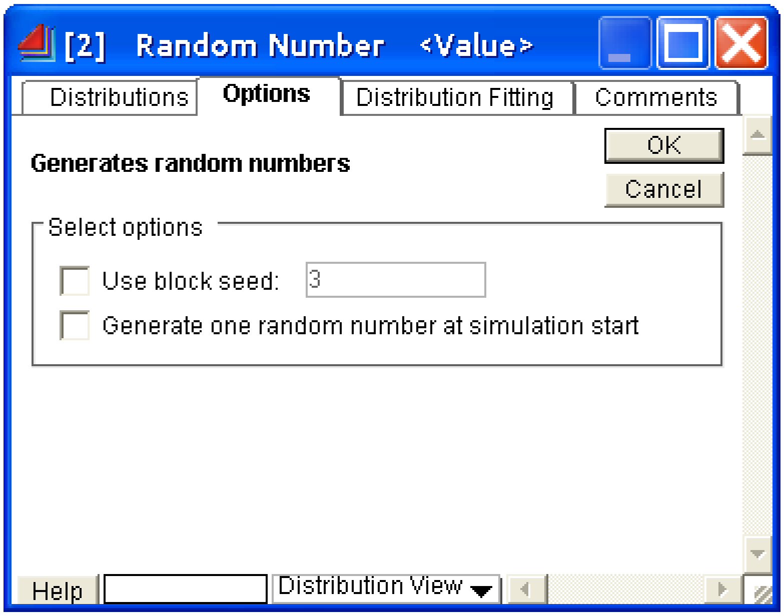
Triangular: Outputs a value N, where N is a real (decimal) number greater than or equal to the real number selected for argument 1 (the minimum) and less than or equal to the real number selected for argument 2 (the maximum) with the added provision that N tends towards its most likely, or modal value. You would use this distribution to specify a distribution in which you knew the lowest possible value, the highest possible value and a central tendency. The actual performance of this distribution will be similar to the normal distribution with the exception that it can be skewed (if the most likely value is specified to the left or right of the mean) and that there is no possibility of outlying values. Note that the most likely value is the mode and not the mean (or average). To determine the mean of the triangular distribution, sum the minimum, maximum, and most likely values together and then divide by 3.

Uniform integer: Outputs an integer (whole) number greater than or equal to the integer selected for argument 1 and less than or equal to the integer selected for argument 2. In this distribution, all integer values between the minimum and maximum are equally likely to occur. For instance, you would use this distribution to indicate that the expected pricing for a new product is from 200 to 400 or to show values that represent "best case/worst case" scenarios.

Uniform Real: This is the default selection. Outputs a real (decimal) number greater than or equal to the value selected for argument 1 and less than or equal to the value selected for argument 2. In this distribution, all the values between the minimum and maximum are equally likely to occur. For instance, you would use this distribution to indicate "best case/worst case" scenarios, or that the least a piece of equipment would cost would be $347.50 and the most it would cost would be $452.95.

Weibull: This distribution can assume the properties of other distributions (such as the Exponential or Rayleigh) depending on its (1) Scale and (2) Shape arguments, both of which are non-negative real numbers. It is commonly used to describe failure rates, life-time expectancies, or the time to complete a task. The curve of the distribution changes considerably depending on the value of Scale and especially the value of Shape. The Shape variable should be greater than 0. For example, given a Scale of 1 and a Shape of 1, the Weibull is essentially an exponential distribution. However, given a Scale of 1 and a Shape of 2 the curve resembles a skewed normal distribution. Note that there are other terms used for the scale and shape of the Weibull distribution; check the documentation for the source of the distribution carefully. In Stat::Fit, alpha is the shape and beta is the scale.

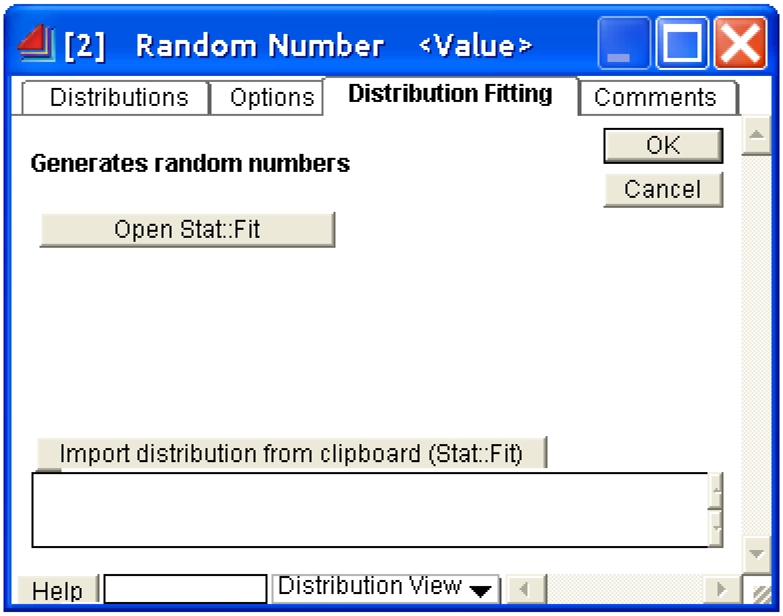
Options Tab



Generate one random number at simulation start: If checked, the Random Number block will generate one value at the start of the simulation run. This value will stay the same throughout the entire simulation.

Use block seed: Sets the offset value for the random number seed used by this block. If this is not checked, the offset is the block number (a unique identifier for each block) + 1. In most cases, each block which generates random numbers should have its own, unique seed value. The Statistics library (included with the Manufacturing or BPR libraries) contains the Random Seed Control block which can check for duplicate seed values.

Distribution Fitting Tab



Distribution fitting software: Distribution fitting software will help you to select the appropriate ExtendSim statistical distribution based on historical data. Use this pop-up menu to select your distribution fitting software. Currently, three Windows distribution fitting software packages are supported. These include:

- BestFit(R) from Palisade Corporation - (800) 432 7475 - http://www.palisade.com
- ExpertFit(TM) from Averill M. Law & Associates - (520) 795 6265 - http://www.averill-law.com
- Stat::Fit(TM) from Geer Mountain Software - (860) 927 4328 - http://www.geerms.com

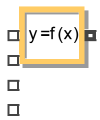
In addition, the statistical analysis software package, JMP(R) from the SAS Institute - (919) 677 8000 - http://www.jmp.com - is supported for both Macintosh and Windows.

Import distribution from clipboard (Stat::Fit): Use this to paste a distribution copied (exported) onto the clipboard from Stat::Fit. A preview of pasted distribution appears below this button.

Open: Opens the currently selected distribution fitting software.

Path: Selects the path for the distribution fitting software. In most cases you can use the default path entered by ExtendSim. You will need to change this, however, if you have installed you distribution fitting software in a non-default location or if you have selected "Other" as your distribution fitting software.

APPENDIX G – EXTENDSIM EQUATION BLOCK

Symbol: 

Purpose:

Outputs the results of an equation entered in the dialog. You can use ExtendSim's built-in operators, functions, and some or all of the input values as part of the equation. The equation can have any number of inputs and any number of outputs. As you expand the Input Variables table, and the Output Variables table, the number of input connectors and output connectors will be expanded automatically.

ExtendSim's operators are: +, -, *, /, ^ (exponentiation), MOD or % (modulus), AND or &&, OR or ||, NOT or !, == (equals), != or <> (not equal), <, <=, >, >=

To define multiple inputs or outputs, click on the resize button on the appropriate table. This button (the green +- icon in the lower right hand corner of the table) will allow you to resize the table to whatever size you wish.

ModL functions from ExtendSim's development environment can be used in equations. Using these functions can greatly expand the range of things that can be done in equations. See the ExtendSim Developers Reference, or the ExtendSim online help (available under the help menu,) for more information about ModL functions.

Options on the options tab allow you to control when the equation block will execute. You can set the block to execute at the simulation initialization, at the end of the simulation, when the 3D window initializes, and several other choices. By default the equation is set to execute when necessary during the simulation.

Each input must be named in the Input Variables table in order to use it in the equation. Each output must be named in the Output Variables table. You can use the default input and output variable names or specify new names. ExtendSim will warn you if an input is used in the equation but it is not connected. This requirement is not the case for outputs. You can define an output variable that is not used in the equation, if desired.

The Equation block is discussed fully in the ExtendSim manual; refer to the manual for more information.

Warning: When doing arithmetic using integer variables, any resulting remainders will be lost.

Input Equation Variables: In addition to the properties on the item, the input variable types that can be defined are _DB Read Value, _DB Read Index, _DB Address, _DB Index, _Static first run init, _Static multi run init, _Connector:

_DB Read Value: This variable gets assigned a value from a fixed location in the ExtendSim database. If the this variable is pointing to a child field, the value assigned to it is from the parent's record value.

_DB Read PRI (Parent Record Index): Similar to the _DB Read Value variable, this variable points to a fixed location in the database. However in this case, the location it points to must be a child. That's because this variable takes on the parent's record index not the parent's record value. Consequently, this variable type can only be used if it is pointing at a child field.

_DB Address: This variable is assigned one or more elements of DB address, e.g., this variable could take on the value of a database index or a database index plus table index plus field index plus a record index. This type of variable can be useful since some ModL database API functions require a DB Address as a parameter.

_DB Index: This variable contains a single DB address reference point, e.g. a reference to a record index only or maybe a field index only.

_Static First Run Init and _Static Multi Run Init: In general, a static variable is a local variable that retains its value between different calculations of the Equation block so they can be used to keep track of values over multiple calculations. The first run init will only initialize to the starting value on the first run of a multi run simulation, while the multi run init wil initialize at the begining of every run.

_Connector: The value of this variable is equal to the value of its associated input connector.

Output Equation Variables: In addition to the properties on the item, the output variable types (equation results) that can be defined are _DB Write Value, _DB Write Index, and _Connector:

_DB Write Value: This variable writes its value to a fixed location in the database. If this variable is pointing to a child field, the value being written must be a value that currently resides in the parent. Otherwise an error message will appear.

_DB Write PRI (Parent Record Index): Similar to the _DB Write Value variable, this variable points to a fixed location in the database. However in this case, the location it points to must always be a child. That's because in this case the value being written in interpreted as a parent's record index. Consequently, if the value being written to the child is less than 1 or greater than the number of records in the parent, an error message will be posted.

_Connector: The value of this variable defines the value for the associated output connector.

