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Concept Development to Control Non-value Added Logistical Costs in a Primary Aluminium Casthouse by Interfacing Linear Optimization and Simulation

Konzeptentwicklung zur Steuerung nicht-wertschöpfender Logistikkosten in einer Primär-Aluminium-Gießerei durch die Kopplung linearer Optimierung und Simulation

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The aim of this study is to quantify and reduce the non-value added logistical costs in the aluminium industry's supply chain. This study attempts to simulate the internal supply chain of a primary aluminium casthouse and identify the wastes by implementing a lean thinking approach. After highlighting the possible improvements, optimization models attempt to reduce these wastes which create non-value added costs to the system. This concept is further developed by interfacing the simulation model with the optimization model to validate the improvements. The success of the concept is tested by measuring the reduction in redundant logistical costs of a case study founded on the real casthouse specifications. Scenarios are defined to analyze the casthouse supply chain under different perspectives. The potential gain of the new concept is verified by applying it to these scenarios. In conclusion, the results analysis of the scenarios indicates the success of the main objective of this study; to develop a new concept that controls the non-value added logistical costs in the primary aluminium casthouse supply chain.

[Primary aluminium casthouse, supply chain analysis, lean thinking, logistics simulation, and linear optimization]

Das Ziel dieser Studie ist die Quantifizierung und die Reduzierung von nicht-wertschöpfenden Logistikkosten in der Lieferkette der Aluminium-Industrie. Mit dieser Studie wird der Ansatz verfolgt, die interne Lieferkette einer Primär-Aluminium-Gießerei zu simulieren und die Verluste durch die Implementierung eines Lean-Thinking-Ansatzes zu identifizieren. Nach dem Aufzeigen möglicher Verbesserungen wird mit dem Einsatz von Optimierungsmodellen versucht, die nicht-wertschöpfenden Kosten des Systems zu reduzieren. Zum Validieren der Verbesserungen wird dieses Konzept durch eine Kopplung eines Simulationsmodells mit den Optimierungsmodellen entwickelt. Der Erfolg des Konzepts wird mit einer Fallstudie basierend auf realen Spezifikationen einer Primär-Aluminium-Gießerei getestet. Verschiedene Szenarien werden definiert, um die Gießerei-Lieferkette unter unterschiedlichen Perspektiven zu analysieren. Der potenzielle Nutzen wird durch die Anwendung des neuen Konzepts auf diese Szenarien überprüft. Zusammenfassend zeigen die Analyseergebnisse für die Szenarien, dass das Hauptziel dieser Arbeit erreicht wurde, ein neues Konzept zu Verringerung von nicht-wertschöpfenden Logistikkosten in der Lieferkette der Primär-Aluminium-Gießerei zu entwickeln.

[Primär-Aluminium-Gießerei, Analyse der Lieferketten, Lean-Thinking, Logistiksimulation, Lineare Optimierung]

1 INTRODUCTION

Before the financial crisis in 2008, the ultimate goal of industry was to increase the sales and also the production amount. Nowadays, the direction of the storm changes to reduce the operational expenditure to find a place in the shrinkage of the market share with lower sales price.

The aluminium industry has also been influenced from this unstable economic situation. Tremendous decrease of demand in the automotive industry increased the stock levels of aluminium in the last four years. And also the gap between high supply and low demand reduced the sales price of aluminium.

In addition to effects of the financial crisis, CO_2 tax regulations due to its environmental impact increased the

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energy prices day by day. Besides that, inevitable growth of aluminium production in China creates big challenges in the aluminium industry, especially in Europe.

The technological developments in aluminium industry focus on how to reduce the production costs. Energy consumption forms the main part of these costs due to high energy prices. Therefore, the production process is tried to be optimized so that it consumes less energy. However it is also recognized that logistical activities in the facilities have a potential for improvement.

The main focus of this paper is the development of a concept that controls the logistical activities creating extra unpredictable costs in a part of the primary aluminium supply chain. In a smelter concept, the electrolysis first comes into the mind because the actual production process takes place in this sub facility. However, the selected unit of smelter for this study is the casthouse area due to its potential for improvement in logistical perspective and its direct contact to the external customer which brings more challenge for the investigation.

