Affidavit

I declare in lieu of an oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume.

_____   _____

Calendar date   Signature

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First of all I would like to thank the KNAPP Systemintegration GmbH located in Leoben (Austria) for giving me the opportunity to write a master thesis concerning this exciting issue. I have to thank especially Karl Engelbogen for providing this issue and supervising me while conceptualising the modules and implementing the database prototype. Moreover I have to say thank you for sending me to their customer, who is interested in the results of the master thesis, in Milton Keynes (UK) for being able to visit the customer's distribution centre and for having the chance to talk to some responsible persons.

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Abstract

An automated distribution centre can also be regarded as a production system like a manufacturing plant. The input factors labour, material and production facilities have to be synchronised accurately to generate the expected output. Due to the fact that within an automated warehouse the processes are operating close to the optimum, we can only expect minor improvements in productivity when doing further process optimisation. As the companies are interested in a further increase of the economic efficiency, the input factor labour becomes the focal point of interest because this factor has the largest portion of the warehouse costs. So, within the scope of this master thesis we have to develop a concept for a labour management tool, which provides the opportunity to determine the number of operators required for a certain period of time in advance on basis of a forecast regarding the future workload. In addition to this, the operators have to be distributed to the single processes in accordance with the expected workload. The challenge that has to be met is to facilitate savings regarding manpower costs due to a more efficient utilisation of personnel without disrupting the material flow owing to a bottleneck situation caused by a lack of operators. The tool to be created shall be built of single modules, which are doing the required analyses of data and calculations, due to a simplification of the implementation process. The modules, which are required for doing labour management, have to be described in reference to their objective, the required input data and the method of calculation needed. Subsequently, a database prototype has to be implemented to check both the transferability of the concept into a database structure and whether the given methods of calculation are appropriate to achieve the desired results.

Kurzfassung

Ein automatisiertes Distributionszentrum kann, ebenso wie ein Betrieb der herstellenden Industrie, als Produktionssystem verstanden werden. Um den erwarteten Output generieren zu können ist es nötig, die Einsatzfaktoren „Mensch", „Material" und „Maschine" sorgfältig aufeinander abzustimmen. Aufgrund der Tatsache, dass in einem automatisierten Lager die Prozesse bereits nahe am Optimum operieren, sind bei jeder weiteren Optimierung in diesem Bereich also nur noch kleine Steigerungen der Produktivität zu erwarten. Da jedoch Unternehmen daran interessiert sind, weitere Steigerungen der Wirtschaftlichkeit zu erzielen, richtet sich der Fokus auf den Einsatzfaktor „Mensch", da dieser Faktor den größten Anteil an den Kosten hat. Es ist also im Rahmen der vorliegenden Diplomarbeit ein Konzept für ein Werkzeug zu erstellen, das in der Lage ist, die Anzahl der benötigten Mitarbeiter auf Basis einer Prognose der künftigen Arbeitsbelastung für einen bestimmten Zeitraum im Voraus zu ermitteln und die Arbeitskräfte anschließend gemäß dem erwarteten Bedarf den einzelnen Bereichen zuzuteilen. Das Kunststück, das es hierbei zu vollbringen gilt, ist einerseits Einsparungen im Bereich des Personals durch effiziente Nutzung desselben zu ermöglichen, ohne jedoch andererseits den Materialfluss durch personelle Engpasssituationen empfindlich zu stören. Das zu erstellende Werkzeug ist im Interesse einer anschließenden Implementierung aus einzelnen Modulen aufzubauen, welche die benötigten Analysen und Berechnungen durchführen sollen. Die benötigten Module sind hinsichtlich ihrer Zielsetzung sowie der benötigten Daten und erforderlichen Rechenvorgänge im Detail zu beschreiben. Im Anschluss daran ist auf Basis des Konzeptes ein Datenbank-Prototyp zu erstellen und zu prüfen, ob das Konzept in eine Datenbankstruktur übertragen werden kann, sowie ob die vorgeschlagene Berechnungsmethodik in der Lage ist, die angestrebten Resultate zu erzielen.

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List of abbreviations

WMS   warehouse management system

LMS   labour management system

SKU   stock keeping unit

VNA   very narrow aisle

ER   entity relationship

OSR   order storage and retrieval

AS/RS   automated storage and retrieval system

List of abbreviations

Glossary

AS/RS

"An automated storage/retrieval system (AS/RS) [...] brings the products to the picker. The AS/RS is a system with high-bay pallet racks where the putaway and retrieval are performed by automated cranes."[1]

Bin

"Storage space for inventory at rest or being staged. A bin may be a physical bin or a virtual bin."[2]

Bundle

A bundle is a package of a certain product which is not divisible. In addition to this, there can be found different goods within one package.[3]

Dolly

"A non motorized, two-wheeled hand truck for moving freight around the dock."[4] Within this master thesis the term is used for a four-wheeled platform, where up to ten bins can be stacked onto.