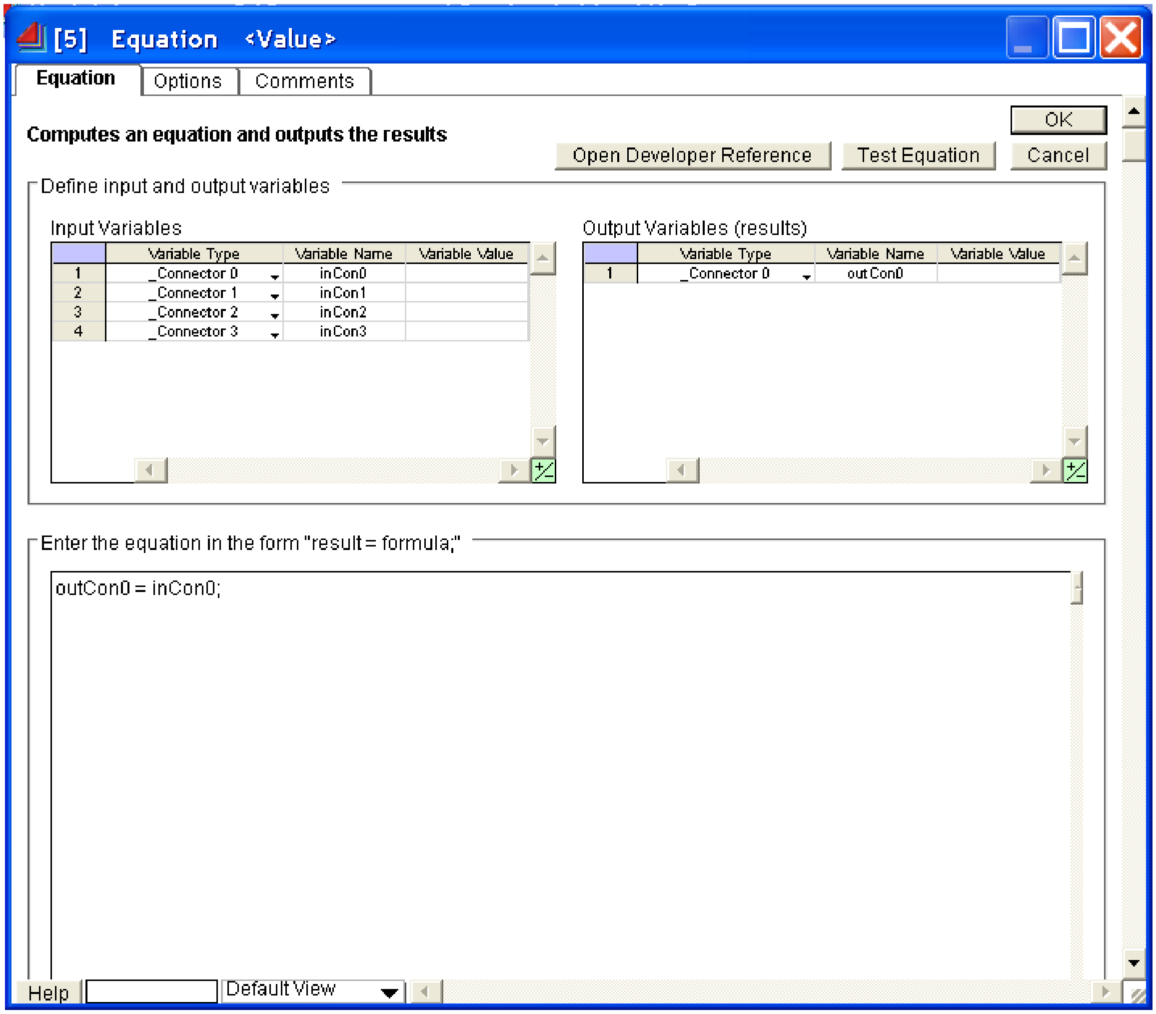
Connecters:

The input connectors correspond to the input variables in the Equation, as defined in the Input Variables table.

The output connectors correspond to the output variables in the Equation, as defined in the Output Variables table.

Tabs:

Equation Tab



Enter the equation...: Type an equation into the text entry box. The variables used in the Input Variables table and the Output Variables table should be used in the equation. Output variables should be assigned values. All input variables defined must be used in the equation.

Input Variables: Each row in this table defines one input variable that can be used in the equation. See the descriptions of the columns of the table to see how to define the variables.

Input Variables table Column 1 (Variable Type): This column of the table allows you to define the type of the input variable defined by this row. See above for the list of types that can be defined for inputs. Clicking on a cell will pop up a popup menu listing the possible types.

Input Variables table Column 2 (Variable Name): This column of the table allows you to define the name of the input variable defined by this row. This is the variable name that can be used in the text of the equation. Clicking on the cell will allow you to edit the variable name.

Input Variables table Column 3 (Variable Value): This column of the table displays different things for different Variable types. For Connector variables, it will display the last value that was present at the connector. For DB Read, DB Attribute, and DB Index types it will display a database reference, and can also be used to edit that reference by clicking on the cell. For Static Variable types, it displays both the initialization value for the static variable, and the current value of the static variable. The number to the left of the colon will be the initialization value, and the number to the right of the colon is the current value. Clicking on the cell will allow you to edit the initialization value.

Output Variables: Each row in this table defines one output variable that can be used in the equation. See the descriptions of the columns of the table to see how to define the variables.

Output Variables table Column 1 (Variable Type): This column of the table allows you to define the type of the output variable defined by this row. See above for the list of types that can be defined for outputs. Clicking on a cell will pop up a popup menu listing the possible types.

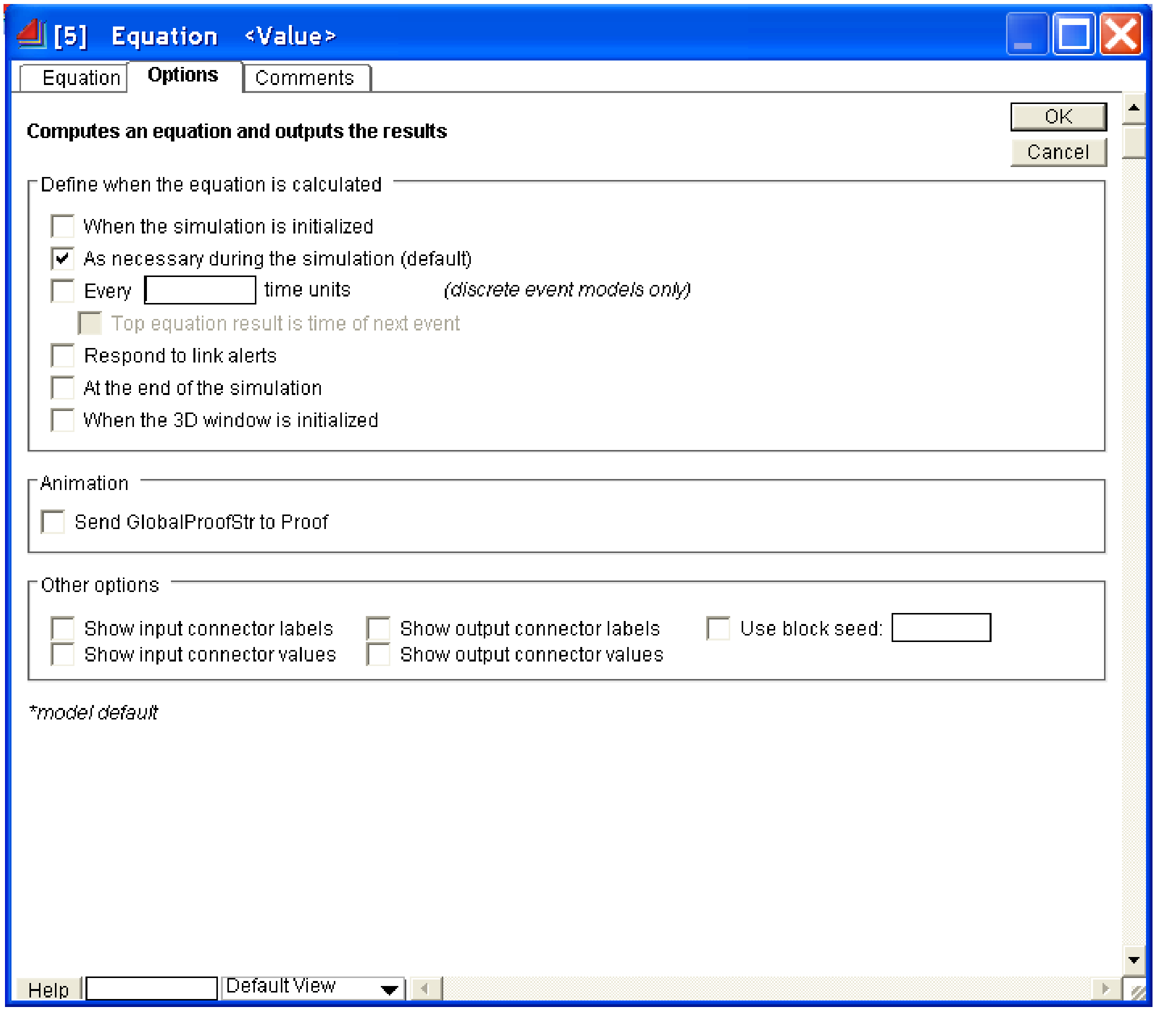
Output Variables table Column 2 (Variable Name): This column of the table allows you to define the name of the output variable defined by this row. This is the variable name that can be used in the text of the equation. Clicking on the cell will allow you to edit the variable name.

Output Variables table Column 3 (Variable Value): This column of the table displays different things for different Variable types. For Connector variables, it will display the last value that was output at the connector. For DB Write types it displays a database reference, and can also be used to edit that reference by clicking on the cell.

Test Equation: Clicking on this button will execute the equation.

Open Developer Reference: Clicking on this button will open the Developer Reference.

Options Tab



As necessary during the simulation (default): If this checkbox is checked, the equation will be executed during the simulation, as necessary. This means when a message comes into the block in a DE model, and on each step in a continuous model.

At the end of the simulation: If this checkbox is checked, the equation will be executed when the simulation ends.

Every __ time units: This option allows you to specify that the equation should be executed every Nth time unit during the model run. This option is only allowed in Discrete Event models.

Respond to link alerts: This option will cause the equation to be executed if one of the variable inputs is associated with a DB Read and if the data in the DB cell has changed.

Send GlobalProofStr to Proof: Assign a Proof command to GlobalProofStr to be sent to Proof. For example the equation:

```
outCon0 = inCon0;
GlobalProofStr = "WRITE ARRIVALS "+ outCon0;
```

would send a write command to Proof to change the Arrivals message to the value of inCon0. This can be used to send virtually any Proof command. This option is available if Proof is installed.

Show input connector labels: Shows labels on the input connectors.

Show input connector values: Shows values on the input connectors.