2 PRIMARY ALUMINIUM CASTHOUSE SUPPLY CHAIN

In aluminium life cycle, there are two important processing steps which are called primary aluminium and secondary aluminium production. Primary aluminium production is the reduction of aluminium oxide to aluminium. Secondary aluminium production is re-melting of scrap aluminium recycled after usage.

After the development of Hall-Héroult process [GK93] which is an electrochemical process used to produce primary aluminium from alumina, production of aluminium increased continuously. The electrolysis unit in an aluminium smelter facility contains many cells where the aluminium is produced. Smelter may have two other main units except electrolysis. The first one is the carbon plant where the anodes are produced from coke and pitch. And the second one is casthouse where the liquid aluminium is casted as an end product to be delivered to customer. There are some other auxiliary plants such as fume treatment plant, bath treatment plant etc.

The casthouse is the last unit in the process flow of an aluminium smelter and has a direct interface with electrolysis by receiving hot metal from this unit. However, there is not any material flow between carbon plant and casthouse. Figure 1 shows the internal supply chain of a primary aluminum casthouse. The boundary of this supply chain starts with delivery of hot and cold metal and ends with shipment of end products to customer.

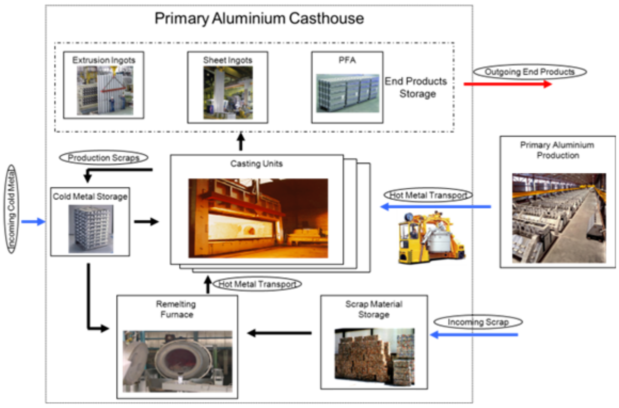

Figure 1. Internal supply chain of primary aluminum casthouse

3 SIMULATION MODEL DEVELOPMENT FOR ALUMINIUM CASTHOUSE

Logistics simulation studies performed in metal industry have become challenging in the recent years. The reason is that attitude toward simulation models are changing. According to Guo [Guo03], in the past expectations were “quick and dirty” simulation models with “Know-how” approach, but today it is expected to model the system as accurate as possible to find the answer to the question “Why”. Additional to that, due to safety reasons in the heavy metal industry, detailed analysis of the human behaviors is also intended to be in the main focus of logistical studies done for the metal industry.

Several simulation studies have been done to analyze the material and information flow in the aluminium production. Eick et al. [EVB01] and Meijer [Mei10] focused mainly on material flow of the electrolysis and made some investigations only for the pot room part of the smelter. Harton [Har10] simulated the hot metal flow between electrolysis and casthouse. Tikasz et al. [TBPM10] and Pires et al. [PBTM11] investigated the full smelter logistics with the objective to improve the system from the safety perspective. Jaouen [Jao11] made a simulation study for the downstream part of aluminium casthouse.

Winkelmann et al. [WEDS09] defined a full smelter simulation approach to map the system in more accurate way and also to eliminate the risks (e.g. inaccuracy in hot metal flow) occurring due to some simplifications in the system interactions.

This simulation study differs from others by aiming to map the whole material flow taking place in the casthouse of an aluminium smelter, and also having a flexible model, which can be applied to different casthouses. The flexibility brings the challenge to consider many possible control approaches that can be used in the material flow field. For that reason, various casthouses were studied to have wide eligible logistical perspectives in the model.