Dollytiser

A machine which is able to stack up to ten bins onto a dolly and moreover secures the bins for transport automatically.

Miniload

"A Miniload AS/RS is an AS/RS for small products. The products are kept in bins or drawers that are moved in and out of the system by the automated crane. Each drawer or bin can be subdivided in several compartments, so that different products can be held together in the same container."[5]

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[1] [Berg2007], p. 59
[2] [Obal2006], p. 198
[3] Cf. [BrZo2007], p. 216
[4] [Obal2006], p. 221
[5] [Berg2007], p. 59

Order line

or customer order line: "A customer order line represents a unique product type ordered by a customer order. The associated attributes include module location, rack location, and quantity ordered."[6]

Order storage and retrieval (OSR)

The order storage and retrieval system is a "highly dynamic shuttle system for the automatic storage, picking and sorting of goods […]. New technology makes simultaneous storage and retrieval possible on every rack level."[7]

Pick-to-light system

"In a pick-to-light system, an indicator light and an electronic numeric display inform the order picker on where to pick from and in what quantity."[8]

Stock Keeping Unit

"Abbreviated SKU. A product or a set of products referenced by the manufacturer by a unique part number."[9]

Tote

"A container that can be handled by one person, where a picker can place individual items into the tote. The tote may be passed to another picker […], to a workstation, or placed on a take-away conveyor. Once empty, the tote is nested together with other totes to save space."[10]

Very Narrow Aisle (VNA)

"A warehouse aisle that is purposed designed to be narrow. Normally this type of aisle has a wire imbedded in the center of the floor, so that a forklift can sense the wire and stay precisely centered on the wire as it moves down the aisle."[11]

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[6] [SaKa2010], p. 145
[7] [Knapp_OSR_2010]
[8] [Lahm2008], p. 303
[9] [Obal2006], p. 296
[10] [Obal2006], p. 180
[11] [Obal2006], p. 311

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List of views (SQL code)

1   Introduction

An automated or semi-automated warehouse respectively distribution centre can be regarded as a production system like a manufacturing plant, where the input factors "labour", "material" and "production facilities" have to be synchronised accurately to generate the expected output. While we are able to assume that the input factors "material" and "production facilities" are used close to the optimal level, the input factor "labour" provides a further possibility for an increase in economical efficiency, as this resource represents the largest amount of costs within a warehouse. Therefore we are looking for a method to increase the labour efficiency. Due to the fact, that the workload of a warehouse is a subject to seasonal, weekly and even daily fluctuations, we would like to develop a tool which is able to determine the number of operators required and how to allocate the operators best throughout the day according to the expected demand of manpower. So, with regard to the logistical principle we are able to say that we would like to have the operators

- o   with the right qualification/training

- o   in the right quantity

- o   at the right moment

- o   working within the right area

available. In addition to this the allocation according to the workload fluctuations is reasonable not only to avoid dissipation (if too many operators are working within one process) but also to prevent a negative influence on the subsequent processes within the supply chain (if a bottleneck occurs due to a lack of operators working within one process), which would affect the productivity of a warehouse in a counterproductive way.

1.1   Objective

Within the scope of this master thesis we have to develop a concept for a labour management tool, which enables us to forecast the workload for the warehouse processes and moreover has to provide the opportunity to determine the number of operators in accordance with the expected workload, which has to be estimated before. In addition to this, the operators have to be allocated best to the single processes throughout the whole day according to the expected workload fluctuations within the warehouse. Finally we have to implement a first prototype on basis of the developed concept, to see if the concept can be easily transferred into a database and moreover to check if the prototype, which is based

on the concept, is able to provide the expected functionality to match the target of this master thesis.

This leads to the following specification of our central research questions:

- What benefits can be expected when using a labour management tool within a warehouse?

- Which kind of difficulties do we have to expect when doing labour management for several warehouse processes?

- How should such a tool be structured for being able to provide the expected functionality?

But why can we say that this master thesis, which is mainly concerning labour issues, is relevant for a master thesis with a logistical background? The reason is that a warehouse respectively a distribution centre is a very important element within a supply chain due to having a big influence on customer satisfaction, whereas it is not important if it's an internal or external customer. Moreover we can consider the material flow within a warehouse as an "internal supply chain", where we would like to reduce the amount of labour resources to achieve an increase in resource utilisation and therefore a reduction of costs. Though the reduction regarding the number of operators would be a very simple task, we have to meet the challenge to adjust the number of operators respectively utilise the operators optimally while working within the several warehouse areas without affecting the material flow in a negative way.