Show output connector labels: Shows labels on the output connectors.

Show output connector values: Shows values on the output connectors.

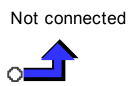
Top equation result is time to next event: This option is associated with the every __ time unit's option. If this checkbox is checked, the top equation result will be used as the time to the next event. So each time the Equation is executed, the next time the equation is to be executed will be set by the top equation result.

Use block seed: This option allows you to set a block seed for the equation. This is only relevant if the block accesses random number functions.

When the 3D window is initialized: If this check box is checked, the equation will be executed when the E3D window is initialized.

When the simulation is initialized: If this check box is checked, the equation will be executed when the simulation is initialized.

APPENDIX H – EXTENDSIM THROW BLOCK

Symbol: 

Purpose:

This block sends flow received by Catch Blocks or Merge blocks even though the blocks aren't connected by connection lines. The connection between the blocks is made in the dialog of the blocks by specifying in its dialog the label and block number of the block to connect.

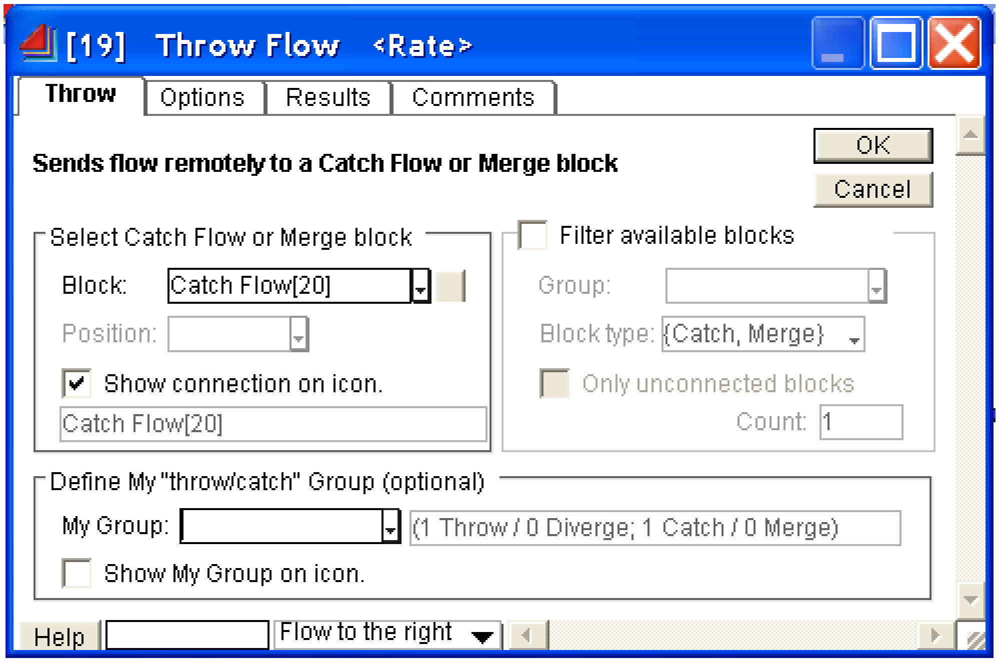
The Throw Flow and Catch Flow blocks (and the Merge and Diverge blocks in certain modes as well) can be used to move flow without the use of connection lines. By creating a throw/catch connection via block dialogs, flow can be routed from a throwing type block to any catching type block in the model.

Connecters:

The input connector corresponds to the input flow which needs to be thrown.

Tabs:

Throw Tab



Block: This field is used to select the Catch or Merge block you want to throw to. The block number can be typed directly into the dialog or can be selected in the popup list on the right of the dialog item.

Position: If throwing to a Merge block, a position (i.e., a Merge branch) must be chosen because Merge blocks can have more than one catch branch. The position can be typed directly into the dialog or can be selected in the popup list on the right of the dialog item.

Show connection on icon: If this checkbox is checked, the catch type block you've selected this block to throw to will be displayed above this block's icon.

Filter available blocks: This checkbox enables the filtering capabilities. Since there can be many throw and catch type blocks in a model, it can be useful to organize them into groups. This can be used to create filtered lists or subsets of catch type blocks your Throw block can see.

Group: This is where you can choose a group to filter the list of catch type blocks that your Throw block can select.

Block type: This popup allows you to use block type to limit the list of potential catch type blocks your Throw block can select.

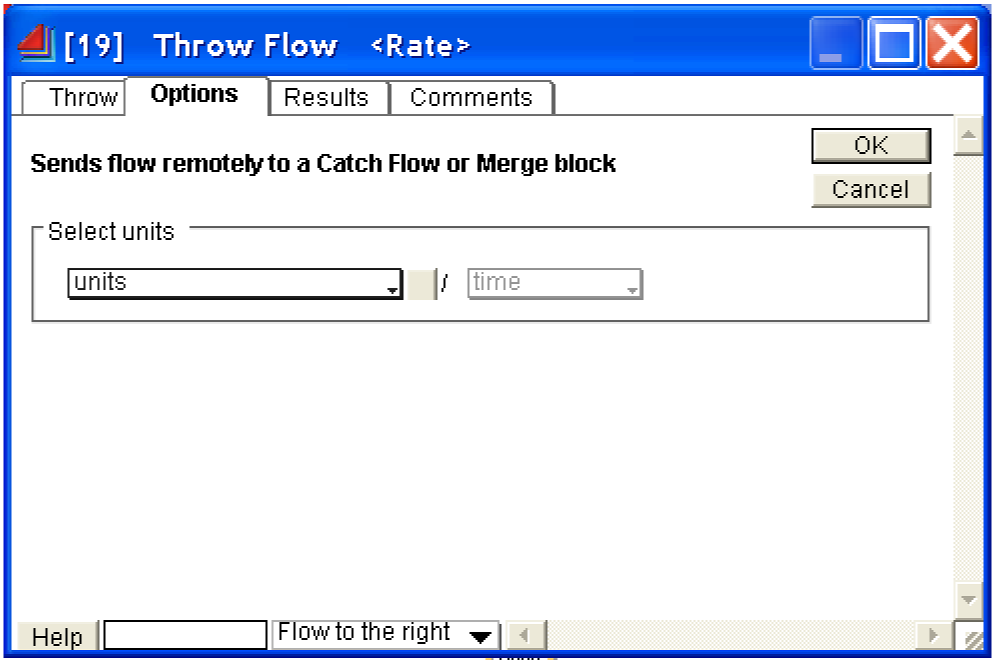
Only unconnected blocks: This checkbox further limits the list of potential catch type blocks to those blocks that have not already been assigned a "Throw/Catch" connection.

Count: This field displays the number of potential catch type blocks available to this Throw block.

My Group: This is where you assign your Throw block to a group. This is useful if you want the catch type blocks in your model to see a list of potential Throw blocks filtered by Group.

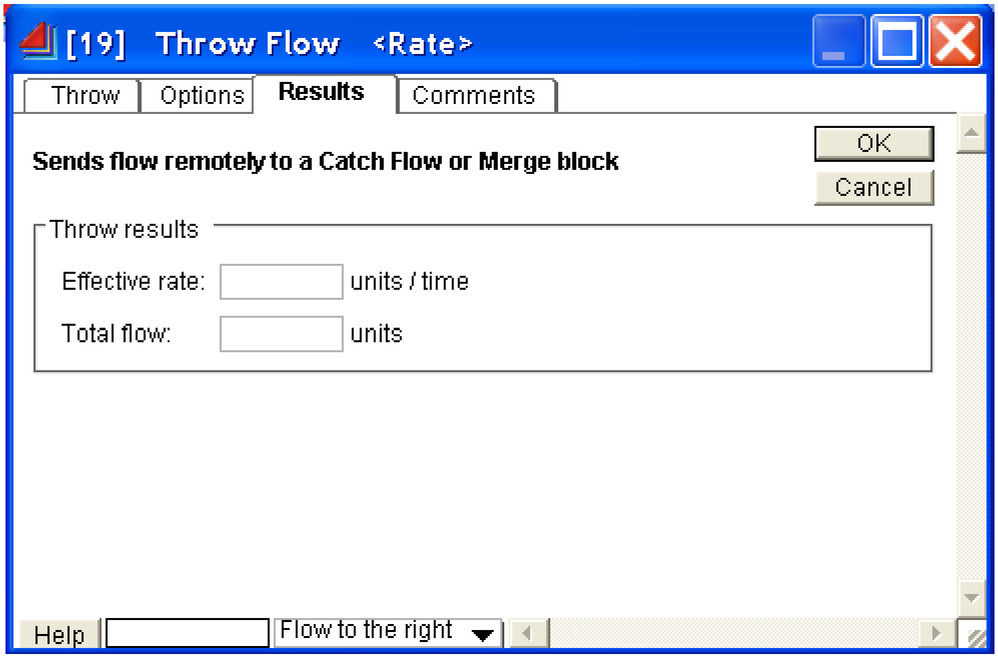
Show My Group on icon: If this checkbox is checked, the My Group selection will be displayed above this block's icon.

Options Tab



Select units: In the "Select units" frame, the first popup allows the user to choose the flow units for all the blocks residing in this block's unit group by either selecting an existing flow unit category or by creating a new one. A unit group is a collection of blocks connected together through flow connections and sharing the same flow unit. Notice that once you've made your selection here, the flow units for all blocks in this unit group will have changed. When the square button to the right of this popup menu is pressed, all blocks included within this block's unit group are selected. The second popup allows the user to define the time units for this particular Bias block.

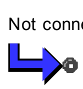
Results Tab



Effective rate: This field displays the current effective rate of flow through this particular Throw block.

Total flow: This field displays the total volume of flow that has passed through this particular Throw block.

APPENDIX I – EXTENDSIM CATCH BLOCK

Symbol: 

Purpose:

This block catches flow sent by Throw Blocks or Diverge blocks even though the blocks aren't connected by connection lines. The connection between the blocks is made in the dialog of the blocks by specifying in its dialog the label and block number of the block to connect.