The model boundary of the simulation study contains not only the primary casting furnaces but also re-melting furnaces. Extrusion billets, foundry alloys, sheet ingot slabs and wiring rods are considered as the possible end products of the casthouse. In this study the simulation tool Automod, is used to analyze the internal supply chain of aluminium casthouse.

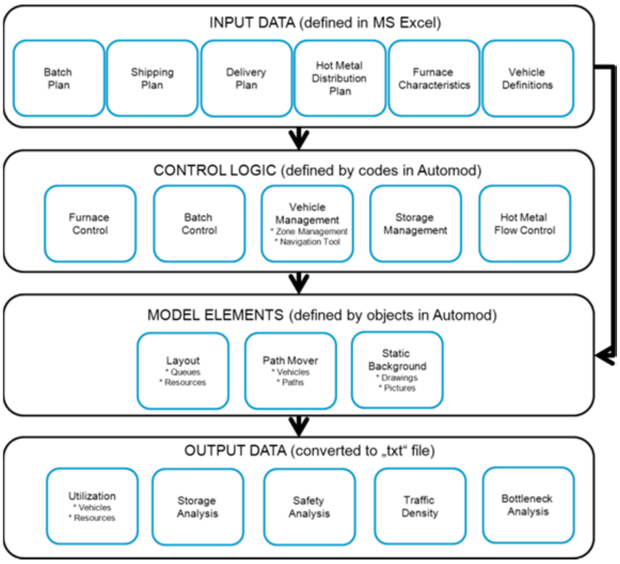

Figure 2. Casthouse simulation model structure

Structure of the casthouse simulation model contains four layers which are shown on Figure 2. These layers are classified according to their attributes and file format. Arrows show the direction of information flow occurs in between these layers in the simulation model structure. The first layer is input data definition which is done in MS Excel, the second and the third parts, control logic and model elements, are defined in Automod simulation software. The last part is determined in Automod and converted to "txt" format.

4 LEAN THINKING APPROACH IN THE PRIMARY ALUMINIUM CASTHOUSE SUPPLY CHAIN

The aim of the lean thinking approach is to increase the efficiency in an application field. Wastes are identified in the supply chain by differentiating between value added activities and non-value added activities in the flow. Wastes or non-value added activities in this context contain the processes which do not create any value in the production cycle of the product. There are seven groups of wastes categorized in the lean thinking approach [Ohn88]. These groups are: Overproduction, waiting time, unnecessary transportation, poor processing, inventory, extra movements and defective products.

According to Abdullah [Abd03], the application of the lean thinking approach to continuous processes is not that common compared to discrete manufacturing. It was created for the automotive industry which has discrete assembly operations instead continuous processes. Therefore, the number of publications concerning lean thinking in metal industry is restricted (e.g. steel production [Abd03], steel mill facility [AR07] and chemical process industry [Mel05]). The casthouse supply chain can be defined as a mixed system which combines continuous and batch-wise production. The continuous process in electrolysis has an impact on the batch-wise production of casting furnaces.

Studies done in the casthouse area were mostly focused on a single concept in the supply chain. For example, Peterson et. al. [PN02] studied to minimize gross melt loss during skimming process. Jensson et. al. [JKG05] and Yuan et. al. [YKSBT04] examined the casthouse production in minimizing the setup times. Maiwald et. al. [ML06] focused on finding optimum temperature regime in casting furnace which has impact on productivity and efficiency. However, they did the optimization for each waste separately without combining them.

	In Scope	***Out of Scope***
Waste of overproduction	*Surplus production*	
Waste of waiting time	*Hot metal waiting time*	
	Longer batch lead time	
Waste in transportation		*Storage reshuffling*
Waste in processing	*Longer idle time in furnaces*	
	Late delivery of an order	
Waste in inventory		*Inventory of incoming materials*
		Inventory of internal scrap and surplus
	Inventory of finished goods	
Waste of movement		*Furnace charging strategy*
		Specific traffic rules for vehicles
Waste of defective products		*Rejected products in quality check*

Figure 3. Categorization of wastes depending on improvement possibility in the scope of the optimization model

In this study, the analysis contains the non-value added costs depending on logistical activities such as traffic, transportation, buffering, stocking, production planning and scheduling etc. Additionally, it is also described how these items are quantified and measured in the simulation model. The process of elimination or reduction of wastes contains optimization models which focus on the identified non-vale added costs. The categorization of wastes depending on improvement potential within the scope of the optimization model is listed on Figure 3. Some of them are kept out of the scope of the optimization model due to the operational strategy of the casthouse or the inconvenience of the improvement approach.