1.2 Approach

To start with the master thesis we have to obtain some theoretical background information regarding the importance of a warehouse for a supply chain and which tasks respectively processes are usually conducted within a warehouse. Moreover we have to define the scope of the term "labour management", why it can be a crucial factor for warehousing business and what advantages the use of such a tool can offer. In addition to this, we have to do a research for information regarding which tasks have to be done for being able to do labour management.

In terms of a holistic approach, it would be desirable to create a labour management tool for a whole warehouse, but as far as the master thesis at hand is concerned, we are only going to choose several warehouse processes. Furthermore we have to consider the chosen processes both from the theoretical point of view and how the processes are implemented at a distribution centre, which represents the practical aspect of these considerations. Moreover

we have to work out the difficulties of the considered processes which may affect the accuracy of the results when doing labour management.

After finishing these considerations, we are able to start with developing a concept for a labour management tool. For this reason we have to figure out which modules are essential for being able to do labour management and moreover to ascertain the targets of the single modules and which functionality they are expected to provide. To complete the concept, we have to implement a prototype for all of the modules needed for labour management for at least one of the chosen processes. Furthermore the sequence and the result of the implementation have to be documented properly.

The basic data which is needed for the testing of the prototype will be delivered by the semi-automated distribution centre of the John Lewis partnership, which is located within the Magna Park in Milton Keynes (UK). This distribution centre was planned, equipped and activated by KNAPP Systemintegration GmbH. After finishing the ramp-up phase of the facility, which started in May 2009, the data which is now provided for testing the prototype has a sufficient quality and moreover allows calculating valid forecasts. Finally we have to present the results that have been calculated by using the prototype on basis of the provided data.

1.3   Industry partners

Due to supporting this master thesis, the industry partners and their business area has to be presented shortly.

1.3.1 KNAPP Systemintegration GmbH, AT

KNAPP Systemintegration GmbH "is a member of the KNAPP AG family of companies headquartered out of Graz, Austria. As a worldwide leader in warehouse and distribution center automation, KNAPP has been developing comprehensive material handling and software solutions for more than four generations. Solutions that give our clients a competitive edge that helps achieve industry-leading results. By combining state-of-the-art software with unique picking and storage technology, KNAPP develops the perfect high-performance automated material handling solution. Customized to suit not only specific industries, but the individual goals of every client we serve [...]. KNAPP Logistics Automation continues a tradition of excellence by helping our customers quickly and efficiently manage internal processes that increase accuracy, reduce inventory costs, and improve customer service. From accurate and safe pharmacy automation solutions to innovative systems for

audio/video, pharmaceutical wholesale distribution, health, beauty and cosmetics and more, KNAPP is the one partner you can count on."[12]

1.3.2 John Lewis Partnership, UK

 "The John Lewis Partnership is a major United Kingdom worker co-operative retailer which operates John Lewis department stores, Waitrose supermarkets and the direct services company Greenbee. The company is owned by a trust on behalf of all its employees - known as partners - who have a say in the running of the business and receive a share of annual profits, which is usually a significant addition to their salary. The group is the third largest UK private company in the Sunday Times Top Track 100 for 2008. The chain's image is upmarket, and it appeals strongly to a middle to upper class shoppers. Recently, however, John Lewis have broadened their marketing strategy towards all types of buyers, with the introduction of the 'Value' range to John Lewis and the 'Essential' range to Waitrose, and with the expansion of the business. The partnership also supplies the Ocado web supermarket with Waitrose own-brand foods and John Lewis own-brand non-food items."[13]

One part of the partnership is John Lewis, which "is a chain of upmarket department stores operating throughout Great Britain and is popular amongst the middle class for its high quality goods. The chain is owned by the John Lewis Partnership. All permanent employees are partners in the business. There are currently 29 stores throughout England, Scotland & Wales and a further 8 stores are confirmed to open in the next 5 years."[14]

2 Basic information

Before we are able to start with developing a concept for a labour management tool for an automated distribution centre, we have to give some basic information regarding the two main topics "warehouses" and "labour management" within this chapter. But as we have already discussed about distribution centres before, why do we only provide information about warehouses? This is, because the distinction between a warehouse "and a distribution centre has become cloudy and ignored by many authors and researchers"[15]. For this reason we do not have to make a big difference between these two terms.