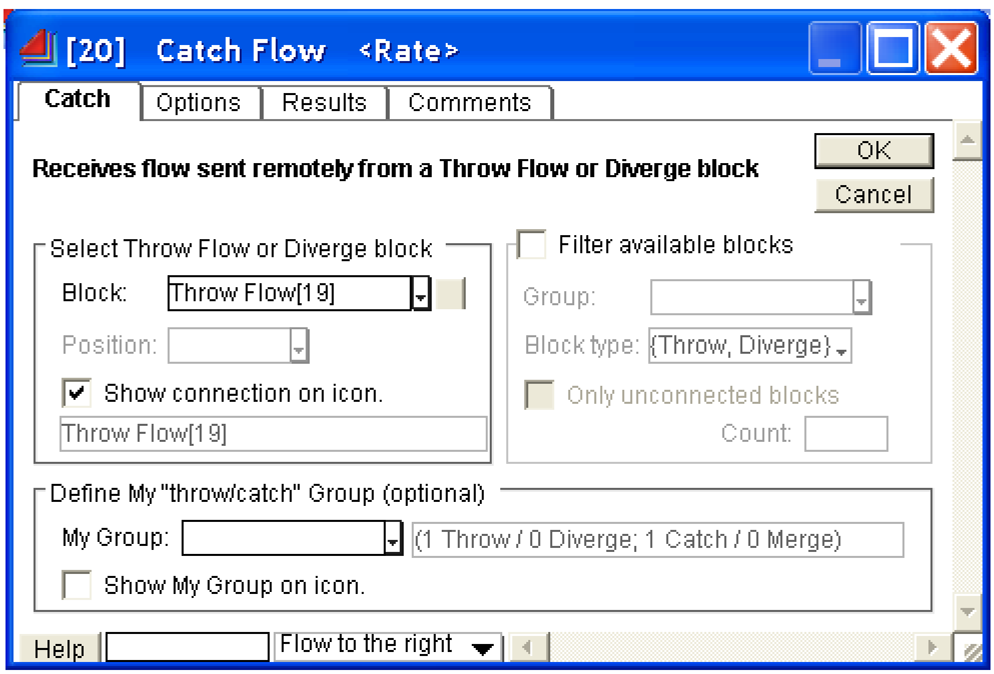
The Throw Flow and Catch Flow blocks (and the Merge and Diverge blocks in certain modes as well) can be used to move flow without the use of connection lines. By creating a throw/catch connection via block dialogs, flow can be routed from a throwing type block to any catching type block in the model.

Connecters:

The output connector corresponds to the output flow which needs to be caught.

Tabs:

Catch Tab



Block: This field is used to select the Throw or Diverge block you want to catch from. The block number can be typed directly into the dialog or can be selected in the popuplist on the right of the dialog item.

Position: If catching from a Diverge block, a position (i.e., a Diverge branch) must be chosen because Diverge blocks can have more than one throw branch. The position can be typed directly into the dialog or can be selected in the popuplist on the right of the dialog item.

Show connection on icon: If this checkbox is checked, the throw type block you've selected for this block to catch from will be displayed above this block's icon.

Filter available blocks: This checkbox enables the filtering capabilities. Since there can be many throw and catch type blocks in a model, it can be useful to organize them into groups. This can be used to create filtered lists or subsets of throw type blocks your Catch block can select.

Group: This is where you can choose a group to filter the list of throw type blocks that your Catch block can select.

Block type: This popup allows you to use block type to limit the list of potential throw type blocks your Catch block can select.

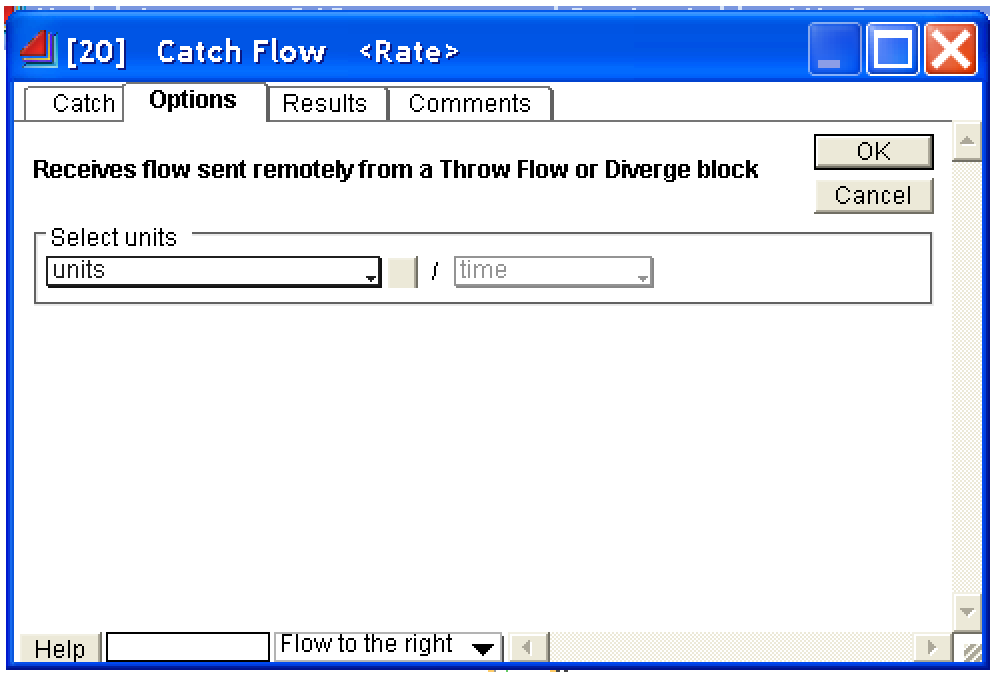
Only unconnected blocks: This checkbox further limits the list of potential throw type blocks to those blocks that have not already been assigned a "Throw/Catch" connection.

Count: This field displays the number of potential throw type blocks available to this Catch block.

My Group: This is where you assign your Catch block to a group. This is useful if you want the throw type blocks in your model to see a list of potential Throw blocks filtered by Group.

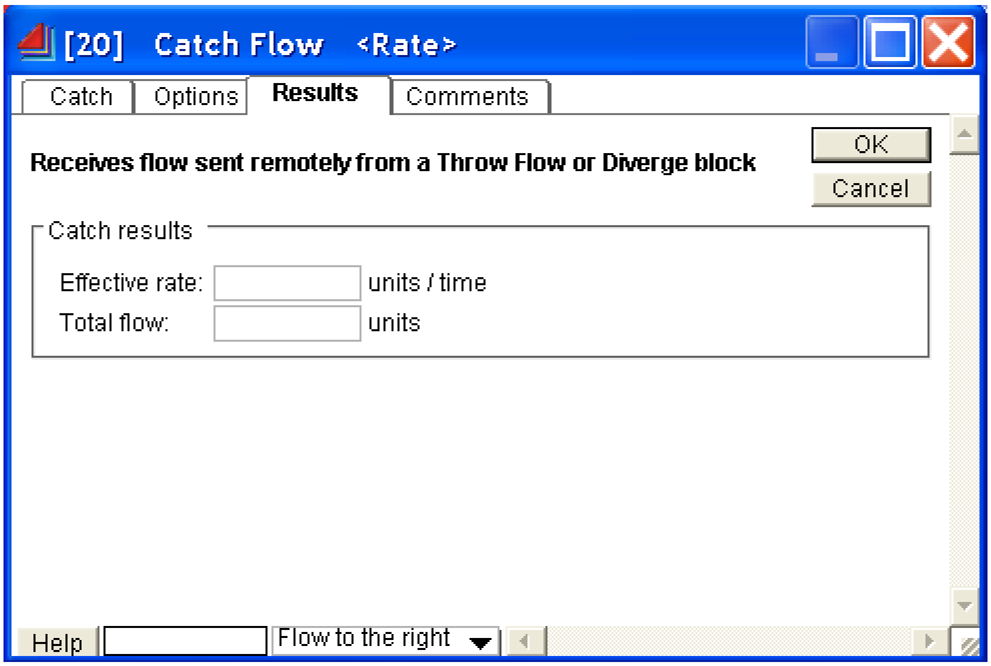
Show My Group on icon: If this checkbox is checked, the My Group selection will be displayed above this block's icon.

Options Tab



Select units: In the "Select units" frame, the first popup allows the user to choose the flow units for all the blocks residing in this block's unit group by either selecting an existing flow unit category or by creating a new one. A unit group is a collection of blocks connected together through flow connections and sharing the same flow unit. Notice that once you've made your selection here, the flow units for all blocks in this unit group will have changed. When the square button to the right of this popup menu is pressed, all blocks included within this block's unit group are selected. The second popup allows the user to define the time units for this particular Bias block.

Results Tab



Effective rate: This field displays the current effective rate of flow through this particular Catch block.

Total flow: This field displays the total volume of flow that has passed through this particular Catch block.

APPENDIX J – SAMPLE OF CUSTOM BLOCK CODE IN MOD-L

This block receives values from a spreadsheet. One selects the file to read values from by typing its path name, or one can leave the name blank so ExtendSIM prompt's for the name and fills in the path name. By typing in the sheet name, one may read the values from a specific sheet in the workbook. If the "Sheet name" is left blank, the values will be read from the top sheet. This block reads in the value at the cell defined by the values at the row and column connectors.

