APPLICATION OF DYNAMIC SIMULATION FOR METALLURGICAL INDUSTRY

Dr Alexander LEBEDEV, Pr.Eng.
Lebedev Consulting
P.O.Box 73621
Lynnwood Ridge
0040
South Africa
Tel +27 (12) 361-1964
Fax +27 (12) 361-1966
Email: lebedev.consult@gmail.com

Dr.-Ing. Alexander BOROWIKOW
Gesellschaft für metallurgische Technologie- und Softwareentwicklung mbH
Heinersdorfer Str. 12
13086 Berlin
Germany
Tel +49 (3338) 33421812
Fax +49 (3338) 33421822
Email: alexander.borowikow@gmt-berlin.com

Abstract

Benefits of dynamic simulation for the metallurgical industry are discussed. These include equipment right-sizing, capacity and logistics planning, de-bottlenecking, performance optimization and others. Three case studies are discussed to illustrate practical applications of dynamic simulation

1. Introduction

Simulation is a broad subject covering a wide variety of methods and applications. For example, a numerical model describing distributions of stress and temperature in a steel slab in the process of hot rolling can be classified simulation without a doubt. This kind of simulation employs methods which are largely based on fundamental laws converted into analytical relationships correlating system inputs (e.g. slab dimensions, temperature, quality of steel etc.), controls (such as roll diameter and force applied) and outputs (slab output thickness and alike).

In this paper, a somewhat different simulation will be discussed, and before we proceed, it is worth defining the type of simulation that has been successfully applied to the metallurgical and other industries.

First of all, simulation concerned is non-deterministic, which not only implies that he magnitude of an outcome is unknown, but even the very nature of an outcome may substantially differ. This effect typically takes place in systems whose components have multiple interlinks, which may react differently even to the same type of an input. In the metal forming production environment, for example, time to complete forging will not only depend on the properties of an ingot itself but also on the performance of an operator.

Secondly, as it clearly follows from the paper title, we will discuss simulation in relation to time, where the time scale is virtually unlimited and can stretch over many years. Using the previous example, performance of a hammer may deteriorate over its lifecycle specifically in terms of availability and consequently equipment uptime thus resulting in a decreasing productivity and, for instance, increasing deviation of the final product dimensions.

Thirdly, simulation in question can handle both discrete and continuous processes, and what is even more important, conversion of discrete and continuous processes into one another. A good example from the metallurgical industry is a continuous casting machine where liquid metal charged into a caster on a continuous basis is converted into slabs, which are discrete entities. On the contrary, coils of thin sheet are discrete but sheet annealing that takes place in a typical Continuous Annealing Line is obviously continuous.

From examples given above it becomes evident that this type of simulation goes far beyond a single metallurgical process, such as pressing, forging or rolling but integrates a number of processes which are usually fundamentally different in nature, into a single model. Simulation under consideration will not focus on processes occurring in a piece of metal being formed (although it does not mean it is impossible to include those), but will address issues such as metal supply chain, appropriate settings of machinery to process the metal, availability of transport to a further production stage and such like. It is therefore simulation of production systems on a macro level looking at a whole workflow including transport, storage and processing of metal (or other products).

It is possible to define this type of simulation as an applied methodology to describe the behaviour of systems and predict future behaviour i.e. the effects produced by changes in the system or in its method of operation (a so-called "what-if" analysis). The word "behaviour" assumes variability of reaction to changes depending on conditions not necessarily directly associated with the process itself.

Visual interface and interaction with the user is of paramount importance to dynamic simulation, that's why dynamic simulation is always associated with animation. Another useful definition of dynamic simulation was proposed in [1]: "Visual Interactive Simulation is one which has features for graphical creation of simulation models, dynamic display of the simulated systems and user interaction with the running program. Interaction implies that the simulation halts and requests information from the user, or the user stops the simulation at will and interacts with the running program."

The following fundamental concepts are used in dynamic simulation modelling:

- Monte Carlo simulation
- Queuing theory
- Theory of Constraints

Paper [2] gives a concise explanation of how the above concepts are utilized in simulation of the discrete-event stochastic systems.