2.1 Warehouses

From the logistical point of view, the best warehouse would be having no warehouse due to different reasons. On the one hand a warehouse requires a lot of space and on the other

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[12] Cf. [Knapp2010]
[13] [Wiki2010_JLP]
[14] [Wiki2010_JLds]
[15] [LaRi2005], p. 68

hand a lot of capital is tied up, both invested capital to create the facility and the capital lockup which is caused by having several goods on stock. But in reality, warehouses are essential and there can be some good reasons adduced for having goods available on stock.[16]

2.1.1 Reasons for warehouses

As there can be found numerous reasons within the literature for having goods available on stock, we concentrate on some main reasons. At first, we have to say that inventory helps us to assure the delivery capability, if we have to satisfy the customer demand this fast that producing and transporting the goods to the customer would take too long or would cause a large amount of additional costs. Moreover having goods available on stock provides a buffer for balancing variances between the demand and supply patterns due to seasonal fluctuations, machine malfunctions or quality issues. In addition to this, the operations within a warehouse help to adjust the package sizes between the batch sizes provided by the suppliers and the sizes which are usually demanded by the customers.[17]

Furthermore, the procurement of goods often causes fixed costs for placing an order, that's why procurement managers often purchase bigger amounts of goods. But these bigger amounts are not only bought to reduce the fixed costs which are caused per order procedure, but also due to volume discounts, which may be offered by the supplier, if a big amount of goods is ordered.[18] In addition to this, the buffering of goods within a warehouse may help to reduce the production costs due to a decrease of set-up times when being able to produce the goods in bigger lot sizes. Last but not least, one of the most important reasons is to offer an excellent service to the customer regarding delivery capability and flexibility as well as quick deliveries.[19]

2.1.2 Definition of warehouse/distribution centre

For finding out why it is reasonable to have a warehouse within a supply chain, we have to provide a definition for a warehouse. "A warehouse is a large commercial building where raw materials or manufactured goods may be stored for any period of time. Warehouse buildings are frequently co-located with distribution centres and manufacturing facilities."[20] In addition to this, "warehouses are used by manufacturers, importers, exporters, wholesalers, transport businesses, customs, etc. They are usually large plain buildings in industrial areas of cities

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[16] Cf. [Koet2008], p. 50
[17] Cf. [Koet2008], p. 24 et seq.
[18] Cf. [Koet2008], p. 25
[19] Cf. [RuOxCr2000], p. 115
[20] [SuRa2009], p. 320

and towns. They come equipped with loading docks to load and unload trucks; or sometimes are loaded directly from railways, airports, or seaports. They also often have cranes and forklifts for moving goods, which are usually placed on ISO standard pallets loaded into pallet racks."[21]

As the issue warehousing considers not only warehouse facilities, but "includes the physical process of material handling and stocking as well as the underlying methodologies [...]. Given the increasing marked volatility, wider product range proliferation, and the increased demand for higher customer service levels, warehouses have become crucial components of any distribution network and play a significant role in enhancing SC performance."[22] The different roles of a warehouse within a supply chain are discussed within chapter 2.1.4.

So we can say that "warehouses and DCs are important nodes in a supply network; they perform valuable functions that support the movement of materials. Storing goods (temporarily or longer), processing products, de-aggregating vehicle loads, creating SKU assortments, and assembling shipments are all activities commonly performed in these facilities."[23] To be more precise, a distribution centre "is, in fact, a specific type of warehouse."[24] But it is "a type of warehouse where the storage of goods is limited or non-existent. As a result, distribution centres focus on product movement and throughput (receiving, putaway, order picking, order assembly, and shipping), and information collecting and reporting (throughput and utilization, transportation documentation, loss and damage claim support), rather than storage."[25]

To complete this chapter, we have to mention the small differences between warehouses and distribution centres: "Warehouses store all products; distribution centres hold minimum inventories, and of predominantly high-demand items. Warehouses handle most products in four cycles (receive, store, pick, and ship); DCs handle most products in two (receive and ship)."[26]

2.1.3 Basic warehouse processes
As we got to know the definition of a warehouse respectively distribution centre, we are now able to regard the processes which are typically performed within a warehouse. If we consider the whole warehouse as a process, whose input are the deliveries from the supplier

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[21] [SuRa2009], p. 320
[22] [Bidg2010], p. 163
[23] [LaRi2005], p. 68
[24] [LaRi2005], p. 68
[25] [LaRi2005], p. 68
[26] [LaRi2005], p. 68