SAMPLE MOD-L CODE:

```
procedure GetNewEmbeddedWorkbookID()
{

        integer i,j;
        integer numbEmbeddedWorkbooks;
        integer workbookFound;
        string nextWorkbookName;
        integer lengthNextWorkbookName;
        string svWorkbookID;
        integer numberFound;
        string svTestNumber;
        real rvWorkbookID;

        if(badChosenEmbeddedWorkbookID == OLD_EMBEDDED_ID_DISABLED  ||
useEmbeddedWorkbook_CB == FALSE)
                return;
```

```
	XL_BuildEmbeddedWorkbookLists();			//build		up
embeddedWorkbookBlockNumsList, embeddedWorkbookNamesList

	numbEmbeddedWorkbooks							=
GetDimension(embeddedWorkbookBlockNumsList);
	//find	which	embedded	workbook	corresponds	to
badChosenEmbeddedWorkbookID
	i = 0;
	workbookFound = FALSE;
	while(i < numbEmbeddedWorkbooks  &&  workbookFound == FALSE)
		{
		nextWorkbookName = embeddedWorkbookNamesList[i];
		lengthNextWorkbookName = StrLen(nextWorkbookName);
		svWorkbookID = "";
		numberFound = FALSE;

		//start at end of workbookName and work back until run into a "non-
number" char
		for(j=1; j<=lengthNextWorkbookName; j++)
			{
			svTestNumber		=		StrPart(nextWorkbookName,
lengthNextWorkbookName - j, j);
			if(StrToReal(svTestNumber))
				{
				numberFound = TRUE;
				svWorkbookID = svTestNumber;
				}
			else
				break;
```

```
                }
            if(numberFound == TRUE)
                rvWorkbookID = StrToReal(svWorkbookID);
            else
                rvWorkbookID = 0;
            if(rvWorkbookID == badChosenEmbeddedWorkbookID)
                workbookFound = TRUE;
            i++;
            }//while(i < numbEmbeddedWorkbooks  ||  workbookFound == FALSE)
        if(workbookFound == TRUE)
            chosenEmbeddedWorkbookID   =   embeddedWorkbookBlockNumsList[i-
1];
        else
            chosenEmbeddedWorkbookID                                        =
NO_EMBEDDED_WORKBOOK_CHOSEN;
        badChosenEmbeddedWorkbookID = OLD_EMBEDDED_ID_DISABLED;
}//procedure GetNewEmbeddedWorkbookID()


procedure ReceiveData()
{
        TranslateRowColumnIndices(rowIndex, columnIndex);

        if(!useEmbeddedWorkbook_CB  &&  !FileIsOpen(externalWorkbookName_ET))
            OpenFile();

        if(connectionType_POP      ==      DDE_OR_APPLE_EVENTSCONNECTION)
        //02/14/03
            {
```

```
if (sheetName_ET == "")
        conversation = IPCConnect(server,externalWorkbookName_ET);
else
        {
        setSheetStrng();
        conversation = IPCConnect(server,sheetStrng);
        }

if (!conversation)
        {
        userError("Extend failed to connect with "+server+". "+server+" may have been busy opening the spreadsheet "+
        "when connection was attempted. Try running simulation again. Call Technical Support if this occurs repeatedly.");
        abort;
        }

DataOut = strToreal(IPCRequest(conversation,svRowColumn));
datarec = DataOut;
IPCDisconnect(conversation);
Conversation = 0;
}

else if(connectionType_POP == OLE_CONNECTION)
{
worksheetRangeObjectHandle = XL_GetRangeObjectHandle();
DataOut = DoPropertyGetReal(worksheetRangeObjectHandle, _EXCEL_RANGE_VALUE);
datarec = DataOut;
```

```
        }

}//procedure ReceiveData()

// This message occurs for each step in the simulation.
on simulate
{
    if (!advise && !discrete && (!triggerCon || (triggerCon && triggerIn > 0.5)))
        ReadVal(TRUE);
    if (advise)
        dataOut = dataRec;
}

on dataOut
{
    if ((readWhen == Out OR readWhen == Any) && !StartOnly)
        {
        if (triggerCon)
            {
            sendMsgToOutputs(triggerIn);
            if (triggerIn < 0.5)
                return;
            }
        if(RowCon)
            {
            sendMsgToOutputs(rowIn);
            rowIndex_P= RowIn;
            }
        if(ColCon)
```

```
                {
                sendMsgToOutputs(colIn);
                columnIndex_P = ColIn;
                }
        ReadVal(TRUE);
        }
}

on RowIn
{
    if (readWhen == RowCol OR readWhen == Any)
        {
        if (triggerCon)
                {
                sendMsgToOutputs(triggerIn);
                if (triggerIn < 0.5)
                        return;
                }

        if(ColCon)
                sendMsgToOutputs(colIn);

        ReadVal(TRUE);

        sendMsgToInputs(DataOut);
        }
}

on ColIn
```

```
{
	if (readWhen == RowCol OR readWhen == Any)
		{
		if (triggerCon)
			{
			sendMsgToOutputs(triggerIn);
			if (triggerIn < 0.5)
				return;
			}

		if(RowCon)
			sendMsgToOutputs(rowIn);

		ReadVal(TRUE);
		sendMsgToInputs(DataOut);
		}
}

on triggerIn
{
	if (triggerIn < 0.5)
		return;
	if(RowCon)
		{
		sendMsgToOutputs(rowIn);
		rowIndex_P= RowIn;
		}
	if(ColCon)
		{
```

```
			sendMsgToOutputs(colIn);
			columnIndex_P = ColIn;
			}
		ReadVal(TRUE);
		sendMsgToInputs(DataOut);
}


on BlockReceive0
{
		if(FirstTime)
			{
			if(RowCon)
				{
				sendMsgToOutputs(rowIn);
				RowIndex_P= RowIn;
				}
			if(ColCon)
				{
				sendMsgToOutputs(colIn);
				ColumnIndex_P = ColIn;
				}
			ReadVal(FALSE);
			}
		SetDialogVariable(cloneInjectedBlockNumber_P,cloneInjectedDialogVariable_E
T,dataOut,0,0);
}
```

```
// If the dialog data is inconsistent for simulation, abort.
on checkdata
{
//		12/19/02 6.0 DJK added deletion of global arrays storing conversation information in checkdata
	if(GaGetIndex("IPCCon") >= 0)
		GADispose("IPCCon");
	if(GaGetIndex("IPCFile") >= 0)
		GADispose("IPCFile");
	advise = FALSE;
	rowCon = rowIn;
	colCon = colIn;
	triggerCon = triggerIn;
	if (!rowCon)
	{
		if (noValue(rowIndex_P))
		{
			usererror("Data Receive Block number "+myNumber+" is missing cell location parameter.  \
			Please use the row and column connectors or enter values for the begining row and column in the block dialog.");
			abort;
		}
	}
	if (!colCon)
	{
		if (noValue(columnIndex_P))
```

```
        {
                usererror("Data Receive Block number "+myNumber+" is missing cell location parameter.  \
                Please use the row and column connectors or enter values for the begining row and column in the block dialog.");
                abort;
        }
    }

    if(!useEmbeddedWorkbook_CB)
        {
        if(externalWorkbookName_ET  ==  "")
            {
            UserError("Please choose a workbook for Data Receive block number " +
                            MyBlockNumber() + ".");
            abort;
            }

        else if(!FileIsOpen(externalWorkbookName_ET))
            OpenFile();
        }

    exec                        = sysGlobalint1;                    // the id number of the exec block**
```

APPENDIX K – SAMPLE DATA FOR FICTIONAL EXAMPLE AND USE OF THE MODEL

Day	Feed	Scooping		Hauling (OP)		Mucking		Hauling (UG)		Crushing		Skipping	
		In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
1	7067	4075	7462	4780	4780	4813	5883	3488	4550	4780	7046	4194	6453
2	6806	3090	4473	4483	6467	5305	6557	3929	4800	4483	7086	4566	6466
3	7294	4825	5778	5454	6709	4377	6103	5633	5259	5454	5454	4092	7578
4	5997	3116	4967	4238	6605	5144	6545	4083	5168	4238	6505	6000	6214
5	7175	3456	6124	4429	5554	6206	6539	4808	6897	4429	7180	3631	7888
6	6545	3704	5696	4878	7717	4942	4942	4585	5813	4878	5186	4544	5945
7	6060	3000	6626	4028	5857	5526	6862	4173	7425	4028	6229	3831	6740
8	7933	4161	6782	4961	4961	4756	6320	3444	5312	4961	6108	5314	4941
9	6778	5201	5988	4707	5661	5161	5843	3570	5580	4707	4707	5534	7743
10	7047	3024	7401	4269	7186	5698	7315	4317	7992	4269	5303	4060	6127
11	7622	2297	5770	3807	6275	4617	4401	3358	4989	3807	6061	4496	6551
12	6730	2889	5637	4144	7026	5596	5117	4282	5573	4144	5863	4467	5513
13	5869	4486	5716	5821	7753	2822	6514	1712	4786	5821	5544	5337	6456
14	7403	3452	5462	4761	7057	5327	6519	5273	6584	4761	8009	2468	7405
15	6039	3671	6236	4848	6281	5357	5711	3901	7841	4848	5400	4559	6558
16	7186	4401	5135	5942	6912	4548	6441	3417	6240	5942	6556	4160	6332
17	6700	2191	6333	3495	7094	5324	5605	4514	6611	3495	6671	5076	6214
18	7101	3842	8643	4062	4062	4168	7179	2707	7161	4062	6573	5261	5864
19	7668	5203	4717	5167	5167	4132	5604	2828	6189	5167	6815	4497	8040
20	7313	2296	5799	3496	7132	4528	5122	4722	6904	3496	5557	3601	4788
21	7388	4128	5660	5131	7087	5378	5378	4855	6965	5131	5606	3833	8134
22	5939	2222	6046	3340	5876	6062	5542	4427	6177	3340	5381	4258	6636

23	7234	3335	6774	4580	6615	4980	6509	4626	3545	4580	7514	4055	6636
24	7592	3264	8587	4414	6075	4986	4986	5039	6162	4414	5037	3986	6488
25	7436	2391	6623	3531	7529	4107	7449	2843	4896	3531	5968	4034	6483
26	7338	5307	6643	5166	5934	5084	5292	4524	6513	5166	5166	4208	5202
27	7106	2618	5987	4079	7149	4506	6209	3113	5640	4079	6037	5289	4996
28	6772	5395	5904	6373	7448	4953	4892	3551	8255	6373	6037	4393	6869
29	7371	3518	4317	4482	4482	5609	7141	4260	5426	4482	6835	3375	7552
30	7192	2957	7939	4278	5009	4396	5794	2974	6430	4278	6542	5129	7844
31	8116	3609	7071	5114	5973	3007	5611	1869	6155	5114	5982	5779	5853
32	7363	4508	8386	5624	6309	3560	5973	2079	4215	5624	5907	3590	6861
33	6740	3530	7218	4998	5130	5280	5946	4143	8190	4998	5711	3493	7687
34	6395	4109	6144	5196	5744	4307	5242	2862	6526	5196	5323	5094	5992
35	5645	4197	6254	4524	4524	6535	6994	5124	5880	4524	5249	4184	7291
36	6234	3558	6431	4945	6998	4273	5525	2751	7515	4945	5157	4357	5098
37	5795	4337	7826	5490	5915	5591	5919	4268	5122	5490	6697	4913	6444
38	6501	4947	4421	5561	5523	4143	5206	2712	6559	5523	6665	4319	7369
39	8130	2938	5253	4049	7559	4649	5461	3341	5479	4049	6925	4805	6421
40	6726	3645	4781	4791	5088	4794	5496	3466	5616	4791	7378	4680	6056
41	5889	3476	6572	4701	7265	5102	7982	3819	5408	4701	6701	4609	5644
42	5358	2981	6111	4227	6275	4344	7331	3093	5114	4227	6143	5364	6860
43	6583	3050	6907	4225	7712	5466	5933	4250	5955	4225	7448	4565	4565
44	7243	3308	8910	4772	5962	4731	5702	4608	5021	4772	7598	3758	5462
45	6409	2987	4677	4279	4995	4603	6033	3080	5273	4279	4070	5881	5909
46	8208	2873	4487	4154	6433	3789	6250	2656	4886	4154	6982	2287	6017
47	8349	2539	7863	3861	5695	3448	5165	2110	4615	3861	5906	5847	5519
48	6362	2919	8159	4202	6984	5183	5340	3511	5773	4202	5051	4354	5719
49	6569	3495	8459	4878	6660	4428	8120	2945	6047	4878	7431	5403	4881