Special simulation software tools have been developed to build dynamic models, with GPSS/H being one of the veterans and a multitude of other packages such as Arena, Witness, Promodel, AutoMod, to mention just a few, and the likes. More than 48 different simulation software tools are available in the marketplace presently according the Institute for Operations Research and the Management Sciences (INFORMS) survey [3], many of them packaged in various versions with different functionality. It is interesting to mention, however, that none of the software vendors specified metallurgy as an application area which obviously does not mean that their products cannot be applied to the industry.

Simulation models used in case studies discussed in this paper were built with Witness™ developed by Lanner Group in the UK, the former AT&T Istel. Information on the software applications, industries, white papers and case studies are available on the company's website [4]. According to the ARC Advisory Group, Witness™ takes up over a 14% share in the simulation software market and is the most extensively used package in the world [5].

This paper does not pretend to be very scientific, instead, it aims at introduction to simulation as a tool to solve practical problems that the industry encounters on a regular basis.

2. Case Study 1: Raw Materials Feed System to Furnaces

In this case study, an expansion of an existing Ferrochrome Smelter will be discussed. The smelter presently employs two open electric arc furnaces and will add three new furnaces of larger capacity in the future resulting in raw materials intake increase of 290% by volume. Most of the presently used 10 raw materials are delivered by road in trucks of different payload capacity, operating in daylight hours only. Pellets and part of lumpy ore are supplied by internal sources which were excluded from the scope. The existing raw materials handling system comprises a single truck unloading facility, a feed conveyor to the surface stockpiles (bunkers), underground vibrating feeders and a conveyor to the existing two furnaces. Due to spatial restrictions, the reclaim conveyor has to be shared with the future feed system to the three new furnaces, which obviously raised a concern on its capacity. Furnaces have feed bins to store each of the raw materials separately for further batching into the furnace. Since the raw materials

The objective of the simulation study was to quantify the minimum required installed capacity of the raw materials handling system to ensure that the future requirement can be met.

The following inputs were used in the model:

- Truck arrival schedule, payload and unloading duration
- Draw rate from each of the day bins for each of the furnaces
- Production rates of pellets and "internal" lumpy ore
- Capacity of furnace day bins
- Conveyor purging time, i.e. time delay between batches of different raw materials to avoid contamination

Controls applied in the model were:

- Capacity of and reclaim rate from a truck unloading bin
- Storage capacity of and reclaim rate from surface raw materials stockpiles (bunkers)
- Capacity of conveyors

The key outputs from the model were

- Quantities of raw materials fed to each of the furnaces
- Average day bin levels
- Conveyor system utilization

Animation screenshot of the dynamic simulation model of the smelter appears in Figure 1

