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Main Theme: *Challenges for mining and steel making facing the current and future quality of the reserves of iron ore and coal*

A HIGH LEVEL DYNAMIC ANALYSIS TOOL TO STUDY THE IMPACT OF SURGE CAPACITY/STOCKPILE SIZING EARLY STAGE OF THE IRON ORE PROJECTS*

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Abstract

In the early stage of front end studies of an Iron Ore Project, the sizing of surge capacities and stockpiles are normally assumed based on the experience of the study team. Understanding and sizing of these capacities at the early stages of the project are important for future stages of the project as drastic changes in sizes will impact the economics of the project at that stage. An innovative user configurable high level dynamic modeling tool has been developed to assist in speedy evaluation of assumptions made by the study team. This model incorporates systems or facilities that are commonly used iron ore project from mine to port. This model includes subsystems that will simulate all the logistical components, major process plant systems required for an Iron ore project. The output data provided by this high level dynamic simulation tool will enhance the confidence level of engineering carried out during the early stage of the project. This paper discusses the innovative tool capabilities and a test case comparing various techniques used in iron ore project front end studies.

Keywords: Iron ore project; Storage capacity optimization; Dynamic simulation.

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1 INTRODUCTION

The efficiency of complete mineral processing facilities depends on various subsystems utilization and their degree of decoupling [1]. The intermediate stockpiles and surge bins are important components that help to avoid unscheduled shutdowns. In the current economic conditions, every investment dollar that requires to be spent on surge storage systems in these facilities shall match the production system utilization. Any deviation from it will result in either losing the production or poor capital investment efficiency.

All the iron ore projects today, go through some form of front-end (FEL) studies, in line with IPA definitions [2], before reaches implementation stage. The investment community is not willing take as many risks in the year ahead and putting more pressure on mining companies to deliver the project efficiently [3,4]. Many of the projects starts with a scoping study (FEL1), followed by pre-feasibility study (FEL2) and feasibility study (FEL3) before it is approved for implementation (FEL4). For all the stake holders, it is very important to sustain project's viability through these phases with the exception to the identified risks that may change the project course in the future. The changes to the project configuration established in the early stages are expected to include mitigation of risks identified in the previous phase or additional data availability that supports better definition of the project. Most of the stake holders understand and agree to most of these changes when they are related to better definition of the process or mitigation of the risks foreseen in the previous stage(s). However, some of the parameters that form these studies, do not get much scrutiny during the early stages are sizing of stockpiles, effective utilization of the plant as a total system, etc. The values for these items are assumed based on the experience in most of the studies; the estimated values may cause change in the costs in the future phases of the project. These assumptions can impact the current study outcome or the later phase. Any major changes to these parameters can influence the cost of the project. To enjoy the investor confidence in the long term, it would be prudent to carry out the front end studies of the project with a better defined set of utilization and storage parameters where the future project changes are directly related to mining or process changes or identified risks. This will reduce some of the uncertainty caused by assumptions that are based on experience during the early stages of the project.

In an iron ore project, the surge or storage stockpiles and bin installations contribute major cost as they are of high capacities and mostly mechanized. The utilization of the system is adversely impacted if the surge capacity or anticipated decoupling of the plant is not sufficient. At the same time, excess surge/stockpile capacity, may decrease the capital efficiency and may result in poor project economics in the early stages of the project that may lead to lose its investment attractiveness. During the initial studies, it is better to size the surge capacities that will address both plant utilisation and capital efficiency.

1.1 Objective of the Dynamic Storage Capacity Calculator

The objective of 'Dynamic Storage Capacity Calculator' is to drive engineering for improved definition of storage/surge capacity sizing during the early stage of the iron ore projects using the total system concept. Further to help as a project parameter

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verification tool to ensure that the plant utilization and individual production rates are less prone for surprises during the future project phases.

1.2 Why Simulation

Simulating a system in its totality, and not as isolated subsystems, the simulation approach yields globally optimal solutions that meet overall system objectives [5,6], as some investments in a determined area do not increase the global performance [7].
Simulation has been around since the 1950's and has been used extensively by the steel industry since the early 1960's. It continues to be of crucial importance to the steel industry due to the large capital expenditures that are involved, as well as the complexity of achieving synchronized operations across the melt shop and the entire steel plant [8].
Simulation, by far, is the preferred tool for evaluating complex, large-scale systems due to its practicality in representing reality, its power to quickly evaluate what-if scenarios, and its utility to find global solutions. It is a powerful tool which, when used properly, can provide the insights necessary to both prevent poor system designs and to produce productive and efficient ones [9,10]. With the model, it's possible to analyzes and remove bottlenecks, optimize and compare alternatives in terms of logistic capacity and storage, effectiveness of capital investments, investment schedule and operational efficiency [11,12].

1.3 Iron Ore Project Configurations

Iron Ore Projects around the world were built in different configurations with similar building blocks in varying capacities and equipment. The system blocks generally include one more transport system using rail, pipeline, road and water. In general, all the iron ore projects have at least one or more storage systems between each system from mine to port. The following figure shows all the major system components that may be used in an Iron ore project.

