Master thesis

Material flow analysis and new conceptual design of plant components for a filler material producer

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In cooperation with:

voestalpine Böhler Welding Austria GmbH

voestalpine Böhler Welding

STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Graz, am 19.05.2014 ………………………………………………
(Sarah Dober)

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Abstract

The company voestalpine Böhler Welding Austria GmbH produces welding consumables in Kapfenberg, Styria. In the master thesis at hand the production of stick electrodes and cored wire will be treated on the basis of material flow investigations. Bulk solids are dosed in order to be mixed with water glass and pressed around the core rods of stick electrodes or in case of cored wire for filling of the tabular wires. Currently the needed raw materials are dosed manually according to particular recipes. Manual dosing causes elevated dust loading and thus the working conditions are affected negatively. In addition to that potential contaminations can occur and the material loss is increased. Since the planned increase of the order volume cannot be fulfilled without an increase in personnel, a new dosing system is to be designed. Besides the dosing process the previous and subsequent production steps also need to be adapted.

The objective of the thesis is to come up with several concept variants with different levels of automation for implementing a new dosing system.

The implementation of the master thesis is divided in two major parts. First a detailed material flow analysis of the actual system is conducted. Operational procedures and related material flows are analysed. With the help of time measurements, employee surveys and a material flow simulation, requirements for redesigning the dosing system can be deduced.

The second part of the thesis builds on the findings of the as- is analysis and material flow planning and layout planning tasks are executed. By developing and adapting new respectively existing planning methods eight different concept variants with different levels of automation are created and evaluated. Subsequently the ideal alignment of raw materials and the ideal bin sizes respectively system geometries are determined for three preferred concept variants. By calculating the time slices needed for production the overall process times of the single systems can be defined and for the two most promising variants a real layout is drafted. The real layouts are compared and evaluated by means of value benefit analysis and the results of the analysis serve as background for the decision- making process, in which an appropriate concept for implementation of a dosing system manufacturer will be selected.

Kurzfassung

Die Firma voestalpine Böhler Welding Austria GmbH produziert Schweißzusätze am Standort Kapfenberg, Steiermark. In der vorliegenden Masterarbeit wird die Produktion von Schweißelektroden und Fülldraht auf der Grundlage von Materialflussuntersuchungen behandelt. Dabei steht der Dosierprozess von pulverförmigen Schüttgütern, die im Falle von Schweißelektroden mit Wasserglas gemischt als Hülle um den Kerndraht gepresst bzw. im Falle von Fülldraht als Füllung des Drahtes verwendet werden, im Vordergrund.

Derzeit werden die benötigten Rohstoffe manuell nach vorgegebenen Rezepturen eingewogen. Die dadurch entstehende Staubbelastung beeinflusst die Arbeitsbedingungen negativ und führt neben möglichen Kontaminationen auch zu einem nicht unerheblichen Materialverlust. Da künftige Produktionssteigerungen mit dem derzeitigen System ohne Personalaufstockung nicht bewältigbar sind, soll ein neues Dosiersystem entworfen werden. Neben dem Dosierprozess müssen auch vorgelagerte wie auch nachgelagerte Arbeitsschritte in die Planung integriert werden.

Ziel der vorliegenden Arbeit ist es, mehrere Varianten mit unterschiedlichen Automatisierungsgraden für die Implementierung eines neuen Einwiegesystems zu entwerfen und zu bewerten.

Der praktische Teil der Masterarbeit wird in zwei Teilbereiche unterteilt. Im ersten Teil wird eine ausführliche Materialflussanalyse des bestehenden Systems durchgeführt. Dabei werden die Arbeitsabläufe und vorliegenden Materialströme analysiert und mithilfe von Zeitmessungen, Mitarbeiterbefragungen und der Simulation der Materialflüsse können Anforderungen an die Neugestaltung abgeleitet werden.

Der zweite Teilbereich baut auf den Erkenntnissen der Ist- Analyse auf und eine Materialfluss- und Layoutplanung für die Neukonzipierung des Dosiersystems wird durchgeführt.

Unter Verwendung von angepassten und zum Teil neu entwickelten Methoden werden acht unterschiedliche Konzeptvarianten mit unterschiedlichen Automatisierungsgraden entworfen und bewertet. Für drei Vorzugsvarianten werden im Anschluss die optimale Anordnung der benötigten Rohstoffe und die geeigneten Lagerbehälter bzw. Systemgeometrien ermittelt. Durch die Berechnung der benötigten Zeitanteile können die Prozesszeiten der einzelnen Systeme bestimmt werden und im Anschluss wird für zwei Vorzugsvarianten ein Reallayout erstellt.

Durch die Gegenüberstellung und Bewertung der Reallayouts mit Hilfe einer Nutzwertanalyse kann die Entscheidungsfindung zur Umsetzungen des Projektes unterstützt werden und die Ergebnisse der Arbeit dienen als Grundlage für die Auswahl am Markt verfügbarer Technologien für die Neukonzipierung der Einwiegerei.

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List of Abbreviations

vaBWA	voestalpine Böhler Welding Austria GmbH
VBA	Visual Basic for Applications
VDI	The Association of German Engineers (Verein Deutscher Ingenieure)
FY	Fiscal Year
ISO	International Organization for Standardization
DIN	German Institute for Standardization
kg	Kilogram
dm^3	Cubic decimetre
s	Second
V	Volume
IT	Information Technology
FM	Ferritic- martensitic (un- and medium- alloyed)
RSH	Stainless, acid and heat- resistant (high- alloyed)
WD	Working day
SE	Stick electrode
CW	Cored wire
ERM	Entity- relationship- model

1 Introduction

In the course of this master thesis the production of stick electrodes and cored wire at the production site of voestalpine Böhler Welding Austria GmbH in Kapfenberg, Styria will be treated on the basis of material flow investigations. The dosing system, where raw materials are dosed according to particular recipes, is to be modernized and adapted to the state of art.
In the beginning the company and the main products and their manufacturing processes will be presented. Moreover the main problems will be specified and the objectives will be determined.

1.1 The company *voestalpine Böhler Welding*

The company voestalpine Böhler Welding is part of the voestalpine Group.
The voestalpine Group incorporates 500 companies and locations in over 50 countries on all continents with more than 46.000 employees in total. [VOE14a]
The Group is subdivided in four divisions:

- Steel Division
- Special Steel Division
- Metal Engineering Division
- Metal Forming Division.

The product portfolio of the Group includes amongst others steel strip, precision strip, heavy plates, tool- steel, high speed steel, special forgings, rails and rail- switches, and welding consumables. [VOE13]

Figure 1-1: Divisions of the voestalpine Group (according to [VOE13])

The company voestalpine Böhler Welding offering solutions and different products for welding brazing and soldering applications, is integrated to the Metal Forming Division of voestalpine Group.

As global top- supplier in different industry sectors ranging from chemical and oil & gas industry to automobile and energy industry, voestalpine Böhler Welding is represented globally. [VOE14b]

In Austria, voestalpine Böhler Welding is represented by voestalpine Böhler Welding Austria GmbH in Kapfenberg, Styria. The company voestalpine Böhler Welding Austria GmbH has a total staff of 270 employees and a turnover of EUR 74,3 million (fiscal year 2012/2013). [VOE13]

Figure 1-2: Locations of voestalpine Böhler Welding globally (according to [VOE13])

voestalpine Böhler Welding Austria GmbH produces welding consumables for customers in 126 countries worldwide.

The product portfolio includes

- stick electrodes for different applications starting from unalloyed grades to high-strengths grades and high and super- alloyed grades,
- solid wire, copper-coated and bright wires un- or low-alloyed, and
- cored wire from soft-martensitic, stainless steel, to super-duplex steel grades
- and others (fluxes, brazing metal, strips). [VOE13]

Stick electrodes Solid wire Cored Wire

Figure 1-3: Main products of vaBWA (according to [VOE13])

1.2 Production of welding consumables

In the following a short introduction to the manufacturing process of welding consumables at the production site of voestalpine Böhler Welding Austria GmbH in Kapfenberg, Styria, will be given.
The detailed analysis and further remarks will be discussed in chapter 3.

The process of welding is a joining process used to create substance- to- substance bonds. Two metal parts are joined together by means of heat or pressure. For many welding processes welding consumables are needed. [DIL07]
Since the further implementation of the master thesis at hand will consider stick electrodes and cored wire, these two possible welding consumables and their manufacturing processes are discussed below.

1.2.1 Stick electrodes

A stick electrode consists of a core rod and coating layer. Stick electrodes are used in arc welding processes.
Consumable electrodes provide material for filling the weld seam in gas metal arc welding or shielded metal arc welding processes, while non- consumable stick electrodes are needed to build up an electrical current flow during the welding process. [FST11]

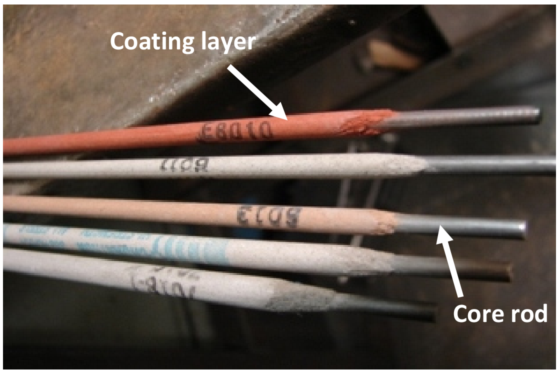

Figure 1-4: Stick electrodes[1]

According to Fahrenwaldt, Schuler and Twrdek the coating layer of a consumable stick electrode has different functions:

- Stabilization of the arc during welding
- Building up an additional shielding gas layer around the arc
- Formation of cinder for oxidation protection and for improving the weld material quality
- Alloying up the weld material.

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[1] According to http://www.weldingtipsandtricks.com/images/welding-steel-stick-electrodes.JPG [27/3/2014]

In order to fulfill these functional requirements the composite of raw material forming the coating layer is critical. In addition to that the coating layer and its substances of content influence the stability and ductility, as well as the ignition behavior of the stick electrode. [FST11]

Manufacturing process of stick electrodes

The core rod and the coating layer of a stick electrode are manufactured in two parallel processes, before the two parts get joined by pressing.

The raw material for the core rod is wire rod which can be alloyed or unalloyed. By drawing, directing and cutting the wire rod is turned into core rod for stick electrodes.

The coating layer consists of several raw materials. The raw materials are dosed according to particular recipes. After sieving and mixing of the raw mass transport containers are filled and transported to a blender. There the raw mass is blended under dry and by adding water glass under wet conditions before the press cylinder of the electrode press can get filled.

The electrode press is pressing the blended raw mass around the core rod. After pressing the stick electrodes need to be brushed and a striking aid is added. As last process step before packaging the stick electrodes get dried under low and high temperature with subsequent cooling.

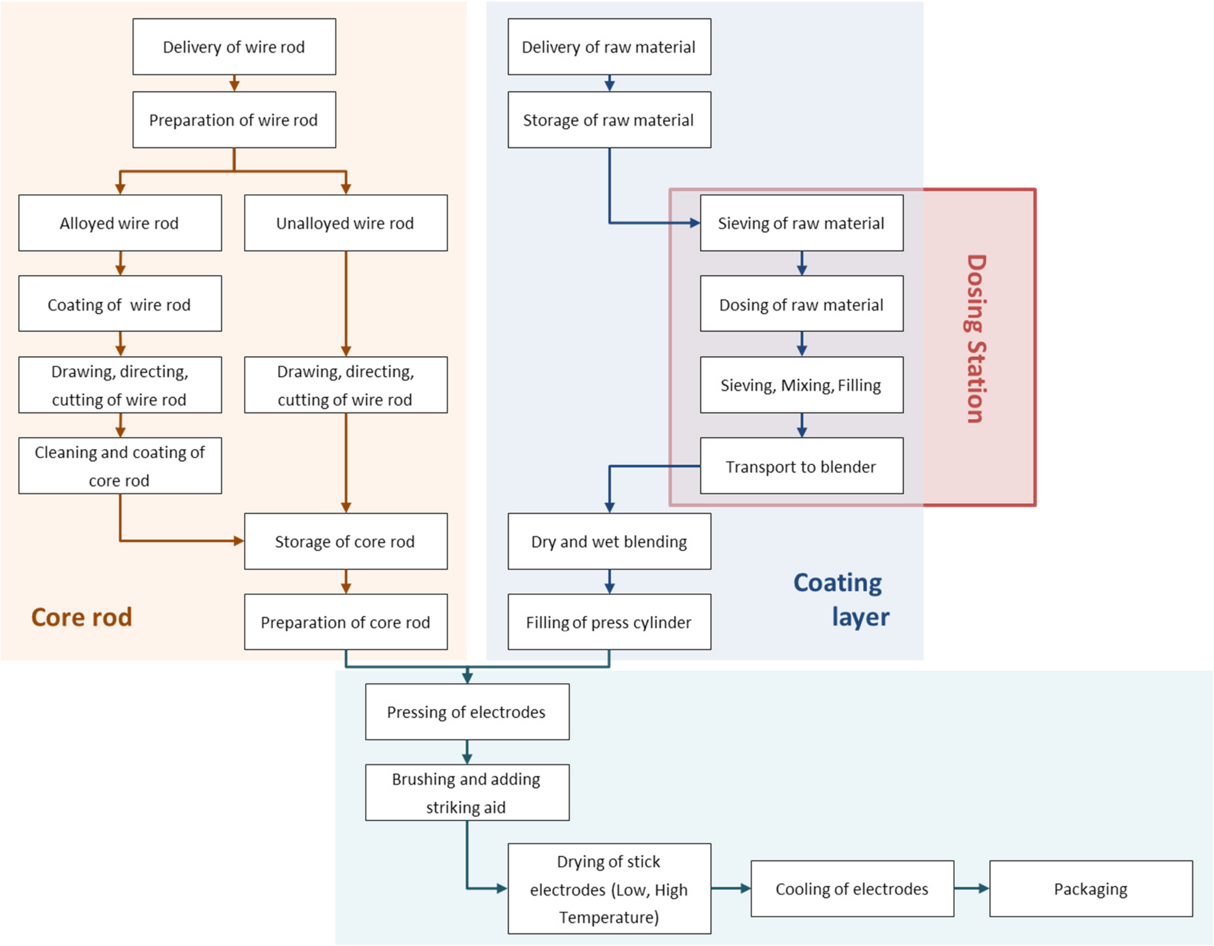

Figure 1-5: Manufacturing process of stick electrodes

1.2.2 Cored wire

According to Fahrenwaldt, Schuler and Twrdek cored wire can be described as “upended stick electrode”. The coating layer of a stick electrode exists in form of the filling of a tubular wire. Cored wire is used as welding consumable in gas- shielded arc welding.

Figure 1-6: Cored wire[2]

The reasons for using cored wire instead of solid wire are the same as for stick electrodes. The filling, consisting of different raw materials, is used for forming cinder for oxidation protection and for improving the weld material quality. The filling can also contain alloying elements. Furthermore the spray arc is reached in a lower voltage range compared to solid wires. [FST11]

Manufacturing process of cored wire

First the filling of the cored wire is produced. For that purpose sieved raw materials are dosed according to particular recipes. Subsequent mineral raw materials need to be sieved once again, before the powder is transported to the blender. After blending the rolling line is fed with the blended mass. After adjusting the filling degree, rolling and drawing of the wire a coating of the blended mass is deposited on the wire. By drawing and winding the cored wire is finished. For packaging and further quality checks rewinding is needed as last step.

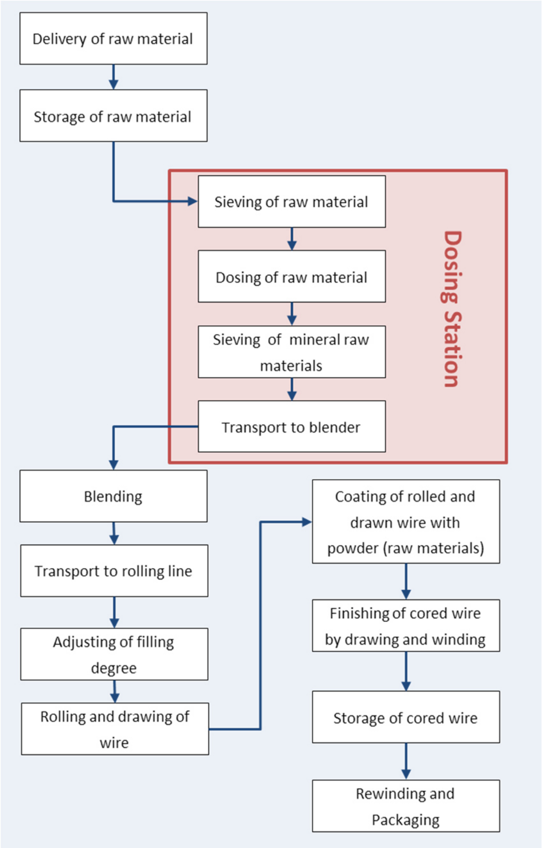

Figure 1-7: Manufacturing process of cored wire

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[2] According to http://www.odermath.de/UserFiles/Image/technologie_draehte.jpg [28/3/2014]

1.3 Problem definition and objectives

Since voestalpine Böhler Welding Austria GmbH produces stick electrodes and cored wire in Kapfenberg, Styria, raw materials need to be dosed according to particular recipes.
The existing dosing system is to be modernized and adapted to the state of art. The strategy of storing raw materials has to be matched with the subsequent production processes and transport processes which link the dosing system to the following production steps need to be adapted.

Since the dosing stations need to be operated manually, the work loading is very high. In addition to that manual dosing causes elevated dust loading. The workers need to wear personal protective equipment. In the area of the dosing and refilling stations exhaust systems are installed, to minimizing dust loading. By reducing the dust loading, the material loss of the production is increased. Besides a predicted increase of the lot size and production efficiency, another main trigger for analysing and redesigning the production system is a reduction of work loading for the workers in combination with a reduction of dust loading in the production hall.

The master thesis at hand aims for the analysis and simulation of the material flow of the existing dosing system and the previous and following production steps in order to come up with concept variants for redesigning and modernizing the existing dosing system.
In chapter 2 the available literature and theoretical foundations of material flow analysis, planning and simulation as well as factory planning as superordinate topic will be discussed. Subsequently the implementation of the master thesis at hand will be presented in chapter 3. Based on the analysis of the initial situation eight concept variants with different levels of automation for modernizing the dosing process will be designed. Afterwards the concept variants will be assessed according to the specification of voestalpine Böhler Welding Austria GmbH and the derived requirements of the as-is analysis. Based on the findings three preferred variants will be specified in depth. The ideal alignment of raw materials and the ideal bin sizes respectively system geometries will be determined. For the two most promising variants real layouts will be drafted and evaluated by means of value benefit analysis.

The outcome of the master thesis serves as background for the decision-making process, in which an appropriate concept for implementation of a dosing system manufacturer will be selected.

2 Course of Investigation

In the following chapter basic approaches for material flow planning and analysis will be discussed. Since material flow planning and analysis can be seen as a sub task of factory planning, a short introduction to factory planning and its processes and aims will be given.

2.1 Factory planning

According to Schmigalla the object of factory planning is the system “factory” itself. The system contains different elements in form of single parts and assemblies, machines and workers. Additionally relations between these elements are included in the overall system “factory”. Besides that the environment influences the system and vice versa. The relations between the environment and the system itself can be described with certain input and output flows. By describing the factory as just mentioned, conducting a systematical factory planning is possible. [SCH95]

The term factory planning implies the identification of potential locations for building up new production sites, the alignment of needed production halls and buildings, the design of production processes including all relevant processes for handling and processing material and the implementation and realization. [GRU09]

Kettner, Schmidt and Greim specify four general aims of factory planning:

(1) Cheaper production flow
(2) Human- oriented working conditions
(3) Proper use of room and space
(4) High flexibility of buildings and machinery

These aims need to be completed by particular aims derived from the initial situation of the planning process.

Grundig describes five possible initial situations:

(1) New building of a production site
(2) Rebuilding and redesign of an existing production site
(3) Expansion of an existing production site
(4) Deconstruction of an existing production site
(5) Reactivation of production sites

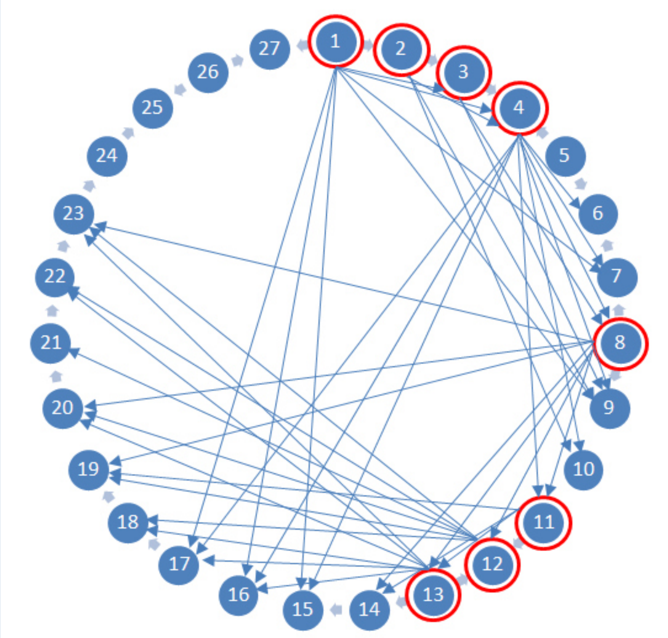
The initial situation influences the proceeding during the planning process. In the first case of building up a new production site the proceeding will be focused on identifying the right location within a working infrastructure. The planning of manufacturing processes of the new production site is characterised by a high degree of freedom, only influenced by a general land-use plan. [GRU09]

For cases (1) to (4) the planning procedure will be completely different. Existing buildings, machinery, access roads and transportation systems build up a complicated network of constraints for the planning process.

In terms of factory planning methods and tools Grundig and Kettner, Schmidt and Greim discuss several planning basics, which need to be applied to any factory planning case to ensure that set goals will be reached and defined aims will be fulfilled.
The most important planning basics are to be discussed below:

- **Holistic Planning**

  Factory planning includes many single tasks. All single tasks and sub- tasks which need to be conducted are linked among each other. An ideal solution for one sub-task will not necessarily lead to the overall solution. That is why in the first steps of a factory planning an ideal overall system will be developed. [KSG84]
  Figure 2-1 shows the different sub- steps of factory planning. The red marked sub-tasks and their pictured interconnections will be used to structure the further implementation in the master thesis at hand. As most important sub- step the material flow, will be the focus of further proceeding. Chapter 2.2 will discuss material flow planning and analysis in detail.



1: initial situation

2: forecast

3: production program

4: production method

8: material flow

11: ideal layout

12: real layout

13: planning of transports

Remaining sub- tasks: **5** location planning,**6** general land-use plan,**7** estimation of floor space required ,**9** economic feasibility study, **10** estimation of time- limit,**14** detailed planning,**15** identification of needed space, **16** staff requirements, **17** energy requirements, **18** construction schedule,**19** facility costs, **20** arrangement of machinery, **21** installation planning, **22** structural design, **23** construction analysis, **24** request for proposal, **25** costs of construction, **26** time schedule of construction, **27** relocation planning

Figure 2-1: Sub- tasks of factory planning (according to [MAN75][3])

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[3] Cited according to Kettner, Schmidt and Greim

- **Gradual Proceeding**

  Consecutively top-down operated tasks ensure that no task is carried out at a wrong time during the whole planning process. [KSG84]
- **Working with variants**

  Grundig states that as a rule the solution of a factory planning task allows different solution variants. If different solution variants are analyzed, discussed and assessed, a reasonable compromise in form of a preferential solution can be established.

- **Necessity of ideal planning**

  Uncompromising ideal planning is according to Kettner, Schmidt and Greim the only objective criterion to rate the subsequent real planning and finding of an optimal solution.

In addition to these four basics, economic efficiency of the planning process, interdisciplinary planning teams and flexibility by means of anticipatory planning lead to an effective and successful factory planning process.

2.2 Material flow analysis and planning

According to the guiding principle VDI 2689 the success of a company significantly depends on how effective the material needed for production is stored, processed and handled. All processes which are related to extraction, handling and processing of goods amount to the term material flow.

As mentioned above material flow planning and analysis is one crucial sub- step of factory planning.

2.2.1 Conducting a material flow analysis

Kettner, Schmidt and Greim propose a general systematic procedure with three main stages for analysing material flow problems:

(1) **Preparation of material flow analysis**

During this step the reasons and objectives of the material flow planning need to be specified for determining the scope of the analysis. Furthermore the step includes the organisation and scheduling of the analysis. [KSG84]

The reasons for a material flow analysis can be diverse. Additional products or new variants of products, change of production methods, increased costs for storage and general material flow, capacity problems and material flow dysfunctions are just a few mentioned in the guiding principle VDI 2689.

Depending on the reason for a material flow analysis the objectives can vary considerably.

Amongst others the guiding principle VDI 2689 mentions the following possible objectives of material flow analysis:

- Planning and design of material flow in case of rebuilding and redesigning projects
- New alignment of material flow elements caused by new product variants or rising lost sizes
- Detection and elimination of bottlenecks within the material flow
- Increase of economic efficiency
- Verification of degree of capacity utilization of transport and storage elements
- Improved usage of room and space

Only with defining one or multiple objectives the focus of the material flow analysis can be determined.

(2) Acquisition, evaluation and assessment of data

According to Kettner, Schmidt and Greim and Grundig two basic data acquisition methods can be distinguished: Direct methods of data acquisition can be used during ongoing production, while indirect methods are based on existing internal data like documents, papers, record etc.

Amongst others Grundig mentions the following methods, which are summarized in table 2-1 .

Table 2-1: Data acquisition methods

Direct methods	**Indirect methods**
Measurement/counting of events, time, space etc.	Layout plans
Questioning with the use of interviews or questionnaires	Engineering data like bill of materials, working plans
Short- term/permanent monitoring	Statistics (storage, space, transports, staff, etc.)

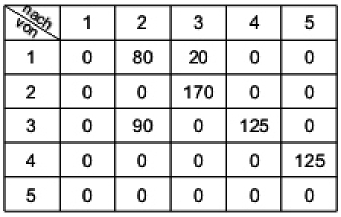
Subsequent to data acquisition, the data needs to be evaluated and assessed. Evaluation and assessment of data make great demands on the material flow planer. Due to the depth of in part unclear data the effort of this step is often underestimated. In particular a plausibility check of the evaluated data is inevitable. [KSG84]

As a result of data acquisition, evaluation and assessment of the as- is state, strengths and weaknesses need to be carried out and illustrated.