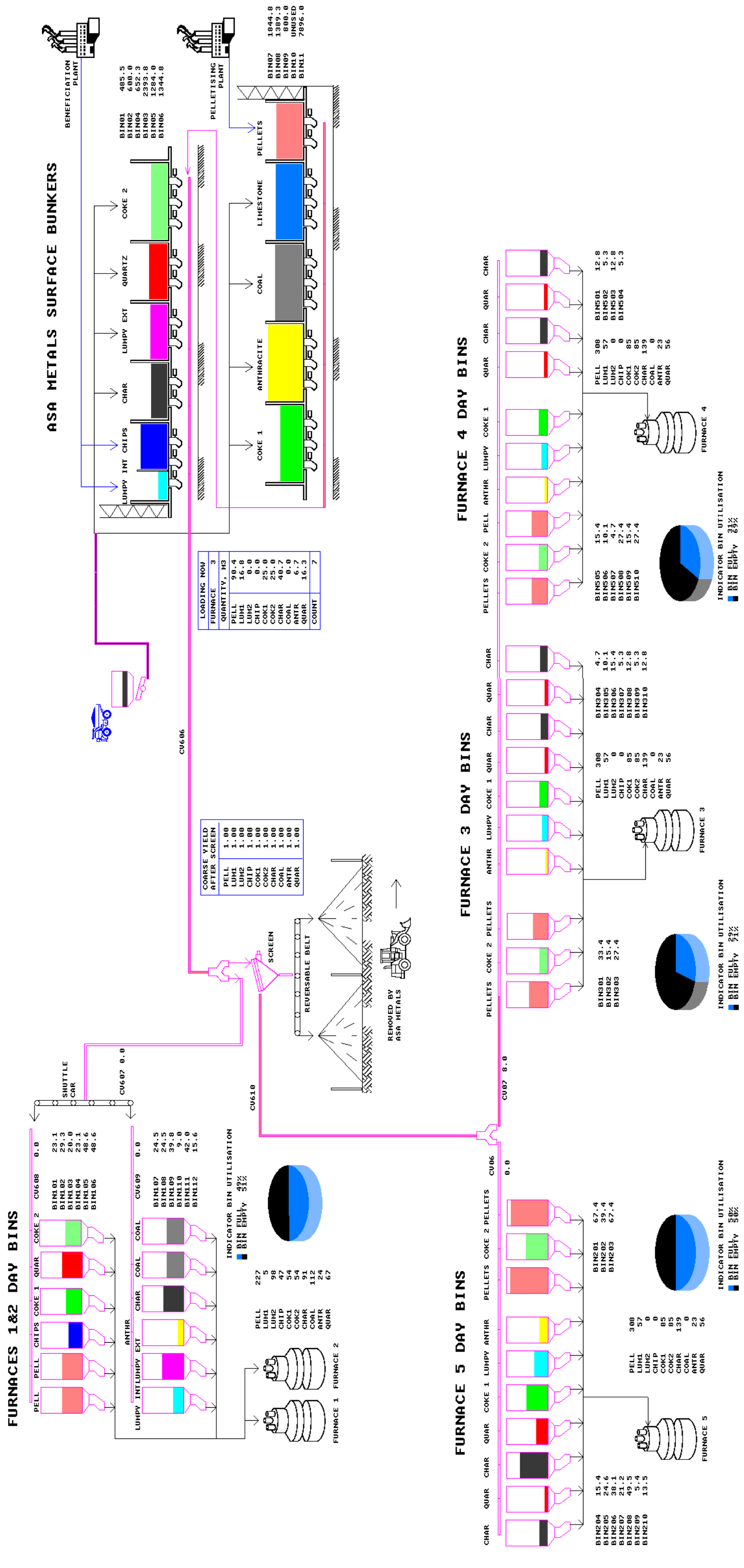

Fig 1: Animation screenshot of the FeCr smelter simulation model

A control algorithm was developed in order to control the flow of the raw materials from the shared surface bunkers to the furnace day bins. It was based on the selection of the indicator bins for each of the furnaces, i.e. the bins with the lowest ratio of bin volume to material turnover, which is equivalent to the duration of material supply from that bin. The algorithm of raw materials supply was furnace-centric, i.e. once a furnace to receive raw materials was selected, all of the raw materials were then supplied to it (i.e. furnaces were rotated in the supply cycle). It must be noted, that an alternative material-centric algorithm based on the supply of a specific material to all furnaces (i.e. raw materials were rotated in the supply cycle) was also tested, but was not proven as practically viable.

In the result of experimentation with the model, minimum values of the extraction rate from the truck unloading bunker and reclaim rates from the surface bunkers were obtained that ensured adequate supply of all raw materials to all five furnaces. A truck arrival schedule was also established, based on time allotment to each of the raw materials which was then used in negotiations with transport contractors. The capacity of the conveyor system from the surface bunkers to the furnaces was also quantified in volumetric and mass terms. Volumetric capacity requirement was essential to size the geometry and the speed of the conveyor belt critical for conveying light materials, such as coke and char, while the heavy materials, such as pellets and ore required sufficient drive power ratings to ensure sufficient mass conveying capacity.