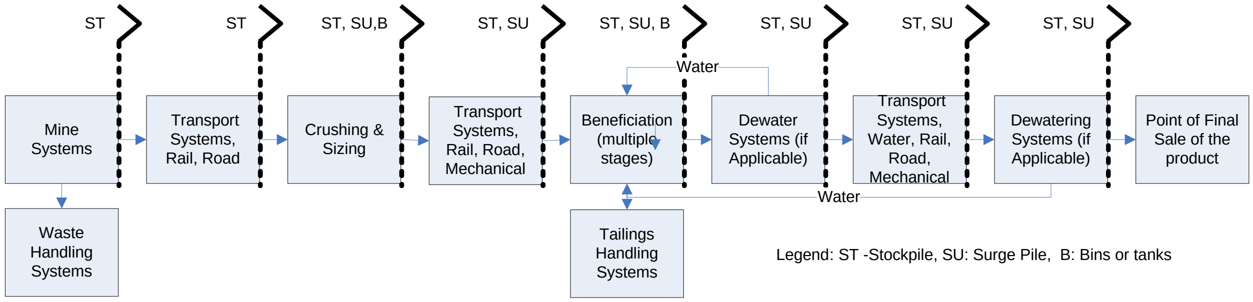

Figure 1 - Iron Ore Project configurations

The above figure also shows the material transport direction from mine to the final point of sale. Most of the iron ore projects may not use all the systems shown above; however, they are configured using one or more systems blocks shown above.

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1.4 Iron Ore Beneficiation Processes

The worldwide decline in the production of lumps due to poor ore characteristics of new ore bodies has prompted to develop the alternative forms of raw materials such as sinter, pellets, scrap to fill the void for steel making. Iron ore beneficiation processes are used to improve the iron content while reducing the gangue material in the ore. As a precursor to beneficiation of low grade ore, the run of mine is crushed before the start the beneficiation process. The following methods are generally used in beneficiating the low grade iron ores.

a) Magnetic separation at either high or low intensity
b) Gravity separation using either heavy media, jigging, tabling or spirals.
c) Floatation

Other types of beneficiation methods include Electrostatic separation, magnetic roasting followed by low intensity separation, washing and calcining may be used in some projects, and however these processes are not commonly considered in the current projects due to capacity and cost reasons.

The following block flow diagrams depict generic beneficiation routes for hematite and magnetite ore that are considered in the developing the tool.

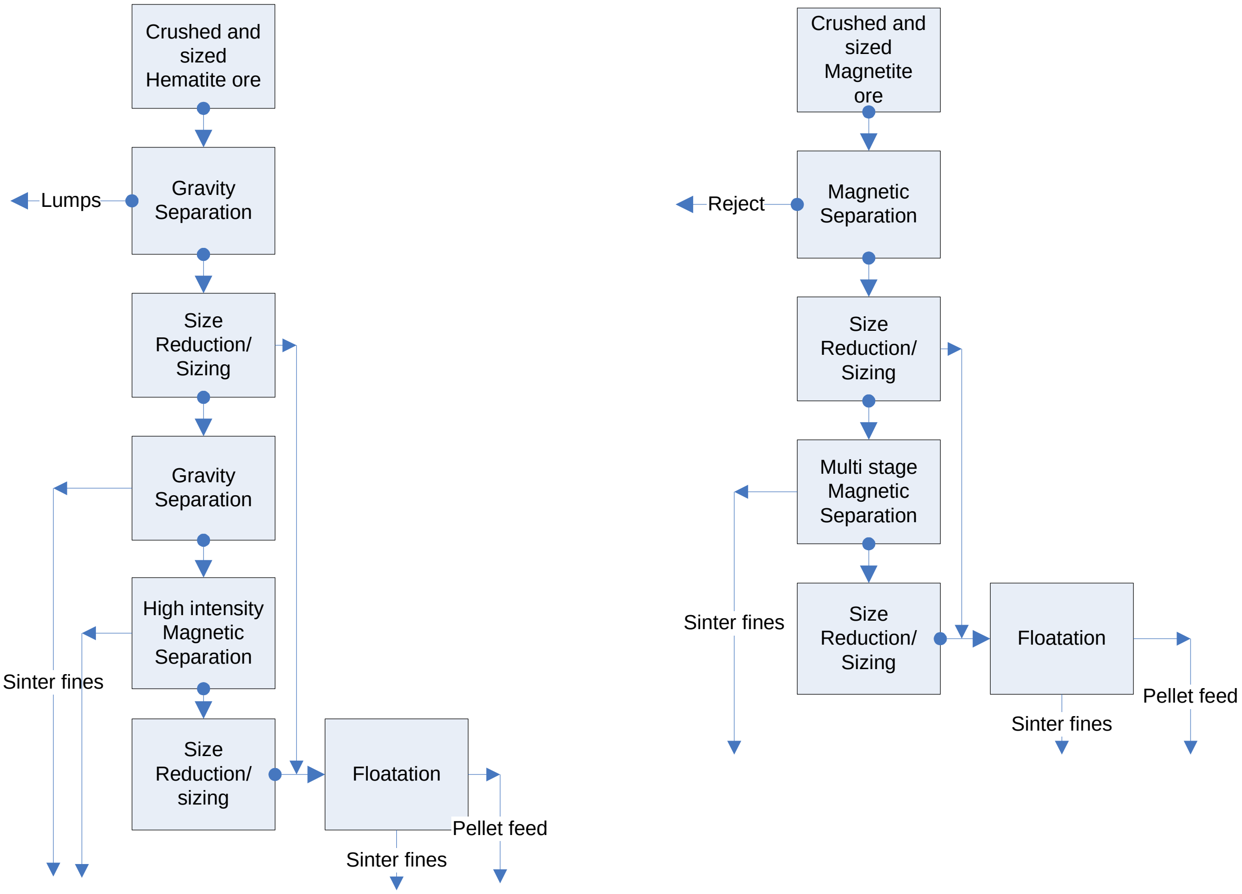

Figure 2 - Typical Hematite and Magnetite Beneficiation routes

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1.5 Iron Ore Transport Systems