50	6259	4077	5679	5523	6396	5026	4649	3592	6553	5523	6809	5017	5854
51	7025	4051	5957	5281	7174	3591	5020	2450	5147	5281	6290	4892	4949
52	6969	5042	5516	4662	4662	4201	5639	2846	5588	4662	5880	5202	6045
53	7090	2915	5168	3999	7870	5472	5472	5356	6871	3999	6638	3782	6297
54	7394	3641	5048	4916	7433	5897	6108	4714	5956	4916	4622	4196	6164
55	7705	4725	4905	5860	5753	5880	6106	5521	5147	5753	5908	4152	6904
56	6360	3059	5644	4119	6222	4247	6763	2822	6024	4119	6468	4714	5480
57	8320	3035	6253	4093	6234	4823	4823	4759	4905	4093	4681	4717	5403
58	7497	3896	7582	5350	6266	4722	5959	3124	5454	5350	5904	5272	5272
59	7231	3213	6754	4635	4985	6685	7168	5631	7059	4635	6375	4229	7513
60	6673	2828	6180	4232	7654	4185	5346	2870	6365	4232	5370	5277	6287
61	6786	2871	7708	4286	7479	5374	6276	3670	6875	4286	7350	4334	7595
62	7350	4742	7762	5937	7014	4850	7590	3458	5598	5937	6371	3918	4368
63	7582	2545	6993	4021	5949	6094	7043	4621	5434	4021	5991	5528	5897
64	7212	4190	6982	4846	4846	4892	5851	3516	6047	4846	5957	6114	6276
65	6429	2749	5238	3902	8047	4526	8022	3443	7643	3902	7583	5067	5369
66	7501	3293	8266	4585	7121	4610	5434	3332	7705	4585	6550	4798	7937
67	7070	2759	5912	4055	5837	5966	8317	4230	6613	4055	5126	3939	6344
68	6913	1987	5532	3275	7296	5476	5933	4138	6838	3275	5561	4639	7280
69	6125	2720	7121	4032	4590	3570	6658	2369	5966	4032	6468	4852	7484
70	7041	2614	7134	3783	7106	4480	6365	3276	8230	3783	7270	3709	7805
71	7670	3223	7962	4271	4790	4341	7814	2981	6041	4271	5926	3904	4589
72	7355	3821	5399	4664	4664	4871	5213	3528	8536	4664	5840	5377	4884
73	7737	4849	5319	6096	6162	5740	7235	4516	4631	6096	7463	4092	7045
74	6344	4691	7987	5910	5944	6976	6383	5552	8237	5910	5998	5135	6502
75	7024	3644	5806	4716	5012	4221	5606	2963	6641	4716	5577	4000	7385
76	6218	2582	6525	3666	6684	5079	7400	3585	6431	3666	7043	4330	6249

77	6217	3371	6021	4717	4861	4569	6320	3407	5752	4717	6254	5214	5464
78	6977	5022	7840	6446	6381	4344	5353	2787	5791	6381	6796	6572	6281
79	6777	2929	6856	4346	7627	5570	6522	3959	5398	4346	6220	4081	5946
80	7733	3744	8063	5215	6988	4335	4335	5192	4650	5215	6970	3658	6896
81	8236	4035	8775	5264	6929	4881	6800	3444	7462	5264	5842	4315	6946
82	7180	3633	5752	4993	5705	4268	4782	2691	5880	4993	6576	4750	6182
83	7150	1575	7851	2777	7016	4202	5869	2922	4868	2777	6331	4861	4956
84	7396	3629	6707	4958	7863	5285	6074	3841	5925	4958	6399	4755	6721
85	7073	2873	7850	4096	6352	2947	6339	1604	8007	4096	6739	5189	7499
86	6473	3132	7941	4375	6470	4596	6289	3416	6137	4375	7077	3690	5270
87	6718	3921	6801	5325	6886	3561	5342	1962	7050	5325	5933	4811	7480
88	6272	3999	8334	4988	6068	5347	5347	4535	6691	4988	5775	4720	5629
89	7645	3103	6427	4386	6125	4888	6998	5005	8532	4386	6381	3944	7381
90	6572	4072	7331	5260	6875	5429	5421	4136	6482	5260	5490	5563	5324
91	6460	3984	4417	5440	7392	4944	7346	4433	6259	5440	5478	5397	5397
92	7168	3989	5526	5303	7229	5635	5488	4353	5267	5303	7772	4498	6498
93	5720	3050	4085	4416	5440	4615	5526	3069	6994	4416	5997	4276	7188
94	5746	3711	5554	4729	7163	4849	5921	3631	5566	4729	6967	5452	7105
95	7480	3079	5380	4395	6199	4275	7436	3158	6579	4395	6942	4482	5771
96	6297	4378	6718	5749	6619	5696	8199	4170	6164	5749	6518	3872	6337
97	6838	3656	6361	4901	6053	4475	5390	2990	7085	4901	8215	4512	6144
98	6553	2578	6628	4013	6850	3786	7315	2504	7605	4013	6721	4874	5461
99	7506	2027	4991	3445	6961	6176	6119	4964	7414	3445	4502	4717	4867
100	7208	4548	5755	5369	5369	4107	7696	2821	5645	5369	5918	5624	6907
101	7763	2545	7855	3800	6755	3684	5217	2373	7035	3800	5495	5825	7569
102	7281	2788	6707	4155	6406	5256	8265	4028	5425	4155	5232	3980	6460
103	7665	4541	7598	5902	7197	4078	4408	2649	6312	5902	5693	5635	5764

104	7006	2751	5889	4043	6460	5748	5748	5064	6765	4043	6946	4133	5749
105	6413	4085	5074	5274	7936	5836	5473	5925	4522	5274	6473	5863	6940
106	7930	3650	5787	4663	7240	4845	6071	3477	5980	4663	5984	4188	5765
107	7153	3900	5032	5304	6130	4694	5456	3403	5489	5304	6618	5152	6574
108	7030	2537	4100	3624	5813	4781	5188	3251	8035	3624	7007	5364	5708
109	7350	2833	4345	3969	5301	5166	6373	3465	6684	3969	6681	4953	6665
110	7260	3501	6508	4732	4644	4864	5487	3786	7666	4644	5202	5760	6022
111	7360	3411	5769	4920	7597	4896	6148	3312	5859	4920	6742	4070	5277
112	6542	4387	5767	5670	7008	5264	6645	3701	6100	5670	5919	4913	6102
113	5952	4517	5040	5683	6887	4923	5367	3518	6849	5683	5826	4400	5821
114	8303	4418	6690	5869	5803	5476	5274	4267	3991	5803	6559	6423	5938
115	6713	3442	7328	4946	6898	5099	6472	4992	7056	4946	6179	4443	5655
116	6913	3165	6861	4619	4915	3836	5601	2513	7758	4619	6303	4840	5352
117	7398	2579	6461	3891	5033	5674	6895	4273	5727	3891	5784	4165	5322
118	6601	3720	5207	4913	5865	5317	5799	4594	7266	4913	5282	3615	5605
119	7464	2804	8137	4010	6387	4896	7802	4968	6330	4010	6092	4590	5471
120	8027	4357	4030	5518	6996	4897	4901	3743	5599	5518	7207	6065	5804
121	7461	4550	4856	5384	5384	4956	6439	3695	5225	5384	4785	3625	5937
122	7537	4106	6339	5254	7024	5014	5014	4558	6631	5254	7558	4583	6810
123	6636	3532	6413	4682	6352	4966	5276	3588	7331	4682	6422	4938	6605
124	6615	5149	5326	6569	7767	4787	4532	3490	8570	6569	6554	5077	5077
125	6759	3287	4831	4513	5434	4399	6740	3197	6974	4513	5764	4817	6517
126	7318	3850	5848	5101	7595	4558	4558	4500	5609	5101	6206	4691	6045
127	7508	3003	5184	4146	7519	4622	5588	4880	6253	4146	6221	4149	5954
128	5788	3260	7153	4399	6533	4967	5480	3380	7458	4399	5625	4739	4739
129	6470	3352	5955	4555	5002	6303	7607	4827	7221	4555	6779	5774	6251
130	7059	3226	6139	4505	6974	4148	4233	2652	8170	4505	6323	4381	6350

131	7092	3618	5546	5153	7280	6189	5730	4814	7650	5153	5256	4613	6799
132	7359	3868	5557	5033	7161	4640	7501	3244	5844	5033	4681	4054	6724
133	6989	2793	7229	3887	7004	3993	6604	2781	5503	3887	4912	5080	6401
134	8137	2475	6036	3737	6825	6382	5886	4984	6338	3737	6570	3809	5846
135	6914	4808	5512	5962	7393	5324	6281	3898	4309	5962	6707	4986	4641
136	7168	4352	8053	5450	6997	4670	7378	3140	6074	5450	5321	5774	7175
137	6283	2926	6930	4072	7592	5222	6134	3548	4805	4072	6716	3719	6477
138	7296	1987	6934	3483	7532	4704	5844	3475	6120	3483	5892	4774	4695
139	8346	3738	6576	4854	7076	5451	7339	4069	6140	4854	6092	4501	5708
140	7687	4683	5835	4336	4336	3521	4738	2277	4075	4336	4463	4860	4860
141	6115	3402	4662	4498	5527	3942	6519	2503	5510	4498	7287	2909	6696
142	7121	2880	6641	4025	6879	4786	4490	3408	4661	4025	5606	5103	5023
143	7090	3148	4368	4512	7308	5272	6496	3576	5059	4512	8183	4715	6409
144	7779	2535	5398	4050	7740	5498	6263	4172	4996	4050	7365	5088	5088
145	5889	3631	7035	4855	7278	6040	5892	4487	6932	4855	5642	2911	4938
146	7032	3860	7076	5347	5882	4348	6190	3085	6686	5347	6186	6252	8267
147	6194	3827	6399	5007	7855	6251	6053	4833	6782	5007	6159	4053	6499
148	7083	4077	6577	5110	5771	4768	4320	3395	6226	5110	4599	5562	7339
149	6858	4065	8086	5356	5511	4039	6576	2596	6543	5356	6168	4259	6378
150	7070	2687	5057	3848	6913	5724	5724	5774	5441	3848	6585	5648	5648
151	7155	3377	7100	4543	6890	6190	6626	4754	6577	4543	5989	6006	6918
152	7076	4807	5048	5638	5638	4614	7933	3143	7238	5638	5773	4599	5710
153	6562	3390	4498	4948	6601	6228	6020	5006	7398	4948	6788	3973	6477
154	6084	3358	5327	4603	7978	4857	4884	3383	8266	4603	6544	4349	6047
155	6265	4099	8258	5272	5847	4348	4763	2757	6135	5272	5879	4826	6419
156	6666	2951	8619	4157	7475	5018	4728	3590	5727	4157	8399	5634	7238
157	6945	2893	4895	4145	7407	5277	5277	5010	6347	4145	8339	3493	6075