and whose output are the goods delivered to the customer, we can say that the "warehousing process usually consists of a number of subprocesses, including the sequence of receiving, storing, picking, packing, and shipping. In addition, cross-docking and some innovative value-added activities [...] are carried out in the warehouses."[27] The sequence of these activities is shown within Figure 1.
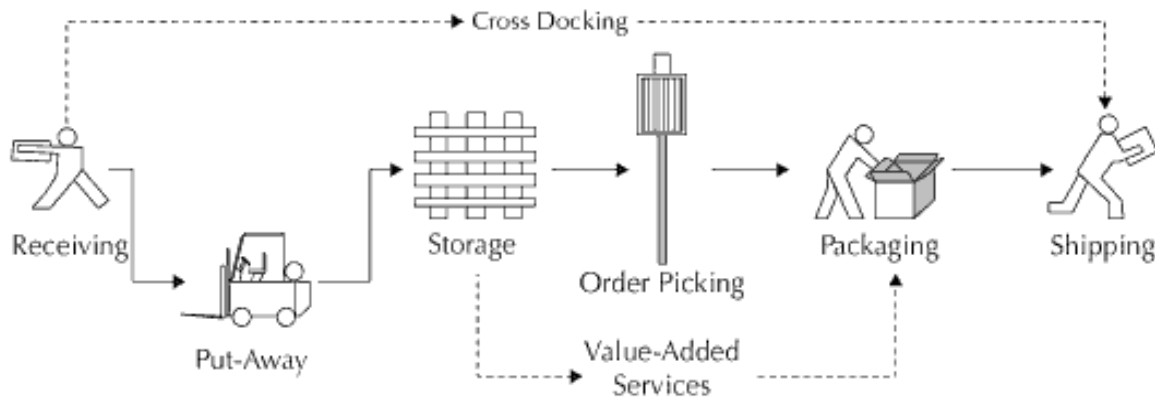
Figure 1: Warehouse processes[28]

As there are a lot of different activities to be done within a warehouse the processes "receiving, storage, order picking, and shipping are generally recognized as fundamental activities."[29] For this reason we are going to describe these main activities shortly.

The first process to be done is receiving, which "is the process of unloading an incoming truck, identifying, registering and perhaps repacking the goods"[30]. After having received the goods, they "can be put away for storage or sent directly from the receiving docks to the shipping docks (cross-docking)."[31] So the following warehouse process is the storage process, which "is the traditional and most basic warehouse activity, and can be defined as the deposit of goods in a facility for safekeeping."[32] In addition to this, "while the goods are in storage, activities may still take place which affect them, e.g. the inventory is counted on a regular basis to verify the inventory quantities (cycle counting) or goods are moved to other locations, e.g. to optimize the space utilisation (internal movements)."[33]

Another important process, which is a critical factor for the picking process but was not mentioned until now, is the replenishment process, being "defined as the process of drawing goods from a bulk storage area to an order-picking area. It may also include making sure

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[27] [Bidg2010], p. 163
[28] [Bidg2010], p. 164
[29] [Bidg2010], p. 163
[30] [Berg2007], p. 60
[31] [Bidg2010], p. 164
[32] [Voor2004], p. 56
[33] Cf. [Berg2007], p. 61

that key items (popular items) are adequately catered for and replenished as stocks are depleted."[34] Having all the goods available within the picking storage area, this provides the basis for the order picking process. "Order picking, the process of picking products to fill customer orders, is one of the most important activities in warehouses [...]. It involves the process of clustering and scheduling the customer orders, assigning stock on locations to order lines, releasing orders to the floor, picking the articles from storage locations, and disposing of the picked articles [...]."[35]

After having picked all the goods required for a customer order, we can prepare the goods for shipment, for this reason the goods have to be packed and marked.[36] Right after finishing these activities, the goods are "consolidated and staged for shipping. Once a shipment is complete, it is loaded into the truck and the truck departs."[37] Some warehouses offer additional services to their customers ("value-added services"), "such as customer-specific or country-specific packing and labelling"[38].

2.1.4 Types of warehouses

Due to a wide variety of industries and goods to be produced, we can retain that "industries and products can be quite different from one another, companies usually adopt different distribution strategies and corresponding distribution arrangements. Warehouses are always designed and managed with respect to these distribution strategies. Thus, warehouses often have strong industrial and product characteristics that may differ in a variety of ways."[39] In addition to this distinctive feature, we have to distinguish between several different types of warehouses in accordance with their task within the supply chain. So "throughout the supply chain we may find different types of warehouses. First we distinguish between production warehouses and distribution warehouses."[40]

- o "A production warehouse holds raw materials, semi-finished goods and finished goods. Goods are delivered to and from a nearby production plant. Finished goods are delivered to customer or other warehouses.

- o A distribution warehouse receives goods from various suppliers and ships these to customers."[41]

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[34] [Voor2004], p. 56
[35] [Bidg2010], p. 164
[36] Cf. [Voor2004], p. 56
[37] [Berg2007], p. 61
[38] [Berg2007], p. 61
[39] [Bidg2010], p. 163
[40] [Berg2007], p. 56
[41] [Berg2007], p. 56

To provide the best possible service to the customer, a warehouse should "be provided right next to the customer, and it would have to hold adequate stocks of all the goods the customer might require. This would obviously be a very expensive solution."[42] For this reason, this would not be the best solution, even if we desire to create a warehouse as close as possible to the customer, there are different strategies to keep inventory to satisfy the customer demands. So "distribution warehouses can be further classified by the region they serve."[43]

o "A central warehouse holds the centralized inventory for a large region. This centralization allows the region to be served while keeping total inventory low. A distribution center that serves the European continent is also known as a European distribution center (EDC).

o A local warehouse serves a smaller geography, e.g. a city, a region or one or more (small) countries. Due to its close vicinity to the local market, the local distribution center can quickly supply goods to customers. Sometimes the local warehouse only carries fast moving products in order to limit the decentralized inventories."[44]

Having now provided some basic information regarding warehouses respectively distribution centres, we will now give some basic information on labour management.