3. Case Study 2: Metal Ladle and Slag Pot Handling in a Smelter

This case study deals with a new heavy minerals smelter producing Titanium Slag and Pig Iron as by-product. Four furnaces were planned to be built with an extensive support infrastructure. In the casting bay, various activities will take place, such as tapping, transport of ladles and slag pots by bogies, handling of metal ladles and slag pots with overhead cranes, movements of slag pot carriers (optional), transfer of metal ladles with transfer car, metal treatment and so on. It was important to understand the logistical implications of these operations to the project, identify the bottlenecks and quantify the effect of various "upset" conditions on the performance of the smelter. Also, a restriction on iron casting temperature was introduced into the model, which was a function of handling time of ladles with liquid metal and treatment procedures.

The objectives of the simulation study were to:

- Quantify the number of slag pots and metal ladles required to maintain an uninterrupted flow of slag and iron;
- Check the sufficiency of the cranage capacity in both slag and metal aisles;
- Verify the number of slagpot carriers to be deployed in the smelter (optional), adequate to handle the slag pots without jeopardizing the slag tapping;
- Quantify the effect of ladle temperature and equipment breakdowns on the smelter performance, in terms of the quantity of metal lost due to emergency casting (pooling) onto the floor;
- Assess the performance of the Metal Treatment Plant (MTP);
- Identify the required number and location for metal ladle pre-heaters.

The nucleus of the simulation model was the circulation of the slagpots and metal ladles with handling equipment "rotating" around these to support a smooth flow of the products.

There were too many inputs, all of them without exclusion sampled from various distributions and not a single one being a constant, into the simulation model to list all of them in this paper, only the key ones are shown below:

- Quantity of metal and slag tapped per cycle;
- Intervals between slag and metal taps;
- Detail operating parameters (acceleration, deceleration, travel speed) of metal and slag cars;
- Detail operating parameters of overhead cranes;
- Distances of metal ladle and slag pot transfers;
- Detail operating cycles of metal ladles and slag pots (re-bricking, cooling, coating repairs etc);
- Liquid metal treatment procedure in ladles;
- Temperature loss of liquid metal in ladles as function of time after tapping;

- Pig caster operating parameters (single- and dual-stream casting).

Liquid metal temperature prior to casting was important as casting was only allowed if T≥1,250^{o}C, if the temperature dropped below the threshold, metal was “pooled”, i.e. discharged onto the floor and discarded after cooling.

It was also important to ensure a specific time after empty ladle pre-heating to next tap, as if a ladle cooled down below a pre-set temperature, it was sent to pre-heater again. Positions and number of pre-heaters were therefore critical in order to eliminate such ladle double handling.