5 OPTIMIZATION MODEL DEVELOPMENT

The optimization part of this study contains two different models which aim to minimize the non-value added costs due to logistical activities. The aim of the first tool is to create a production plan which is capable of distributing the customer orders to the batches for casting furnaces and also allocate these batches to the appropriate furnaces. Tang et. al. [TLRY01] created a production plan in the same direction for the steel casting plant. Their objective was to increase the productivity and energy saving. Nonas et. al. [NO05] also focused on production planning of foundry and their objective was to find an efficient plan which minimizes late delivery. Tan et.al. [TK05] studied rearranging customer orders with the help of computerized method for the casting unit. They succeeded in reducing scrap metal 20% with the new approach.

The aim of the second tool is to schedule the production in aluminium casthouse by arranging the operations at the casting furnaces. This part of the study has a close interaction with the electrolysis part of the smelter due to the impact on the hot metal flow management. According to Freeman et. al. [FKZM05] the basic of casthouse scheduling can be identified as the combination of problems known as lot-sizing, sequencing and scheduling. This definition is based on the combination of continuous operations (e.g. aluminium production in electrolysis) and batch–wise processes (e.g. pot tapping, crucible transport and furnace filling).

Maticevic et.al. [MML08] dealt with scheduling issues in aluminium foundry by aiming to minimize the tardiness in production. Gravel et. al. [GPG02] followed a closer approach to analyze the scheduling problem by aiming to reduce hot metal waiting time, tardiness and early production.

However, after detailed literature survey, any published study about interfacing a production plan or schedule with simulation platform for the aluminium casthouse could not be found. Therefore, the methodology for the interfacing is kept in general which is defined by Matta [Mat08]. According to this study, simulation model sends “system performance” to optimization model and receives “system alternatives”.

5.1.1 SHORT-TERM PRODUCTION PLANNER

The short-term production planner model is aimed to minimize the non-value added costs occurring due to the poor production planning. The model handles the problem by focusing on the casting furnaces. The main parameters of the model are number of batches per shift per furnace, capacity of furnace, allocated casting unit and production period. The objective of short-term planner tool is to minimize the costs due to late delivery of the order, early production causing the inventory cost at the storage of final goods and surplus material because of more production than customer demand

The indices used in the optimization model are:

Indices	***Definition***
furnace	*Furnaces in the casthouse*
order	*Customer orders*
batch	*Produced unit of a customer order*
timeslot	*Slots that shift duration is equally divided in*
shift	*Shifts in the optimization period*

The parameters used in the optimization model are:

Parameter	***Definition***
m	*Total number of furnaces in the casthouse*
k	*Total number of customer orders*
n	*Total number of produced batches*
t	*Total number of slots*
s	*Total number of shifts*
$FurAv_{furnace\ shift}$	*Number of batches assigned to the furnace per shift*
$SmFurCap$	*Capacity of the smallest furnace in the system (ton)*
$BtAm_{order\ batch}$	*Amount of the batch of the order (ton)*
OAm_{order}	*Amount of the order (ton)*
$OPri_{order}$	*Penalty rate of the order depending on the customer*
$LaProT_{order}$	*Latest production time that is planned for this order (day)*
BAm_{batch}	*Amount of the batch (SKU)*
$DelT_{order}$	*Delivery date of the order (day)*
$SalesPr$	*Sales price of the product (Euro /ton)*
$PenRate$	*Penalty rate (% per day)*
$ManHrC$	*Man hour and equipment cost (Euro/ SKU / day)*
$InvC$	*Inventory cost (Euro/ SKU / day)*
CMC	*Market price of external cold metal (Euro /ton)*