2.2 Labour management

The term 'labour management' is not defined within the literature, so we are going to designate it as a combination of 'manpower requirements planning' and 'short-term manpower planning' due to the fact that we would like to know the future demand of labour and at the same time allocate the determined number of operators in accordance with the expected workload. Whereas the manpower requirements planning usually is a planning activity for longer periods, whose result is an estimation regarding the number of operators required for fulfilling a supposed amount of work, the task of short-time manpower planning is to allocate the existing manpower resources optimally to the single processes in terms of the timing of the deployment and the potential of the operators. As these two topics regarding the planning of labour are very comprehensive, we are only going to provide some basic information.

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[42] [RuOxCr2000], p. 115
[43] [Berg2007], p. 56
[44] [Berg2007], p. 56

2.2.1 Manpower requirements planning

A planning procedure generally is the intellectual anticipation of future actions. The orientation towards the future is characteristic of planning as well as the fact that the human behaviour cannot be predicted exactly. For this reason the human resource planning is always affiliated by a certain amount of risk. For being able to minimise the risk by making capable decisions, the planning procedure has to be done systemically.[45]

An important part of the human resource planning is the manpower requirements planning, whose task is to determine how many employees with which qualification will be needed to match a future workload situation.[46] To be a little more precise, the main task of the manpower requirements planning is to determine a future demand of labour. If a lack of capacity is detected in course of the planning procedure, additional personnel have to be recruited. But if there is a surplus of operators due to a significant decrease of workload, the responsible person will have to consider a staff reduction.[47]

Like any other planning procedure, the planning of the labour demand also starts with an analysis of the current situation: The information which is needed for doing the manpower requirements planning is the actual situation regarding the personnel, the actual and future demands of a company and its employees plus several external factors. Having this information complete, it provides the basis for the further planning activities which have to be coordinated across different areas of activities and moreover have to be attuned to corporate planning procedure.[48]

The task of the manpower requirements planning is to ascertain the effective labour demand, which is required for realising current and future deliverables of the company in due consideration of the required qualifications. The planning procedure is separated in two steps:[49]

- o The result of the qualitative manpower requirements planning is the knowledge, which competencies, skills and behaviour are required from an operator.

- o The task of the quantitative manpower requirements planning is to determine the quantity of operators which are required for a certain area and therefore have to be employed until the end point of the planning horizon.

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[45] Cf. [Jung2008], p. 113
[46] Cf. [KnPiZü2009], p. 132
[47] Cf. [BaHu2007], p. 62
[48] Cf. [KnPiZü2009], p. 132
[49] Cf. [Jung2008], p. 117

To accentuate again, the quantitative manpower resource planning has to answer the question, how many personnel is required to achieve the corporate objectives. Following tasks have to be carried out:[50]

- o To assure that the quantitative labour demand can be recognised x years, months, weeks or days in advance. The demand is determined per operator group, which represents a certain set of qualifications is required.

- o To assure that a demand of successors for important jobs and possible followers can be identified x years in advance

- o To recognise other quantitative changes (like staff reduction) at an early stage

To match the target of this master thesis, only the first point has to be considered at the moment due to the fact that we would like to achieve mid-term information – in the sense of several days and weeks in advance – regarding the number of operators which will be required for a certain expected workload. In addition to this, the resources (operators) will have to be allocated optimally to the processes by using the same forecast. The distribution of the operators is derived from the short-term manpower planning, which we are going to describe now.

2.2.2 Short-term manpower planning

Short-term manpower planning is concerned with allocating the operators, which are employed by a company, to the single positions. To assure an optimal performance of the operational tasks, the requirements of the single positions have to be aligned with the skills, needs and the potential for development of the operators.[51] So the short-term manpower planning contains the businesslike and temporal allocation of operators to the fields of activity.[52]

The close collaboration of all departments of a company with the person, who is responsible for the short-term manpower planning, is a crucial factor. Just to give an example, the information of the production planning department is the basis for the planning regarding the number of operators required within the production department. The data should contain the information, what amount of goods is planned to be produced within which period of time, which provides a basis for the decisions regarding the personnel planning.[53]

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[50] Cf. [KnPiZü2009], p. 133
[51] Cf. [Jung2008], p. 186
[52] Cf. [ScVe2004], p. 369
[53] Cf. [BaHu2007], p. 77