Kettner, Schmidt and Greim propose *From-To- Matrices* and special flow diagrams, so- called *Sankey diagrams*, for illustration of data.

From- To- Matrices contain information about relations between particular production stations. Weight units, volume units, number of transports, number of units or transport cost between two or more production stations within the production network can be summarized with the help of *From- To- Matrices*. [KSG84]

Sankey diagrams show the sequence of production stations and the related material flow. The width of the illustrated arrows in figure 2-3 shows the proportionality of the existing materials flows. [PAW08]



nach von	1	2	3	4	5
1	0	80	20	0	0
2	0	0	170	0	0
3	0	90	0	125	0
4	0	0	0	0	125
5	0	0	0	0	0

Figure 2-2: Transport matrix as special form of *From- To- Matrices*[4]

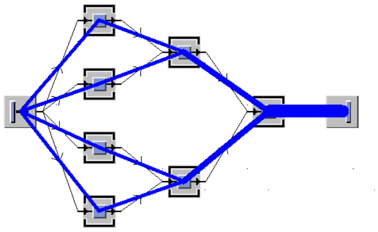


Figure 2-3: *Sankey diagram* of a production process[5]

(3) Decision- making as basis for a subsequent material flow planning

Based on the summary of strength and weaknesses of the as-is state, decisions and a list of measures to be taken for the subsequent material flow planning have to be deduced. [KSG84]

2.2.2 Planning of the material flow

Based on the outcome of a previous analysis of the material flow, planning of the material flow can start.

According to the guiding principle VDI 2498 the main task of material flow planning is the realisation of the cheapest material flow. As reasons for material flow planning the guiding principle VDI 2498 lists the improvement or enlargement of an existing material flow as well as the planning of the material flow in case of new building.

As basis of all following planning steps the aims and objectives of the planning process need to be defined. The guiding principle VDI 2498 recommends summarizing sub goals of material flow planning in form of classes, e.g. economic, qualitative and technical goals.

In addition to that the basic information of the previous material flow analysis is used as starting point for conducting four steps of material flow planning.

Below these four steps are described according to the guiding principle VDI 2498.

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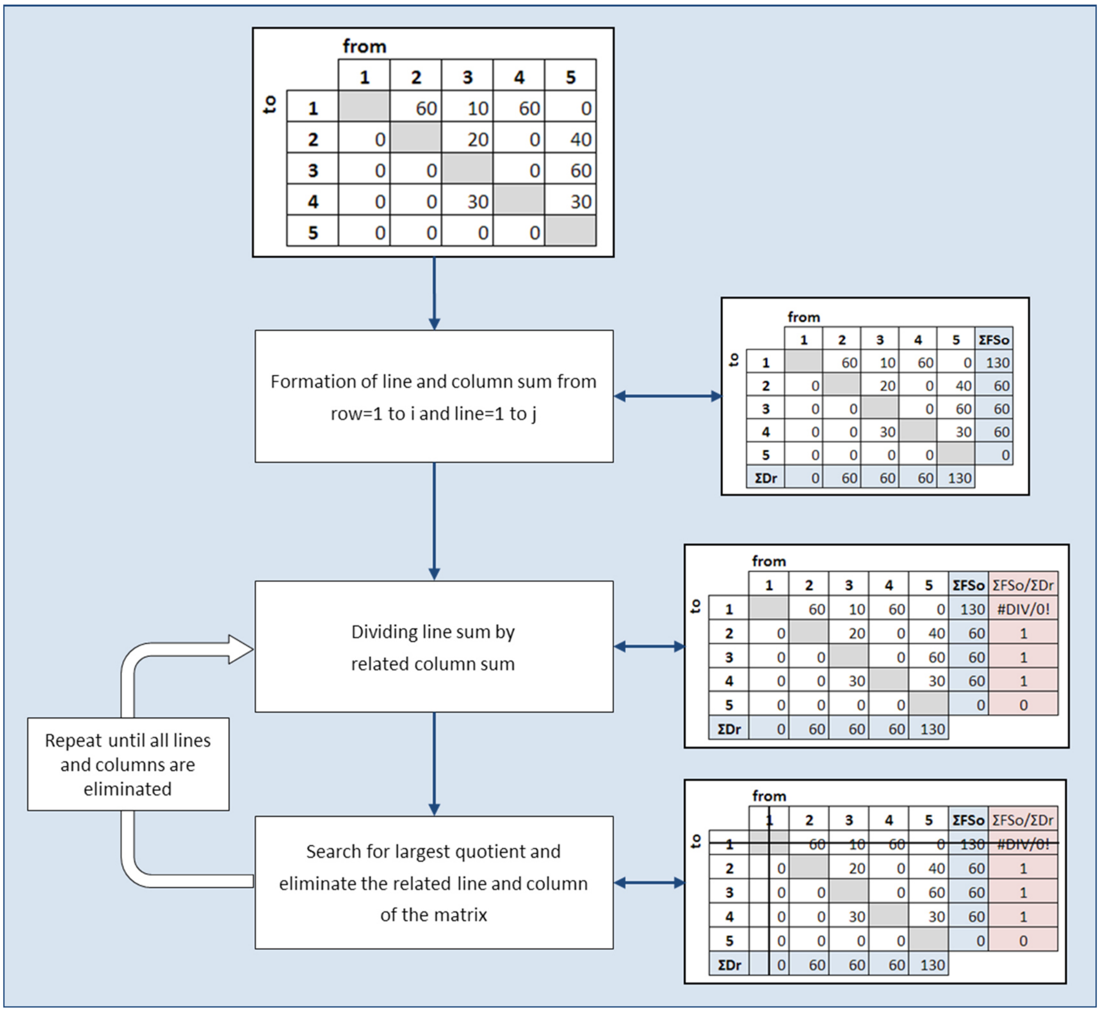
[4] According to http://www.fml.mw.tum.de/fml/index.php?Set_ID=320&letter=T&b_id=3332467B-3646-3643-352D-394345432D34; [22/3/2014]

[5] Example of material flow network according to http://www.bangsow.de; [22/3/2014]

(1) Rough planning

Since material flow analysis has identified problems and weaknesses, the first step of material flow planning is to find solutions for the identified problems in a superordinate context. Relations concerning material flow processes are analysed and technical basic concepts are prepared and evaluated.

Furthermore a so-called block layout is created by arranging the material flow stations or elements in an optimal way. Established material flow matrices - *From-To- Matrices* - need to be optimized for that purpose. [VDI08a]



to	1	2	3	4	5
1		60	10	60	0
2	0		20	0	40
3	0	0		0	60
4	0	0	30		30
5	0	0	0	0	

to	1	2	3	4	5	ΣFSo
1		60	10	60	0	130
2	0		20	0	40	60
3	0	0		0	60	60
4	0	0	30		30	60
5	0	0	0	0		0
ΣDr	0	60	60	60	130	

to	1	2	3	4	5	ΣFSo	ΣFSo/ΣDr
1		60	10	60	0	130	#DIV/0!
2	0		20	0	40	60	1
3	0	0		0	60	60	1
4	0	0	30		30	60	1
5	0	0	0	0		0	0
ΣDr	0	60	60	60	130		

to	~~1~~	2	3	4	5	ΣFSo	ΣFSo/ΣDr
~~1~~		~~60~~	~~10~~	~~60~~	~~0~~	~~130~~	~~#DIV/0!~~
2	0		20	0	40	60	1
3	0	0		0	60	60	1
4	0	0	30		30	60	1
5	0	0	0	0		0	0
ΣDr	0	60	60	60	130		

Figure 2-4: Algorithm to arrange stations (according to [VDI08b])

The guiding principle VDI 2498 describes the following algorithm on this (cf. figure 2-4):

Starting point of the algorithm is the material flow matrix illustrating the interrelations of the material flow stations. As first step the line and column sums of the matrix need to be formulated. These sums represent the frequency one station is acting like a source respectively a drain. Secondly the line sums are divided by the related column sums. As third step the largest quotient is selected and the related line and column is eliminated. Step 2 and Step 3 are repeated until all lines and columns are eliminated.

The order, in which the material flow stations are eliminated in course of the algorithm, represents the optimal arrangement of material flow stations.

(2) Ideal planning

This stage aims at an ideal technical arrangement of material flow stations and elements. For ideal planning economic or spatial constraints are consciously not included. [AF07]

Based on the existing rough planning an ideal layout respectively an ideal arrangement of single material flow stations is designed. The ideal arrangement can consider the differentiation of particular production flows. Conclusions about the design of single material flow stations and the production flow within these stations are not included.

Two different approaches for optimization of the arrangement of material flow stations can be distinguished. Graphical methods like Sankey diagrams and circular diagrams help to simplify complex arrangement problems in an easy realizable way.

Mathematical methods like the so- called triangle calculation methodology can be seen as continuative methods. With the help of the triangle calculation methodology the arrangement of material flow stations cannot only be tried out, but also calculated. [PAW08]

Figure 2-5 shows how the triangle calculation method can be implemented. Firstly the matrix of transport intensities has to be set up. Secondly the maximum within the matrix is searched and the related material flow elements are arranged within a triangular mesh. In the next step the next intensive station is arranged according to the previous elements. These steps are repeated until all material flow stations of the matrix are arranged.

Since the triangular mesh offers divers possibilities to arrange the particular stations, different variants can be generated.

Despite the described methods for setting up an ideal layout, finding ideal arrangements respectively solutions is not always possible. This is why Arnold and Furmans state that on the one hand the relevance of ideal planning are unclear. On the other hand ideal planning scenarios can be appreciated as basis of comparison - they can for example be used to identify influences of existing constraints. [AF07]

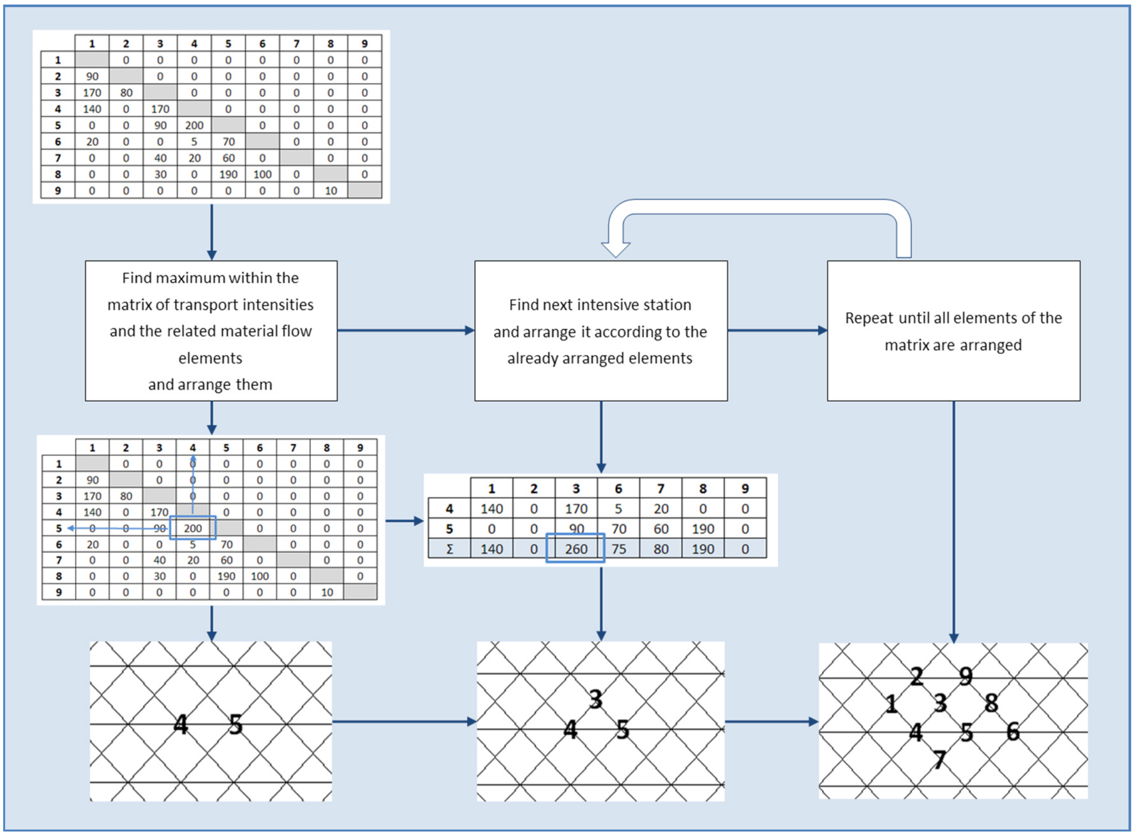
(3) Real planning

The focus of this step is on turning over ideal planning to real planning. The arrangement and layout of ideal planning is now adapted to structural conditions. Different possible concept variants are designed and evaluated. [VDI08a]

The generated concept variants include amongst others (cf. [AF07]):

- appropriate conveyors
- the design of storage
- the commissioning concept
- production facilities and their arrangement
- availability concepts.

With the help of calculation of profitability, efficiency analysis and risk analysis one preferred concept variant can be chosen for detailed planning. [VDI08a]



	1	2	3	4	5	6	7	8	9
1		0	0	0	0	0	0	0	0
2	90		0	0	0	0	0	0	0
3	170	80		0	0	0	0	0	0
4	140	0	170		0	0	0	0	0
5	0	0	90	200		0	0	0	0
6	20	0	0	5	70		0	0	0
7	0	0	40	20	60	0		0	0
8	0	0	30	0	190	100	0		0
9	0	0	0	0	0	0	0	10	

Find maximum within the matrix of transport intensities and the related material flow elements and arrange them

Find next intensive station and arrange it according to the already arranged elements

Repeat until all elements of the matrix are arranged

	1	2	3	4	5	6	7	8	9
1		0	0	0	0	0	0	0	0
2	90		0	0	0	0	0	0	0
3	170	80		0	0	0	0	0	0
4	140	0	170		0	0	0	0	0
5	0	0	90	200		0	0	0	0
6	20	0	0	5	70		0	0	0
7	0	0	40	20	60	0		0	0
8	0	0	30	0	190	100	0		0
9	0	0	0	0	0	0	0	10	

	1	2	3	6	7	8	9
4	140	0	170	5	20	0	0
5	0	0	90	70	60	190	0
Σ	140	0	260	75	80	190	0

Figure 2-5: Triangle calculation methodology (according to [PAW08])

(4) Detailed planning

In contrast to rough planning the single material flow stations or elements need to be designed in detail during this step. In the same detailed way the process interfaces within the production process are specified. Moreover detailed planning includes accurate information about installation of machines, main and emergency routes, power termination and general operating equipment. [VDI08a]

According to Arnold and Furmans all details needed for realisation are elaborated at that step of material flow planning.

2.2.3 Material flow simulation

The simulation of material flows is a useful tool for analysing the outside influences on the material flow system and the related material flow elements. Simulation can be used during rough and detailed planning. [VDI08a]
In addition to that simulations can be used for supporting the implementation as well as for supporting the planning processes for operation. [PAW08]

The definition of the term simulation can be found in the guiding principle VDI 3633. The term simulation is defined as a reproduction of a system with its dynamic processes. The idea behind setting up a simulation is to draw conclusions for the real system. For implementation of simulation studies the following steps need to be conducted according to the guiding principle VDI 3633 [BAN08]:

- formulating of the problem
- examination if simulation is really needed
- defining of objectives
- data acquisition and analysis
- modelling
- conducting simulation experiments
- evaluation and assessment of simulation results
- documentation.

Since some of the mentioned steps have still been discussed in the context of material flow analysis and planning, the focus of the subsequent presentation will be on issues which have not yet been treated.

Modelling as one main part of simulation studies

After the problem has been formulated and the objectives have been defined, the necessarity of the simulation has to be proved. Only if the simulation is really needed, the implementation of a simulation model is meaningful.
As a first step a conceptional model of the system to be analysed and simulated has to be created. Therefore the acqiured and analysed data play an important role. All relevant relationships of the system and the related elements need to be reproduced in the accurate complexity. The higher the degree of complexity is, the longer building up a conceptional model will take. [KÜH06]
For building up conceptional models different tools respectively software tools can be used. In the master thesis at hand the conceptional model for simulating the material flow within the dosing stations will be designed as entity- relationship- model (ERM).
Entity- relationship- models are known from database design and can be easily used as first structural design aid for conceptional simulation models. The basic objects of the ERM are

called entities. An entity is identifiable and related to specific information. Entities are represented as boxes within the ERM[6]. The characteristics an object has, are called attributes. Attributes in the case of material flow systems can be process times, number of storage places etc. As in reality there exist relationsips between different (material flow) objects respectively entities. The relationships are illustrated by diamond- shaped symbols according to the notation of Peter Pin-Shan Chen. [THA98]

Each relationship between entities is described by the cardinality of the relationship. The cardinality determines the actual number of related occurences for each of the involved entities. The basic types of connectivity for relationships are [CHE02]:

- One- to- one
- One- to- many
- Many- to- many.

Figure 2-6 shows a simple entity- relationship- model. Entities, relationships and attribute including primary key attributes are illustrated.

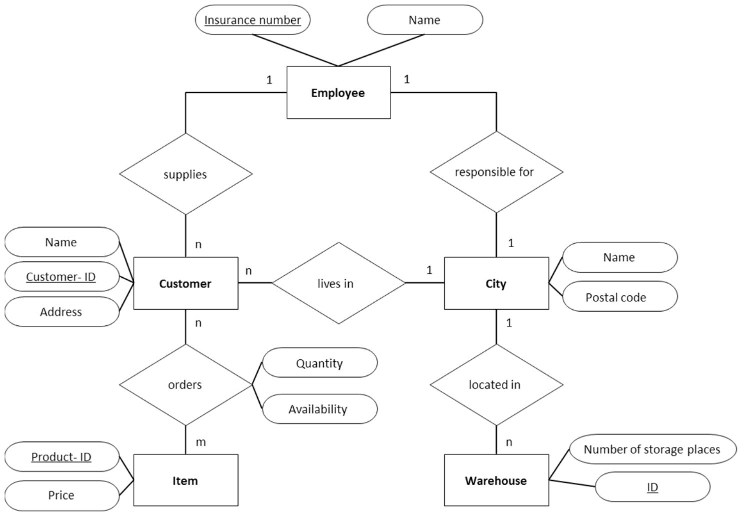


Figure 2-6: Example of an entity- relationship- model (according to [VÖS12])

After the conceptional model has been designed, a simulation model will be set up. This second step is related to an adequate simulation program. By introducing several elements, defining networks and/ or additional programming tasks the conceptional model can be tranferred to a software based simulation model. If an adequate simulation model has be designed, the model need to be verified and validated. [KÜH06]

According to the guiding principle VDI 3633 verification in the context of simulation on the one hand means to ensure that the simulation model which has been built up is mapping the conceptional model. Validation on the other hand can be described as the process of ensuring that the simulation model is able to map the real system and the real system behaviour. [RSW08]

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[6] ERM notation of Peter Pin-Shan Chen is used.

There exist different verification and validation techniques. Rabe, Spieckermann und Wenzel mention amongst each other animations, reviews, dimensional consistency tests, extreme-condition tests and structured walkthrough.

Conducting simulation experiments and subsequent evaluation and assessment of simulation results

After validation and verfification of a simulation model, simulation experiments are conducted. The aim of simulation experiments is to simulate different scenarios for determining output limits of a defined system per parameter variation, designing of system solutions for a fixed output limit or validation of a planned system with defined system loads.

The design of simulation experiments and the related scenarios is strongly depending on the real system to be analysed. In general it can be stated, that the higher the number of elements and parameters within a system is, the higher the number of possible parameter variations respectively simulation experiments will be. [KÜH06]

The results of the conducted simulation experiments are needed for deducing measures which will influence the system to be simulated. Therefore the results have to be interpreted and when thereof the need arises the simulation model respectively the parameter variations can be changed. [BAN08]

If conclusions and measures for the real system can be deduced of the simulation procedure, the real system will be optimised and/or implemented conforming with the simulation results. Moreover the results of the simulation scenarios even of inappropriate scenarios have to be documented for future problems and planning tasks.

The described tasks which are outlined above and needed for material flow simulations can also be illustrated according to a specific methodological approach of Kuhn, Reinhardt und Wiendahl (cf. figure 2-7). [GRU09]

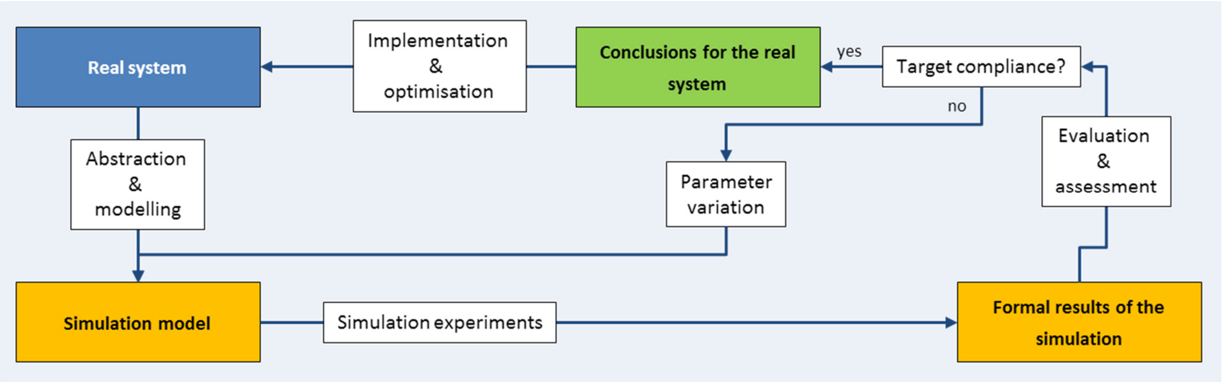

Figure 2-7: Methodology of simulation studies (according to [KRW93] [7])

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[7] Cited in [GRU09]

On the basis of the described theoretical principles of material flow analysis and planning as well as material flow simulation, in the subsequent chapter 3 the practical part of the master thesis will be presented.

3 Implementation

The following chapter describes the implementation of a material flow analysis and planning including material flow simulation procedures for the dosing process at the production site of voestalpine Böhler Welding Austria GmbH in Kapfenberg, Styria.

Since the production of stick electrodes and cored wire of voestalpine Böhler Welding Austria GmbH cannot be compared to classical material flow problems, known methods and approaches need to be changed and adjusted. As basis for further development of methods and tools the described approaches of the guiding principles VDI 2689, VDI 2498 and Kettner, Schmidt and Greim are used.

3.1 Problem structuring

As mentioned in chapter 2.2.1 a material flow analysis and planning can only be conducted, when at least one objective and the scope of analysis are defined. Hence the scope and the main objectives of the material flow analysis and planning at hand should be summarized:

The scope of the material flow analysis at hand is limited to one material flow station within the production process of stick electrodes and cored wire. For producing stick electrodes and cored wire bulk solids and liquid water glass need to be dosed and blended before stick electrodes can be pressed and cored wire can be manufactured. For producing raw masses according to particular recipes dosing station exist. These stations at the production site of voestalpine Böhler Welding Austria GmbH need to me modernized and adapted to the state of art to ensure that future increases in demand can be satisfied.

In addition to that the existing material loss has to be decreased and the working conditions (dust load in the production hall, necessity of wearing personal protective equipment) have to be improved.

For ensuring an increase in efficiency of the dosing process, the strategy of storing raw materials has to be matched with the subsequent production processes and transport processes which link the dosing system to the following production steps also need to be analysed and adapted.

Based on the material flow analysis, the aim of the subsequent material flow planning is to bring up different possible concept variants for redesigning the material flow at the production site in Kapfenberg. The most promising variants are afterwards analysed in depth and with the help of a material flow simulation the chosen concepts are assessed. Consequential economic and financial advantages of the new concepts can be brought out.

3.2 As-is analysis

After problem structuring and defining the scope of the material flow analysis the as- is analysis is the next step to be conducted during material flow analysis and planning. According to chapter 2.2.1 the main focus of this subsequent step will be the analysis of the present situation at the production site of voestalpine Böhler Welding Austria GmbH as well as the acquisition of relevant material flow data.

For that purpose the following section will be sub- divided in the description of the present production system and its process boundaries, the analysis of executed operational procedures and the analysis of the available data. Additionally a conducted material flow simulation and the obtained quantitative findings will be discussed.

3.2.1 As- is state of the production system and operational procedures

For producing stick electrodes and cored wire raw materials need to be dosed according to particular recipes. At the production site of voestalpine Böhler Welding Austria GmbH this is done in a separated production hall. Figure 3-1 shows a plan of the production hall which is related to the dosing process.

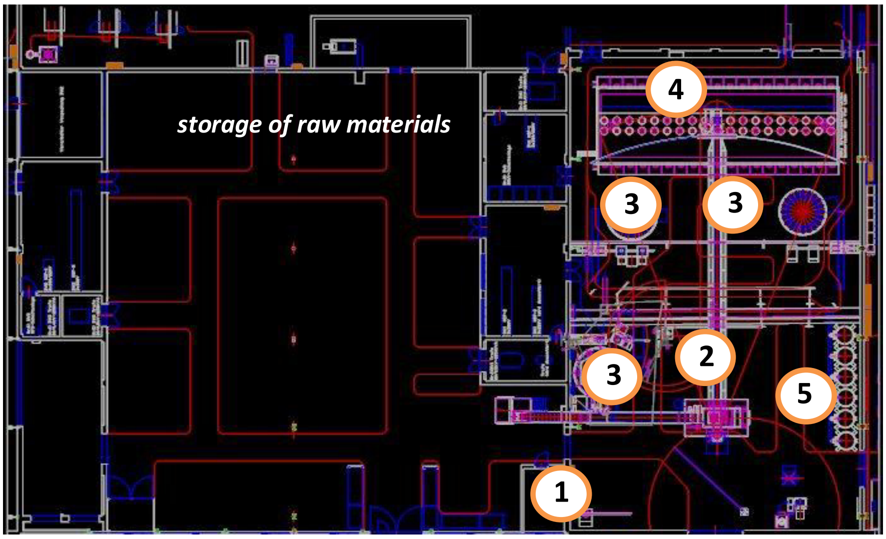


Figure 3-1: Plan of production hall (1: sieving station, 2: slewing conveyor, 3: dosing stations, 4: bunkers for raw material, 5: water glass tanks)

The storage space for storing powdery raw materials can be seen on the left side of the plan. The storage is built up of rack systems as well as simple floor storage systems. The delivery bundle of a raw material determines how the raw material is stored. Different types of delivery bundle are present at the production site in Kapfenberg:

- Big Bags with different volumes
- Bags with a mass of 25 – 50 kg on pallets

- Cans on pallets.