Animation screenshot of the dynamic simulation model appears in Figure 2

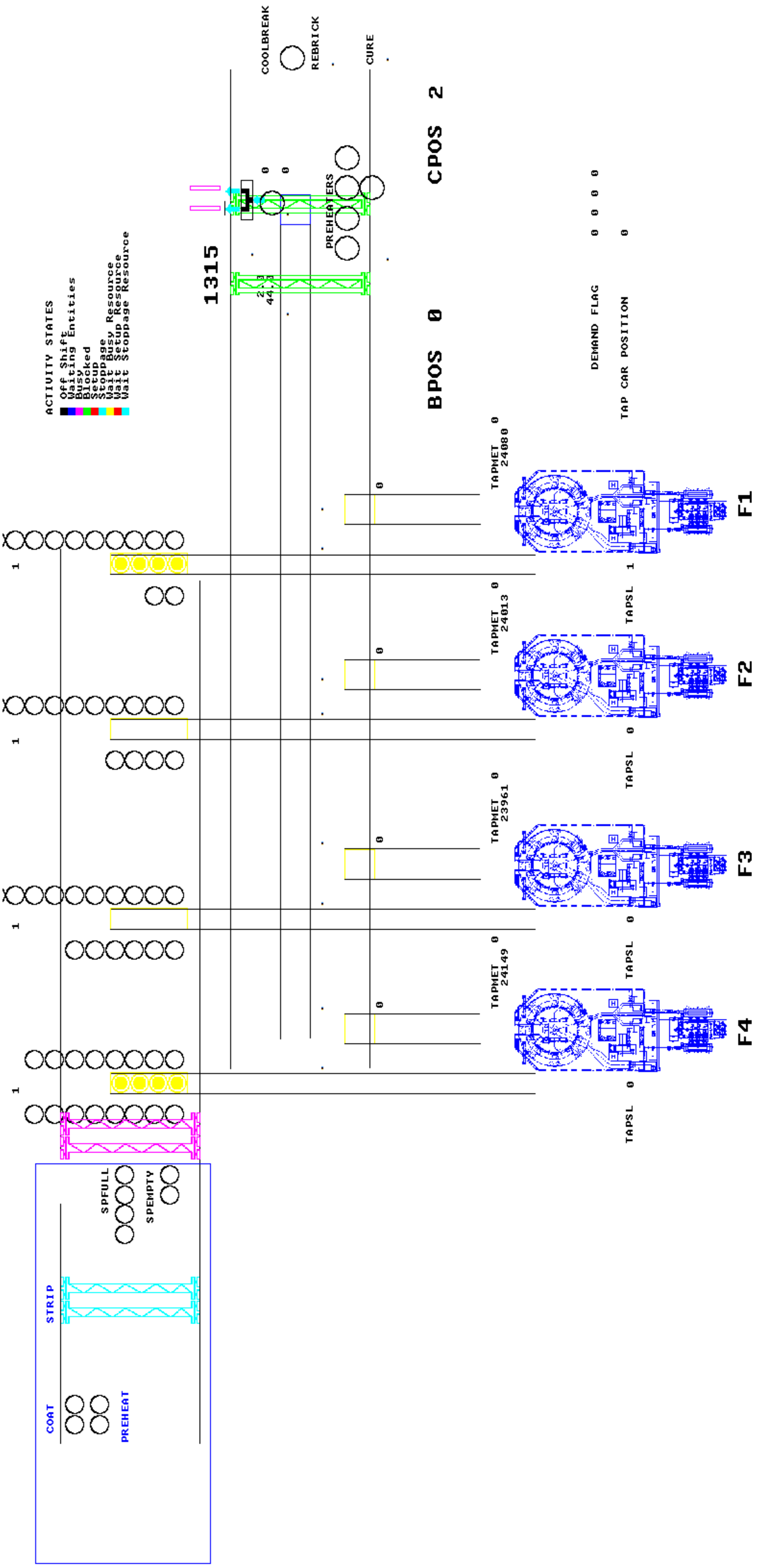

Fig 2: Animation screenshot of the heavy minerals smelter simulation model

One of the interesting findings of the simulation model was the temperature in each of the metal ladles prior to casting (or pooling if it was below 1,250°C, refer to Figure 3