Iron ore from mine-to-port is transported in various modes depending on the size of the ore, distance, and availability of infrastructure and geographical needs of the location. At mine, it is transported either by truck or automated rail system or overland conveyor system, depending on size of the material and distance it is to be transported. The concentrated product, depending on the product size, environmental considerations and economy of transportation, may use rail, road, overland conveyor, water (barge), pipeline or combination of these systems to transfer the material to the ocean-going vessel or to the final point of sale.

1.6 Iron Ore Storage Systems

Iron ore or concentrated product as it passes from mine to port, in various sizes, is stored at different points of the project facilities, mainly to support the constant feeding and to decouple the project systems. Majority of the storage system equipped both stacking and reclaiming machineries coupled with surge bins prior transferring the material to a facility or loading on to a transport system. The iron ore project configuration diagram shows typical locations and type of stockpile or surge systems that are commonly used.

1.7 Dynamic Storage Capacity Calculator Model Design

The model could be developed in any commercially available discrete simulation software [13], however, for the current tool, the model was developed in Arena (by Rockwell Automation) software. Arena is a general-purpose simulation package comprised of a simulation programming language (SIMAN) and an animation product (CINEMA).

Arena also incorporates a general-purpose procedural language, Visual Basic for Applications (VBA) from Microsoft and ActiveX components. Together, these allow Arena to integrate with other programs that support ActiveX Automation. The user interface is developed in Microsoft Excel, and it links to Arena through VBA and ActiveX. The user interfaces to store the input parameters required for what-if scenarios, automatically imported into log files and chart dynamic variables, and report model outputs. Various independent processes and statistical analysis packages are employed for both input and output data analysis.

The input data were divided into tabs in the Microsoft Excel file (Interface), where each tab describes a unique iron ore project system block. The model design allows continuous improvement and expansion, allows inclusion of newer steps in the process arises.

Figure 3 is the model input data template for the Primary Crushing system. At the left of the interface, the flow of the material and the equipment capacities are described and at the right, the planned and unplanned maintenance of the Primary Crusher is described.

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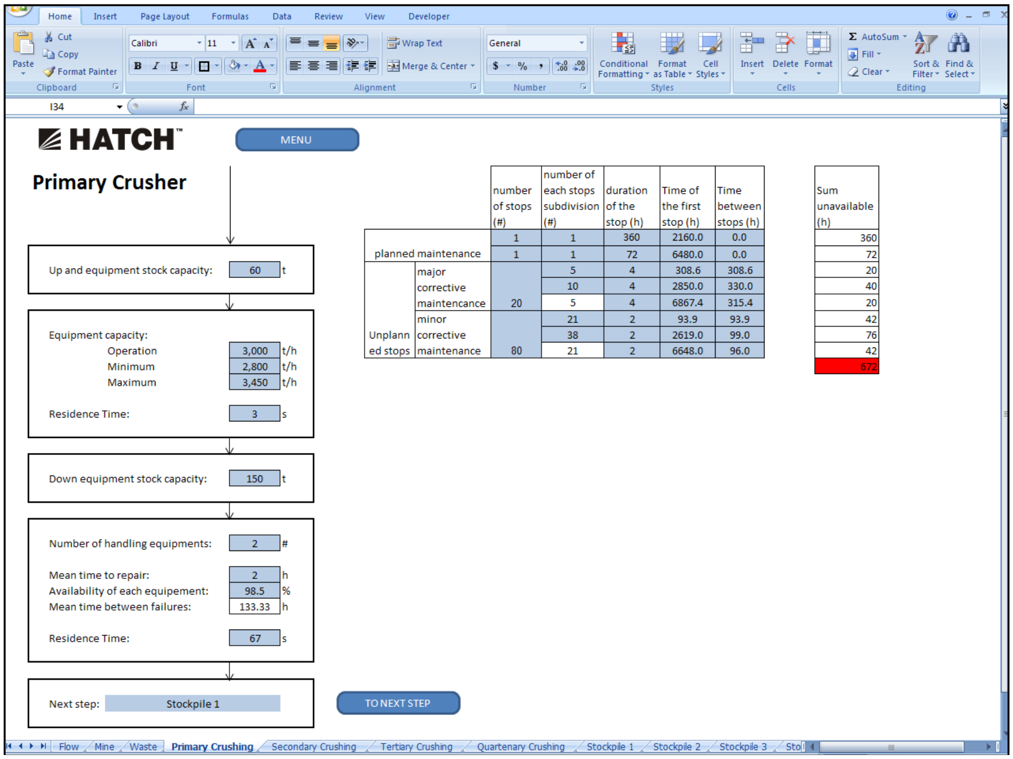