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The decision variables of the optimization model:

Parameter	***Definition***
$FurCS_{furnace\ timeslot}$	*Current status of the furnace per timeslot*
$SurpAm_{order}$	*Amount of over production per order (ton)*
$ODel_{order}$	*Duration of the delay for the order (day)*
$ProT_{order\ batch}$	*Production time of the batch belonging to the related order (day)*
$BRet_{batch}$	*Retention time of the batch in the end product storage (day)*

The objective function of short-term planner tool:

Minimize [COST_LD + COST_EPS + COST_SR]

subject to;

$$FurCS_{furnace\ timeslot} \in \{0, 1\} \qquad \forall_{furnace}, \forall_{timeslot}$$

$$\sum_{timeslot=1}^{t} (FurCS_{furnace\ timeslot}) = FurAv_{furnace\ shift} \qquad \forall_{furnace}, \forall_{shift}$$

$$SurpAm_{order} = \sum_{batch=1}^{n} (BtAm_{order\ batch}) - OAm_{order} \qquad \forall_{order}$$

$$SurpAm_{order} <= SmFurCap \qquad \forall_{order}$$

$$SurpAm_{order} >= 0 \qquad \forall_{order}$$

$$ODel_{order} = \max[0, (ProT_{order\ batch} - LaProT_{order})] \qquad \forall_{order}, \forall_{batch}$$

$$BRet_{batch} = \max[0, (DelT_{order} - ProT_{order\ batch})] \qquad \forall_{order}$$

where;

Cost_LD = CoeffLDtoCost * ODelorder * OAmorder * OPriorder)

Cost_EPS = CoeffEPStoCost * BRetbatch * BAmbatch)

Cost_SR = CoeffSRtoCost * SurpAmorder)

where;

CoeffLDtoCost = SalesPr * PenRate

CoeffEPStoCost = ManHrC + InvC

CoeffSRtoCost = SalesPr - CMC

5.1.2 PRODUCTION SCHEDULER

Like the first optimization model, this tool also focuses on the casting furnaces. The sequence of operations, their durations and starting time are the main parameters of the tool. The logic of the tool divides the time into intervals the length of which depends on the required sensitivity. The shorter the interval means more sensitive the analysis. The length of processes is also determined with respect to the length of the intervals. The processes of each furnace have a sequence, an index and duration definition according to the system characteristics of the casthouse.

The indices used in the optimization model are:

Indices	***Definition***
furnace	*Furnaces in the casthouse*
castingline	*Casting units in the casthouse*
batch	*Produced unit of a customer order*
timeslot	*Slots that shift duration is equally divided in*
shift	*Shifts in the optimization period*
process	*Processes take place at the furnace*

The parameters used in the optimization model are:

Parameter	***Definition***
m	*Total number of furnaces in the casthouse*
l	*Total number of casting units in the casthouse*
n	*Total number of produced batches*
t	*Total number of slots*
s	*Total number of shifts*
p	*Total number of processes take place at the furnace*
$FurAv_{furnace\ shift}$	*Number of batches assigned to the furnace per shift*
$CLCap_{castingline}$	*Capacity of the casting line*
$FurProCap_{furnace}$	*Process duration capacity of the casting furnace (min)*
$HMCap_{shift}$	*Total planned hot metal amount for the shift (ton)*
$AmHM_{furnace\ batch\ shift}$	*Amount of hot metal per furnace per batch per shift(ton)*
$Cap_{furnace}$	*Capacity of the furnace (ton)*
$BatAm_{batch}$	*Amount of the batch (ton)*
PHTP	*Planned hot metal transportation period in the casthouse*
$BatDur_{batch}$	*Lead time of the batch*
$ProDur_{batch\ process}$	*Duration of each process in the batch*
PrNoIdle	*Process number of "Idle process"*
ReqEn	*Required energy to cast one ton aluminium (kWh / ton)*
EnCost	*Energy cost (Euro / kWh)*
TotPro	*Annual production amount of the casthouse (ton/yr)*
SysCap	*System capacity (total capacity of the casting furnaces)*
YrtoHr	*Unit conversion from year to hour (hr / yr)*