But what are the main tasks of a person, who is responsible for doing the short-term manpower planning? One of the main tasks is 'allocating operators to the single positions'. So we can say, that the result of the short-term manpower planning is, which amount of operators with which skills is required at which point of time. But it has to be assured, that there are not too few respectively too many operators allocated to one process. For it is assumed, that the skills of the operators already match the requirements of the positions.[54]

Just to give an example regarding the personnel planning for picking, where we have to compare the capacity demand (which amount of goods has to be picked) to the capacity, which is provided by the operators, which have been allocated to the picking area. While doing the allocation, we have to consider the productivity of the single operators. The personnel planning for the receiving process can be done in an analogue way, on basis of the deliveries which have been announced by the suppliers.[55]

2.2.3 Short summary

Just to summarise the information, we have to highlight what we consider by using the term 'labour management' again. We are thinking of a more short-term manpower requirements planning combined with a longer-term manpower planning. This means that we have to shorten the maturity of the planning regarding the labour demand to a relatively short period whereas we anticipate the operator distribution operation for being able to create a labour management tool which is able to determine the number of operators required and the allocation to the single processes at once – a certain period in advance by using appropriate forecast information. In addition to this we have to structure the information for having sort of a schedule available for a certain week in advance.

3   Labour management in warehouses

In this chapter we are going to combine the basic information of labour management and warehouses. The starting point will be some basics about warehouse management systems which are very common in automated or semi-automated warehouses. It has to be discussed, why labour management in warehouses is important, how labour management tools can be structured and what they are able to achieve.

3.1   Warehouse Management Systems (WMS)

To manage a big warehouse without the aid of information technology systems would be very difficult. For this reason the "use of computer-based information technology is now the

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[54] Cf. [Jung2008], p. 187
[55] Cf. [ScVe2004], p. 369

norm in most warehouses and is essential for the management of large facilities. Even in conventional warehouses, for example with reach trucks and ground-level picking, significant advantages can be achieved in terms of productivity, speed and accuracy with the benefit of a good warehouse management system (WMS)."[56] To be more precise a "warehouse management system is a software system that controls the activities within the distribution centre. The system knows which goods are to be received and shipped. It determines which tasks need to be performed to process the goods and send commands to human operators and automated material handling systems to execute these tasks."[57]

Moreover a warehouse management system "allows goods to be physically controlled, identified, and monitored from the time they arrive at the receiving dock until they are loaded onto a delivery truck. One of the most important features of such a system is its ability to locate and trace every item."[58] To support all warehousing processes it "provides functionality to manage receiving, storage, picking, packing, and shipping operations. It can also support inventory control, returns processing, replenishment, order consolidation, shipping document preparation and yard management."[59]

The warehouse management system has an influence on both the receiving and shipping process. "During the receiving operation, employees no longer have to look up purchase orders and check back-order lists before receiving product. Fast receiving means reduced inventory, since the material becomes available to the facility within minutes of receipt. Manual receiving can take several days before product can be released to the floor. Shipping operations also benefit. Purchase orders (POs) can be directly downloaded to the shipping department for immediate fulfillment."[60]

Furthermore, a WMS allows us to capture "the relevant data on orders, shipments, inventory, warehouse layout, warehouse staff, vehicles, customers, suppliers and activities in the distribution centre, to mention a few. This ensures the tracking & tracing and quality of warehouse activities."[61] This will be a very important factor for our further considerations, because for estimating any future workload situation and achieving operator performance information, we are going to use historical data that is going to be provided by the WMS.

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[56] [RuCrBa2006], p. 349
[57] [Berg2007], p. 83
[58] [Acke1997], p. 536
[59] [Tomp2004], p. 418
[60] [Tomp2004], p. 160
[61] [Berg2007], p. 83

"Finally, a WMS manages and directs labour to the immediate tasks at hand. The primary benefit of labour management is the reduction of deadheading, or an empty return trip. Directing employees through a series of tasks based on each employee's location in the facility can result in shipping and receiving tasks being performed in the same cycle."[62] And in addition to this, warehouse management systems "provide tools to help distribution operations optimize warehouse activities and storage utilization. Most WMS packages provide sophisticated wave management and order release functionality that allow operations to release orders for processing according to capacity, service needs and picking requirements."[63]

To sum up shortly, warehouse management systems are supporting the warehouse processes in regard to a high level of efficiency. Thus it will be necessary to determine other possibilities for a further increase in warehousing efficiency.