Primary Crusher

Up and equipment stock capacity: 60 t

Equipment capacity:
Operation 3,000 t/h
Minimum 2,800 t/h
Maximum 3,450 t/h

Residence Time: 3 s

Down equipment stock capacity: 150 t

Number of handling equipments: 2 #

Mean time to repair: 2 h
Availability of each equipement: 98.5 %
Mean time between failures: 133.33 h

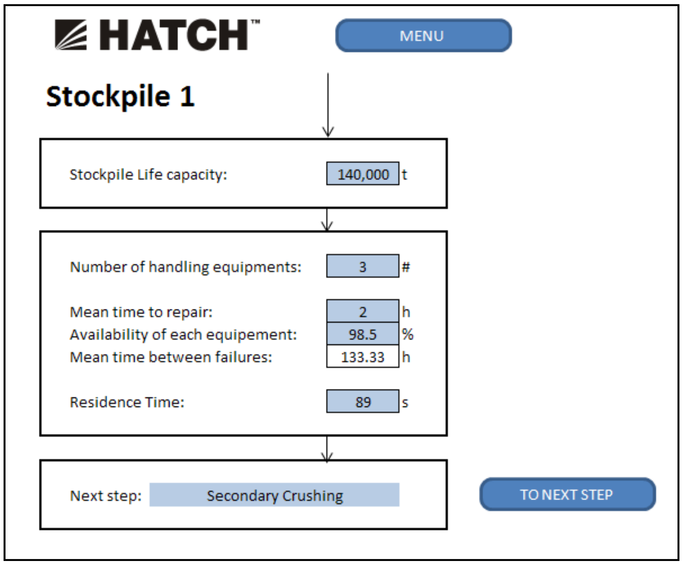
Residence Time: 67 s

Next step: Stockpile 1

		number of stops (#)	number of each stops subdivision (#)	duration of the stop (h)	Time of the first stop (h)	Time between stops (h)	Sum unavailable (h)
planned maintenance		1	1	360	2160.0	0.0	360
		1	1	72	6480.0	0.0	72
Unplanned stops	major corrective maintencance	20	5	4	308.6	308.6	20
			10	4	2850.0	330.0	40
			5	4	6867.4	315.4	20
	minor corrective maintenance	80	21	2	93.9	93.9	42
			38	2	2619.0	99.0	76
			21	2	6648.0	96.0	42
							672

Figure 3 – Primary Crushing Input Interface

The buttons, "MENU" and "TO NEXT STEP" assist in the navigation between steps. The button "MENU" opens the menu showing all the systems that can be used in the calculator, and the "TO NEXT STEP" automatically jumps to the next tab described in the material flow. It's also possible to use the tabs at the bottom to change between steps. In the example above the next step is the Stockpile 1 (one of the many stockpiles), shown in Figure 4.



Stockpile 1

Stockpile Life capacity: 140,000 t

Number of handling equipments: 3 #

Mean time to repair: 2 h
Availability of each equipement: 98.5 %
Mean time between failures: 133.33 h

Residence Time: 89 s

Next step: Secondary Crushing

Figure 4 – Stockpile 1 Input Interface

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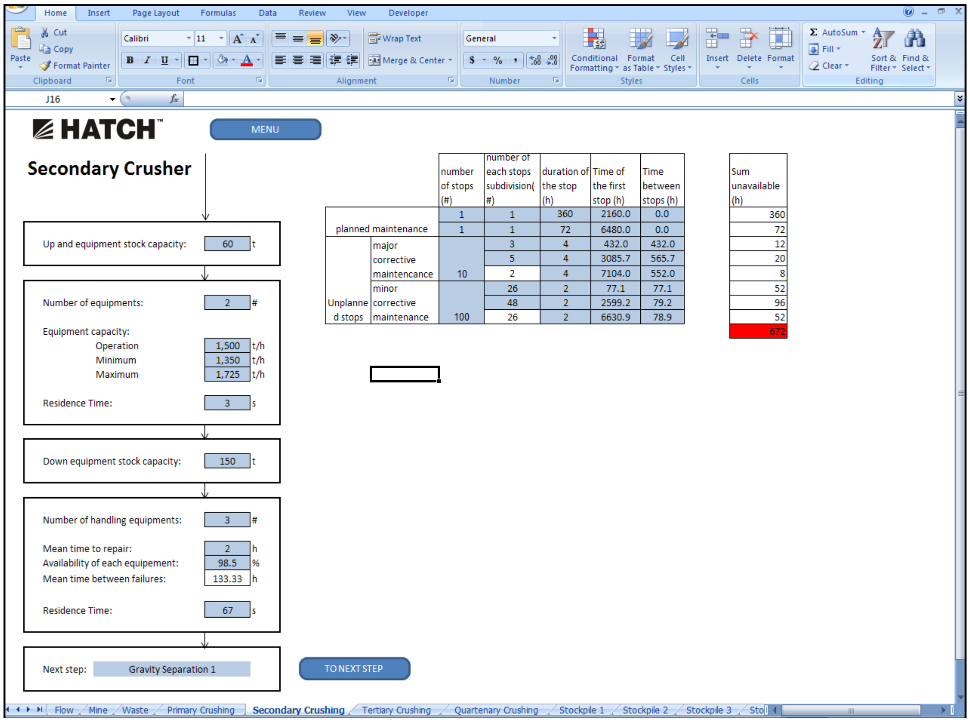
As the process development of early stage continues, so are the equipment details, and system blocks of the project. The input interface of the Secondary Crushing system and Gravity Separation system 1 are shown in the Figure 5 and Figure 6.