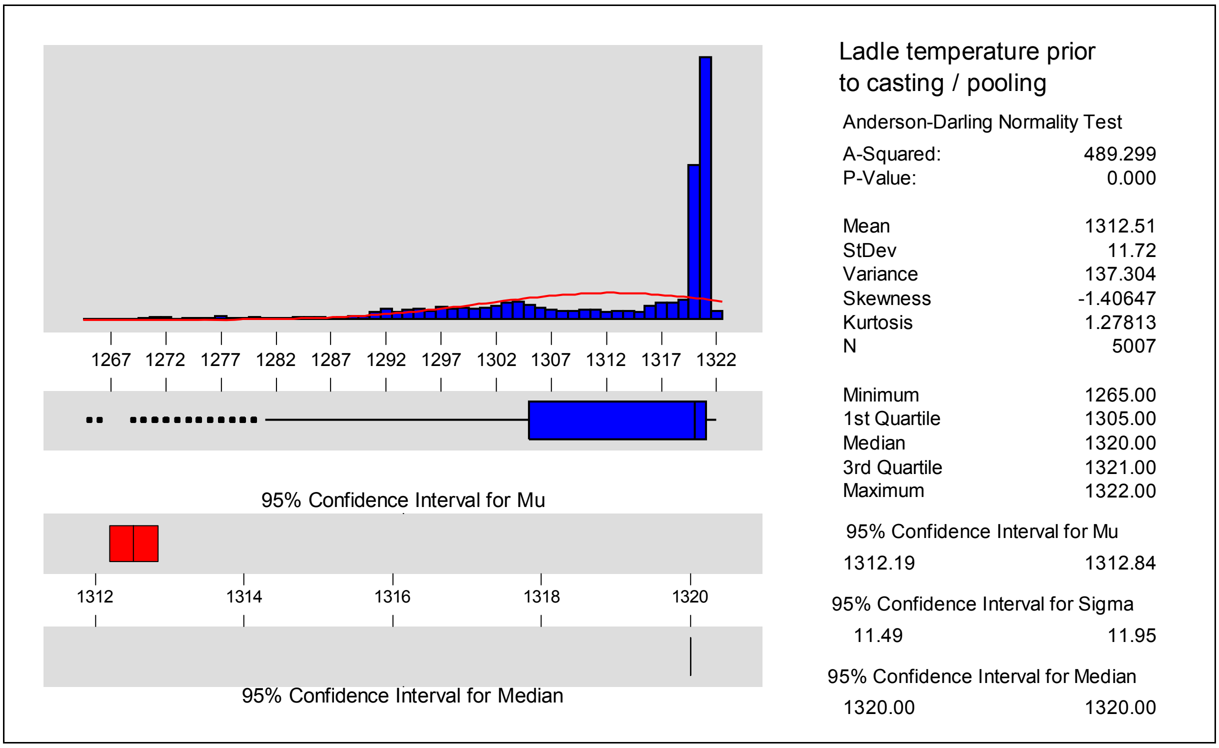

Fig 3: Liquid metal temperature in ladle prior to casting or pooling

It was found, for example, that less than 3% of metal was lost however not due to low temperature but because of the casting machine breakdowns, which was below the target. However to arrive to this result, extensive experimentation with the overhead crane movements was required to ensure that metal ladles are handled without excessive temperature loss.

Similar histograms were obtained for the time from pre-heating to next tap, which was also optimized by changing the location of the pre-heaters.

Numbers of slag pots and metal ladles sufficient to support smelter operation were quantified as well as the number and operating logic of cranes for ladles and slag pots were defined. Even required storage space for metal ladles and slag pots at each location (such as at the furnaces, in the cooling, stripping and repair areas, at the metal treatment station and everywhere else where ladles and slag pots had to be picked up or unloaded).

The simulation model helped identify the required capacity of the entire smelter support infrastructure to ensure that no taps are lost.

4. Case Study 3: Optimization of Continuous Annealing Line Performance

A typical Continuous Annealing Line (CAL) is a plant where discrete and continuous processes interface each other twice: in the front where coils are welded into a continuous strip and in the back where a continuous strip is split up in coils again. The very nature of this conversion requires buffer storage at both ends as well as good sequencing of welding and cutting to maintain a constant strip transport speed in a furnace. This is precisely the problem discussed in this case study, when the operation of a CAL slowed down the upstream process (cold rolling). Common view of plant personnel was that the entry and exit loopers were too small which was used as a motivation for capital investment to increase their capacity. In order to double-check whether the looper capacity was indeed the problem, a dynamic simulation model was constructed to identify other possible bottlenecks, refer to Figure 4 for an animation screenshot of the simulation model.