The decision variables of the optimization model:

Parameter	***Definition***
$FurCS_{furnace\ timeslot}$	*Current status of the furnace per timeslot*
$CLUti_{castingline}$	*Current usage of the casting line*
$FurProAll_{furnace}$	*Total process duration allocated to the casting furnace (min)*
$HMTrans_{shift}$	*Amount of hot metal transportation in the shift (ton)*
$WTHM_{furnace\ batch\ shift}$	*Waiting time of hot metal per furnace per batch per shift (hr)*
$TrHM_{furnace\ batch\ shift}$	*Time of hot metal transportation for the defined batch at the furnace in the shift*
$IdTFur_{furnace}$	*Idle time of the furnace (hr)*
Del_{batch}	*Delay in the batch lead time (hr)*

The objective function of short-term planner tool:

$$\text{Minimize} \quad [COST\_HM + COST\_FI + COST\_OLD]$$

subject to;

$$FurCS_{furnace\ timeslot} \in \{0, 1\} \qquad \forall_{furnace}, \forall_{timeslot}$$

$$\sum_{timeslot=1}^{t} (FurCS_{furnace\ timeslot}) = FurAv_{furnace\ shift} \qquad \forall_{furnace}, \forall_{shift}$$

$$CLUti_{castingline} <= CLCap_{castingline} \qquad \forall_{castingline}$$

$$FurProAll_{furnace} <= FurProCap_{furnace} \qquad \forall_{furnace}$$

$$HMTrans_{shift} = \sum_{furnace=1}^{m} (\sum_{batch=1}^{n} (AmHM_{furnace\ batch\ shift})) \qquad \forall_{shift}$$

$$HMTrans_{shift} = HMCap_{shift} \qquad \forall_{shift}$$

$$BatDur_{batch} = \sum_{process=1}^{p} (ProDur_{batch\ process}) \qquad \forall_{batch}$$

$$IdTFur_{furnace} = \sum_{batch=1}^{n} (ProDur_{batch\ process}) \quad \text{for process} = PrNoIdle \qquad \forall_{furnace}, \forall_{batch}$$

$$WTHM_{furnace\ batch\ shift} = \max[0, (TrHM_{furnace\ batch\ shift} - PHTP)] \qquad \forall_{furnace}, \forall_{batch}, \forall_{shift}$$

$$Del_{batch} = BatDur_{batch} - \sum_{process=1}^{p} (ProDur_{batch\ process}) \qquad \forall_{batch}$$

where;

$$Cost\_HM = CoeffEnLotoCost * \sum_{furnace=1}^{m} (\sum_{batch=1}^{n} (\sum_{shift=1}^{s} (WTHM_{furnace\ batch\ shift} * AmHM_{furnace\ batch\ shift})))$$

$$Cost\_FI = CoeffEnLotoCost * \sum_{furnace=1}^{m} (IdTFur_{furnace} * Cap_{furnace})$$

$$Cost\_OLD = CoeffEnLotoCost * \sum_{batch=1}^{n} (Del_{batch} * BatAm_{batch})$$

where;

$$CoeffEnLotoCost = (ReqEn * EnCost * TotPro) / (SysCap * YrtoHr)$$

5.1.3 INTERFACING WITH THE SIMULATION MODEL

Interface between the simulation model and the optimization model performs to share the data via MS Excel. Firstly, the optimization model calculates system alternatives and then sends them to the simulation model. Secondly, the simulation model responds with the system performance by converting its output in an appropriate form which becomes the input for the optimization part.

The interface between optimization models and simulation model is separately set up. Each optimization model has its own communication path and the data flow has not any influence to the other. The interface between simulation and optimization models is done in a static way so the simulation model can receive and transfer data to both models in the same instant. But the output gained from the simulation model depends on the result of both optimization models.