Secondary Crusher

Up and equipment stock capacity: 60 t

Number of equipments: 2 #

Equipment capacity:
Operation 1,500 t/h
Minimum 1,350 t/h
Maximum 1,725 t/h

Residence Time: 3 s

Down equipment stock capacity: 150 t

Number of handling equipments: 3 #

Mean time to repair: 2 h
Availability of each equipement: 98.5 %
Mean time between failures: 133.33 h

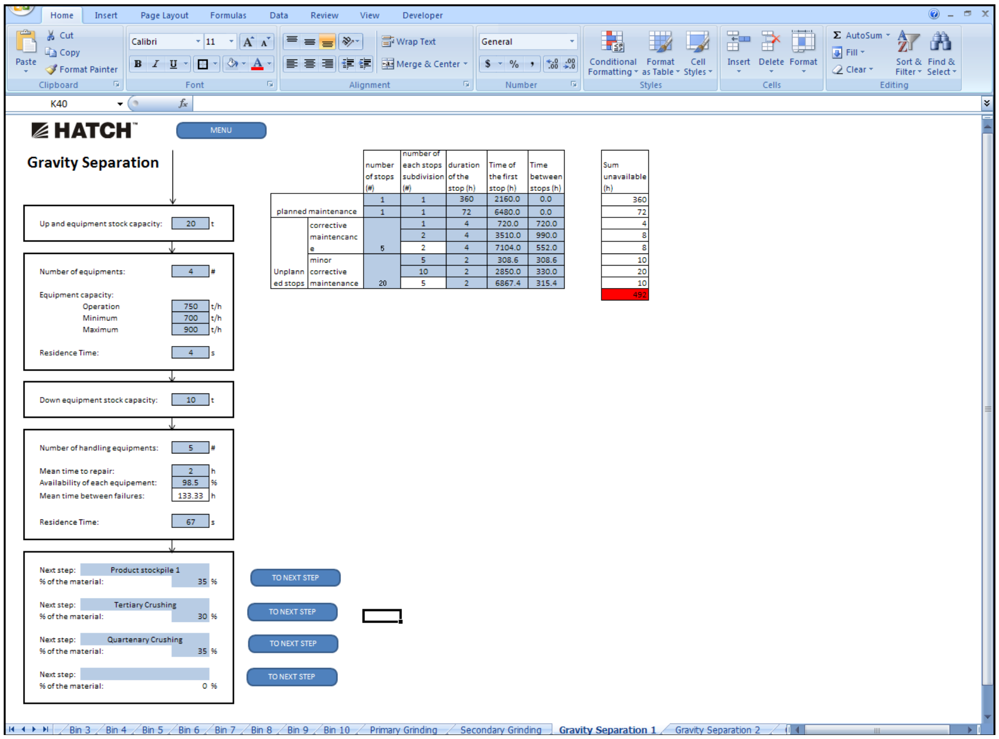
Residence Time: 67 s

Next step: Gravity Separation 1

		number of stops (#)	number of each stops subdivision(#)	duration of the stop (h)	Time of the first stop (h)	Time between stops (h)
planned maintenance		1	1	360	2160.0	0.0
		1	1	72	6480.0	0.0
Unplanned stops	major corrective maintencance	10	3	4	432.0	432.0
			5	4	3085.7	565.7
			2	4	7104.0	552.0
	minor corrective maintenance	100	26	2	77.1	77.1
			48	2	2599.2	79.2
			26	2	6630.9	78.9

Sum unavailable (h)
360
72
12
20
8
52
96
52
672

Figure 5 – Secondary Crushing Input Interface



Gravity Separation

Up and equipment stock capacity: 20 t

Number of equipments: 4 #

Equipment capacity:
Operation 750 t/h
Minimum 700 t/h
Maximum 900 t/h

Residence Time: 4 s

Down equipment stock capacity: 10 t

Number of handling equipments: 5 #

Mean time to repair: 2 h
Availability of each equipement: 98.5 %
Mean time between failures: 133.33 h

Residence Time: 67 s

Next step: Product stockpile 1
% of the material: 35 %

Next step: Tertiary Crushing
% of the material: 30 %

Next step: Quartenary Crushing
% of the material: 35 %

Next step:
% of the material: 0 %

		number of stops (#)	number of each stops subdivision (#)	duration of the stop (h)	Time of the first stop (h)	Time between stops (h)
planned maintenance		1	1	360	2160.0	0.0
		1	1	72	6480.0	0.0
Unplanned stops	corrective maintencance	5	1	4	720.0	720.0
			2	4	3510.0	990.0
			2	4	7104.0	552.0
	minor corrective maintenance	20	5	2	308.6	308.6
			10	2	2850.0	330.0
			5	2	6867.4	315.4

Sum unavailable (h)
360
72
4
8
8
10
20
10
492

Figure 6 – Gravity Separation(module1) Input Interface

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The button “MENU” leads to the main interface (Figure 7) and its links (Figure 8).