In the right half of figure 3-1 the available space for the dosing process is shown. The production hall also includes 38 bunkers for storing bulk solids, which are very often used. The hall was built in 1942 and first dosing systems can be found in production plans of 1950.
The basic size of the production hall amounts to 38,1m in length, 23m in width and 9,9m in height.
In total 2837,3 tons of bulk solids are dosed within in one fiscal year. Depending on the plant utilization the dosed raw masses are produced in two or three shift operation.
The raw materials, bulk solids, are dosed at three separated dosing stations. Additionally a sieving station exists, where the materials needed for producing cored wire are sieved.
Moreover figure 3-1 shows that in the production hall water glass tanks are stored. Liquid water glasses are needed for blending the raw masses after dosing before they can be further processed. For redesigning the dosing system the water glass tanks will stay at the same location and the process of adding water glass to the raw masses will also stay the same. That is why in the material flow analysis and planning at hand, only bulk solids are discussed as raw materials.

Figure 3-2: Storage of powdery raw materials

The dosing stations are built up as carousels. Two of these carousels are used for dosing bulk solids for the production of stick electrodes, while the third is dedicated to the production of cored wire.
Each carousel is divided in 20 places, where containers with raw materials can be placed. The containers are arranged according to the particular dosing recipes. There exist two different sizes of containers: single containers with a volume of 253 dm^3 and double containers with a volume of 506 dm^3 (cf. figure 3-3 and figure 3-4).
Each container is related to one specific material. For each specific material there exist several containers to ensure that in any case all dosing stations can be operated. This leads to the fact that containers which are unused for ongoing dosing processes are simply stabled in the free areas of the production hall.

Figure 3-3: Single container for carousels

Figure 3-4: Double container for carousels

By turning the carousels by simply pressing a pedal on the floor and manually weighing all needed components the workers compose the recipes. In total 389 different recipes for dosing bulk solids exist. Each of these recipes is composed of four to 28 raw materials.

For composing the recipe the worker is guided by a display. The needed material and the needed amount of the material are displayed. To ensure that the worker is using the right materials all containers are marked with a barcode. By scanning the barcodes of all containers placed in the carousel mistakes can be minimized. For dosing two different scales are available. Masses with less than 1 kg require an accuracy of 2 grams while masses with more than 1 kg require an accuracy of 20 grams. Additionally to the refilling of the containers in the beginning of a shift, the containers often need to be refilled during a dosing task. Therefore the worker collects the materials in storage by forklift or directly at the existing bunkers in the production hall, or the containers are manually wheeled to the storage to be refilled. For filling the bunkers a slewing conveyor is installed in the production hall. With a bag and can discharging machine the raw materials are automatically placed on the conveyor. The conveyor is constructed without an enclosure so dust loading is increased during the filling process. In addition to that materials in containers which are placed beneath the conveying system can be contaminated by gushing material.

Figure 3-5: Conveyor system

The described operating mode is the same for all three carousels. The only difference is that the carousels for stick electrodes include an automatic system for providing needed containers, in which the bulk solids are dosed (cf. figure 3-6 and figure 3-7 below).

Since the dosing process is manually operated, dust loading is very high. The workers need to wear personal protective equipment and in the area of the dosing stations exhaust systems (cf. figure 3-6 and figure 3-7 below) are installed. The material loss of the production is thereby increased.

Figure 3-6: Carousel for dosing bulk solids for cored wire

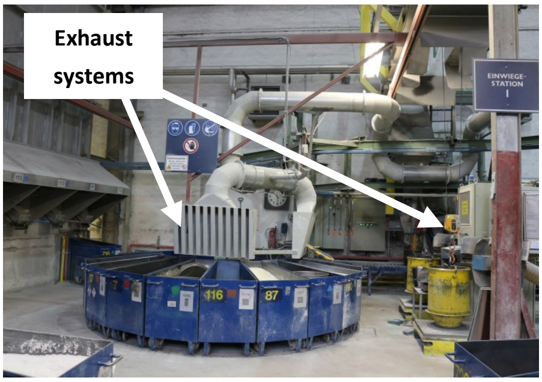


Figure 3-7: Carousel for dosing bulk solids for stick electrodes

For further processing of the completed raw masses after the dosing process, the processes for stick electrodes and cored wire need to be distinguished.

For composing a particular recipe all materials exceeding the 1 kg limit are dosed in advance. In case of stick electrodes the materials are dosed into a container with a total volume of 75 dm^3. The smaller masses are added in the end before the container is handed over to the overhead conveying system in the case of raw masses intended for stick electrode production. After sieving to remove leavings of the package, the containers can manually be transported to the subsequent blender and press lines. There exist four different press lines. The maximum capacity of the press lines determines the maximum capacity of the dosing stations for stick electrodes.

In contrast to the stick electrode production, there exist three different containers for transporting raw masses destined for the production of cored wire. During the dosing process metal, mineral and poisonous bulk solids are dosed separately in containers, cans and bags. The content of the cans, the mineral bulk solids, are sieved before the three bins are transported to the blender and rolling lines by using a forklift.

Figure 3-8: Transport of raw masses for cored wire production

Since the dosing and refilling processes as well as the transport processes are manually operated the work load is very high. The masses a worker has to lift vary from 100 g to 80 kg per raw material.

The described dosing stations including refilling and transport processes build up the system to be analysed. As process boundaries the release from stock at the beginning and the transportation in the end of the dosing process are defined.

3.2.2 Data analysis of FY 12/13

After the system for the material flow analysis and planning has been defined, the needed data for the next steps has to be acquired. As already mentioned in chapter 2.2.1 data acquisition and the followed evaluation and assessment of the data are crucial steps within the material flow analysis and planning.

Figure 3-9 shows the three particular contents of the data analysis and evaluation and there interconnections. Besides the analysis of the order data of the fiscal year 2012/2013, the raw materials and the specific process times will be examined below.

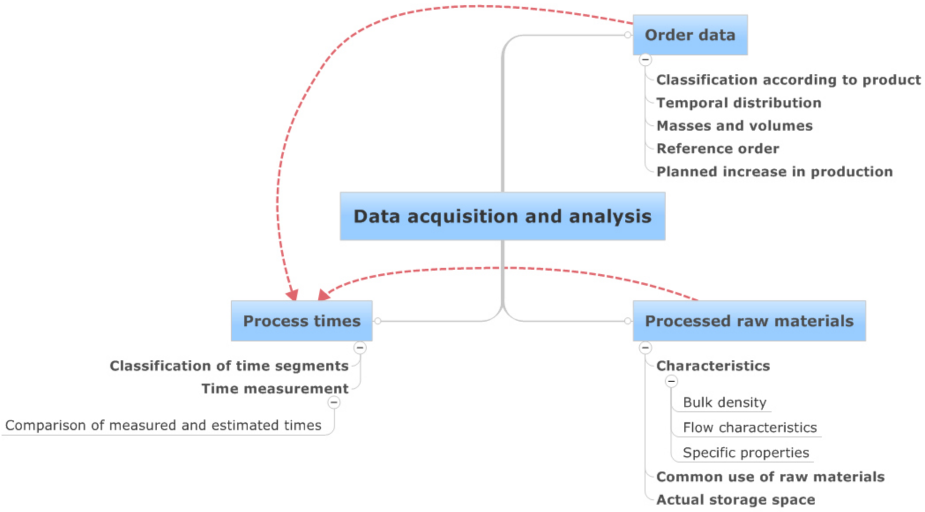


Figure 3-9: Categories of data acquisition and analysis and their interconnections

3.2.2.1 Analysis of order data

During the fiscal year 2012/2013 2837,3 tons of raw materials have been dosed at the production site of voestalpine Böhler Welding Austria GmbH in Kapfenberg. Approximately 80 percent of the total dosed masses have been destined for the production of stick electrodes, while only around 20 percent have been intended for producing cored wire.

The biggest order represents in total 13338 kg. Due to the fact that the bins, used for transporting the dosed masses, have a total volume of 75 dm^3, one order is subdivided in several masses with volumes smaller than 75 dm^3. In future the volume of the bins will be increased to 250 dm^3.

Among 2528 different orders in total, 389 different recipes are produced. The number of recipes for stick electrodes and cored wire has been similarly distributed like the total masses. (cf. table 3-1)

For simplifying the complicated order and recipe structure an attempt to build up reference orders and related reference recipes has been made. Since the number of different recipes is as high and the combinations of raw materials for all 389 recipes are varying, reference orders could not been built up. For all further steps during the analysis and planning all 389 recipes are taken into account. This allows to stay as close to reality as possible.

A temporal distribution concerning the orders during one year known from other industries, e.g. confectionery industry does not exist. The organization of the orders is determined by the receipt of order and the desired date of delivery. This leads to the fact, that the production of stick electrodes and cored wire is dependent on the customers. For planning of a new system this aspect needs to be kept in mind to ensure the needed flexibility to react on changing customer demands.

Based on the total masses of the fiscal year 2012/2013 an increase of 200 percent of stick electrode production and up to 400 percent plus of cored wire production are estimated for the next years. To include the foreseen increase of production as well as the increase of volume of transport bins from 75 dm^3 to 250 dm^3 the received data needed to be re-calculated. For re- calculation of data, the destinations, blender and presses for stick electrodes respectively blender and rolling lines for cored wire, of the dosed masses need to be distinguished. As already mentioned in chapter 3.2.1 four different press lines for producing stick electrodes can be distinguished. At press line 1 and press line 4 two respectively three single masses are mixed together today. With the use of new transport bins two respectively three masses can already be dosed into the bins so that mixing can be omitted. At press line 2 there will be no change concerning the used masses, while at press line 3 the increase of the processed masses varies from time to time. Existing raw masses exceeding a total mass of 80 kg today will be further used as single masses, whereas masses with less than 80 kg today will be doubled.

Concerning cored wire un- and medium- alloyed and high- alloyed cored wires have to be distinguished. For producing un- and medium- alloyed cored wires three different rolling lines named FM 1-3 exist. Dosed masses intended for rolling line FM1 will be doubled, while masses intended for rolling lines FM2 and FM3 will be tripled.

For high- alloyed cored wires four different rolling lines RSH 1-4 exist. The dosed masses intended for producing high- allowed cored wire will be merely increased by 10 to 15 percent.

Table 3-1: Summary of order data of vaBWA (FY 2012/2013)

Number of raw materials	159	151 bulk solids 8 liquid water glasses	
	Total	**Stick electrodes**	**Cored wire**
Number of different recipes	389	298	91
Maximum number of raw materials per order	-	28	20
Minimum number of raw materials per order	-	7	4
Mean number of raw materials per order	-	16	15
Total mass of bulk solids	2837,3 t	2365,7 t	471,6 t
Maximum number of masses within one order	-	130	106
Minimum number of masses within one order		1	1
Mean number of masses within one order	-	16	10
Maximum mass per order	-	13338 kg	657,2 kg
Minimum mass per order	-	61,65 kg	27,96 kg
Mean mass per order	-	1165,4 kg	946,9 kg
Maximum volume per order	-	10107,5 dm^3	6355,0 dm^3
Minimum volume per order	-	55,3 dm^3	8,9 dm^3
Mean volume per order	-	1248,1 dm^3	497,0 dm^3

3.2.2.2 Analysis of processed material

In addition to the general order data, the processed materials need to be analysed specifically. The characteristics of the raw materials used for production, very strongly impact the material flow and the related material flow elements. On the one hand the processed materials are characterized by material specific properties. For material flow analysis and planning on the other hand, the frequency of usage within the orders of a raw material and the deduced usage characteristics can be seen as material properties and thus the usage characteristics will be also analysed in the following.

Since the processed raw materials are almost exclusively bulk solids, the bulk density and compressibility, the flow characteristics, fluidisation and the particle size distribution have to be examined. Fine- grained bulk solids can tend towards cohesive bridging under pressure, while coarse grained bulk solids can tend towards mechanical bridging because the particles are wedged together. If bulk solids tend towards bridging, additional devices for deregulating the flow disturbance have to be planned. In contrast to bridging, fluidisation of bulk solids leads to free flowing bulk solids. [VET02]

Besides that, the bulk density is of particular importance for further planning, because the density determines in connection with the mass the captured volume. The density of a bulk material is always smaller than the solid density, because the space between the single particles of a bulk material is also taken into account. [SCH06]

As already mentioned above 151 different bulk solids are used in production. The bulk densities of these raw materials range from 0,13 kg/dm^3 to 6,65 kg/dm^3. Due to the wide margin of bulk densities, the captured volumes have to be in the focus for the planning tasks.

Since the analysis of data related to raw material usage has shown that there exist incomplete and inconsistent data sets, particular values needed to be assumed. In total the bulk densities of ten raw materials and consequently the total volumes to be handled have been assumed.

Furthermore 22 raw materials out of 151, which are used at the production site of voestalpine Böhler Welding Austria GmbH, are temperature sensitive. This means that the storage locations as well as the containers, out of which the materials are dosed, are supposed to be isolated and cooled.

In addition to that there exist raw materials which need to be sieved before dosing and thus cannot be stored in common with the unsieved raw materials. Since the order data does not provide the needed information whether a raw material is used as sieved or unsieved raw material, the further implementation of the master thesis at hand will assume that only unsieved materials are used.

As already mentioned, the usage characteristics of the raw materials cannot be neglected. They are needed to decide in subsequent planning steps which raw materials are congenial to automation. If used amounts of a raw material vary very widely, the automation of the dosing process involves high requirements concerning the technical implementation.

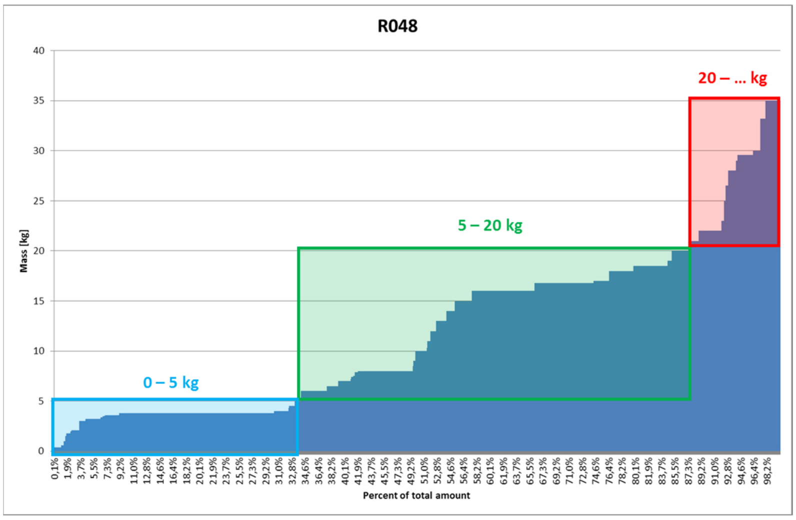
By screening the order data and simply analysing how often and in which amounts the raw materials are used, the usage characteristics could be set up. For comparison of different usage characteristics, the function was subdivided in three fields. Firstly the masses smaller than 5 kg, secondly the masses between 5 and 20 kg, and last but not least amounts bigger than 20 kg of a raw material have been summarized. These limits have been chosen according to possible dosing techniques in the market. Masses with less than 5 kg can easily be dosed manually, while masses with more than 20 kg need to be automatized to ensure human working conditions. For the masses in between different technologies can be used. The detailed description of available dosing techniques will be given in chapter 3.3.

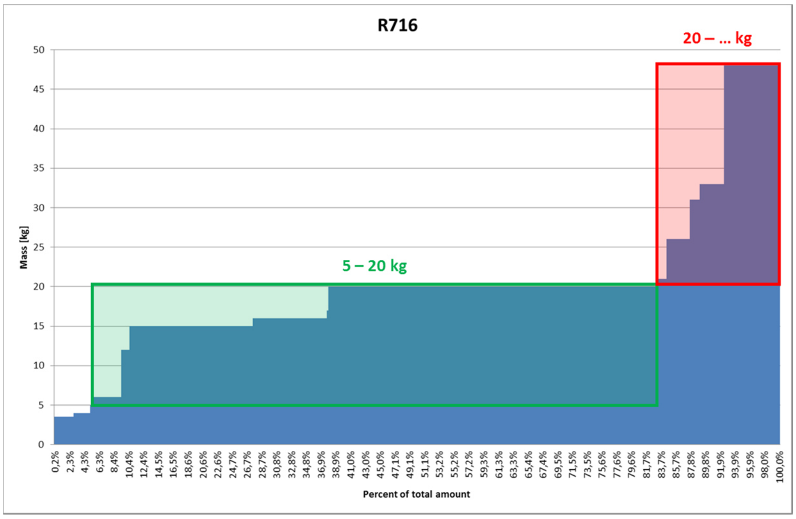
Since the analysis of the order data has shown that the used amounts of only ten raw materials cover almost 60 percent of the total processed mass during the fiscal year 2012/2013, the usage characteristics related to the most used materials have been set up primarily.

With the classification in the three mentioned fields, it was possible to show that five particular usage characteristics can be distinguished.

Table 3-2 and table 3-3 summarize these five cases. Case 1 illustrates a usage characteristic with three significant fields. The related raw material, R048, was needed most within the fiscal year 2012/2013 when considering the total used mass of the raw material. For automation all three different ranges of masses have to be covered to ensure that dosing can be done efficiently. The second case can be divided in two sub- cases 2a and 2b. In both sub- cases two significant fields within the characteristics can be identified. While in case 2a automating of the dosing process for masses bigger than 5 kg is reasonable, in case 2b automating masses bigger than 20 kg and smaller than 5 kg is advisable. The usage characteristics of the raw materials used for building up the third case only show one significant field. The raw material of case 3a, R768, was the most popular processed material concerning the total volume of the considered fiscal year. At least 95 percent of all amounts of the raw materials of case 3 can be assigned to the one significant field. Hence the raw materials are congenial to automation.

Table 3-2: Usage characteristics (case 1, case 2a)

<table>
<tr>
<td>CASE 1:
3 significant fields</td>
<td>


</td>
</tr>
<tr>
<td>CASE 2a:
2 significant fields</td>
<td>


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</tr>
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Table 3-3: Usage characteristics (case 2b, case 3a, case 3b)

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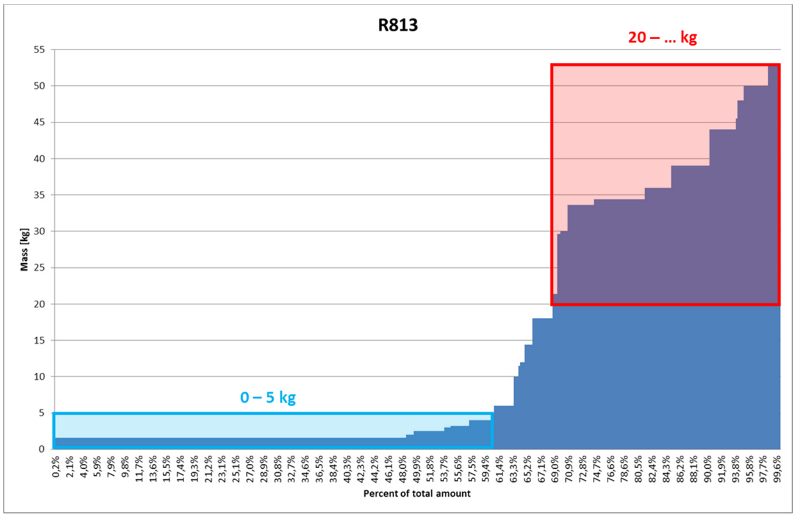
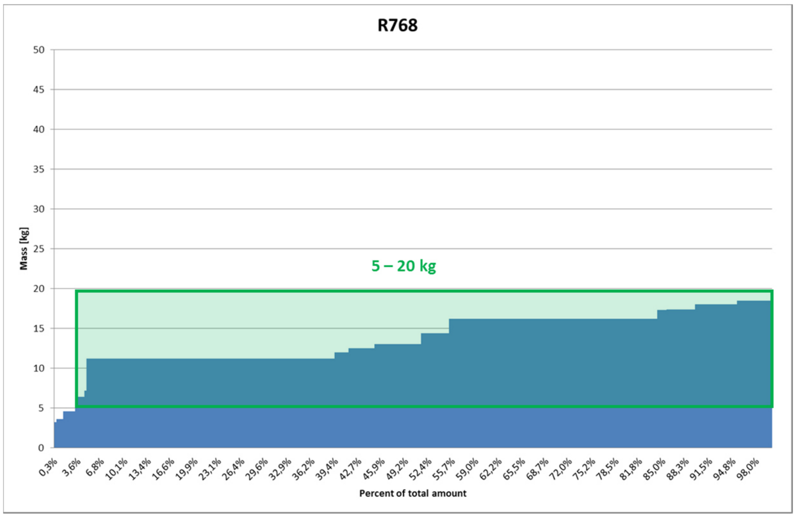
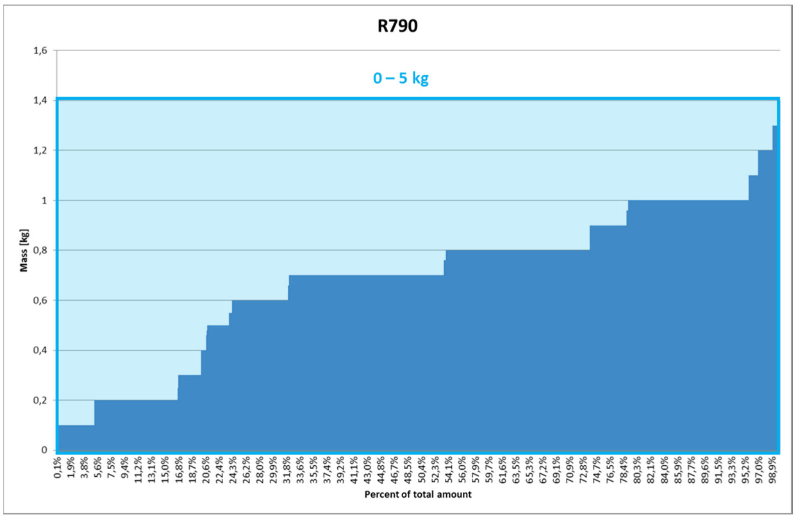
<td>CASE 2b:
2 significant fields</td>
<td>
</td>
</tr>
<tr>
<td>CASE 3a:
1 significant field</td>
<td>
</td>
</tr>
<tr>
<td>CASE 3b:
1 significant field</td>
<td>
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Moreover it has been shown that the described usage characteristics also apply to less popular processed raw materials. This led to the fact that a common use of particular raw materials with similar usage characteristics and similar total masses could be assumed. For detecting occurring combinations combinatorial analysis are used in general. There exist several recent calculation methods for determining combinations within a specified quantity of elements. Since the production of welding consumable at the production site of voestalpine Böhler Welding Austria GmbH and the resulting raw material consumption are strongly influenced by customers' demand, an accurate mathematical calculation of all possible combinations is not necessary. Instead of that, a simplified method for qualitatively evaluating combinations was used. Based on from- to matrices like described in chapter 2.2.2 a matrix with all used materials listed in the first column and the first row was used, so that each cell of the matrix refers to one particular combination of two raw materials. As combinations without recurrence are of interest, the upper half of the symmetric matrix could be neglected. By going through the order data, the common use of the raw materials was calculated (cf. figure 3-10).

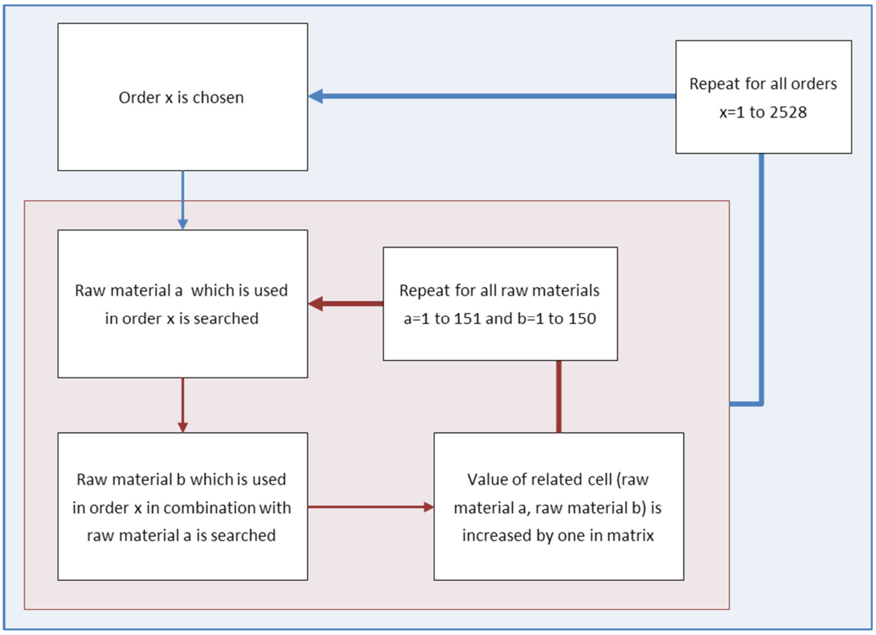


Figure 3-10: Algorithm to create combinatorial matrix

For each order the following procedure was executed. The first used raw material, material a, was searched. Afterwards further raw materials of the order have been examined according to a common use with material a. If a raw material, material b, was used in combination with material a, the value of the related cell in the combinatorial matrix was increased by one. By repeating the procedure for all materials a and b of one order the matrix could be set up.

For the purpose of improved clarity the cells of the matrix have been colour- coded by the frequency of the common use of the related raw materials (cf. figure 3-11). Five different colours (white, green, yellow, magenta and red) have been used for colour- coding.