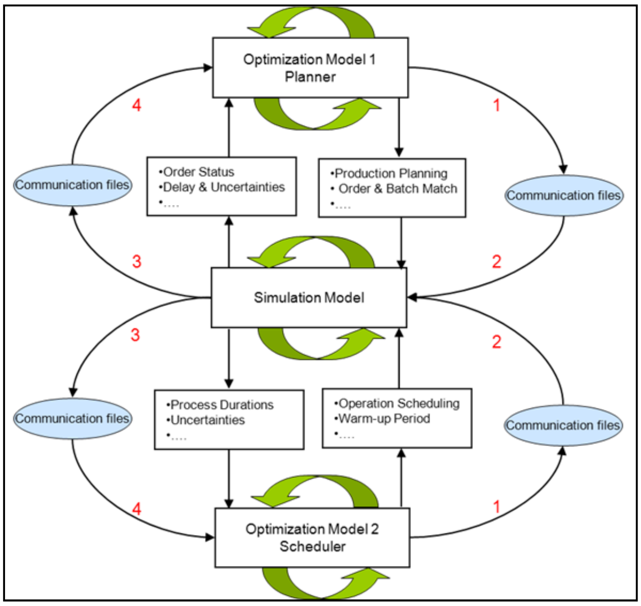

Figure 4. Methodology of the interface between the simulation and optimization models

The steps of the methodology of interfacing shown on the Figure 4 are:

1. The optimization model runs with the initial assumed data and determines the required result with respect to its objective function. The output of the optimization model is transferred to MS Excel table which is prepared in the format as an

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input for the simulation model. This step is valid for both optimization models.

2. The simulation model reads the input data and builds its logic with this data. Simulation duration depends on the required time frame. It also depends on the time interval of the input data received from the optimization model. The calculated time interval of the input data in the optimization model cannot be shorter than the simulation run period.
3. The simulation model creates the output and inserts it into MS Excel platform for the further run of the optimization model.
4. As a last step, the optimization model reads the output data of the simulation model and reruns its logic for the next round of the interface.

The repetition of the communication loop depends on the accuracy expected by the user.

6 EVALUATION

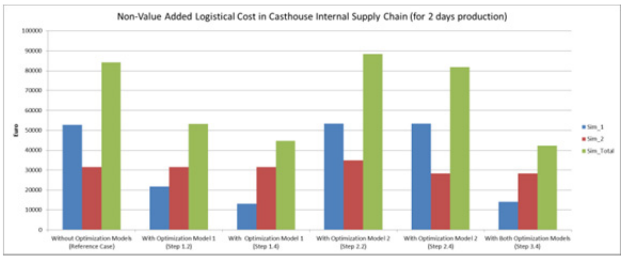
An example case is built to test both the simulation and the optimization models and to verify the interface. For that reason, during the set up period of the case study, system characteristics of the casthouse are considered to touch each single point in both model concepts. As a final, one type of end product is selected.

Both optimization and simulation models have casting furnaces in the center of their concepts, so the example created to verify the study is set up by focusing on the casting furnaces. Two different groups of casting furnaces are considered to see the variances of the furnace specifications on the results. The layout of the casthouse is built by combining different characteristics of casthouses owned by Hydro Aluminium.

6.1.1 SCENARIO I: FIXED PRODUCTION AMOUNT

"Scenario I" represents the case with a fixed hot metal ratio which restricts the production amount of the casthouse. The fixed ratio concept is preferred in some casthouses having constant cold metal supply with high cost. This assumption causes single batch production per furnace per shift. The ratio of hot metal to total batch amount is determined around 63%.

The production plan and schedule are prepared for the reference case, without interfacing the optimization models, according to the historical data analysis obtained from Hydro Aluminium. After each step in interfacing the short-term production planner optimization model with the simulation model, the reduction in non-value added costs increases.



After completing half of the loop in the interfacing concept (Step 1.2), the obvious reduction in the total costs in both objective functions is recognized for two days. By completing the whole loop of in the interfacing methodology (Step 1.4) additional reduction is also gained.