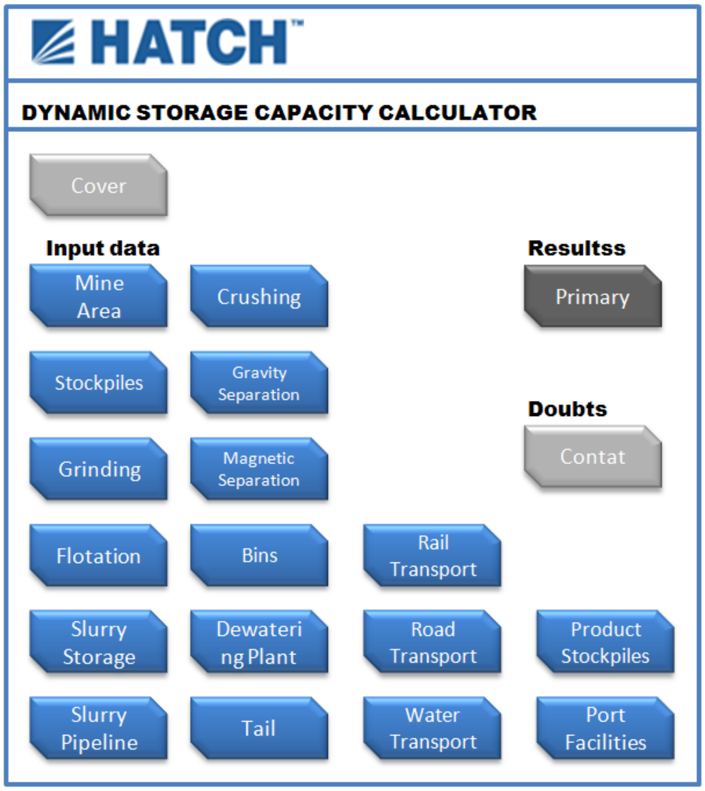

Figure 7 – Menu

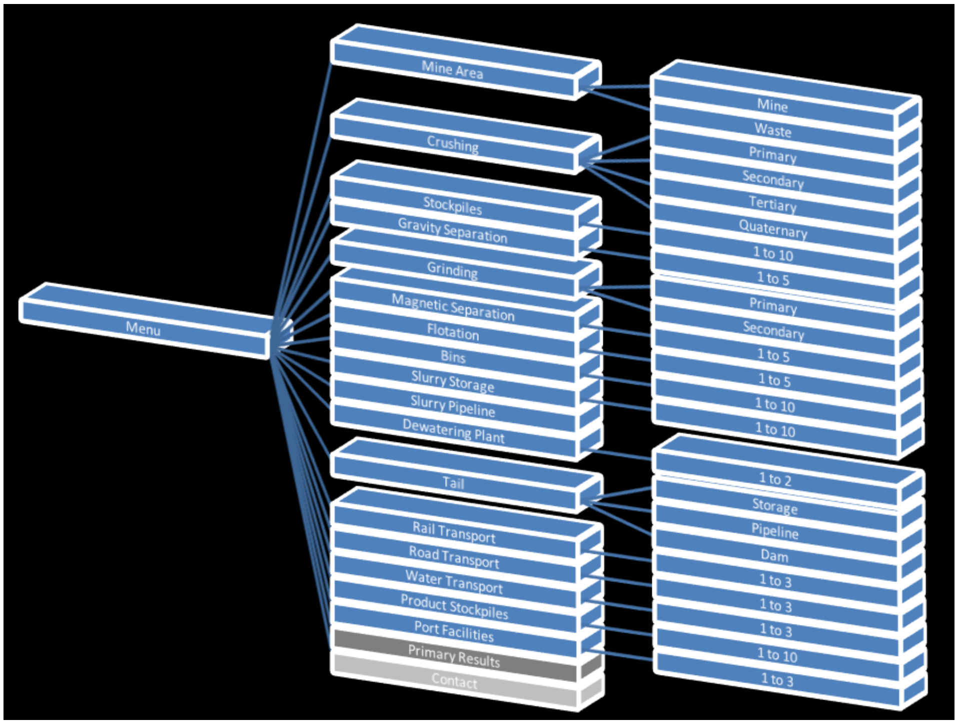

Figure 8 – Menu links

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The model components are developed to allow various combinations or configuration of equipment with no customizing effort at the programming level. When the model is set to run, the VBA gets the input data resident in the MS Excel interface and inserts them into the Arena model, making the links between the system blocks, like the Primary Crushing to the Stockpile 1 and so on. This interface allows an engineer with minimal experience in simulation software can set the input data and run the model.

The results from the model are stored in the tab 'Outputs' and it can be accessed through the navigation button 'Primary'. The typical data stored are, annual throughout, maximum, minimum and average stock levels and equipment utilization. All the data on stockpiles and bins and the necessary information along the simulated time is stored in a separate file.

1.8 Test Case

To validate the tool, Hatch has used a custom developed dynamic model for a front end study as a test case example. The following diagram shows the configuration of the system (Figure 9).