The combinatorial matrix will be used during material flow planning. By further processing the matrix, ideal combinations of raw materials will be determined to build up ideal layout variants. (cf. chapter 3.6)

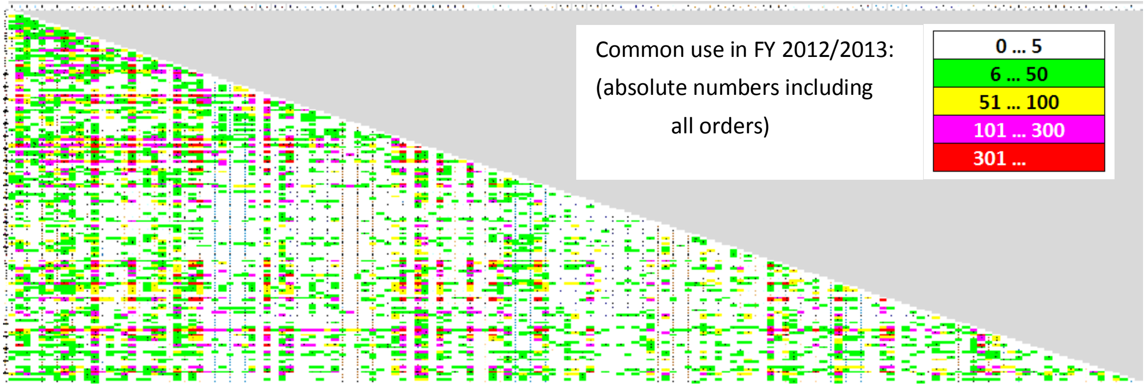


Figure 3-11: Combinatorial matrix

3.2.2.3 Time evaluation of the dosing process

So far only indirect methods for data acquisition have been used. Since for material flow planning and analysis the process times of the elapsing procedures are of interest, a time study has been conducting at the production site of voestalpine Böhler Welding Austria GmbH in Kapfenberg.

The process steps for dosing raw masses including all refilling and transporting actions and the related time steps will be needed in the following chapter to enable simulating the existing material flow system. In the following the results of the time study will be summarized.

As for the production of stick electrodes, the dosing process was measured on two separate days. In total the dosing processes of seven raw masses could be measured. As a result it could be concluded that the mean dosing time for raw masses varies according to the needed mass. Raw materials of which only 1 kg or less was dosed, the mean dosing time per kilogram amounted to 39 s/kg, while masses with more than six kilograms could have been dosed during 1,6 s/kg. Masses between 1,1 and 6 kilograms could have been dosed during 6,9 s/kg.

In particular, the big difference of the mean dosing times results from the fact that masses with less than 1 kg require an accuracy of 2 grams and therefore have to be dosed on the special scale.

Concerning filling and refilling process steps only little information could be gathered. The only time step that could be measured with satisfactory precision was the time needed for refilling containers by using raw material of the existing bunkers. There the mean refilling time amounted to 90 seconds (52 seconds for refilling plus travel time of the worker).

The time required for preparing the dosing stations in the beginning of the shift and transporting the dosed raw masses could only be estimated by the workers. For preparing the dosing stations a mean time of 25 minutes per shift was estimated.

The process times described until now are related to the production of stick electrodes. As for cored wire production, another time study has been conducted. Since only special raw masses have been dosed during the measurement time, the results of the time study were not statistically significant enough to represent a mean manufacturing process of raw masses for cored wire production.

Hence only an existing time study of voestalpine Böhler Welding Austria GmbH from 2001 could be used.

As the data of this study can be seen as obsolete information, the dosing times of the stick electrode production will also be used for the process of cored wire production. The small differences during the dosing process for producing cored wire are negligible, because the time duration of the transport processes within the cored wire production contributes even more to the total process time. For transporting raw masses from the dosing stations to the blender and the rolling lines a mean time of 10 minutes including waiting times for forklifts could be assumed.

3.2.3 Modelling of material flow

By analysing and evaluating all necessary data of the production process, the basis for modelling the material flow system was created. For quantitatively analysing the as- is situation a material flow simulation has been conducted.
The program used for the simulation in the master thesis at hand is called Plant Simulation by Tecnomatix. Plant Simulation can be used for discrete- event simulation of logistics systems. By creating a digital model of the material flow system the system characteristics and its performance can be analysed and optimized. [SIE14]
With the help of the simulation additional requirements for the further planning process will be gathered and bottlenecks within the system will be identified.

3.2.3.1 Simulation model

For setting up the simulation model of the dosing system the input data and the boundaries of the process to be simulated need to be defined. The process boundaries determine which boundary values are taken into account. [KÜH06]
In the case of the dosing process, the process boundaries are the storage processes of the raw materials on the one hand and the transport processes of the dosed raw masses on the other hand.

Conceptional simulation model

According to chapter 2.2.3 a conceptional simulation model has been created as first step of abstraction. As modelling technique the entity- relationship- modelling has been used. For structuring the conceptional model five different sub- fields have been defined:

- order processing
- configuration of systems and system components
- materials-handling technology
- resources
- storage.

In addition to the related entities and relationships, the attributes of the single entities and their manipulability have been defined. To explain all single entities, relationships and attributes would go beyond the scope of the master thesis at hand, but generally all described working procedures of chapter 3.2.1 are mapped in the ERM.

Figure 3-12 shows the simplified essential part of the entire entity- relationship model to reproduce the main material flows and related operational procedures within the production system. For characterising entities the essential attributes including primary keys have been introduced.

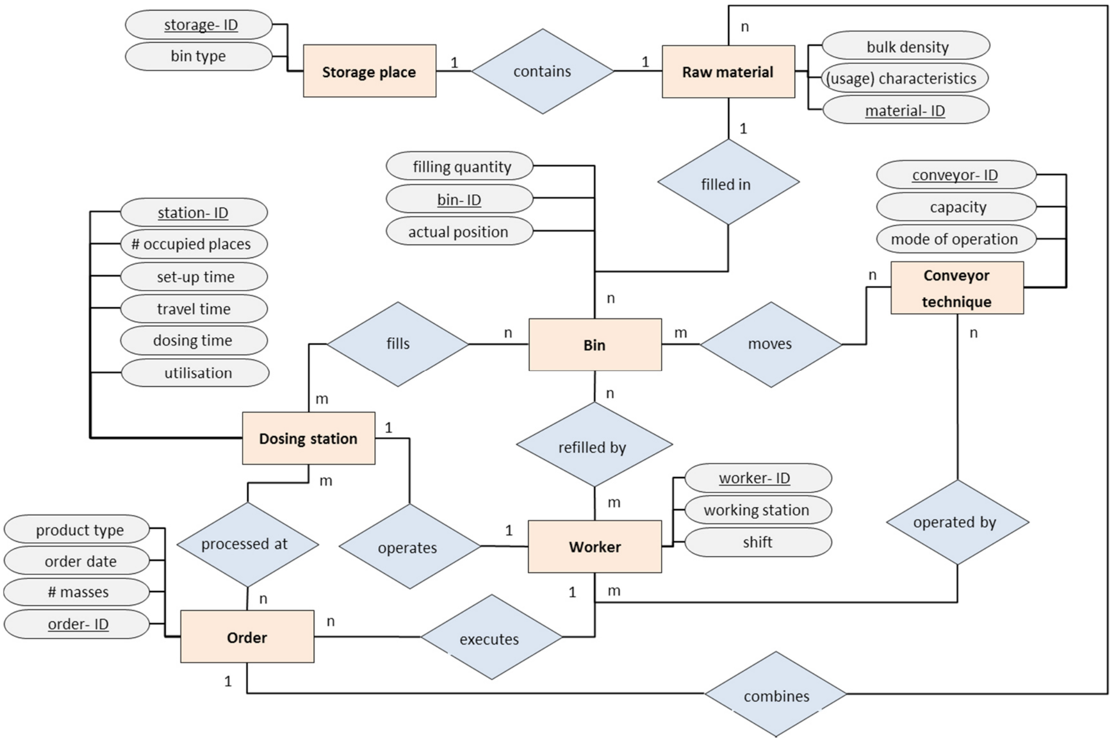


Figure 3-12: Simplified essential part of the ERM

For fulfilling customer’s orders the orders and related production steps need to be executed by a worker. As attributes of an order the order date, the number of masses and the product type need to be specified besides an order identification number. The product type determines at which dosing station the order will be processed. In addition to that the product type determines the destination of the prepared dosed masses for further processing.

The masses are composed of different raw materials. The raw materials are taken out of storage and are filled into bins. The most important attributes which characterise a raw material are the bulk density, the usage characteristics and special material characteristics. With the bulk density the needed volume for storing the raw materials can be calculated.

When the raw materials are filled into bins, the filling quantity of the bins and their actual positions have to be determined. For dosing raw materials the dosing stations get loaded with different bins.

The main attributes of the dosing stations are besides the number of occupied places, the time steps for set- up, travel and dosing procedures. The utilisation of the dosing stations allows analysing the material flow behaviour.

If all raw materials related to one order have been dosed the worker operates the conveyor technique for transporting the dosed masses.

Deduced software based simulation model

Based on the conceptional entity- relationship- model a software based simulation model could be implemented. The simulation program *Plant Simulation* by Tecnomatix offers different basic elements for rebuilding material flow networks. By using the programming language of the software tool, additional features and functions of network elements have been introduced for transferring the entity- relationship- model to an adequate simulation model.

Figure 3-13 shows the created simulation model. The model is built up of four different sub-systems which are marked with different colours below. In the first section, marked in orange, the needed containers and raw materials are inserted into the system. Since Plant Simulation is intended for simulating piece goods, a special method for describing bulk solids has to be found. For each raw material the real number of related containers is inserted into the system. Therefore predefined elements of Plant Simulation have been used. The existing parameters of the predefined elements have been adjusted. By adding variables for representing the filling level, the total mass and the density of the related material, the predefined elements could be used for describing bulk solids.
The green section of figure 3-13 is related to the actual dosing process including the dosing stations. In the third section, marked in light blue, refilling processes are implemented, while the dark blue section represents the transport process of dosed masses as boundary conditions.

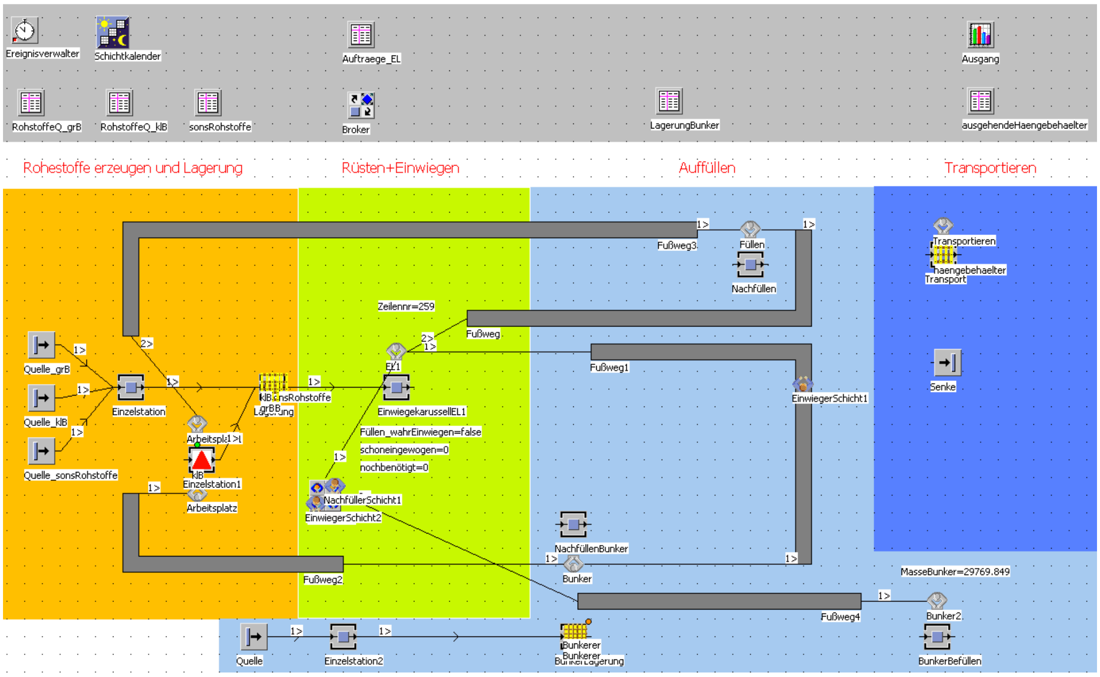


Figure 3-13: Simulation model created in Plant Simulation by Tecnomatix

In the following the assumptions made to set up the simulation model are described:

(1) Only one of the three existing dosing stations is analysed and thereby only one working place is reproduced.
This allows using the simulation model for the production areas of cored wire and stick electrodes.

(2) A shift calendar is integrated to the simulation. Two shifts with eight hours and a pause time of 18 minutes per shift are considered.

(3) In total three workers are simulated. Two of them are assigned to the first shift. A worker is working at the dosing station, while the second worker is responsible for refilling the bunkers.
The third worker is assigned to the second shift, in which he/she is responsible for dosing and refilling processes.

(4) Only powdery raw materials are included in the simulation. Liquid water glasses are not considered.

(5) The dosing times are defined according to the measured and assumed times of the time studies. (cf. chapter 3.2.2.3) Since only one dosing station is reproduced, in the case of stick electrode production the dosing times are halved. This allows representing the two real dosing stations related to stick electrode production.

(6) For the refilling processes, a special strategy was implemented. Only if the remaining quantity of bunkers or containers becoming empty is not enough for the following order, the bunkers or containers are refilled.
This strategy does not really correspond to reality, because the workers have developed their own refilling strategies. Often containers are refilled even if they are half-full.
Since for simulating a defined factor is needed for deciding about refilling processes, the real strategies cannot be implemented.

(7) The times for refilling the containers by using the bunkers are defined according the measured and assumed times of the time studies. (cf. chapter 3.2.2.3)

(8) Travel times for refilling actions by using raw material of stock can only be estimated.

(9) For preparing the dosing stations and all needed containers 15 minutes per order are assumed.

(10) The transport of the dosed masses is not represented in the simulation model. For including the transport process as boundary condition only the amount of masses which need to be transported is represented.

(11) Occurring downtimes are included as follows:

- 30 minutes per week due to IT problems
- 1 hour per month due to other reasons
- 20 hours per month due to planned shutdown of production (in total three weeks per year)

With the help of the developed simulation model all orders of the fiscal year 2012/2013 could have been simulated and analysed. In the following chapter the results will be discussed and requirements for further material flow planning will be derived.

3.2.4 Results of simulation and derived requirements

The result of the conducted simulation equates in sense of duration to the real duration of production. For this reason it could be proved that the made assumptions are justified. For analysing the influence of the dosing time on the overall production time, the dosing time has been modified. Doubling of the dosing time resulted in an increase of approximately 50 percent of the whole production time. It can be concluded that the process times for filling and refilling have a big influence on the total process time. Therefore the filling and refilling processes have been further assessed.

Figure 3-14 shows the summary of the assessment of time slices during the simulated production time. During filling and refilling actions the workers are not available for dosing tasks. Two-fifths of the total working times of the system are spent for refilling of containers and refilling of bunkers. By reducing the refilling times or by parallelising refilling and dosing processes, the efficiency of the whole system could be increased.

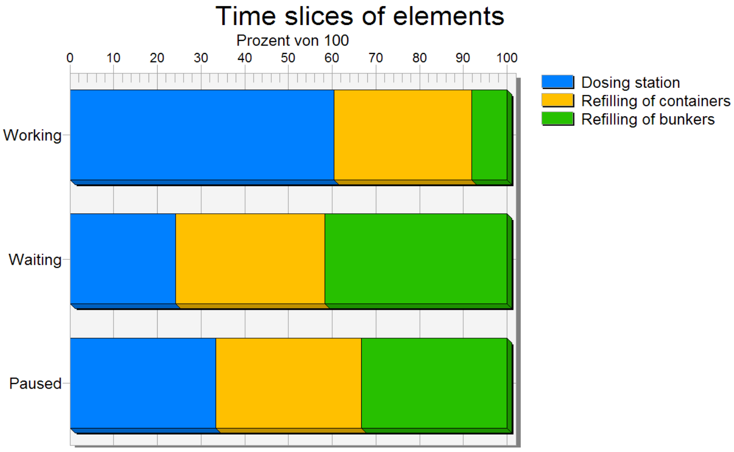


Figure 3-14: Time slices of elements used

Furthermore the following requirements for new conceptual design of the dosing system could be derived from the analysis and simulation:

(1) With the future dosing system a maximum of 32,3 tons of raw materials has to be dosed daily.

(2) The dosing process has to be parallelised as far as possible with the refilling processes to minimize the total process time.

(3) Used bins for dosing have to be refilled as seldom as possible.

(4) The volumes of used bins need to be adapted to the yearly demand of the raw materials.

(5) Raw materials, which are commonly used together, have to be arranged near to each other to minimize travel times.

(6) With the new dosing system batch tracing concerning the used raw materials is to be possible. Thereby quality requirements can be met.

(7) Specific characteristics of the raw materials need to be considered for designing bins and storage spaces.

(8) Spatial constraints of the existing building need to be respected.

(9) Stabling of unused bins in the dosing area should be avoided to minimize possible contamination.

(10) To ensure that the required accuracy of the dosing process can be met, different scales need to be provided.

(11) Travel and run times of the system and of the workers have to be minimized.

(12) Dust loading need to be minimized.

(13) For manually operated system, human working conditions have to be ensured. The masses to be moved by the workers need to be as low as possible and an ergonomic working place has to be designed.

(14) The new dosing system has to be designed in a cost- effective and practically applicable fashion.

By analysing and summarizing the strength and weaknesses of the as-is state, the requirements for the subsequent material flow planning could be deduced. The mentioned requirements will be the basis for building up concept variants to redesign the material flow.

3.3 Concept variants

After the as- is analysis of the actual situation including analysing of available data and simulating the actual situation, material flow planning tasks can be conducted.

As described in chapter 2.2.2 the identified requirements and the related problems of the actual situation are at first considered in a superordinate context in the rough planning phase. The objective is to bring up solutions and concepts for redesigning the existing dosing system.

In general, different technologies and techniques can be used for recipe metering. Two principle techniques have to be distinguished:

- Dosing techniques with measurement:
  For dosing powdery bulk solids different mass effects for indirect measuring the total mass can be used. Besides using inertia forces, heat transmission or radiation absorption phenomena can be used. [VET02]
- Dosing techniques without measurement:
  For dosing without measurement certain cross sections are used. Different flow or conveying cross sections respectively certain filled volumes are related to particular masses to be dosed. Popular technologies in this field are dosing screws, rotary valves and metering valves. [VET02]

Since the main focus of the master thesis at hand is to improve the material flow and increase the efficiency of the production of welding consumables by restructuring and rearranging of the material flow elements, the different dosing techniques will not be further examined in detail.

Furthermore the set requirements cannot be covered by existing dosing systems in the market. On these grounds different concept variants have been elaborated and sub- functions of the dosing system have been defined. [VDI93a]

Based on these sub- functions suitable principles have been sought to come up with principle variants for the defined sub- functions. By combining the received possible solutions the different concept variants could be elaborated.

Table 3-4 shows that the elaborated and examined concept variants can be distinguished according to their operation mode.

Besides an additional manually operated system, six possible semiautomatic concepts as well as one fully automated concept have been designed. In the following these concepts will be described and advantages and disadvantages of each concept will be evaluated.

Table 3-4: Examined concept variants (M ... Manual, A ... Automatic)

	Manually operated	1	Semiautomatic operation	2	3	4	5	6	7	Automatically operated	8
Filling		M		M/A	M/A	M/A	M/A	M/A	M/A		A
Dosing of popular materials		M		A	A	M	M	M	A		A
Dosing of less popular materials		M		A	M	A	M	A	M		A
Refilling		M		M	M	M	A	A	A		A
Transport		M		M/A	M/A	M/A	M/A	M/A	M/A		A

3.3.1 Concept 1: Manually operated

In addition to the existing manually operated system, a second manually operated variant has been developed. As the pictured table in figure 3-15 illustrates, all process steps are manually operated. Besides dosing tasks, refilling and filling processes as well as transport processes are considered as manual processes within the system. As for designing a new material flow layout, the idea of arranging the raw materials in a special geometrical shape in dependence on the existing dosing carousels is taken up. Raw materials which are often used in common have to be arranged side by side or vis-à-vis. As most promising geometrical shape an aisle has been chosen. The idea to arrange the raw materials within an aisle goes back to traditional storage of goods.

Figure 3-15 gives an overview about how the layout for the manually operated aisle can look like. The most popular processed raw materials are dedicated to a fixed place within the vertical aisle. For this reason the setting- up process which has to be conducted at dosing carousels can be omitted for the most popular processed materials. Since a recipe also contains less popular processed raw materials, additional places are provided in a horizontal aisle.

	Manually operated	1
Filling		M
Dosing of popular materials		M
Dosing of less popular materials		M
Refilling		M
Transport		M

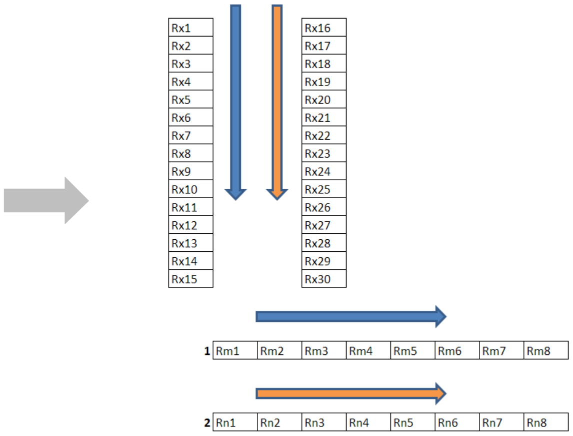


Figure 3-15: Manually operated concept variant

With the chosen layout filling and refilling processes will remain the same as today. Bins with raw materials will still need to be wheeled and consequently also be stored respectively stabled in any free area. In addition to that dust loading will also remain the same as today.

One of the advantages of this concept is that orders can be processed in parallel and hence process times can be reduced. Moreover by accurately arranging raw materials, which are often used in common, the dosing process will get more efficient.

As the transport process will stay manually operated, the existing overhead conveying system can be further used.

3.3.2 Concept 2: Semiautomatic operation

For semiautomatic systems the dosing process or filling and refilling processes or the transport process can be automatized. Table 3-5 summarizes all possible combinations of manual respectively automatic processes within the system. For automation of filling and refilling processes the most promising technology for bulk solids is the transport in pipelines by means of pneumatic systems. Since the raw materials used at the production site of voestalpine Böhler Welding Austria GmbH are partly extremely fine and powdery, they are not suitable for pneumatic conveying. Hence only three semiautomatic concept variants are realisable.

The three realisable concept variants are characterised by the degree of automation concerning the dosing process. Firstly there exists a concept variant which includes automated dosing systems for popular and less popular material. (cf. concept 2 in table 3-5)

The second and third mentioned concept variants consist of a hybrid system. Not only a system for manual dosing, but also an automated system is integrated (cf. concept 3 and 4 in table 3-5). Hence the manual part of the hybrid system has already been discussed in the previous chapter; the focus will be on the realisation of automated concepts.

Table 3-5: Semiautomatic concept variants (M ... Manual, A ... Automatic)

	Semiautomatic operation	2	3	4	5	6	7
Filling		**M/A**	**M/A**	**M/A**	**M/A**	**M/A**	**M/A**
Dosing of popular materials		**A**	**A**	**M**	**M**	**M**	**A**
Dosing of less popular materials		**A**	**M**	**A**	**M**	**A**	**M**
Refilling		**M**	**M**	**M**	**A**	**A**	**A**
Transport		**M/A**	**M/A**	**M/A**	**M/A**	**M/A**	**M/A**

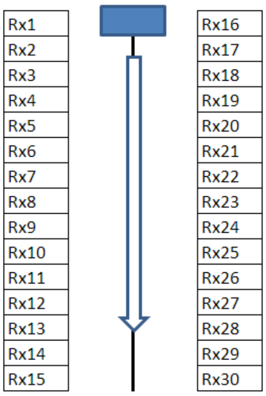


Figure 3-16: Automatic dosing process for large quantities

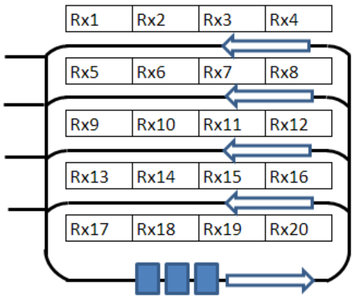


Figure 3-17: Automatic dosing process for medium and small quantities

Since filling and refilling processes cannot be automated, the dosing process has to be operated automatically. As mentioned in the beginning of chapter 3.3 different dosing technologies can be used. In the case of the production of voestalpine Böhler Welding Austria GmbH dosing technologies without measurement show great promise for automation. For arranging the needed raw materials for the dosing process different approaches can be chosen. Figure 3-16 shows the first concept which uses the basic idea of an aisle. The bins, in which the raw materials are dosed, are transported automatically through the aisle. Only the needed raw materials for the current recipe within the aisle are approached. Raw materials which are often used in common will be pooled so that the run time of the moveable bin can be minimized. In addition to that dosing technologies like dosing screws can be used for simultaneous dosing of different raw materials of one created pool for minimizing the total process time. The described system is advisable for raw materials which are used in large quantities. The volumes of the bins which are forming the aisle have to be adjusted to the yearly consumption of the particular raw materials. Thereby refilling times can be minimized.

For automation of the dosing process of raw materials which are used in small or medium quantities per fiscal year a similar system can be used. As shown in figure 3-17 several aisles can be combined. Each aisle comprises raw materials which are used commonly. If raw materials, which are stored in different aisles, are needed for one particular recipe the aisles can be operated parallel and the masses can be subsequently mixed together. The biggest advantage of automated dosing is the prevention of potential contamination by dust loading. By dust- tight usage of dosing screws or other dosing technologies a proper working environment can be created and high accuracy of the dosing process can be assured providing that the correct scales are used. Since the dosing process within a semiautomatic concept will be operated automatically, in case of an unplanned breakdown the system cannot be operated manually. For ensuring that in case of an unplanned breakdown further production tasks can be executed, either a system which can also be manually operated or an additional manually operated backup system has to be designed. The backup system can be implemented as an additional aisle with manual operation. The most challenging task is however to arrange the raw materials within the existing aisles, because the arrangement of raw materials has a big impact on the total process time. In chapter 3.4 an ideal arrangement of raw materials for particular concept variants will be figured out.

Concerning the transport process of the dosed masses of raw materials, the existing overhead conveying system can be used in case of manual transportation. For automation of the transport process the existing overhead conveying system can be upgraded and additional switch points can be supplemented.