158	7349	3930	6220	5285	6045	4306	5332	2965	5868	5285	5237	2789	7951
159	7722	3999	7629	5206	7469	3318	8075	2077	6508	5206	6407	3409	5962
160	6431	2962	7140	4091	4179	5401	6854	4120	5756	4091	6934	3116	6114
161	7169	3704	6220	4992	5907	5520	5653	4151	5989	4992	5489	3893	7742
162	6513	2745	4480	4275	7224	5594	5126	4403	6853	4275	5509	5175	7202
163	6695	1842	6113	3184	7203	5484	6496	4243	7245	3184	4691	4611	4716
164	5807	3781	5959	5266	6973	4607	4667	3330	6120	5266	6469	4927	5756
165	6663	4631	5913	5892	6360	5993	5657	4429	5010	5892	6941	5058	6798
166	7391	2901	5794	4110	4690	5373	6266	4174	4828	4110	5786	4555	6260
167	6827	3487	5260	4573	6300	4951	5969	3626	7861	4573	6743	4342	5496
168	7566	2196	4270	3311	5006	5258	7155	3773	5246	3311	5010	5261	7203
169	7919	2862	6494	4314	6554	4793	6723	4479	4558	4314	4112	3712	7375
170	7052	4973	5463	6356	6586	3410	4688	2063	6279	5578	5578	3566	4818
171	7198	2744	6893	3959	7301	4479	4479	3608	6080	3959	7094	3796	4937
172	6364	3380	7767	4467	6931	4267	6090	2765	4549	4467	7318	5430	6929
173	7125	2441	6684	4099	5765	5426	6943	4111	5243	4099	4361	4431	7026
174	6854	2722	5521	3845	6365	4876	6678	3465	5138	3845	8081	4915	5792
175	6924	3934	5560	5477	5710	3526	6733	2336	5845	5477	5340	4743	4743
176	6360	2613	7365	4015	6393	5803	5803	5473	5108	4015	5025	4632	5101
177	7188	3335	5975	4416	7592	4527	5548	3139	5448	4416	6402	4680	7091
178	7068	4112	8085	5816	7646	5373	5289	4245	3972	5816	6452	4466	4466
179	6896	5076	5718	5680	5680	4135	4135	4832	6895	5680	7454	4052	8012
180	7676	3322	5444	4457	6276	5643	6583	4935	6062	4457	7891	5974	5902
181	7703	4095	6819	5435	7037	4981	4981	4907	5899	5435	6620	4481	4481
182	6975	3847	5579	5056	5244	5524	5887	4186	5853	5056	5607	3899	4170
183	6637	3604	6199	4765	7685	4602	4393	3102	5146	4765	5926	5176	6699
184	6109	4606	8381	4230	4230	4229	5567	2939	6547	4230	6242	4425	6741

185	5986	3040	7190	4322	7306	5044	5044	5337	5266	4322	5810	5166	6943
186	5974	2684	4640	4144	6787	5549	5632	4124	5484	4144	5813	5343	6832
187	6440	3361	6458	4645	6122	4428	4428	4295	5745	4645	5843	4190	4669
188	5971	3785	6639	4966	6851	4866	5406	3611	7546	4966	6457	4786	6766
189	5971	3391	6490	4658	4996	3715	5765	2264	5993	4658	6542	6179	5618
190	8141	4185	5389	5569	6764	4932	7086	3399	4473	5569	5448	5209	6626
191	7122	3292	7293	4930	7857	4924	5848	4033	3627	4930	5932	3814	7375
192	7447	2810	7202	4189	6653	4976	5447	3657	8365	4189	4217	4379	5456
193	7548	4518	5468	4875	6915	5079	6786	4203	7443	4875	4875	4339	4645
194	6971	3015	7847	4375	5090	5893	6226	4667	8469	4375	6809	3833	7119
195	7532	2586	7262	3803	7407	5732	6296	4599	6512	3803	5153	5064	4888
196	7836	4119	6961	5388	7430	4474	6602	3061	4447	5388	5705	4312	7395
197	6704	4883	6318	5462	5462	4453	4717	2800	6243	5462	6919	4226	7744
198	6977	4517	6471	5775	7598	5121	5183	3837	6869	5775	7606	3488	5243
199	7985	3381	7535	4393	6999	4540	7676	3227	6794	4393	6848	4761	5863
200	6985	2668	4816	3841	7598	4677	6998	3061	6177	3841	6796	5657	7270
201	7623	4560	6878	5976	7230	4048	6206	2553	7591	5976	6974	4670	7889
202	7185	3770	5805	4961	4860	4726	4944	3410	7246	4860	6258	3308	4989
203	7132	2182	5669	3434	7072	4832	5758	3575	6565	3434	6866	4899	4899
204	7310	3992	6107	5141	7900	5049	5540	5176	6325	5141	7006	5346	6894
205	7147	4439	4843	5593	5993	4241	5508	2888	6505	4933	4933	4873	5192
206	6699	5488	6573	5720	5720	4080	5325	2724	6556	5720	5401	3998	6857
207	7993	3289	5333	4510	6483	3903	7108	2410	3705	4510	6653	3832	6987
208	6864	5282	8066	5364	5364	4499	5673	3221	7074	5364	6997	4293	7791
209	6863	3550	8267	4660	7410	4298	5634	2828	7922	4660	6048	4460	6715
210	6457	4025	6674	5275	5267	6807	6960	5101	6430	5267	4675	4560	4927
211	7217	3623	6363	4268	4268	4922	7697	3658	5902	4268	6881	5127	7330

212	6508	4962	5343	5489	7184	4247	4726	2841	5510	5489	5489	3870	6884
213	7475	4251	7110	5466	6776	5734	6638	4321	6568	5466	5359	4314	6023
214	6471	4474	6661	4840	4840	4995	5216	3504	5592	4840	6100	5261	5398
215	7764	2756	7299	4017	7280	5009	6079	3456	5675	4017	5783	5041	6821
216	7016	3383	8272	4667	7751	6437	6974	4879	6878	4667	6587	5525	6702
217	7662	3560	5979	4849	7875	4471	6463	2878	6856	4849	7243	5415	5415
218	6136	3168	6662	4455	6843	5672	7287	4235	6232	4455	5830	5370	5137
219	6872	2653	6722	4037	7369	4846	7840	3621	6341	4037	7432	4531	7001
220	6445	4382	7490	5582	5634	5404	5807	3849	7892	5582	5261	4950	5538
221	6872	3522	5203	4583	4828	4319	4319	3725	5795	4583	6185	5256	5586
222	6004	4259	7596	5470	6433	5184	7236	3830	6087	5470	5743	5431	7962
223	6600	1890	7111	3229	6446	5311	7301	3998	7264	3229	7752	4821	6424
224	7864	4370	7647	5100	5100	4302	5886	3112	7256	5100	5463	3379	4908
225	8196	1982	7441	3088	7448	2677	5131	1271	7462	3088	5979	4449	7165
226	7722	3660	7333	4978	6229	3704	5218	2541	4737	4978	4796	3877	6991
227	6611	3355	5867	4423	7152	4336	6159	2967	5828	4423	5952	5842	5260
228	7298	3894	8223	5107	7445	5007	5381	4540	4689	5107	5989	3863	7371
229	6673	4118	8011	5753	6481	5325	6664	3672	3953	5753	7221	4172	7068
230	6057	3137	7949	4500	7338	5360	5607	4103	4393	4500	5367	5144	7837
231	7914	2914	6149	4008	7863	3698	5065	2423	6103	4008	6260	3234	6987
232	6561	3435	6593	4550	6159	5980	7580	4429	5925	4550	5024	5922	6605
233	6971	3582	5769	4900	5783	4625	5379	3042	6104	4900	5784	5566	6329
234	7146	4366	6147	5335	5551	5992	7270	4715	7568	5335	4818	4256	7648
235	6369	3651	6224	5015	7525	4660	4874	3190	6883	5015	6873	4564	4817
236	8004	3322	5444	4457	6276	4394	4729	2985	5312	4457	7891	3938	5385
237	7243	4021	5031	5245	7361	4983	7115	3802	7285	5245	4775	3287	5882
238	6783	2630	6347	3685	7062	3182	5351	1907	6062	3685	8053	4590	6021

239	7364	3139	6956	4315	7633	5017	5769	3937	3894	4315	5980	5131	6272
240	6677	2319	6541	3404	6465	5770	5990	4162	7931	3404	6698	4184	4950
241	5772	3756	5995	4929	5714	4352	6596	2872	6188	4929	6733	5182	6200
242	7891	3133	5475	4169	5392	3422	4610	2209	8723	4169	6743	5372	6679
243	7042	3562	3881	4688	7052	5619	5639	4078	6479	4688	6538	4937	6739
244	8222	4581	4420	5704	6996	4539	6289	3053	4420	5704	6884	4937	4937
245	5716	2474	5712	3640	5960	5055	5413	3579	5218	3640	5725	5064	5133
246	6393	4279	5671	5493	8128	5045	6454	3755	7814	5493	6863	4898	5398
247	8543	5216	6199	6279	7488	4111	4111	4871	5567	6279	6007	5232	5217
248	7314	3143	7240	4421	5154	5395	5230	4114	5338	4421	6755	4510	4510
249	7938	2459	7433	3642	6242	5318	5318	5138	6854	3642	4978	4016	5454
250	7490	4595	4384	5473	7154	3612	4225	2453	8177	5473	5594	3255	4819
251	7392	2357	6207	3791	7099	4631	7215	3828	5930	3791	5972	4342	5703
252	5673	3436	7545	4996	6679	4972	4972	4231	8586	4996	7601	5020	7597
253	7601	4174	7130	5570	6909	4157	7149	2815	6116	5570	6077	5715	6487
254	6095	2666	4555	4007	6897	4776	5043	3537	5020	4007	7513	5220	6199
255	6274	2872	7182	4189	6417	5248	5556	3776	7098	4189	6472	2715	4371
256	5661	3777	7387	5212	8026	5357	5520	3958	4393	5212	5960	5097	6187
257	6410	3129	7647	4213	7906	5042	6653	3534	5509	4213	6810	4996	5278
258	7215	3799	4845	5008	6851	4387	6697	3190	4307	5008	4563	5436	7066
259	6600	3403	7718	4649	6249	4713	8182	3288	7292	4649	5151	3848	6798
260	8205	2603	7977	3850	7412	4454	6722	3230	6807	3850	6467	5272	5077
261	5858	4313	5381	5443	5277	4246	7911	2995	6789	5277	6172	4065	5519
262	5908	1483	7322	2701	7632	5785	5872	4054	4632	2701	7116	3995	6015
263	7094	4987	4723	5342	5342	4697	6227	3432	5514	5342	5497	4606	4606
264	6903	3753	4780	4138	4138	6445	6331	4753	6200	4138	5938	4741	5002
265	5907	3506	7509	4731	8235	3654	5918	2511	5060	4731	6121	5770	6728