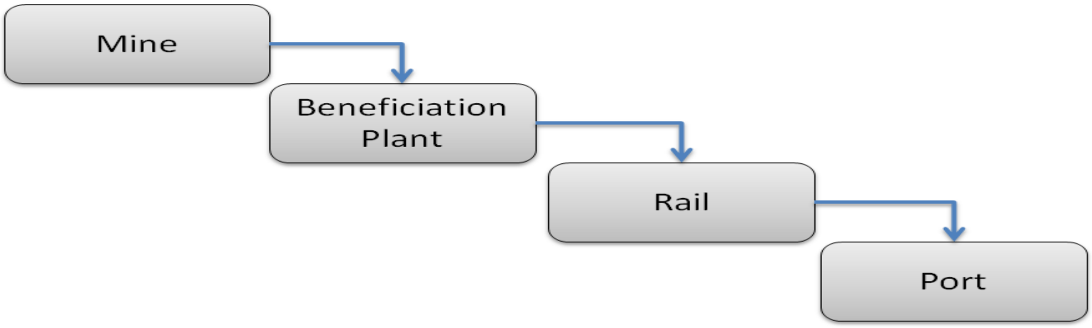

Figure 9 – Configuration diagram of the test case system

The result from this customized model is used to compare "Dynamic stockpile capacity calculator" tool's behavior. The project is to produce three iron ore products and load it on an ocean-going vessel. The test case project is designed to handle 28.5 million tonnes per annum. The production of the plant is: Material 1: 1,500 t/h, Material 2: 1,400 t/h, Material 3: 1,200t/h. The operating hour per annum for this system is 7000 hours with one major annual shutdown of 15 days and another for 3 days. Size of the stockpile is to ensure the rail operation or the load out operation is not stopped due to full or empty stockyard with a high confidence level.

1.9 Traditional Stockpile Size Calculations

In the earlier stages of the front end studies, it is common to calculate the storage size using the number of days or hours or minutes of production based on the experience of the study team and owner's preference. There are other alternative methods used in the industry for sizing the storage such as vessel size, truck size etc, however, it is not considered for comparison in this test case. The following table shows the capacity of stockpiles based on the number of days of storage:

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Description	Optimistic		**Sizing Approach**		Conservative	
Days of storage	**7**	**10**	**14**	**20**	**30**	**45**
Stockpile Capacity1 (tonnes)	**252,000**	**360,000**	**504,000**	**720,000**	**1,080,000**	**1,620,000**
Stockpile Capacity2 (tonnes)	**235,200**	**336,000**	**470,400**	**672,000**	**1,008,000**	**1,512,000**
Stockpile Capacity3 (tonnes)	**201,600**	**288,000**	**403,200**	**576,000**	**864,000**	**1,296,000**

Note: numeric value 1,2,3 represents material 1,2 and 3 respectively.

1.10 Customised Dynamic Simulation

With the same design criteria, the above stockpiles were evaluated using a customized dynamic simulation model. The model was developed in detail and has many subsystems within the system blocks. Following results were obtained from the detailed model:

Stockpile Capacity 1	**Confidence Level:**	**95%**	**99%**	**99.9%**	**99.99%**
	Average- Maximum (tonnes)	457,257	458,197	459,286	460,202
Maximum value in sigma interval	4 sigma [99.994%] (tonnes)	509,730	510,669	511,759	512,674
	3 sigma [99.73%] (tonnes)	496,612	497,551	**498,641**	499,556
	2 sigma [95.44%] (tonnes)	483,494	484,433	485,523	486,438
	1 sigma [68.26%] (tonnes)	470,376	471,315	472,405	473,320

Stockpile Capacity 2	**Confidence Level:**	**95%**	**99%**	**99.9%**	**99.99%**
	Average- Maximum (tonnes)	416,738	417,660	418,732	422,789
Maximum value in sigma interval	4 sigma [99.994%] (tonnes)	468,309	469,232	470,303	474,361
	3 sigma [99.73%] (tonnes)	455,416	456,339	**457,410**	461,468
	2 sigma [95.44%] (tonnes)	442,523	443,446	444,517	448,575
	1 sigma [68.26%] (tonnes)	429,630	430,553	431,625	435,682

Stockpile Capacity 3	**Confidence Level:**	**95%**	**99%**	**99.9%**	**99.99%**
	Average- Maximum (tonnes)	358,152	358,990	359,961	363,641
Maximum value in sigma interval	4 sigma [99.994%] (tonnes)	404,922	405,759	406,730	410,410
	3 sigma [99.73%] (tonnes)	393,229	394,066	**395,038**	398,717
	2 sigma [95.44%] (tonnes)	381,537	382,374	383,345	387,025
	1 sigma [68.26%] (tonnes)	369,845	370,682	371,653	375,333

The entire project systems were modeled to suit the operational requirement and production needs. The storage capacity required is calculated from the difference between the maximum and minimum of the storage pile logs. Figure 8 is an example of log.