3.3.3 Concept 3: Automatically operated

For building up a completely automated system all related processes need to be automatized. As aforementioned the automation of the filling and refilling processes at the production site of voestalpine Böhler Welding Austria GmbH in Kapfenberg is not realisable. For this reason a completely automatically operated system cannot be design. Furthermore the automation is almost impossible due to the high number of raw materials. Additionally the fully automated concept will implicate a big disadvantage. In case of an unplanned breakdown of the system, the whole dosing process will stand still. Consequently the fully automated concept variant can be neglected.

3.3.4 Preferred concept variants

As mentioned in chapter 2.2.2 the rough planning stage of material flow planning includes the design of a block layout of the used material flow elements. Since until now some concept variants for redesigning the dosing system do not seem promising enough to fulfil the set requirements block layouts are only designed for the most promising and thus preferred concept variants.

For setting up a block layout an attempt has been made to further particularise the elaborated concept variants. The dosing procedure of a raw material respectively a pool of raw materials has been subdivided according to a weighted assessment. The four categories for the weighted assessment and the related weighting factors are listed in table 3-6.

For all four categories the raw materials have been ranked from the largest to the smallest value. Subsequently the resulting ranking positions have been multiplied by the related weighting factors.

By summing up the received values and by dividing by the sum of all weighting factors the weighted assessment could be completed and the following sub processes of the overall dosing process could be determined:

- dosing of largest quantities
- dosing of large quantities
- dosing of medium quantities
- dosing of small quantities.

Table 3-6: Categories and weighting factors for weighted assessment

Categories	**Weighting factor g**
1. the total mass of the raw material in the FY 12/13	$g_1 = 4$
2. the total volume of the raw material in the FY 12/13	$g_2 = 3$
3. the number of orders, in which the raw material was used in the FY 12/13	$g_3 = 2$
4. the medium weight of the raw material involving all orders, in which the raw material was used in the FY 12/13	$g_4 = 1$

In table 3-7 the received concept variants considering the sub processes are pictured. The automatically operated concept and the semiautomatic concepts with automatic refilling and filling processes are neglected (cf. chapter 3.3.2 and chapter 3.3.3).

With a manually operated concept the set requirements concerning working conditions and the decrease of the work load cannot be met and so the manually operated concept became less important. Since the automation of dosing small quantities is not economically meaningful only three semiautomatic concepts have shown great promise for implementation.

Table 3-7: Preferred concept variants

	Manually operated	1	Semiautomatic operation	2	3	4	5	6	7	Automatically operated	8
Filling		M		M/A	M/A	M/A	M/A	M/A	M/A		A
Dosing of largest quantities		M		A	A	A	M	M	M		A
Dosing of large quantities		M		A	A	M	M	M	A		A
Dosing of medium quantities		M		A	M	M	M	A	A		A
Dosing of small quantities		M		M	M	M	A	A	A		A
Refilling		M		M	M	M	M	M	M		A
Transport		M		M/A	M/A	M/A	M/A	M/A	M/A		A

For the three preferred concept variants 2, 3 and 4 block layouts have been designed. For all three variants the automatically operated processes and the manually operated processes are arranged in parallel. In figure 3-18, figure 3-19 and figure 3-20 the rough block layouts are illustrated.

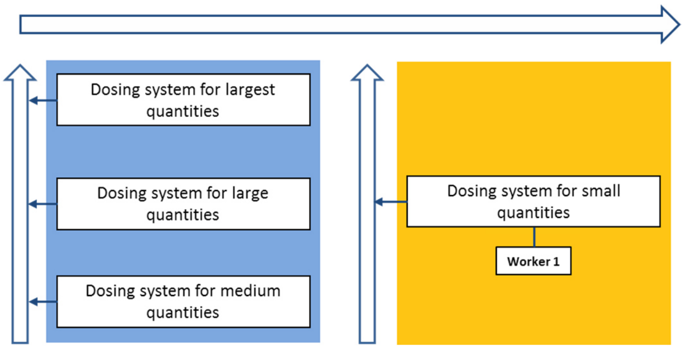


Figure 3-18: Block layout for concept variant 2

The block layout for concept variant 2 includes an area for automated dosing as well as for manual dosing processes. The automated processes for dosing largest, large and medium quantities of raw materials are again arranged in parallel to minimize the process times. On condition that the time needed for automatically dosing equates to the time needed for manual dosing procedures, the layout has the potential to be an effective solution to the set of problems.

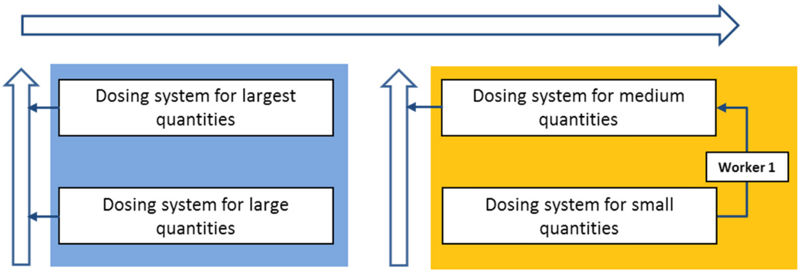


Figure 3-19: Block layout for concept variant 3

For concept variant 3 the layout pictured in figure 3-19 has been designed. The automated processes for dosing largest and large quantities are running in parallel with two manual dosing processes. For the manually operated material flow stations for dosing medium and small quantities the question arises of whether a worker per shift is enough to ensure clearly shorter process times.

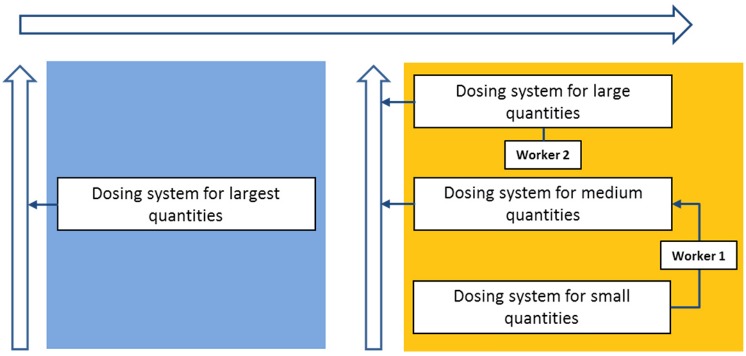


Figure 3-20: Block layout for concept variant 4

The block layout for concept variant 4 can be seen as the opposite of concept variant 2. Only the processes for dosing largest quantities are automated, so that at least two workers are needed per shift to complete the needed manual dosing procedures. As illustrated in figure 3-20 a worker has to complete all dosing tasks of medium and small quantities. As aforementioned it has to be checked whether only one worker is able to fulfil all dosing tasks for small and medium quantities.

Since the alignment of the raw materials within the material flow elements of the preferred concept variant influences a lot the overall process times, the optimal alignment of the raw materials is needed to further specify the block layouts. In the subsequent chapter the appropriate approach for the optimisation of the alignment of raw materials will be discussed.

3.4 Optimisation of the alignment of raw materials

As mentioned before, the alignment of raw materials within a new material flow system strongly influences the efficiency and the throughput times. Therefore the optimisation of the alignment of raw materials has been one main issue in the master thesis at hand. As basis for the optimisation process the combinatorial matrix, which has been described in chapter 3.2.2.2, was used. By using the combinatorial matrix all existing raw material combinations can be taken into account.

Since the alignment of raw materials is similar to an arranging process of different material flow elements an attempt has been made to use the described algorithm of the guiding principle VDI 2498 (cf. chapter 2.2.2). Due to the fact that a recipe only consists of a maximum of 28 raw materials, the described algorithm for arranging all different raw materials could not be easily adopted. Only for each particular recipe the algorithm could be implemented. As a result a high number of possible arrangements would be set up, which then need to be further combined and rearranged. For that reasons the existing algorithm has to be modified and adapted for generating a global solution.

The first steps of the developed algorithm are similar to the described algorithm of the guiding principle VDI 2498. The line and column sums of the combinatorial matrix are set up. For further processing a new parameter N has been introduced. The parameter is needed to describe the dosing technology in detail. As mentioned in chapter 3.3.2 simultaneous dosing of different raw materials out of one particular pool can minimize the total process time. In order to factor the possibility of simultaneous dosing into the algorithm, the number of raw materials which can be simultaneously dosed is described by the new parameter N.

To ensure comprehensibility the next steps of the algorithm will be described for a system in which three different raw materials can be dosed simultaneously (cf. figure 3-21 : N = 3).

After the number of raw materials for simultaneous dosing is specified, the ideal combination of raw materials is sought. For that purpose two different combinations are compared:

- In the first case the maximum line sum and the first and second largest column sums are added together. (If N = 4, the maximum line sum and the first, second and third largest column sums will be added together)
- In the second case the maximum column sum and the first and second largest line sums are added together. (If N = 4, the maximum column sum and the first, second and third largest line sums will be added together)

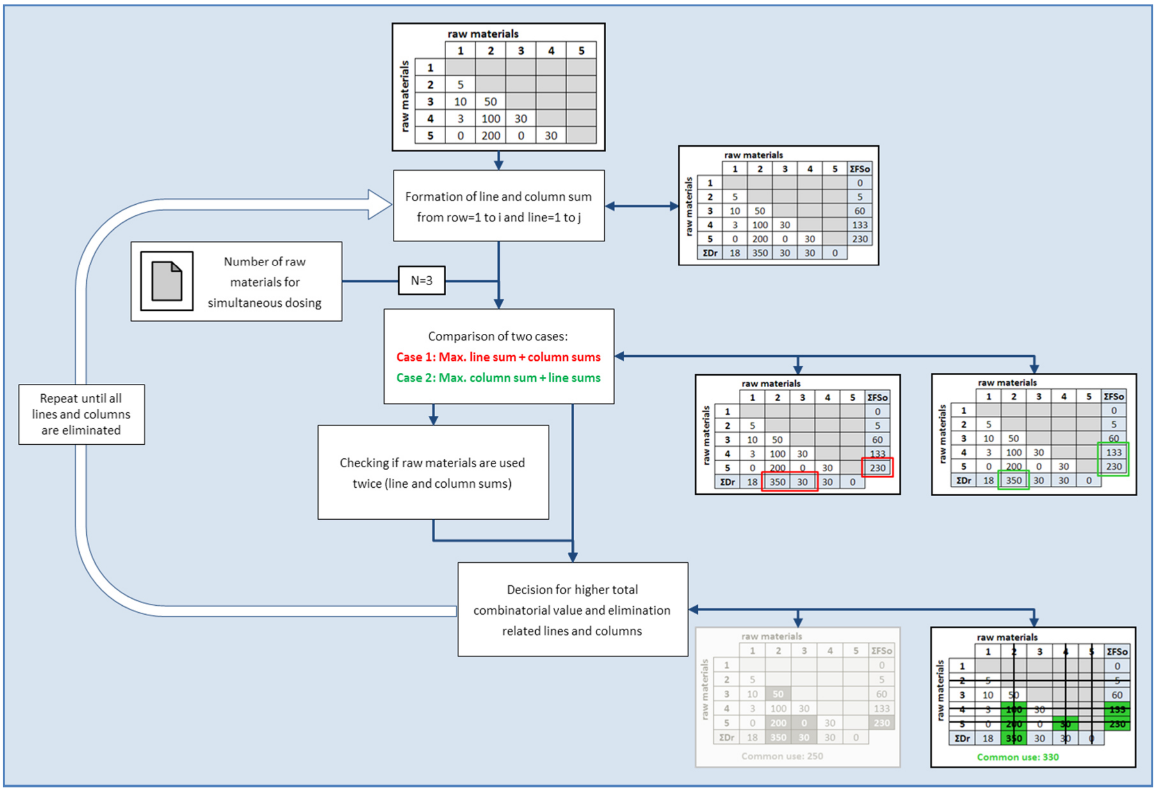


Figure 3-21: Algorithm for arranging raw materials

Since the number of raw materials used at the production site of voestalpine Böhler Welding Austria GmbH is as high and the column and line sums of the materials may correspond, it needs to be checked if any raw material is used twice during summation. If one particular raw material is used twice the next largest column sum (case 1) / the next largest line sum (case 2) and the related raw material is used. Afterwards the combination with the higher total value is chosen, the related lines and columns of the combinatorial matrix are eliminated and the procedure is repeated until all lines and columns are eliminated. In the end the ideal raw material combinations are determined and the order, in which the raw materials have been eliminated, determines how the particular pools of raw materials have to be arranged. If a particular geometry, e.g. an aisle, is realized in the new dosing system, the pool of raw materials, which has been eliminated at first, has to be placed in the front part of the geometry to optimize overall process times.

The algorithm described above will be used in the following chapters for further detailing the block layouts and for simulating the related material flows of the preferred concept variants.

3.5 Analysis of preferred concept variants

Based on the block layouts of the preferred concept variants and the algorithm for optimisation of the alignment of raw materials, the preferred concept variant are further analysed and evaluated by means of a simulation of material flows. The simulation serves as basis for building up ideal layouts including the alignment of raw materials.

3.5.1 Simulation of preferred concept variants

As aforementioned the simulation of the preferred concept variants is essential for building up detailed ideal layouts and in addition to that the simulation will reveal the realizable concepts and consequently the most promising system variant can be selected. The course of action for the simulation, which will be described in detail below, is summarized in figure 3-22.

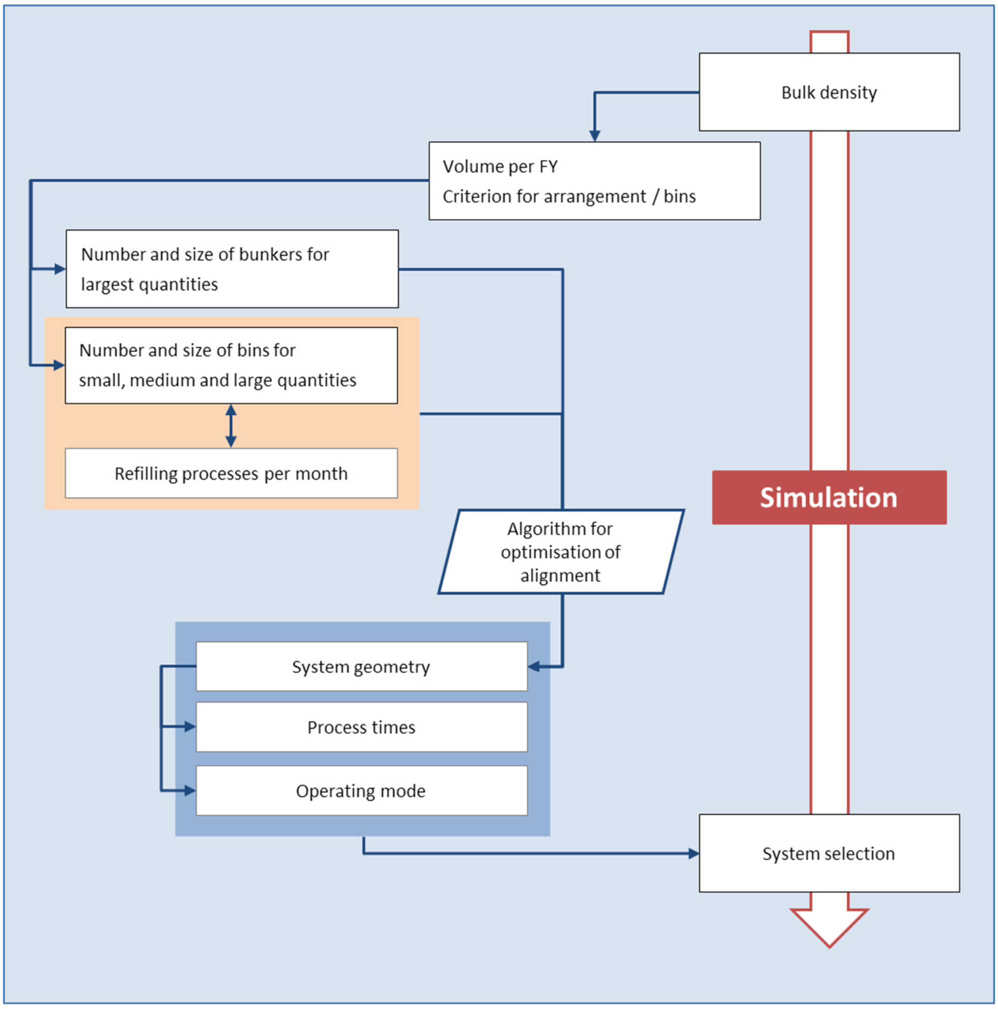


Figure 3-22: Course of action for system selection

For conducting the simulation, the order data and raw material data was needed at first. The bulk densities of the processed raw materials and the resulting volumes, which are processed within the fiscal year 2012/2013, serve as main criterion for the arrangement and definition of bins. Since the dosing processes of the preferred concept variants have already been subdivided according to the quantities (cf. chapter 3.3.4), it has been assumed that for each sub system particular bins would be used. For automated dosing of largest quantities bunkers with a volume of 8000 dm^3 have been chosen as particular bins according to the existing dosing system. The number of bunkers has been increased from 39 of the existing system to 44 to ensure that at least 80 percent of the total mass (based on FY 2012/2013) could have been automated. The raw materials which are stored in the bunkers have been chosen according to the described ranking of chapter 3.3.4. .

For the remaining sub systems the bins have been defined in coordination with voestalpine Böhler Welding Austria GmbH and in dependence on the level of automation. In addition to that the delivery bundle of the related raw materials has been involved to find the accurate bin sizes.

As result bins with a volume of 1000 dm^3 for dosing of large quantities, bins with a volume of 250 dm^3 for dosing medium quantities and bins with a volume of 62,5 dm^3 for dosing of small quantities have been chosen. The volume of 1000 dm^3 for large quantities corresponds to the filling capacity of a big bag. Since many raw materials are delivered in big bags, no refilling process is needed and the big bags can directly be used as bins for dosing procedures. The bin volume for dosing of medium quantities has been defined as one quarter of the total volume of bins for dosing of large quantities. Furthermore the bins for small quantities have again been defined as one quarter of the bins for medium quantities. The sizes have been deliberately chosen to ensure a certain degree of compatibility between the single systems. After the definition of used bins the number of the particular bins per system has been calculated. For that purpose refilling ratios for the single systems have been defined. This is necessary because the refilling ratios determine how often the bins within the single systems need to be refilled. Since the number of refilling processes needs to be minimized to fulfil the set requirements (cf. chapter 3.2.4), the assignment of the raw materials to the single systems plays an important role. For all raw materials, which have not already been assigned to the bunkers the mean monthly refilling ratios are calculated and then compared to the previous defined refilling ratios of the single systems (cf. figure 3-23). All raw materials, whose mean monthly refilling ratios are smaller than the defined ratio of the dosing system for small quantities, have been dedicated to this system. According to this principle the residual raw materials have been assigned to the dosing systems for medium respectively large quantities. In total each raw material has been assigned to one single bin. That allows batch tracing and consequently increases the product quality.

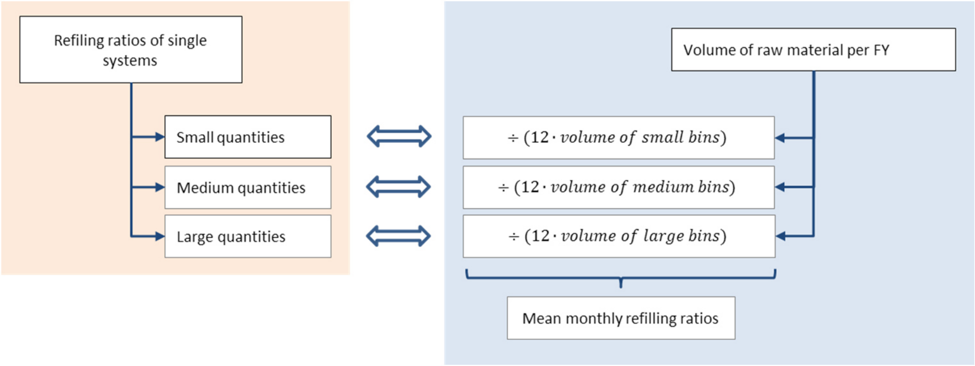


Figure 3-23: Comparison of refilling ratios

By assigning the raw materials to the single systems, the number of bins, which will remain fixed in place within the single systems, has been defined.

Using the described algorithm for the optimisation of the alignment of raw materials (cf. chapter 3.4), an optimal arrangement of the raw materials for each single system could be specified. Hence the system geometry has been determined by the number and size of bins per single system.

As next part of the simulation, the process times for the single systems have been defined and the overall process time has been calculated by running through all orders. The calculation process and the related parameters are pictured in figure 3-24 below.

Since the raw materials have already been assigned to the single system the type of raw material has determined which system had to be operated for dosing. The four single systems have been further divided according to the accuracy of the used scales. As mentioned in chapter 3.2.2.3 masses with less than 1 kg require an accuracy of 2 grams and therefore have to be dosed on a special scale. With the knowledge of the appropriate system, the bin size and the position of the raw material have been determined. This in turn influenced the dosing and travel and run time. The dosing times have been estimated according to the time evaluation of chapter 3.2.2.3. For masses with less than 1 kg, which are manually dosed 39 s/kg have been assumed for dosing, while masses with more than 1 kg required 7 s/kg for dosing. For automated dosing 45 s per raw material have been assumed according to internal information of voestalpine Böhler Welding Austria GmbH.

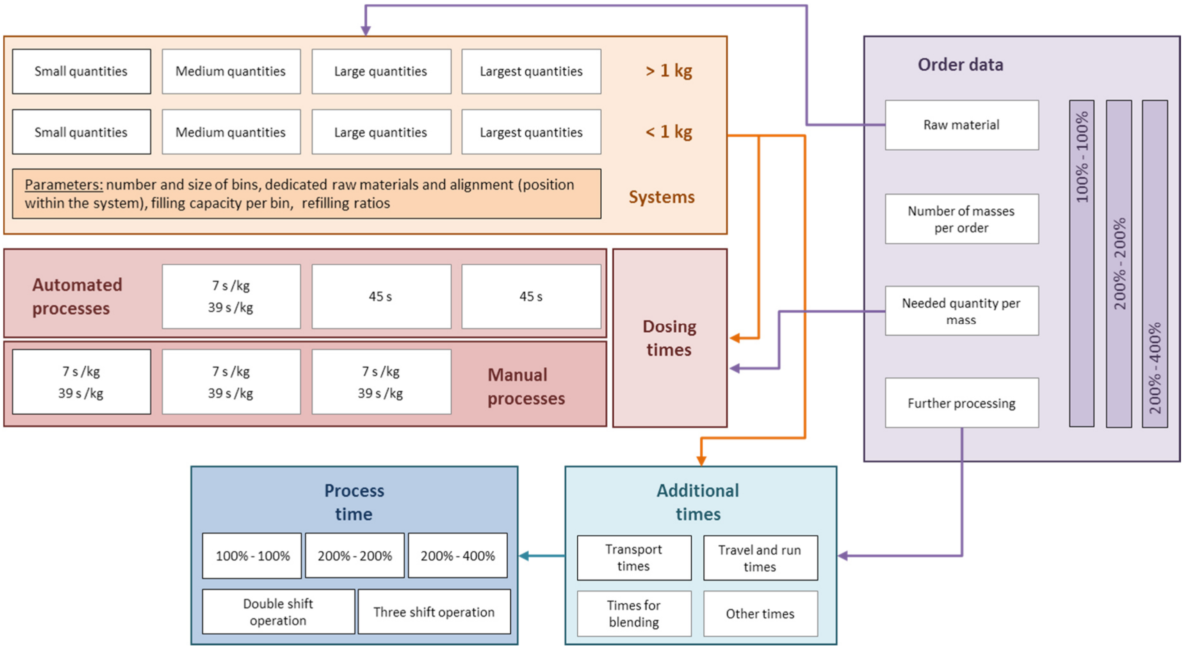


Figure 3-24: Calculation of overall process time

The needed additional times result from transport processes (20 s per dosed mass), blending process (20 s per dosed mass), travel and run processes within the single dosing systems. Additionally other time steps for handing over the dosed masses from automated systems to an overhead conveying system (10 s per dosed mass) have been included.

For minimizing travel and run times within the single dosing systems the principle of minimized distances has been applied. Raw material pools resulting from the algorithm for the optimisation of the alignment have been arranged according to the total usage frequencies. Raw material pools with high total usage frequencies have been arranged in the front part of the chosen dosing system geometries, while raw material pools with very low usage frequencies have been arranged in the rear part of the system geometries (cf. figure 3-25). If for completing an order more than one raw material pool within a single system needs to be approached, the farthest of the pools has been approached at first. Afterwards the other needed pools are approached one after the other by simply travelling to the beginning of the dosing system geometry. As travel time from one pool to another 2 s are assumed. By summing up all mentioned relevant time steps the overall process time could be established.

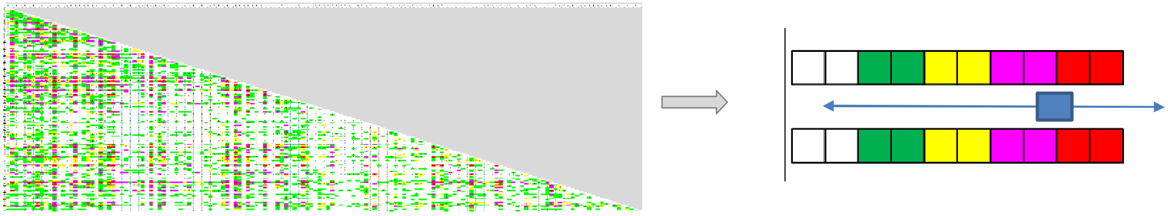


Figure 3-25: Principle of minimized distances

3.5.1.1 Simulation results

The simulation described above has been conducted for three specific cases. Firstly the as- is state of the order volume has been analysed. For the second and third case the planned increase of the production program has been included. In the second case the production of stick electrodes and cored wire is doubled, while in the third case the stick electrode production is doubles and cored wire production is quadrupled. So a maximum of 32,3 tons of raw materials has to be dosed daily.
Besides that the refilling ratios for the single dosing system as well as the number of raw materials per raw material pool within the single systems have been varied (cf. table 3-8).