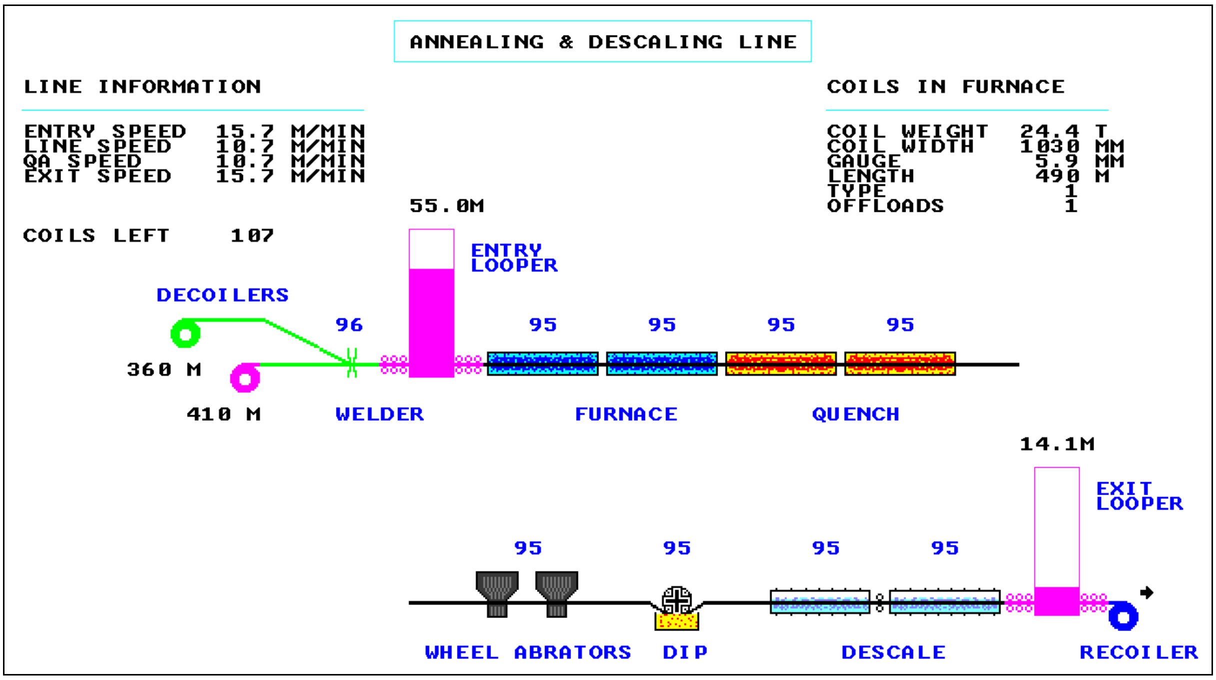

Fig 4: Screenshot of the CAL simulation model animation

The following inputs were used in the model:

- Width, length, thickness, steel grade in each coil;
- Time to load coils into decoilers
- Strip inspection and welding time
- Speed in the furnace
- Cutting time of strip at the exit
- Time to wind coils
- Time to unload coils from recoilers

The following controls were applied in the model:

- Inspection and welding time of coils at the entry
- Capacity of entry and exit loopers

In the result of experimentation it was found that there was no need in the either entry or exit looper capacity increase, instead, the operation of the welder was the route of the problem as too cautious rules were applied to strip welding, which caused a need to slow down the speed in the looper and the furnace itself. In the result, simplified yet appropriate rules were implemented in the plant, including constant line speed of looper roll at start of weld. Also, an automatic mechanism was proposed which indicated line speed required given current weld time and level in entry looper.

Thus the simulation model permitted to avoid unnecessary capital investment and instead introduce more effective operating procedures to de-bottleneck the plant.

5. Conclusions

Three case studies briefly discussed above suggest that simulation can be a useful tool in order to:

- Reduce the uncertainty and risk before you decide;
- Quantify the impact of any changes to system;
- Assess the answers to “what-if” questions;
- Identify bottlenecks and problem areas etc...

Typical benefits of dynamic simulation modeling include, but definitely are not limited to:

- Right-sizing of system prior to launch;
- Better utilisation, improved throughput;
- Shorter time to market;
- Effective management practices;
- Streamlined organisational structure;
- Cost efficiency (capital and operating expenses).

To be fair, it is necessary to note that simulation has its limitations. For example, it cannot solve inverse problems, such as give a direct answer to a question "What should be done to achieve the objective?" Simulation always works from front to end, i.e. once a set of resources and inputs (such as machinery and equipment in the plant, source and arrival of parts or materials to be processed) has been defined, the model will then produce and output which must be compared with the required target. Should the target be achieved, the model can then be used to optimize the set of production resources in such a way as to minimize the installed capacity yet achieving the target. If the target was not achieved, something should be done to either the production resources, or the supply of parts and materials, or both. Thus doing multiple simulation iterations, the required set of resources and inputs is identified.

Simulation is also not the most appropriate tool should a mathematical model be available or if a problem requires a typical linear programming approach, although it can still be used but the time and effort spent on building a simulation model may be higher.

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