If the simulation runs only with optimization model 2 without any data flow in the direction from the simulation to the optimization model (step 2.2), the costs in the objective functions are increased. This means that the system creates more non-value added costs compared to the reference case. The reason of this result is that the predefined parameters (in step 2.1) for the optimization tool 2 have considerable difference compared to the parameters obtained from the simulation run (in step 2.3).

On the other hand, after completing the interfacing concept, by reaching to step 2.4, the result gets better than the reference case by around 3 %. Additionally, it is also recognized that values obtained from the optimization models and the simulation model become closer in each step.

6.1.2 SCENARIO II: VARIABLE PRODUCTION AMOUNT

During the detailed analysis of scenario I with the production scheduler optimization model, a possible production amount increase was recognized. Fixed ratio of hot metal to the batch size limits to increase the production capacity in the casthouse. In this part of the analysis, a new scenario is prepared by removing this restriction. With this scenario, it is possible to increase the production capacity by replacing required hot metal with cold metal. This analysis is useful in the real case when electrolysis cannot supply the demand or cold metal prices go down in the market. This new assumption has direct impact on the objective function of the second optimization model. Therefore, the analysis of this scenario is done only with the production scheduler.

The allowance of adding more cold metal to the batch recipe enables the system not to have a fixed ratio of hot metal to the production amount. In scenario I, the hot metal ratio was assumed to be around 63 %. However, due to the melting rate of the furnaces minimum hot metal rate is assumed to be 55 % for scenario II. Therefore, hot metal ratio in the casting furnace may vary between 55 % and 65 % for this new scenario depending on the situation in the casthouse. On the other hand, this causes more

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melting duration compared to scenario I. The restriction of having one batch production per furnace per shift is kept for this scenario due to the availability of casting lines.

Figure 5 presents the graph of the comparison of results for the scenarios with and without optimization tools. The benefit gained from interface of simulation and optimization models can be seen on the graph. The difference in values of the objective function of simulation and optimization tools gets smaller after interfacing the models. Without the interface, the optimization model delivers lower cost value compared to the simulation model. As mentioned before, the results obtained from the simulation model represent more reliable values compared to values from optimization model due to mapping the dynamic interaction between the operations.

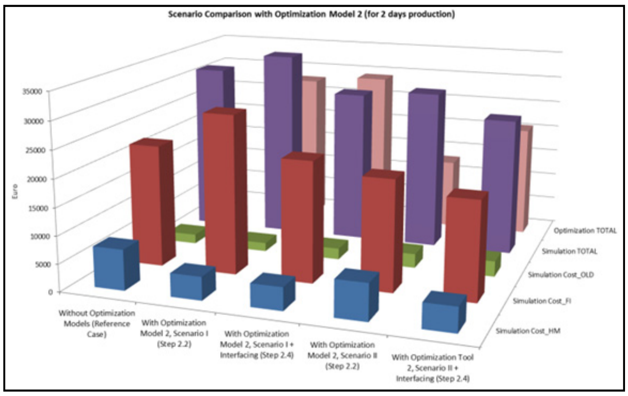

Figure 5. Scenario I and II comparison with and without optimization model 2 (the production scheduler)

7 SUMMARY & FUTURE WORK

In this study, it was verified that the interfacing between the simulation and optimization models helps to reduce the non-value added logistical costs in the primary aluminium casthouse supply chain. After interfacing with the simulation model, both of the optimization models separately succeeded in improving the casthouse supply chain by reducing the non-value added logistical costs specified by lean thinking approach. The study gave the best result after interfacing both of the optimization models at the same time with the simulation model.

However, further investigations can be done for cases containing the extended supply chain boundary or different industrial requirements. A simulation model can be prepared for the electrolysis unit which will interface with the casthouse simulation model to identify and analyze the effects of other logistical activities occurring in electrolysis on the hot metal flow. Addition to that, the interfacing between the simulation model and the optimization models was done manually in the study. The data flow may be progressed automatically by using a computer program providing a dynamic interface.

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