Table 3-8: Parameter variations

	Small quantities		Medium quantities		Large quantities		Largest quantities	
	Number of bins	Raw materials within one pool / refilling processes per month	Number of bins	Raw materials within one pool / refilling processes per month	Number of bins	Raw materials within one pool / refilling processes per month	Number of bunkers	Raw materials within one pool
1	41	8 / 2	52	4 / 4	14	4 / 8	44	4
2	41	6 / 2	36	4 / 2	30	4 / 8	44	4
3	41	6 / 2	52	4 / 4	14	4 / 8	44	6
4	41	8 / 2	52	4 / 4	14	4 / 8	44	6

Under these conditions the three preferred concept variants with semiautomatic operation mode have been simulated. It very quickly has become apparent, that the preferred concept variant 3 with manual dosing for small, medium and large quantities and automatic dosing for largest quantities cannot be implemented. The reasons for that are multifaceted. On the one hand at least two workers are needed per shift to fulfil the requirements concerning the total dosed masses and thus no staff savings are realistic. On the other hand the planned increase of the production program would not be realizable. In addition to that it has to be considered that the refilling processes would stay parallel to the dosing processes and therefore an additional worker would be needed. On these grounds the other preferred concept variants are further analysed in detail.

By simulating concept variant 2 it has become obvious that 44 percent of the actual working time of 235 working days can be economised by automation of medium, large and largest quantities. If the order volume is increased, the total working time will result in around 200 working days. That means that with the maximum order volume increase, about 15 percent of the actual working time can still be saved. Additionally it has been shown that a variation of the refilling ration and the number of raw materials combined to a pool do not influence a lot the overall process time (cf. figure 3-26).

CONCEPT VARIANT 2		100% SE 100% CW Double shift operation	200% SE 200% CW Three shift operation	200% SE 400% CW Three shift operation		
Manual dosing only for small quantities	**1**	133	177	202	[WD]	S:41 - 8/2, M: 52 - 4/4, L:14 - 4/8, B: 44 - 4
	2	131	175	199	[WD]	S:41 - 6/2, M: 36 - 4/2, L:30 - 4/8, B: 44 - 4
	3	131	174	199	[WD]	S:41 - 6/2, M: 52 - 4/4, L:14 - 4/8, B: 44 - 6
	4	131	174	199	[WD]	S:41 - 8/2, M: 52 - 4/4, L:14 - 4/8, B: 44 - 6
Average		**131,5**	**175**	**199,75**	[WD]	
% of total working time		56,0	74,5	85,0	[%]	(total working time: 235 WD)

CONCEPT VARIANT 3		100% SE 100% CW Double shift operation	200% SE 200% CW Three shift operation	200% SE 400% CW Three shift operation		
Manual dosing of small and medium quantities	**1**	136	181	207	[WD]	S:41 - 8/2, M: 52 - 4/4, L:14 - 4/8, B: 44 - 4
	2	132	176	201	[WD]	S:41 - 6/2, M: 36 - 4/2, L:30 - 4/8, B: 44 - 4
	3	134	178	205	[WD]	S:41 - 6/2, M: 52 - 4/4, L:14 - 4/8, B: 44 - 6
	4	134	178	205	[WD]	S:41 - 8/2, M: 52 - 4/4, L:14 - 4/8, B: 44 - 6
Average		**134**	**178,25**	**204,5**	[WD]	
% of total working time		57,0	75,9	87,0	[%]	(total working time: 235 WD)

Figure 3-26: Analysis of overall process time

If concept variant 2 with manual dosing for small quantities and concept variant 3 with manual dosing for small and medium quantities are compared, the influence of the automation level is not very wide. On average about three to four days plus are needed if small and medium quantities are manually processed.

Building on this knowledge a detailed ideal respectively real material flow and layout planning considering spatial constraints will be conducted in the following chapter.

3.6 Real layout planning

Since the ideal arrangements of single dosing systems and the optimal alignment of raw materials can be evaluated by means of material flow simulation as mentioned in chapter 3.5.1, real layouts with subsequent simulation and evaluation can be set up. As basis and guiding principle the most promising concept variants 2 and 3 and their related layouts are used (cf. chapter 3.3.4). In close collaboration with voestalpine Böhler Welding Austria GmbH two real layouts have been generated for modernising and rebuilding the existing dosing system. Below the two layout variants will be described in detail. For raw materials which need to be sieved before the dosing process and thus cannot be further stored in combination with the non- sieved part of the raw materials, extra bins respectively bunkers will be planned. Since the order data does not determine whether a raw material is used as sieved raw material or not, subsequent material flow simulation cannot include this difficulty to be solved.

3.6.1 Layout variants related to preferred concept variants

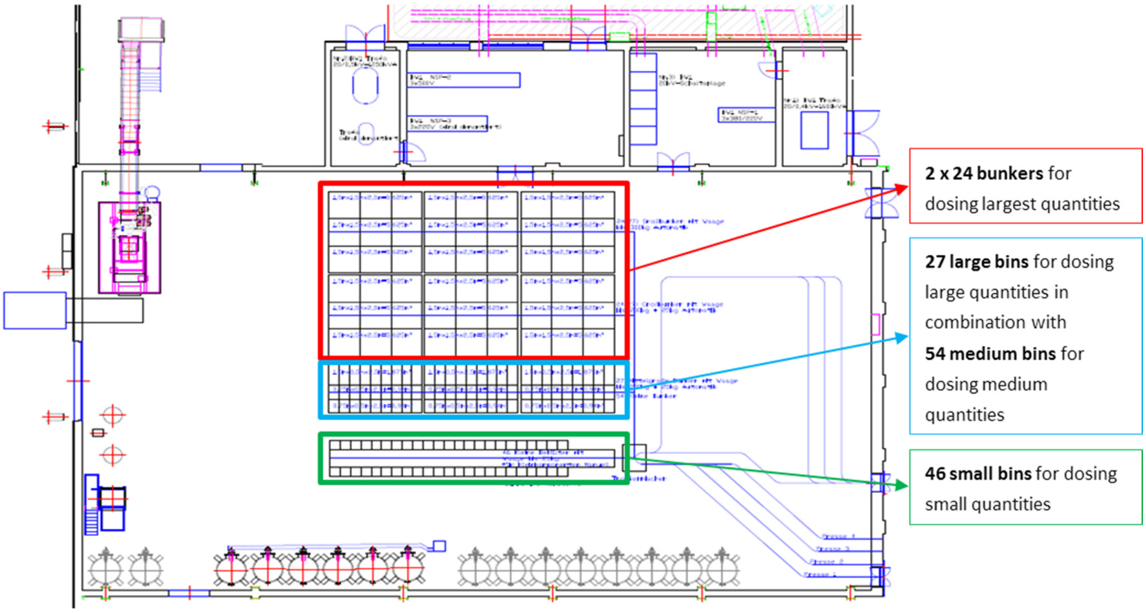
As already mentioned the block layouts for the concept variants 2 and 3 (cf. chapter 3.3.4) are used as basis for building up real layout variants. As main idea during the layout planning phase the layouts to be established should correspond as far as possible to the generated block layouts. However since areas for refilling, filling and transport processes are needed beside the real dosing processes, the residual free area has been limited to one third of the total area within the production hall. Based on that fact the dosing systems to be established had to be space saving and cost efficiently designed.

3.6.1.1 Real layout 1 and related material flow simulation

At first a real layout for concept variant 2 has been set up. The dosing processes for medium, large and largest quantities have to be automated, while dosing of small quantities will stay a manually operated process.

Multiple dosing processes can be parallelized by using the real layout 1 (cf. figure 3-28). For dosing of largest quantities the system can be subdivided two aisles. One aisle has been designed for containing raw materials which are always needed in masses greater than 1 kg and hence has only been equipped with a scale for large masses. The second aisle has been equipped with two scales to ensure that masses with less than 1 kg can be accurately dosed.

For large, medium and small quantities only one aisle within the systems has been realized. That is why two scales for masses bigger and smaller than 1 kg are needed for dosing of large, medium and small quantities. The bins which are used for dosing and subsequent transport processes of the dosed masses have a volume of 250 dm^3. (cf. chapter 3.2.2.1)



2 x 24 bunkers for dosing largest quantities

27 large bins for dosing large quantities in combination with **54 medium bins** for dosing medium quantities

46 small bins for dosing small quantities

Figure 3-27: Detailed real layout 1

For transporting the dosed masses an overhead conveying system has been planned. Parts of the existing overhead conveying system would be integrated and in order to improve the execution of the transport processes the overhead conveying system leading to the presses for manufacturing stick electrodes is subdivided into four lines. Each line is corresponding to one press line. For the case of an unplanned breakdown of one line or for channelling in supplementary masses switches are used. For feeding the single dosing systems with empty bins for dosing a second overhead conveying system has to be installed. Bins which are emptied at the press lines are directly transferred to the second conveying system. By introducing a buffer zone of several parallel conveyor lines in the dosing area, bins will be available all time.

For producing cored wire the dosed masses need to be still transported by forklift. Considering that the blender for mixing the dosed masses of the single dosing systems has to be arranged in order that enough free space for travelling of forklifts is remaining for ensuring appropriate transport processes.

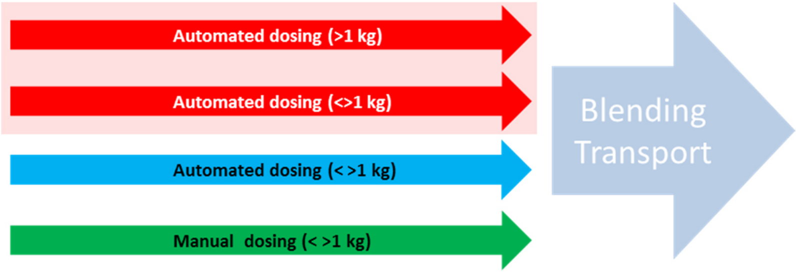
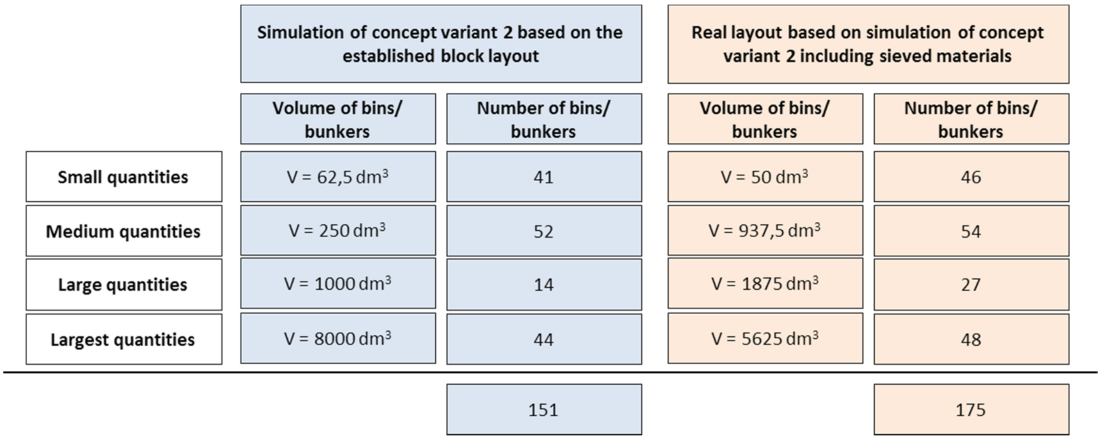


Figure 3-28: Parallel dosing processes within real layout 1

For optimal land use the single dosing stations have been designed equally in length and height. Combined with the objective to build up a space saving system the volumes for the bins and bunkers could have been determined.

For dosing largest quantities bunkers have been designed. The total volume of a bunker amounts to 5624 dm^3. For medium and large quantities a combined system has been introduced. For large quantities bins with a total volume of 1875 dm^3 have been used, while for medium bins half the volume of large bins is defined. Raw materials which will be dosed in the system for small quantities are stored in bins with a total volume of 50 dm^3.

For including the aforementioned sieved raw materials in total 175 bins respectively bunkers have been designed. Figure 3-29 depicts the comparison of the values of the simulation (cf. figure 3-26 / parameter variation 3) based on the block layouts of rough planning and the defined volumes and numbers of bins of the first real layout.



	Simulation of concept variant 2 based on the established block layout		Real layout based on simulation of concept variant 2 including sieved materials	
	Volume of bins/ bunkers	Number of bins/ bunkers	Volume of bins/ bunkers	Number of bins/ bunkers
Small quantities	V = 62,5 dm^3	41	V = 50 dm^3	46
Medium quantities	V = 250 dm^3	52	V = 937,5 dm^3	54
Large quantities	V = 1000 dm^3	14	V = 1875 dm^3	27
Largest quantities	V = 8000 dm^3	44	V = 5625 dm^3	48
		151		175

Figure 3-29: Comparison of simulation of block layout and real layout 1

As biggest difference besides the total number of raw materials to be processed the volume of bins used in the dosing system for medium quantities attracts attention. The volume for the medium bins is about the fourfold volume of the medium bins used for simulating the block layouts and the related material flows. Hence refilling processes can be minimized, but need to be conducted parallel to the dosing processes.

For evaluating how cost efficient and effective the designed real layout 1 would be in operation, a material flow simulation, as described in chapter 3.5.1, has been conducted. Furthermore it has to be analysed if the required process times of the single dosing systems are equivalent. Only if the process times of the single dosing systems correspond to each other the necessary process parallelisation can be realised. Since the dosing systems for medium and large quantities are pooled (cf. figure 3-27) the developed simulation procedure had to be enhanced. Figure 3-30 illustrates the course of action for simulating the material flow and for evaluating and assessing the real layout variant. The initial point for simulating the material flow and the input data (bulk densities, related volumes per fiscal year) remain the same.

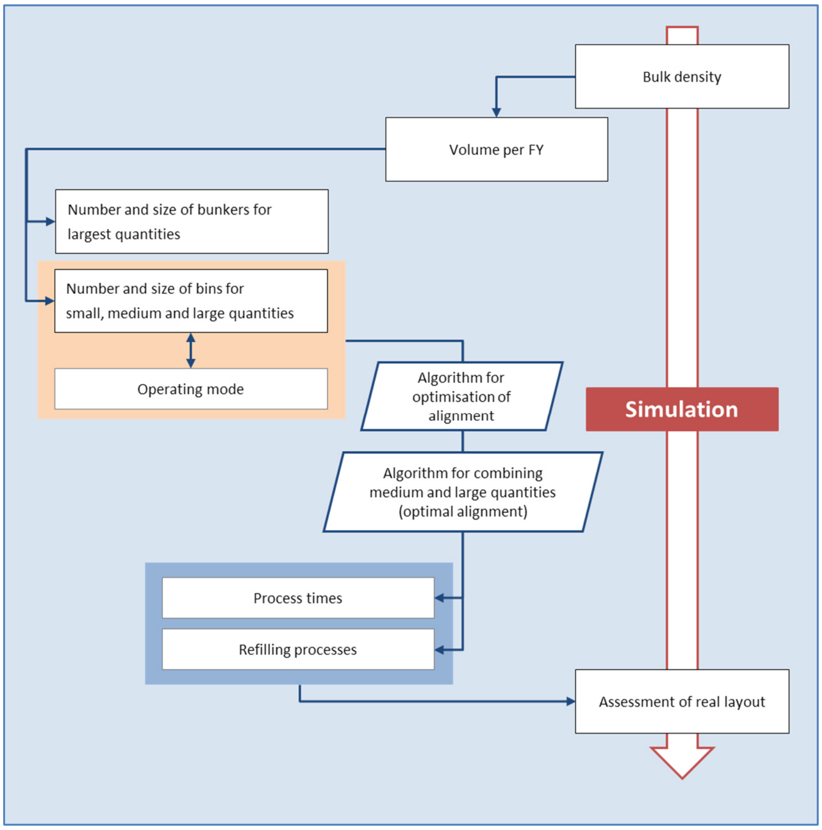


Figure 3-30: Enhanced simulation procedure

Since the number and size of the used bins respectively bunkers and the operating mode of the single systems have already been determined by setting up the real layout, the simulation approach has been reversed. Instead of defining the number of bins per system the refilling processes have been calculated. For the optimisation of the alignment of raw materials the described algorithm of chapter 3.4 has been used. For determining the ideal combinations of raw material pools related to large and medium quantities an algorithm for optimisation has been introduced (cf. figure 3-31).

The algorithm for optimisation of the alignment of raw material determines the optimal raw material pools and their alignment of each dosing quantity class. The raw material pools for medium and large quantities are used as starting point for the supplementary algorithm. Additionally a combinatorial matrix including all raw materials related to medium and large quantities is set up. For each combination of raw material pools of medium and large quantities the common usage is determined. Afterwards the pools with the maximum common usage are aligned.

After the raw materials and raw material pools have been optimally arranged, the process times and the refilling frequency have been calculated. Therefore the approach of figure 3-24 has been chosen.

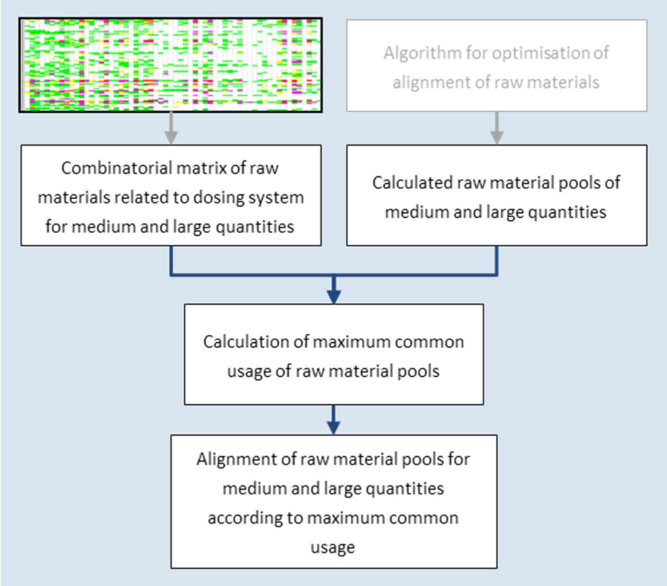


Figure 3-31: Algorithm for ideal combination of raw materials related to medium and large quantities

As result of the calculation the overall process times for the actual order volume and for the planned increase of order volume have been obtained (cf. table 3-9).

For completing the actual order volume the planned system will need 150 working days with double shift operation. That roughly corresponds to 64 percent of the actual total process time of 235 working days. In case of doubling of the order volume for stick electrodes and cored wire three shift operation is needed to fulfil all orders within 235 working days. Also in case of additional unplanned breakdowns the processes related to the doubled order volume would be executable. For the maximum increase of the order volume 240 working days will be needed.

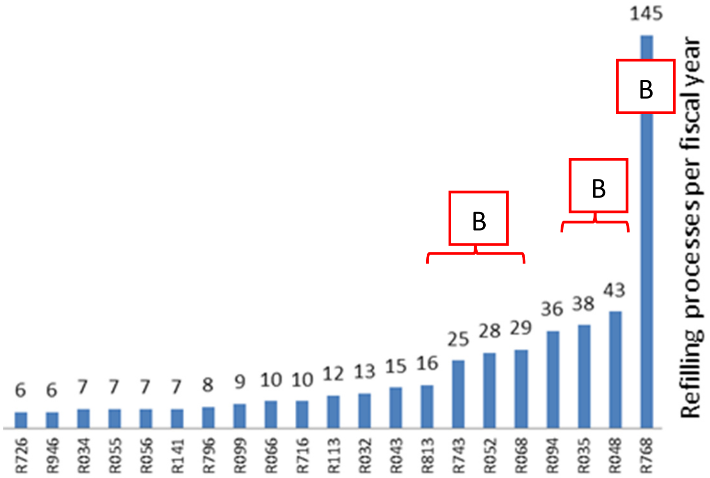
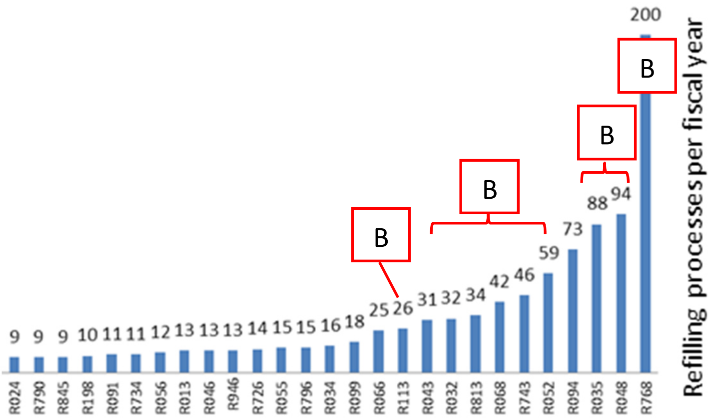
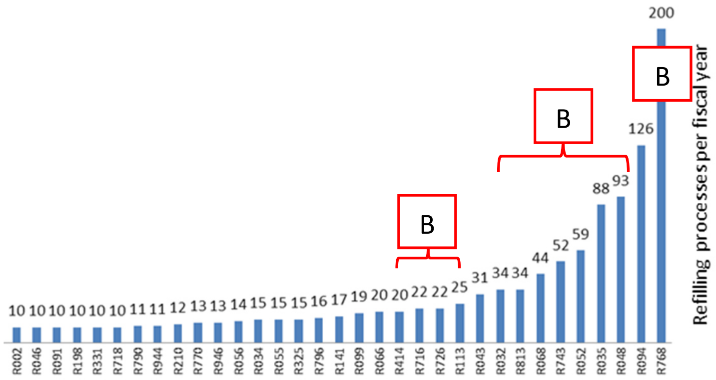
Table 3-9: Calculated process times for real layout 1

	100% SE 100% CW	**200% SE 200% CW**	**200% SE 400% CW**	
total WD	**Double shift operation**	**Three shift operation**	**Three shift operation**	
235	150	205	**240**	[WD]
% von 235	63,8	87,2	102,1	[%]

Considering that refilling processes need to be executed parallel to the processes related to dosing, number and frequency of refilling process within one year is of interest.

Table 3-10 depicts an extract of the yearly refilling processes per raw material. The raw materials which need to be refilled most often are almost entirely stored in bunkers. In case of actual order volume the maximum refilling ratio of a raw material amounts to 145 times per fiscal year. That means on average more than three refilling processes are needed weekly. It total 643 refilling processes are needed for executing the actual order volume.

Table 3-10: Refilling processes for real layout 1 (B ... stored in bunker)

 Figure 3-32: Extract of yearly refilling processes for actual order volume of real layout 1	**Actual order volume**
 Figure 3-33: Extract of yearly refilling processes for order volume increase of 200 %	**Increased order volume** **200% SE – 200% CW**
 Figure 3-34: Extract of yearly refilling processes for increased order volume (200% / 400%)	**Increased order volume** **200% SE – 400% CW**

If the order volume is doubled, the number of refilling processes is also increased. The maximum refilling ration of a raw material amounts in that case to 200 times per year. Since

235 working days are available for dosing, almost every day a refilling process needs to be executed to fulfil the order volume. In addition to that the number of bins which need to be refilled at least twice a month is strongly increased.

The assumption of an increase of 200 percent of stick electrode production paired with an increase of 400 percent of cored wire production leads to a partial increase of refilling processes. Raw materials and related bins which are mostly used for cored wire production need to be refilled more often, while the maximum refilling ratio stays the same as for the doubled order volume.

Table 3-11 summarizes the refilling ratios of all simulated scenarios by absolute numbers. Thus it appears that there exist raw materials which do not have to be refilled during one fiscal year. The percentage of raw materials, which never need to be refilled, fluctuates between 31 and 15 percent, but is inversely proportional to the order volume. Moreover it can be seen that the number of raw materials and related bins which only need to be refilled once every two months, is relatively high, while the number of bins which need to be refill more than once a week is limited. For raw materials which need to be refilled more than once a week, a stationary refilling system could facilitate the operational procedures.

The total number of yearly refilling processes is increased by an increase of the order volume. As for the actual situation 653 refilling processes are needed, while the maximum increase of the order volume requires two and a half of the actual refilling processes. If the scenarios related to an increase of the actual order volume are compared among each other regarding the total number of refilling processes, the increase only amounts to 18 percent. The small difference is caused by the fact, that for producing cored wire other raw materials are used than for stick electrode production.

Table 3-11: Comparison of refilling processes related to real layout 1

		up to 6 refilling processes per year *once every two month*	**up to 12 refilling processes per year** *once a month*	**up to 24 refilling processes per year** *twice a month*	**up to 48 refilling processes per year** *once a week*	**49 and more refilling processes per year** *more than once a week*	**Total** *yearly*
100% SE - 100% CW	Refilling processes	180	77	47	204	145	**653**
	Related raw materials	85	9	3	6	1	**104**
200% SE - 200% CW	Refilling processes	263	152	117	236	514	**1282**
	Related raw materials	84	18	8	7	5	**122**
200% SE - 400% CW	Refilling processes	278	227	221	168	618	**1512**
	Related raw materials	79	26	13	5	6	**129**

In summary, it can be stated that for refilling the employment of a worker is necessary. Since the needed refilling processes are yearly distributed according to the order sequence the mean refilling processes per week/month strongly depend on how the orders are batched. That is why for implementation and for successful operation of the whole dosing system the order batches need to be continually observed and monitored and if possible resorted. Furthermore the time needed for refilling varies, because the refilling ratios are non- constant system parameters.

3.6.1.2 Real layout 2 and related material flow simulation

The second real layout is based on the block layout of concept variant 3 with manual dosing of small and medium quantities and automated dosing of large and largest quantities.