266	7261	3153	6399	4417	7148	6345	6157	4975	6412	4417	5851	3498	5129
267	6992	3841	7541	5081	7462	3955	7343	2570	5780	5081	6716	3877	6136
268	6393	3578	7533	5024	7590	3981	7614	2819	6583	5024	8046	5753	7711
269	7510	5181	5892	4199	7026	4046	7310	2820	6460	4199	4199	7095	7604
270	6672	3426	5997	4630	7022	5116	6062	3772	6031	4630	5209	5053	6023
271	6760	3234	6968	4520	5786	4881	7316	3572	5316	4520	5254	3775	6543
272	6627	5299	4989	5863	5863	5492	5656	4118	5541	5863	5828	4888	4518
273	6516	2824	6509	3747	7070	5744	6191	4455	4549	3747	8082	4965	6664
274	6562	2579	6882	3774	5914	3996	7230	2847	5678	3774	6033	4996	5278
275	6735	3783	6534	4858	7579	5692	6726	4327	6631	4858	5650	4578	4550
276	8592	3600	5391	4743	6766	5448	6205	3944	5898	4743	5360	5229	5229
277	7364	3523	5656	4536	6760	4404	5031	3240	5923	4536	5089	4499	6049
278	6512	4706	5235	5966	7701	4328	6119	2543	5152	5173	5173	4507	5950
279	6174	2913	6922	4269	5423	4931	4377	3631	6777	4269	5883	4065	5484
280	7068	4032	7582	4489	7222	4436	5883	2945	6922	4489	4489	5209	5525
281	6299	2742	8501	4030	7402	5491	7870	3959	6352	4030	7175	4741	6271
282	7399	2472	8285	3547	5447	3932	6914	2501	5348	3547	6771	4740	7321
283	6836	4274	5173	5624	5467	5814	5807	4362	4305	5467	5258	3959	7160
284	6877	2741	5536	4102	6739	3610	6338	2308	6518	4102	7715	5271	4745
285	5652	2047	6663	3294	6325	5117	6105	3559	6801	3294	7021	3891	7744
286	7879	3594	4627	4775	5647	4141	5526	2874	5091	4775	5620	6002	5931
287	6863	3206	6336	4296	6064	5469	6170	4068	5523	4296	6563	4330	5281
288	7203	2338	5315	3486	5231	5532	5045	4093	7622	3486	4729	5153	6007
289	6628	1705	6912	2871	7368	4313	4313	4241	5400	2871	7211	5251	5040
290	7576	3666	7879	4717	5447	6126	7291	5920	6877	4717	7058	4036	6528
291	7818	5391	7337	6446	7408	3625	7082	2055	7097	6446	5982	4404	5298
292	7194	2612	6600	3734	6927	4659	4335	3259	6880	3734	5609	6001	6001

293	7060	2792	7965	4210	7285	5487	6049	4133	5707	4210	5144	5192	7877
294	6707	3083	6793	4240	4536	5178	5343	3839	6716	4240	5675	5136	6049
295	6521	3836	4479	5041	4897	4710	8187	3495	5415	4897	6478	5475	4879
296	6627	3577	6687	4820	6896	4388	6385	3025	5166	4820	6913	5012	7058
297	5939	3369	6222	4717	6981	5618	5734	4494	6550	4717	5829	3548	5888
298	6358	3656	7383	5035	6744	4906	4661	4386	5314	5035	6258	5225	6991
299	5835	4804	5320	5978	6596	4884	6372	3352	7165	5978	6916	5332	6002
300	7283	4499	6768	5705	7477	5099	6355	3770	7869	5705	6384	4575	6877
301	6679	3353	6456	4720	5079	4080	4080	3518	7832	4720	6474	5899	7569
302	7196	5586	6820	4467	7146	5030	5896	3507	8144	4467	4467	4151	5033
303	7374	3063	5841	4261	7840	4577	4280	3294	4697	4261	4889	5135	5904
304	7245	3703	4978	4893	6900	4955	6406	3768	6732	4893	7318	4558	5938
305	6311	4002	5901	5227	7465	5152	6788	3842	5997	5227	6194	3462	5003
306	8320	3739	8634	4914	5241	4039	6017	2676	4230	4914	5853	5317	5663
307	6623	4930	5651	5305	6316	4990	6443	3930	3824	5305	5305	5092	6375
308	6613	3676	8564	4749	7321	6058	6488	4490	4986	4749	7272	3763	4711
309	7746	2427	5201	3682	5960	4800	7056	3474	5863	3682	5050	4719	6764
310	6939	3562	4535	4850	7468	5367	5367	4550	7853	4850	5985	3982	6343
311	6193	3121	6358	4319	7163	4742	6286	3912	5236	4319	6198	4504	6169
312	7645	3246	6387	4339	6965	4299	5926	2983	6749	4339	5989	4634	5758
313	7530	4325	7665	5362	6552	4717	6342	3058	5275	5362	6924	5926	6853
314	6522	3838	7983	5114	8062	5363	6623	4886	6877	5114	7318	5465	5829
315	7530	2768	5167	4042	4914	4842	7882	3565	6064	4042	7132	5374	5077
316	6292	2518	7885	3739	6852	4213	6278	2567	6709	3739	7093	4859	7281
317	6496	4030	3840	4929	7224	4355	6095	3218	7318	4929	7425	4404	6906
318	6136	2621	5942	4010	7381	5802	6264	4667	7097	4010	4830	4982	5778
319	6239	4075	5451	5169	7273	3508	6660	2353	6670	5169	7715	4000	7078

320	5587	4641	7829	5794	5794	6909	7749	6151	7545	5794	6694	4494	4494
321	7291	2463	7624	3817	6964	6218	6146	4926	6613	3817	7186	4855	7542
322	7912	2205	6185	3637	6343	4469	6275	3270	5490	3637	5399	4445	6881
323	6432	4330	6552	5527	7431	4691	4540	4034	6945	5527	5951	4234	7646
324	7848	3614	3829	4866	8134	5373	4841	3986	6869	4866	7929	5145	4578
325	7175	3560	5068	4832	6261	5279	7345	3935	5978	4832	4350	5007	6931
326	6471	3653	4461	4780	6013	4475	6514	3225	8236	4780	5251	4454	7068
327	7492	4174	7010	5639	7645	5738	5762	4054	7757	5639	7186	6147	6092
328	6510	4253	7536	5215	5215	4232	4455	2661	6618	5215	6097	5083	5173
329	8046	2843	6941	3996	6713	4731	6039	3571	6209	3996	5762	5644	5522
330	7325	3890	4217	5281	6483	4782	6233	3524	3942	5281	6898	3286	7198
331	7563	4414	8304	5830	6816	3106	6455	1617	6604	5830	7630	5500	6885
332	7451	2899	7415	3990	6036	4494	6229	2989	5651	3990	4621	5181	6055
333	7567	4549	5802	5717	8035	5431	5353	3914	6592	5717	7742	5134	6684
334	7612	3554	7208	4978	5607	4191	5804	4314	7201	4978	5533	5158	5881
335	8144	4657	7700	5138	5138	4995	4995	5180	6482	5138	5636	4825	5957
336	7800	4481	7739	4602	4602	6088	6891	4908	6459	4602	4632	6230	6897
337	7719	4902	7306	5140	7049	5078	5078	4418	6647	5140	5140	4587	7104
338	6697	2504	3853	3840	7055	5483	6113	4276	7982	3840	5758	3977	7789
339	6519	3298	5693	4555	5630	5412	6007	4147	7465	4555	7877	5051	5051
340	6647	2900	5077	3939	7866	4559	4559	4784	4587	3939	7647	4215	7403
341	6681	2943	5956	4066	7086	3538	6587	2151	5502	4066	5943	4302	6495
342	6624	3833	8411	4902	5164	5283	6264	3863	7545	4902	6905	4612	5517
343	7047	3350	5036	4607	8215	4147	6403	3006	8584	4607	7580	5457	5457
344	4980	3508	4601	4906	6198	5374	5280	4227	8798	4906	7782	3820	6166
345	6819	3000	7017	4160	7536	5248	4937	3674	7403	4160	5349	5279	6926
346	7598	2769	7320	4061	6388	6165	6142	4890	5124	4061	5953	6326	7637

347	6554	3947	5690	5291	7137	4369	6576	3024	5643	5291	5022	5425	7513
348	6960	3187	6915	4593	4990	3690	5691	2255	6615	4593	5203	3414	7997
349	7537	5437	6487	5218	6474	4485	4485	3877	6078	5218	5218	4968	4546
350	6176	4730	5897	5194	5194	6312	5780	5246	6497	5194	5265	4493	4493
351	6754	2884	8225	3960	5874	4080	7254	2856	5565	3960	5763	4675	6842
352	7066	2942	5156	3946	6896	5021	7398	3519	6954	3946	6243	5187	5403
353	7141	5193	5596	6525	7230	4826	7019	5596	5574	5808	5808	5249	5532
354	7050	3135	7818	4294	8241	4664	7509	3146	7858	4294	6271	3578	6694
355	7058	1704	7372	3045	7460	6273	6914	5011	5662	3045	5892	5266	5454
356	6937	2448	8647	3710	6642	4118	6390	2747	7643	3710	5889	5148	7320
357	7106	3556	3940	4951	6582	4793	7969	4097	4210	4951	5938	4693	6989
358	7490	3291	7632	4706	6893	5462	5462	5307	6853	4706	7733	5760	7044
359	5858	3153	4845	4225	7965	4550	5334	3364	6128	4225	5154	4163	5704
360	6896	2848	5488	4073	7304	4363	8320	3001	6471	4073	5529	4393	4226
361	7011	2591	7110	3756	6615	3740	8206	2466	5047	3756	6132	3601	6583
362	6385	5006	5374	6216	6074	5256	5214	3928	8259	6074	7142	5102	5398
363	7408	3705	6625	5038	7738	5574	5263	3911	6759	5038	7136	4024	6276
364	6366	4340	6233	5519	6359	4693	4693	4374	5260	5519	8342	4614	5608
365	7566	3932	6487	5277	5306	3136	7170	1689	7725	5277	7811	4199	5491

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