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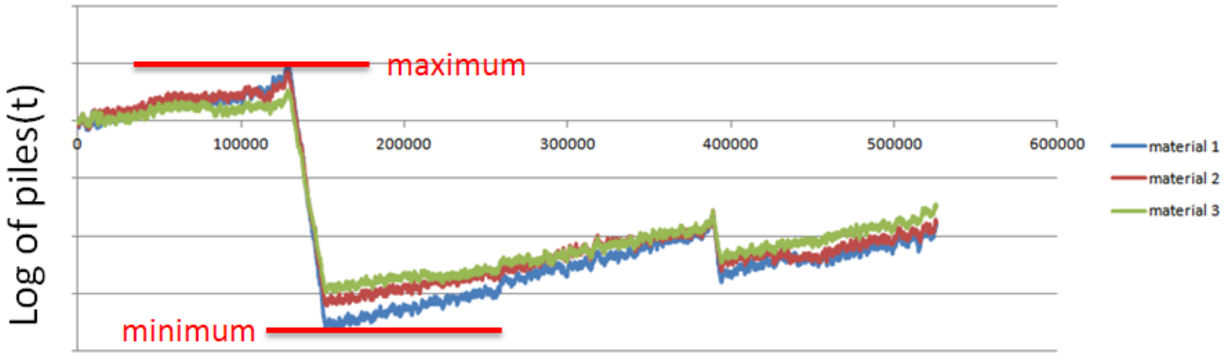

Figure 10 – Product stockpiles

The values obtained for each replication are statistically analyzed, first by obtaining mean, standard deviation and number of samples. Later, it is tested at various Confidence Intervals of the Mean and sigma intervals to get the maximum amount required.

1.11 Dynamic Storage Capacity Calculator:

The "Dynamic Storage Capacity Calculator" uses system block level details that can be assessed by the experienced team or based on the past data; the calculator yields the following results for each stockpile for the same design criteria:

Stockpile Capacity 1	**Confidence Level:**	**95%**	**99%**	**99.9%**	**99.99%**
	Average- Maximum (tonnes)	533,872	534,959	536,222	537,282
Maximum value in sigma interval	4 sigma [99.994%] (tonnes)	594,657	595,744	597,007	598,067
	3 sigma [99.73%] (tonnes)	579,460	580,548	**581,811**	582,871
	2 sigma [95.44%] (tonnes)	564,264	565,352	566,614	567,675
	1 sigma [68.26%] (tonnes)	549,068	550,156	551,418	552,478

Stockpile Capacity 2	**Confidence Level:**	**95%**	**99%**	**99.9%**	**99.99%**
	Average- Maximum (tonnes)	536,138	537,203	538,440	543,123
Maximum value in sigma interval	4 sigma [99.994%] (tonnes)	521,257	522,322	**523,559**	528,242
	3 sigma [99.73%] (tonnes)	506,376	507,441	508,677	513,361
	2 sigma [95.44%] (tonnes)	491,495	492,560	493,796	498,480
	1 sigma [68.26%] (tonnes)	536,138	537,203	538,440	543,123

Stockpile Capacity 3	**Confidence Level:**	**95%**	**99%**	**99.9%**	**99.99%**
	Average- Maximum (tonnes)	466,562	467,525	468,642	472,873
Maximum value in sigma interval	4 sigma [99.994%] (tonnes)	453,116	454,079	**455,196**	459,427
	3 sigma [99.73%] (tonnes)	439,670	440,633	441,750	445,981
	2 sigma [95.44%] (tonnes)	426,224	427,187	428,304	432,535
	1 sigma [68.26%] (tonnes)	466,562	467,525	468,642	472,873

As it can be seen from the above tables, the results of the last two evaluation methods, the storage capacity obtained were closer to each other than the traditional calculations. It is expected that there will be some marginal differences in results due to the difference in the details of the system incorporated in the two models. The product stockpiles (Figure 10Figure) at the load out station in the beneficiation plant had a difference within the accuracy expected at that stage (~15% in this case), showing further details can optimise the storage requirements at a later stage of the project. In this case, detailed modeling of the rail system influenced the optimal storage requirements.

2 DISCUSSION

The “Dynamic Storage Capacity Calculator tool” generates results considering all the system blocks of the project, and the results are closer to the optimum storage requirements using total system utilization and capacities. The work is carried out with standard information available to the study team during the early stage of the project but with less engineering effort as compared to a detailed dynamic simulation model. As compared to the traditional method of calculations that may be anywhere between suboptimal (~50% of the required) and excessive storage (plus 300% of the required storage), the tool provides technically justifiable storage capacity commensurate with the input data. The domain expert judgment or operating staff input on systems or the experience of the user is required to obtain reliable results from this tool. However, it does not require modeling software experience.

Using this tool, one can assure that the storage systems are sized based on the system dependability and system dynamics to achieve the anticipated utilization of the systems included in the project. This innovative way of ensuring the quality of the engineering work can enhance investor confidence in the project as the project evolves into the next level. The results also show that evaluating the system as a whole rather in isolation would drive the values closer to optimized system. However, the tool is not meant to be used in the later stages of the project as it is necessary to simulate the system with more details to optimise the project systems or when there are more details of the system is available. The tool helps to combine the total project systems and provide data for sizing of the storage systems instead of intuitive sizing based on experience that may lead to surprises in the future phases of the project. This tool can help in early detection of capacity and utilization issues of the complete system and allows corrective action to update the specific system configuration and design.

Further work to enhance the tool is being undertaken to incorporate related systems such as water storage requirements, to make this tool more effective by considering all the systems that influence the production or sizing in the early stages of the project.

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