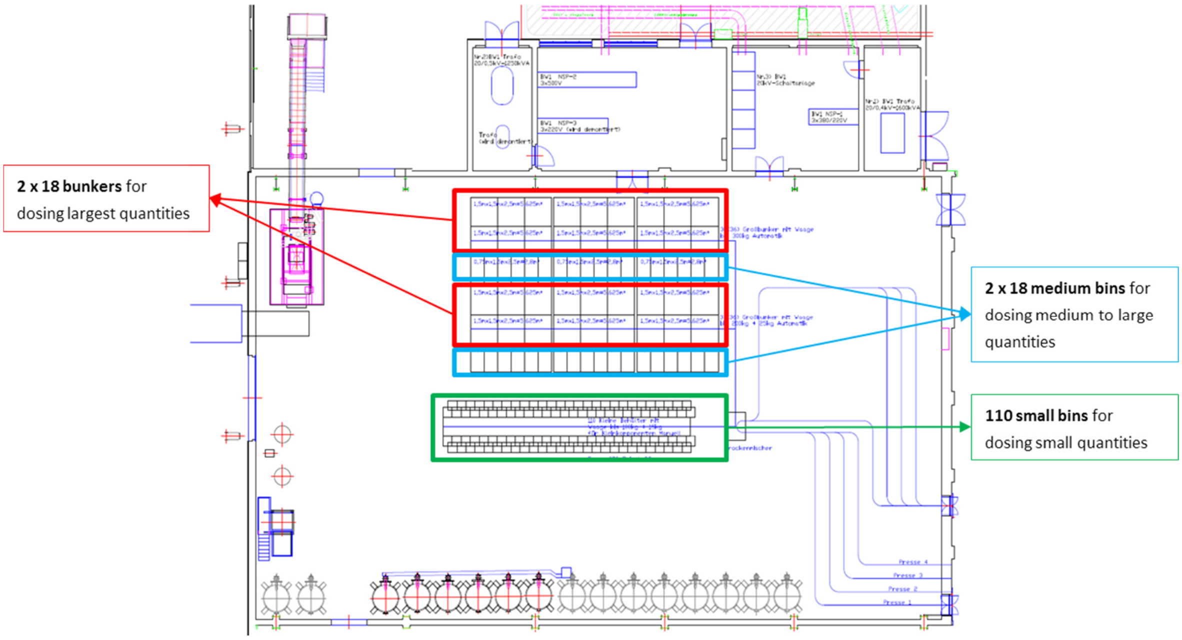
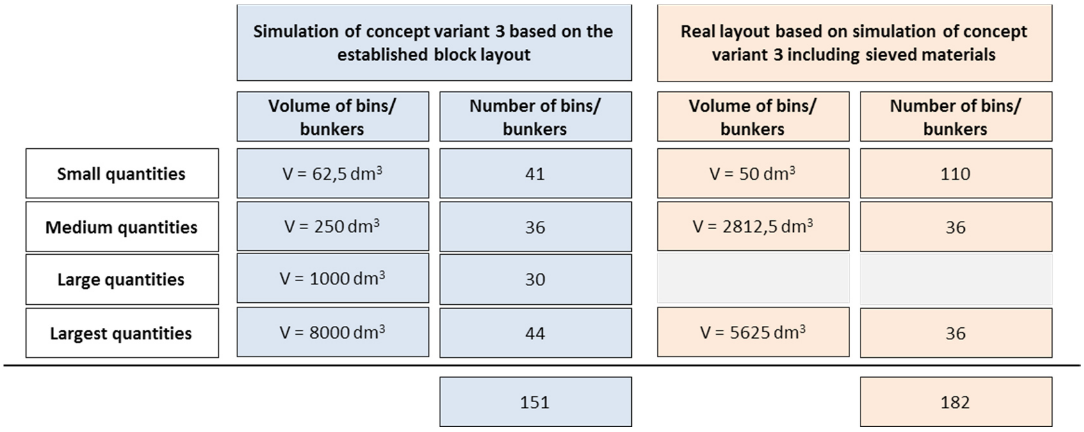


Figure 3-35: Detailed real layout 2

Since the available space for realisation is limited, the basic idea for building up the real layout has been to reduce the number of different bin sizes within the single dosing systems. Only three different bin sizes have been realized. For dosing largest quantities 36 bunkers with a total volume of 5625 dm^3 have been defined, while for medium and large quantities only a medium bin size (V= 2812,5 dm^3) has been used. For the remaining raw materials 110 small bins with a volume of 50 dm^3 have been introduced (cf. figure 3-36).



	Simulation of concept variant 3 based on the established block layout		**Real layout based on simulation of concept variant 3 including sieved materials**	
	Volume of bins/ bunkers	**Number of bins/ bunkers**	**Volume of bins/ bunkers**	**Number of bins/ bunkers**
Small quantities	V = 62,5 dm^3	41	V = 50 dm^3	110
Medium quantities	V = 250 dm^3	36	V = 2812,5 dm^3	36
Large quantities	V = 1000 dm^3	30		
Largest quantities	V = 8000 dm^3	44	V = 5625 dm^3	36
		151		182

Figure 3-36: Comparison of simulation of block layout and real layout 2

Considering that the medium bin size is half of the bunkers for largest quantities a combined dosing system for largest, large respectively medium quantities has been realized and optimal land use can be guaranteed. As for the first real layout, the automated dosing processes have been further subdivided in dosing processes for masses bigger and smaller than 1 kg. Figure 3-37 illustrates the consequent processes. Two parallel automated dosing processes for largest, medium and large quantities are conducted beside a manually operated dosing process of small quantities. For the automated dosing processes of masses smaller than 1kg an adequate scale is used to ensure the needed accuracy. For transporting the dosed masses an overhead conveying system has been introduced as for the first layout. The arrangement of the blender for mixing the dosed masses of the single dosing systems is also equal to the layout described in chapter 3.6.1.1. Consequently the paths for transporting dosed masses destined for producing cored wire also remain the same and thus are practical.

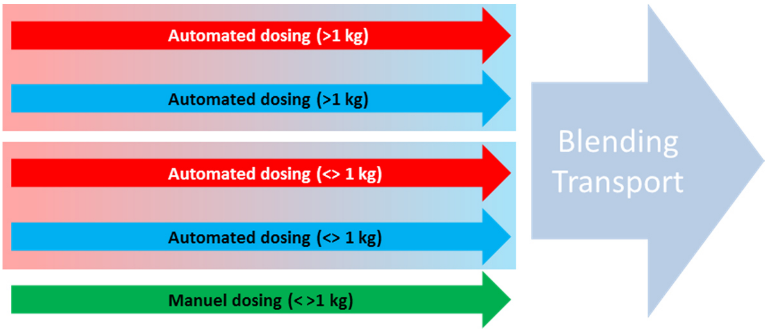


Figure 3-37: Parallel dosing processes within real layout 2

For calculation and simulation of material flows and for determining the optimal alignment of raw materials the approach already described for the first layout has been used (cf. figure 3-30).

Since the second real layout also contains dosing systems, in which different bin sizes are combined, the optimisation of raw material pools related to the different bin sizes is necessary. Instead of using the developed algorithm shown in figure 3-31 for medium and large bin sizes and related raw materials, raw material pools of largest and medium respectively large quantities are examined for that purpose. After optimal arranging of raw materials for the single dosing systems, the process times including the refilling frequency have been calculated (cf. figure 3-24).

As result of the calculation the overall process times for the actual order volume and for the planned increase of order volume have been obtained (cf. table 3-12). For completing the actual order volume the planned system will need 177 working days with double shift operation. That roughly corresponds to 75 percent of the actual total process time of 235 working days. In case of doubling of the order volume for stick electrodes and cored wire three shift operation is needed to fulfil all orders within 242 working days. For the maximum increase of the order volume 273 working days will be needed.

Since three shift operations have still been assumed for the scenarios of increased order volume, the increase of the order volume will not be manageable at all within the actual total working time.

Compared to the first real layout the calculated process times for the future increase of the order volume exceed the actual total working time. This is largely because the number of raw materials which need to be dosed manually is higher and thus the level of automation is lower. Based on that fact it could be assumed that the refilling frequencies of the second real layout will also exceed the discussed values of real layout 1.

Table 3-12: Calculated process times for real layout 2

total WD	100% SE 100% CW Double shift operation	200% SE 200% CW Three shift operation	200% SE 400% CW Three shift operation	
235	177	**242**	**273**	[WD]
% von 235	75,3	103,0	116,2	[%]

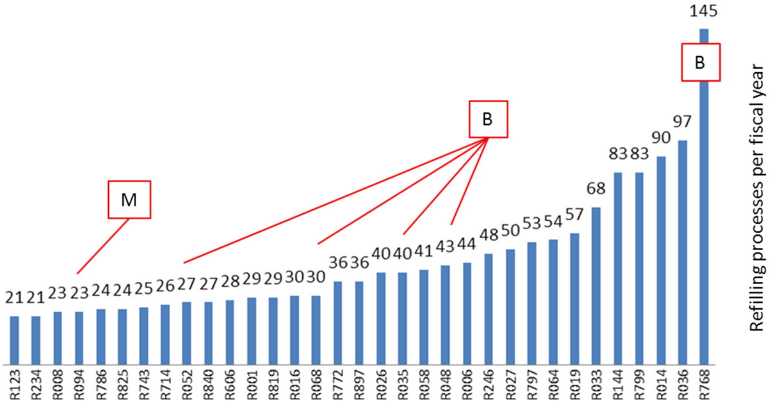
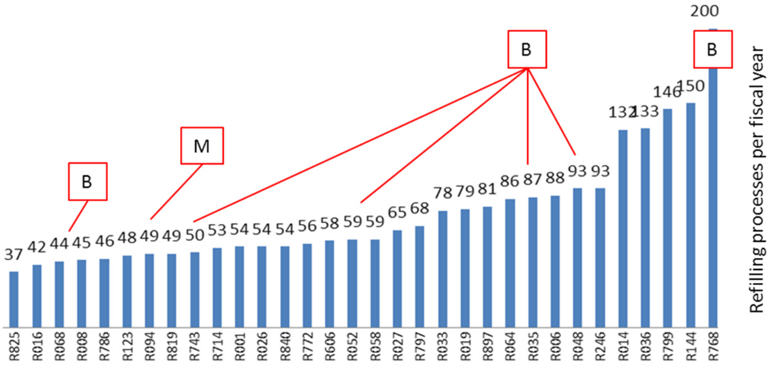
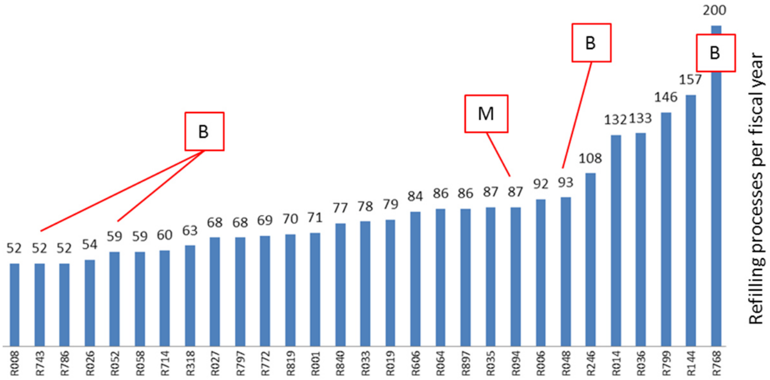
Table 3-13 depicts the summarized refilling ratios and related frequencies and raw materials for the three examined scenarios. For completing all actual orders 2050 refilling processes would be needed in total and among these 780 refilling processes would be executed more than once a week. By analysing the total refilling ratios of the scenarios with increased order volume it can be seen that the refilling processes to be executed more than once a week will rise extremely. For an order volume increase of 200 percent in the sector of stick electrodes and 400 percent of the cored wire production 4060 refilling processes are needed for the whole production. As average value about 18 refilling processes need to be conducted per working day. Since refilling of bunkers respectively bins is always linked to a certain amount of time, the reasonableness of as many refilling processes has to be questioned.

Table 3-13: Comparison of refilling processes related to real layout 2

		up to 6 refilling processes per year *once every two month*	**up to 12 refilling processes per year** *once a month*	**up to 24 refilling processes per year** *twice a month*	**up to 48 refilling processes per year** *once a week*	**49 and more refilling processes per year** *more than once a week*	**Total** *yearly*
100% SE - 100% CW	Refilling processes	187	187	317	579	780	**2050**
	Related raw materials	63	21	18	17	10	**129**
200% SE - 200% CW	Refilling processes	113	254	475	542	2174	**3558**
	Related raw materials	37	29	27	15	26	**134**
200% SE - 400% CW	Refilling processes	127	265	465	582	2621	**4060**
	Related raw materials	35	29	27	17	31	**139**

In addition to that table 3-14 provides an extract of the refilling characteristics of the three analysed scenarios. The maximum values of refilling processes per raw material correspond to the values related to the first real layout. On closer consideration it becomes obvious that the majority of the raw materials and the related bins, which need to be refilled very often, are assigned to the dosing system destined for small quantities. Only between 17 and 21 percent of the thirty raw materials, which need to be refilled most often, are stored in bunkers respectively medium bins. These data suggest that the defined bin volumes for dosing of small quantities are too little and the degree of automation is too low.

Table 3-14: Refilling processes for real layout 2 (B ... stored in bunker, M ... stored in medium bins)

 Figure 3-38: Extract of yearly refilling processes for actual order volume of real layout 2	Actual order volume
 Figure 3-39: Extract of yearly refilling processes for order volume increase of 200 %	Increased order volume 200% SE – 200% CW
 Figure 3-40: Extract of yearly refilling processes for increased order volume (200% / 400%)	Increased order volume 200% SE – 400% CW

3.7 Comparison of real layouts and results

Based on the calculations and simulation results of the previous chapter the real layouts have been compared by using value benefit analysis. The set requirements and objectives for redesigning and adapting the dosing system have been summarized in three main criterion categories for the analysis (cf. table 3-15). Firstly all issues relevant to costs have been listed. Besides cost of purchase and maintenance costs of the new dosing system, costs for removal of the current system have been included. The number of workers directly influences the costs related to the operation of the new dosing system.

As second criterion category material handling and related issues have been determined. The objectives of decreasing material loss, improving working conditions and batch tracing have been summarized among this category. In addition to that objectives (adequate storage, reduction of refilling processes) derived from the as- is analysis in the beginning of material flow analysis and planning have been listed. Furthermore the usability of the existing conveying system could be determined as on main criterion.

In the third criterion category the flexibility and expandability of the dosing system has been treated. There the calculated throughput times, the space utilization needed for determining if the system will be expandable, and the possibility of bypassing respectively manual operation of the system in case of unplanned breakdowns have been involved.

Table 3-15: Criterions and weighting factors for value benefit analysis

	Criterion categories	*Weighting factors of category*	*Weighting factors of criterions*	*Weighting factors of criterions considering the category weighting factor*
1	**Expenditure**	**0,35**		
1.1	- cost of purchase		**30**	**10,50**
1.2	- costs for removal of current system		**20**	**7,00**
1.3	- costs related to workers (number of workers)		**20**	**7,00**
1.4	- maintanance costs		**30**	**10,50**
	Sum		100	
2	**Material handling**	**0,35**		
2.1	- sucessful batch tracing		**25**	**8,75**
2.2	- decrease of material loss		**10**	**3,50**
2.3	- adequate storage (temperature sensitivity)		**20**	**7,00**
2.4	- improvement of working conditions		**20**	**7,00**
2.5	- reduction of refilling processes		**10**	**3,50**
2.6	- usability of existing conveying system		**15**	**5,25**
	Sum		100	
3	**Flexibility and expandability of system**	**0,3**		
3.1	- max. throughput (per day/per year)		**50**	**15,00**
3.2	- space utilization		**30**	**9,00**
3.3	- bypassing of unplanned breakdowns (manual operation)		**20**	**6,00**
	Sum		100	
	Sum	1		100

Subsequently all criterions have been rated according to their importance. The ratings have been based on the findings of the as- is analysis and the set requirements as well as on targets of voestalpine Böhler Welding Austria GmbH.

With the obtained weighting factors and established rating factors (insufficient, medium and good fulfilment of the particular criteria) the two real layouts could be evaluated and assessed (cf. table 3-16 below).

Table 3-16: Evaluation of real layout variants - value benefit analysis

			Concept variants			
			Real layout 1		*Real layout 2*	
	Criterions	*Weighting factors*	*Rating 1*	*Value of benefit*	*Rating 2*	*Value of benefit*
1	**1.1**	**10,50**	3	31,5	5	52,5
	1.2	**7,00**	4	28	4	28
	1.3	**7,00**	6	42	3	21
	1.4	**10,50**	4	42	5	52,5
2	**2.1**	**8,75**	9	78,75	9	78,75
	2.2	**3,50**	8	28	7	24,5
	2.3	**7,00**	7	49	7	49
	2.4	**7,00**	7	49	5	35
	2.5	**3,50**	7	24,5	5	17,5
	2.6	**5,25**	9	47,25	9	47,25
3	**3.1**	**15,00**	5	75	1	15
	3.2	**9,00**	5	45	5	45
	3.3	**6,00**	5	30	6	36
		Sum	**570**		**502**	

Established factors to rate the different criterions:
1 … 3: insufficient fulfilment
4 … 6: medium fulfilment
7 … 9: good fulfilment

For rating the criteria related to costs respectively expenditure absolute numbers have not been available. Hence the fulfilment of the particular criteria has been estimated by combining already obtained facts. The cost of purchase for real layout 2 will be lower than for real layout 1 due to the lower level of automation. Since both real layout variants have been designed as a combination of distinct dosing systems the cost of purchase will be as high that good fulfilment of the criterion has to be excepted. The same applies to the criterion of maintenance costs.

With regard to costs for removal of the current system, the rating has been the same for both layout variants. A medium fulfilment has been assumed, because all current system elements need to be removed or at least displaced.

In case of costs related to the workers needed to execute all production process, the evaluations of the layout variants differ from each other. Since the second real layout is characterized by a lower level of automation, at least two workers are needed per shift for executing the manual dosing tasks. In addition to that at least one additional worker would be needed for refilling of bins respectively bunkers. For the first real layout only two workers are required for daily operations including dosing and refilling tasks.

The criteria related to material handling have been rated as follows.

With the implementation of automated dosing processes and adapted bin sizes batch tracing can be realised, if the bins respectively bunkers are refilled not until they are empty. So for both layouts the criterion can be fulfilled. The same applies to the criterion of usability of the existing conveying system. As for the decrease of material loss, both layouts can also fulfil the set criterion. The first layout has been higher rated, because the level of automation is higher and so the amount of dustproof dosing procedures is higher than for the second layout. The criterion related to material loss is directly linked to another criterion. If dust loading and thereby material loss is decreased, the working conditions can be ameliorated. Another factor influencing the working conditions is the level of automation of the dosing systems. In case of real layout 1 very few dosing procedures are operated manually and so the masses, the workers have to lift, are in total smaller than they are in the current situation. Since the level of automation is lower for the second layout the overall rating of working conditions is also lower than of the first layout. The third criterion within the category of material handling, the adequate storage strategy for raw materials which are for instance temperature sensitive can be fulfilled by either case. The situation is different with the second last criterion related to refilling processes. Since the bin volumes of the second layout are considerably smaller than the bin volumes of the first layout, a lot more refilling processes are needed to ensure daily operations.

Last but not least the flexibility and expandability of the designed real layouts have been rated. The calculations and simulations of the material flows of the designed real layouts have shown (cf. chapter 3.6.1.2) that the predicted increase of order volume would not be manageable at all with the second layout. With the maximum order volume increase and the related increase also the first layout would be stretched to its limits. That is why the rankings of this criterion are comparatively low. Concerning the space utilization both layouts have been ranked equally. The single dosing stations have been arranged in order to be expandable by modules, so the available remaining space could be used. As for the possibility of bypassing in case of unplanned breakdowns the second real layout benefits from the lower level of automation. In case of an unplanned breakdown the raw materials stored in the manually operated system could easily be dosed.

By multiplying the rankings by the calculated weighting factors and by summing up the resulting numbers, the overall ratings for the two real layout and the underlying concept variants have been obtained.

If the overall ratings of the two real layouts are compared, it can be seen that both layouts would be potential designs for implementation of a new dosing system.

Since the calculated process times and the examined refilling processes of the second real layout cannot fulfil the basic requirements concerning the maximum order volume and the daily throughput, the second real layout would be non- realisable in this form. The level of automation and/or the volumes of bins have to be changed and adjusted for potential implementation.

Hence the first real layout with the higher rating of the value benefit analysis has been identified as the most promising variant and sole realizable design for implementation.

The simulation of the material flows and the calculation of the related process times already have shown that the real layout 1 is suitable for redesigning the actual dosing system at the production site of voestalpine Böhler Welding Austria GmbH in Kapfenberg. The set requirements related to the total mass to be dosed and the total process times can be met in case of actual and doubled order volume. As described in chapter 3.6.1.1, the predicted maximum order volume will not be manageable without any changes concerning bin sizes or additional modules. Since the single dosing systems are arranged in order to be expandable by modules the available remaining space could be used and thus the maximum order volume will also be manageable.

Since most of the raw materials would be dosed automatically and dustproofed dust loading could be decreased. The working conditions would be equally increased. Moreover stabling of bins in the dosing area is completely avoided by automated systems on the one hand, and fixed places for manually operated bins on the other hand.

In summary it can be said that the executed material flow analysis and planning tasks led to promising concept variants. The real layout 1 which has been drafted for implementation of one of these concept variants proved to be the most promising design for implementation. The real layout 1 and the underlying concept will serve as background for the decision- making process, in which an appropriate concept for implementation of a dosing system manufacturer will be selected.

4 Validation and evaluation of implementation

With the help of material flow analysis and planning tasks as well as material flow simulations positive and negative aspects of material flow systems can be examined and the redesign respectively a new conceptional design for the material flow system can be elaborated. Since the dosing process for filler material production cannot be compared to classical material flow problem, e.g. the alignment of material flow elements according to the related transport intensities, known methods and approaces needed to be adjusted and redesigned.

Data acquisition, evaluation and assessment for analysing the actual material flows within the production system were conducted as first crucial step of material flow analysis. The fundamentals of Kettner, Schmidt and Greim described in their book (Leitfaden der systematischen Fabrikplanung) proved to be beneficial for it. In addition to that the guiding principles of VDI as well as the implementations of Grundig helped to structure the as- is analysis needed for further planning tasks in the master thesis at hand.
For acquisition of needed data, the two basic data acquisition methods, direct and indirect, were used. With direct acquisition methods like measuring of time and interviewing of the workers, a big amount of data can be gathered in a very short time. The usefulness of the gathered data strongly depends on the workers which are interviewed and in case of time measurements the usefulness of the measured data is also directly linked to the workers, which have executed the measured procedures. It has to be proved that an environment can be created where the workers feel that they can openly admit possible weaknesses of the existing system and procedures without fear of consequences. As for indirect data acquisition methods layout plans, order data and statistical data were used in the master thesis at hand. By combining the results of the different data acquisition methods a basis for further material flow planning steps could be established.

For illustrating and visualising the gathered data, from- to matrices are recommended by Kettner, Schmidt and Greim. In the master thesis at hand from- to matrices could not be used according to the descriptions in literature. Since the material flow system to be analysed is limited to one particular production step, a similar kind of matrices was used. All combinations of raw materials occurring during production of filler material are summarized in a combinatorial matrix. Admittedly the combinatorial matrix cannot be used for calculating transport efforts respectively transport costs, but the usage as initial point for aligning the raw materials in an optimal way is possible and similar to the usage of from- to matrices.
As additional tool for analysing the as- is situation a material flow simulation was conducted as part of the master thesis. With the help of the material flow simulation the preliminary findings could be checked for plausibility. In addition to that, the simulation provided data for deducing requirements for the subsequent material flow planning.
Based on the analysis of the as- is situation the main task of the master thesis at hand, was to build up concept variants for redesigning the dosing system at the production site of

voestalpine Böhler Welding Austria GmbH in Kapfenberg. The main questions were how the raw materials need to be arranged within particular dosing systems and which dosing processes respectively related raw materials could be automated.

As basic strategy for answering the main questions the procedures of material flow planning described in the guiding principle VDI 2498 were used. The process of optimal arranging material flow elements by using an algorithm based on from- to matrices, which is described in VDI 2498, was adapted to the combinatorial matrix and instead of material flow elements the raw materials have been arranged.

For building up different concept variants which fulfil the set requirements of the as- is analysis the guiding principle VDI 2221 was used. The idea to subdivide a complex system into smaller subsystems and to determine relevant functions of the subsystems to create an efficient overall system proved necessary.

As main evaluation method for the resulting real layouts based on the elaborated concept variants a value benefit analysis was used. The advantage of using value benefit analysis for evaluating different variants was that all set requirements and objectives needed to be fulfilled by the new designs of the dosing station could be integrated to the analysis. By setting up rating factors the concept variants respectively planned real layouts could easily and understandably be assessed and the most promising concept could be detected.

In summary it can be stated that by involving different approaches for material flow analysis and planning as well as approaches for designing and assessing different technical solutions and concept variants, meaningful solutions could be introduced for redesigning of the dosing system at voestalpine Böhler Welding Austria GmbH and even a promising real layout could be introduced.

5 Summary and conclusion

After induction to the available literature and theoretical foundations of material flow analysis, planning and simulation and developing of a detailed process comprehension of the filler material production, the material flow of the dosing processes at the production site of voestalpine Böhler Welding Austria GmbH was analysed.

As first step the single operational procedures and the related resources were examined by means of time measurements, employee survey and observation of daily operations. Subsequently the corresponding order and resource data were evaluated to provide a basis for simulating the material flow and for further planning tasks. Concerning the raw materials used for dosing usage characteristics were set up and specific material properties were studied. Since the analysis of data related to raw material usage had shown that there existed incomplete and inconsistent data sets, particular values needed to be assumed. In total the bulk densities of ten raw materials and consequently the total volumes to be handle had been assumed. Due to that fact the further calculations and planning tasks involved a slight uncertainty concerning the volumes to be handled caused by the made assumptions.

As result of data acquisition, evaluation and assessment a combinatorial matrix including all relevant raw material combinations for producing stick electrodes and cored wire could be created.

For defining detailed requirements for subsequent redesigning of the material flow and the dosing stations a material flow simulation of the as- is state was conducted. It could therefore be shown that for dosing a required daily mass of 32,3 tons of raw materials, dosing and refilling processes have to be parallelised, the raw materials have to be stored in bins respectively bunkers with fixed places and fitted volumes and raw materials which are often used in common have to be aligned very closely to each other to minimise travel and run times.

Additionally the importance of improving human working conditions was established as one general objective besides cost- effective and practical applicable system design.

Based on the set requirements rough material flow planning tasks were executed. Eight concept variants, including a manually operated, six semiautomatic and one automatically operated concept variant were elaborated. For setting up block layouts as required for rough material flow planning the concepts were further particularised. The dosing procedure as main task was split up in sub tasks for dosing small, medium, large and largest yearly quantities of raw materials by means of a weighted assessment of raw materials.

Eventually three block layouts related to three most promising semiautomatic concept variants could be created. For evaluation of the block layouts respectively concept variants a material flow simulation was conducted to calculate overall process times and the needed system geometries by using the actual order data, the defined numbers and sizes of bins to be implemented and an algorithm for optimisation of the alignment of raw materials. With the help of the simulation of the remaining concept variants it could be proved, that automation of dosing processes will strongly decrease the needed total process time. In fact the preferred concept variant with the lowest degree of automation could be neglected because the predefined total working time would be exceeded if the order volume is increased. For the remaining variants with a relatively high level of automation (only dosing of small respectively small and medium quantities is operated manually) all orders could be fulfilled during the predetermined working time of 235 working days even if the order volume for stick electrodes is doubled and the order volume for cored wire is quadrupled.

Building on this knowledge the two remaining concept variants and their block layouts were carried forward to real material flow and layout planning. Two real layouts were designed according to the preferred concept variants. Simulating the material flows of the designed layouts revealed that the number and bin sizes used for storing raw materials strongly influences the total process times. As for the second layout too many raw materials would be stored in too small bins and thus an enormous number of refilling processes would be needed to ensure production. Additionally the planned increase of the order volume would not be possible, because the time needed for dosing all raw masses would exceed the set limit.

For quantitatively comparing the real layouts a value benefit analysis was conducted. All set requirements and objectives of the as- is analysis could be integrated to the analysis and as result thereof only the first real layout was deemed as realisable. With a future implementation of the first real layout and the underlying concept variant the most of the set requirements of voestalpine Böhler Welding Austria GmbH will be fulfilled. Only the predicted maximum order volume will not be manageable without any changes concerning bin sizes or any additional dosing modules. Since the single dosing systems were already arranged in order to be expandable by modules the available remaining space could be used and thus the maximum order volume will be accomplishable.

The single dosing systems which are automatically operated allow dustproof dosing procedures and thereby dust loading will be decreased. The working conditions will be equally increased. Moreover stabling of bins in the dosing area is completely avoided by automated systems on the one hand, and fixed places for manually operated bins on the other hand.

The underlying concept of the first real layout will serve as background for the decision-making process, in which an appropriate concept for implementation of a dosing system manufacturer will be selected.

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A. Appendix

Appendix 1: Conceptional simulation model – ERM

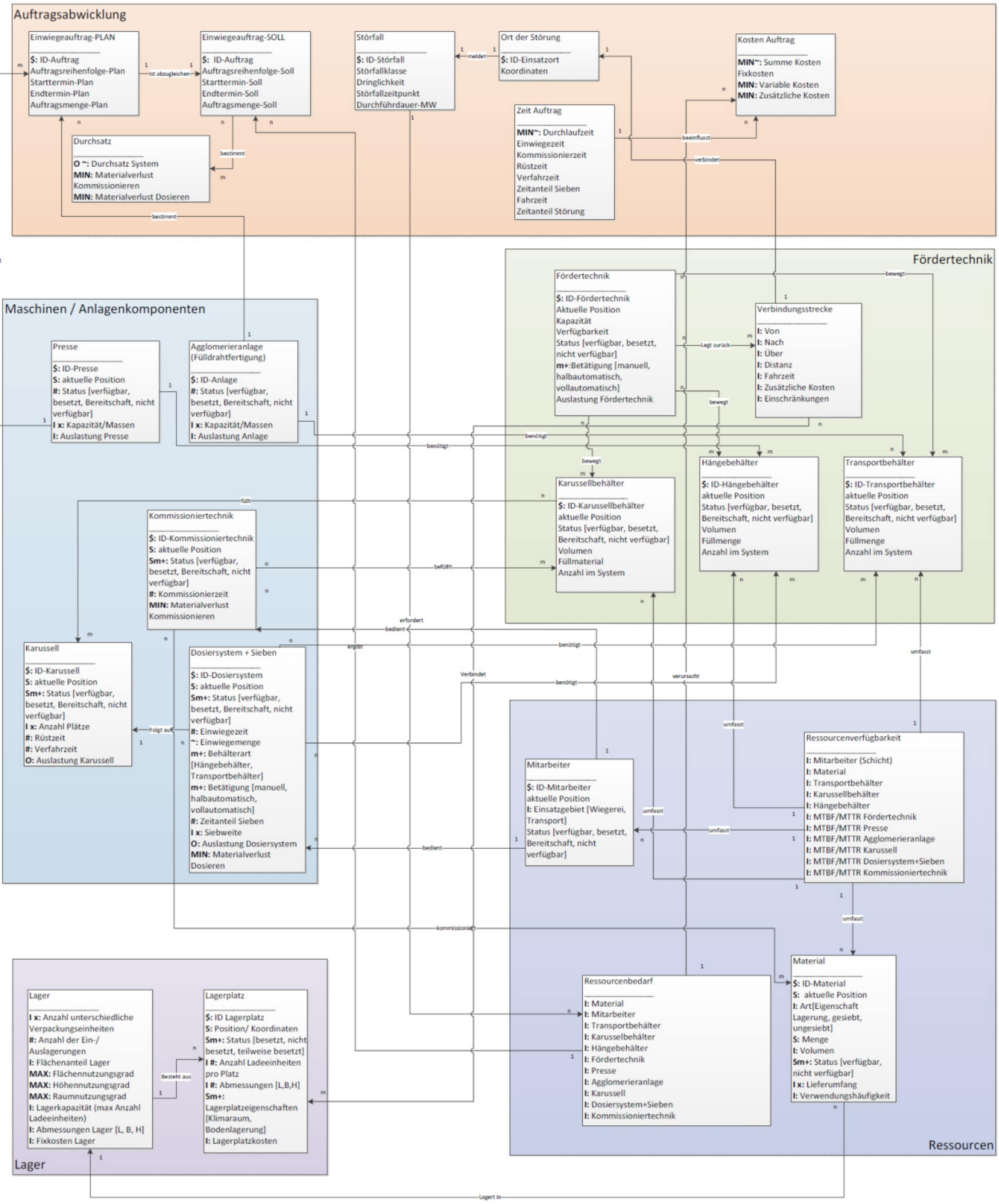
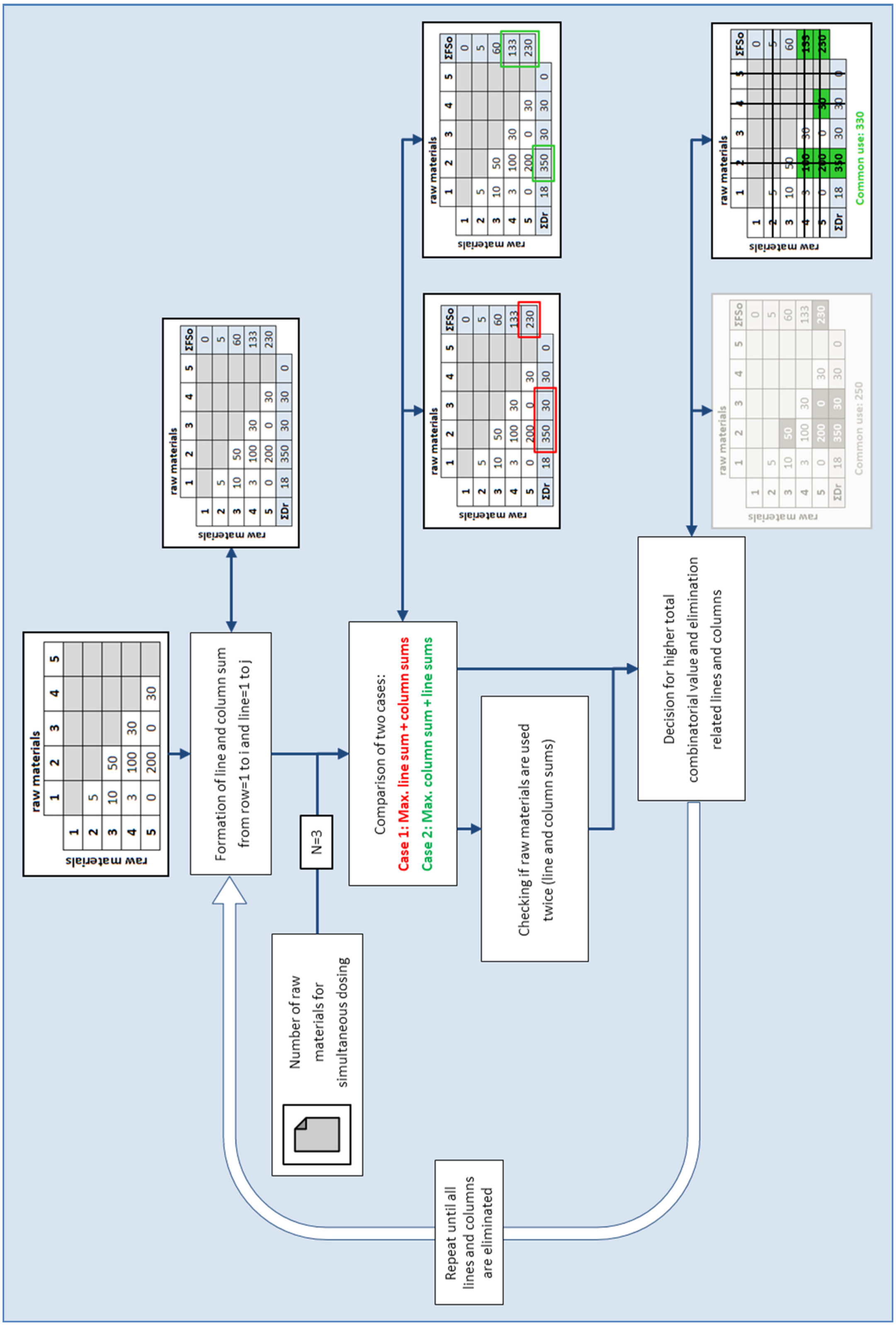


Figure A-1: Conceptional simulation model - ERM

Appendix 2: Algorithm for arranging raw materials



	1	2	3	4	5	ΣFSo
1						0
2	5					5
3	10	50				60
4	3	100	30			133
5	0	200	0	30		230
ΣDr	18	350	30	30	0	

Figure A-2: Algorithm for arranging raw materials

Appendix 3: Real layout 1 – Dosing/ refilling processes and assigned raw materials

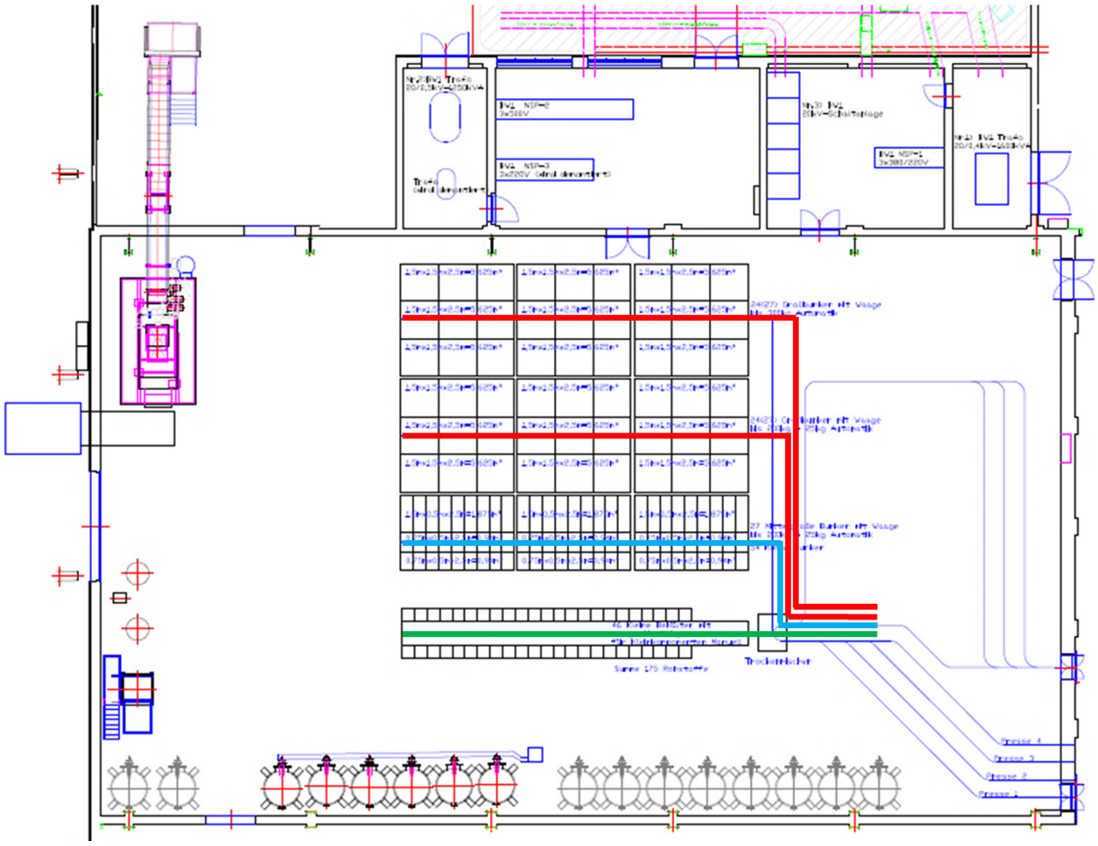
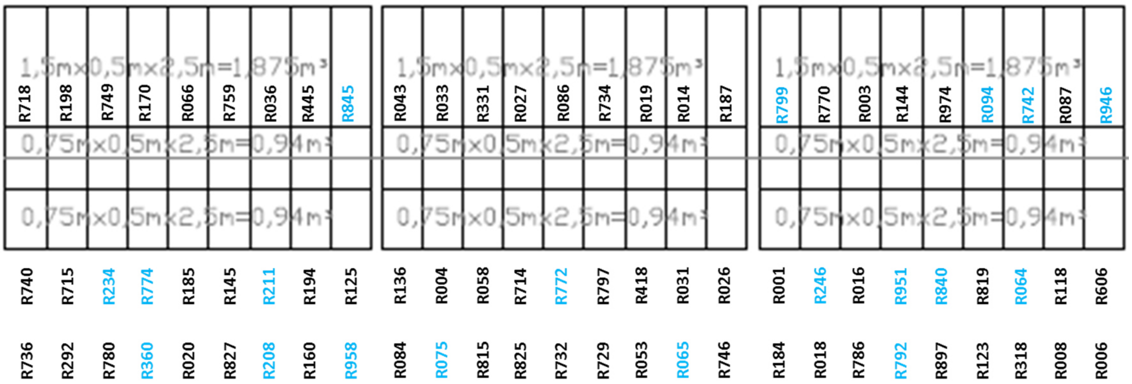


Figure A-3: Parallel processes of real layout 1

The raw materials shown in light blue are raw materials which required special storage conditions, because they are temperature sensitive.



R718	R198	R749	R170	R066	R759	R036	R445	R845
R740	R715	R234	R774	R185	R145	R211	R194	R125
R736	R292	R780	R360	R020	R827	R208	R160	R958

R043	R033	R331	R027	R086	R734	R019	R014	R187
R136	R004	R058	R714	R772	R797	R418	R031	R026
R084	R075	R815	R825	R732	R729	R053	R065	R746

R799	R770	R003	R144	R974	R094	R742	R087	R946
R001	R246	R016	R951	R840	R819	R064	R118	R606
R184	R018	R786	R792	R897	R123	R318	R008	R006

Figure A-4: Dosing system for medium and large quantities with related raw materials

Figure A-5: Dosing system for small quantities with related raw materials

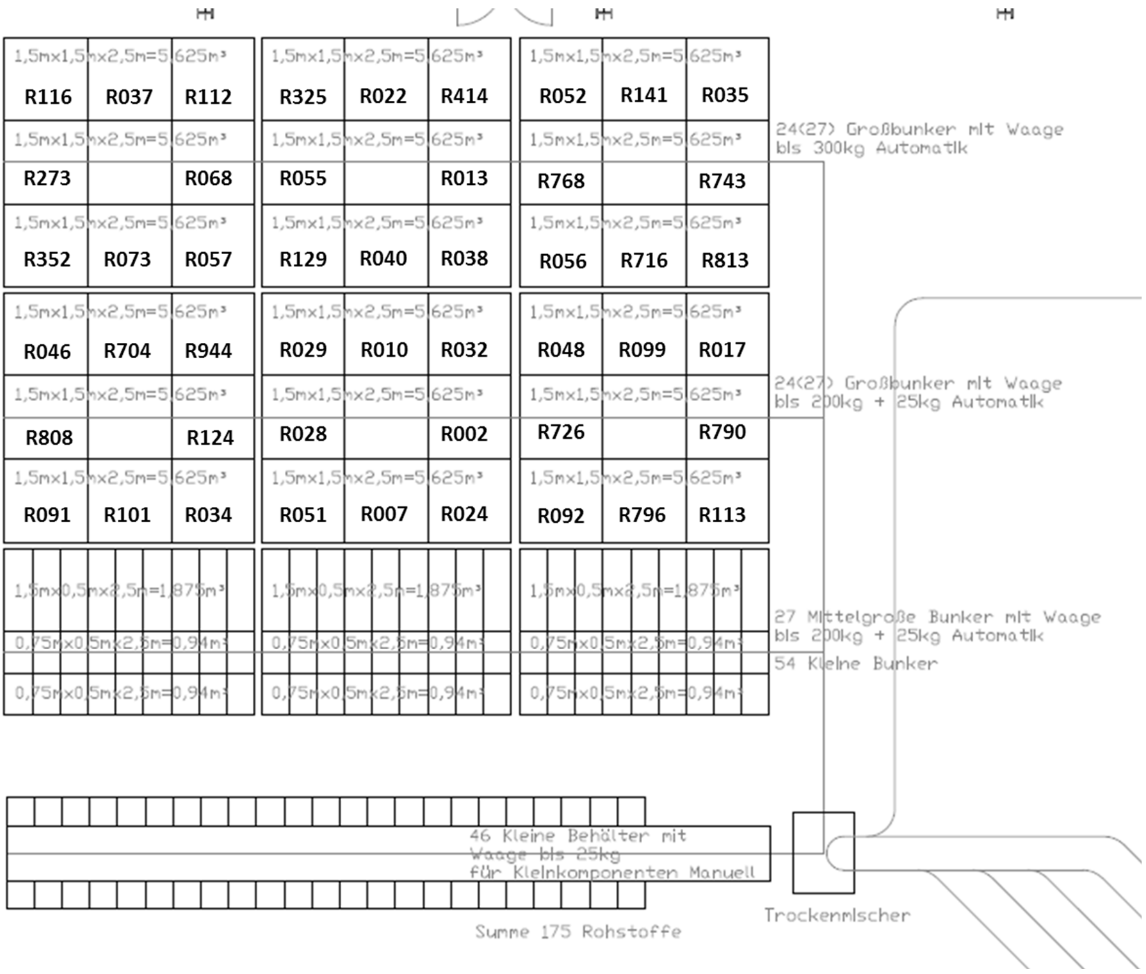


Figure A-6: Dosing system for largest quantities with related raw materials

Appendix 4: Real layout 2 – Dosing/ refilling processes and assigned raw materials

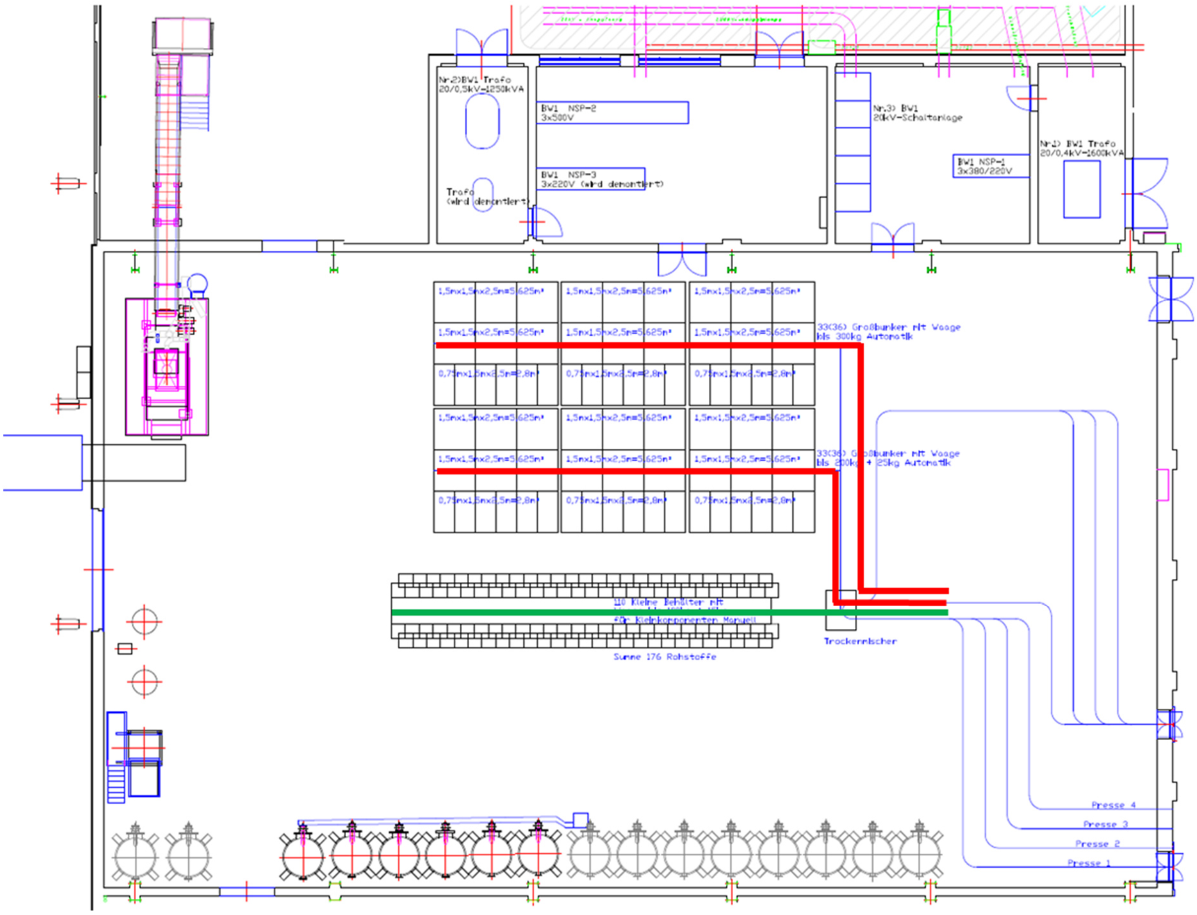


Figure A-7: Parallel processes of real layout 2

The raw materials shown in light blue are raw materials which required special storage conditions, because they are temperature sensitive.

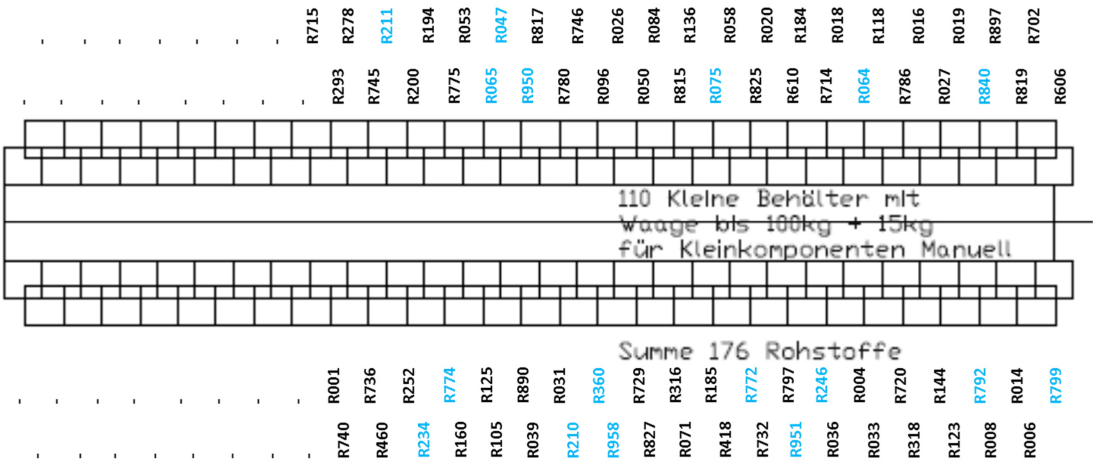


Figure A-8: Dosing system for small quantities with related raw materials

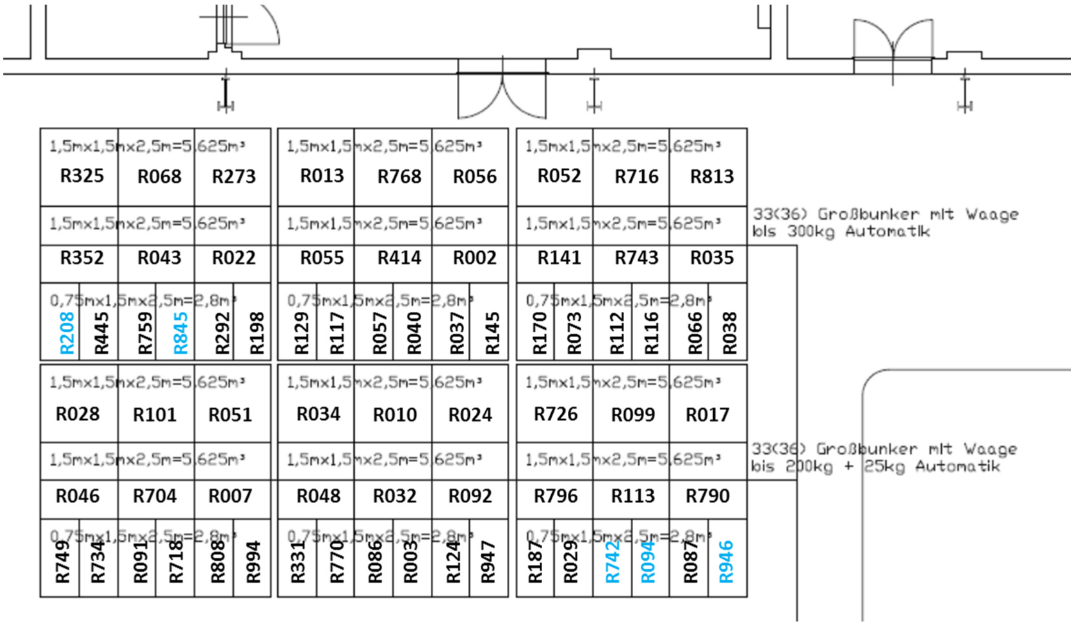


Figure A-9: Dosing system for largest and large respectively medium quantities with related raw materials