3.2 Reason(s) for labour management in distribution centres

A "distribution centre is an essential link in the supply chain. It makes goods available when (and how) we need them and it creates efficiency in upstream and downstream activities. If the distribution centre can provide competitive service levels against substantially lower costs, then this gives the company, or even the entire supply chain, a major advantage."[64] As mentioned in chapter 3.1, if a warehouse management system is used for processing warehouse operations, the warehouse processes are operating at a very high level of efficiency. So for our further considerations, we are able to "assume that the efficiency of the processes can no longer be improved. However, there are still other ways to increase the warehouse productivity."[65] This further increase in economic efficiency, which is desired by the companies operating a warehouse, can be achieved "through a better utilization of the resources, i.e. people, machines, vehicles and warehouse space."[66]

As a result this gives us an idea for four possible starting points for increasing the warehouse productivity. But why is the factor labour that interesting, that we are concentrating our further considerations on it? The main target of many organizations is to reduce costs at a constant service level. So within the literature the reason for integrating a labour management tool into the existing warehouse management system can be found very quickly, because "labour constitutes the largest variable expense at any warehouse, and

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[62] [Tomp2004], p. 160
[63] [Tomp2004], p. 418
[64] [Berg2007], p. 9
[65] [Berg2007], p. 153
[66] [Berg2007], p. 153

labour planning, scheduling, and tracking has become a well-established process that is also supported by most of the leading warehouse management systems. In fact, simply optimizing the labour usage in a warehouse can sometimes provide enough return on investment (ROI) to justify automation of a facility using systems and technology."[67] To be more exact, the costs for labour "typically account for 65 percent of overall warehouse costs"[68].

However some of the existing warehouse management systems are not able to provide this functionality. For this reason new planning and control tools have to be created either by the vendor of the warehouse management system or by an external software specialist.[69] But before being able to create a concept for a labour management software tool for extending an existing warehouse management system, we have to get an idea of the considered processes and what difficulties may arise while achieving the number of operators required for a certain process and influence the accuracy of the calculation results in a negative way.

The costs regarding the resource "labour" are without doubt the most important incentive for labour management. Another reason is the motivation of each single operator. If they have too much or too little work to do, they may get discouraged, which may result in a decrease of performance of single operators respectively an increase regarding the number of staff away sick.[70]

3.3   Labour Management Systems (LMS)

Some vendors of warehouse management systems offer an add-on module to their customers called labour management system (LMS). This tool helps the manager of a warehouse to optimize the resource allocation concerning labour within a warehouse. This tool calculates how many operators are required for a certain amount of orders.[71]

Due to the use of a warehouse management system, the processes within a distribution centre run very efficiently. These systems are used for managing the material flow, while "warehouse Labor Management Systems (LMS) do not directly support inventory movement within the supply chain, they help distribution operations to optimize their labor utilization. Since labor represents a major portion of supply chain execution costs, a LMS can directly contribute to the overall efficiency of a supply chain. Depending on the situation, a LMS can enable a distribution operation to achieve substantial reduction in labor costs through

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[67] [Sehg2009], p. 135
[68] [BoHaCo2004], p. 49
[69] Cf. [Berg2007], p. 153 et seq.
[70] Cf. [Bode2005], p. 53
[71] Cf. [Berg2007], p. 158

productivity improvements and effective planning."[72] A reduction of labour costs is exactly what we would like to achieve by using the labour management tool to be created with this master thesis, but first we have to understand how such tools are working.

"The LMS first determines which tasks need to be performed to fulfill the orders. It then considers the actual inventory locations of the products in the distribution center and uses the same putaway and inventory allocation rules as the WMS to compute which tasks need to be performed. Subsequently, the system applies engineered labor standards, i.e. detailed standard times for the tasks, to calculate labor estimates. As such, the estimates of the workload are highly accurate."[73] But there is one problem: when estimating the future workload situation we do not know exactly what articles are ordered and where they are going to be stored within the warehouse.

The interesting aspect for the creation of a labour management tool is, that "LMS packages are work measurement tools that provide the capability to define the discrete tasks and the associated time values are that inherent in a specific warehouse work activity. They provide the means to calculate standard time values for preferred work methods."[74] And moreover they "usually provide the ability to report actual activity time by employee against standard values."[75]

Even if there are several solutions available on the market, "there are various aspects missing from the available LMS's which are needed for adequate resource planning. These functions should be included in the next generation of capacity planning tools"[76], to be exact they are called capacity planning (see chapter 3.3.1) and resource planning (see chapter 3.3.2).

3.3.1 Capacity planning

Due to the fluctuation regarding the demand of end customer demands, the "workload in the distribution center fluctuates. In practically every market, we see daily, weekly, monthly and seasonal patterns. Some fluctuations are predictable from historical behavior, e.g. Monday is always busier than Friday. Others can be explained by external influences, such as sales promotions, the weather, a rich or poor harvest or special events (e.g. the soccer world championship boosts the sales of many products, from drinks and snacks to consumer electronics and sportswear). Finally, there remain fluctuations that are totally

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[72] [Tomp2004], p. 420
[73] [Berg2007], p. 158
[74] [Tomp2004], p. 420
[75] [Tomp2004], p. 420
[76] [Berg2007], p. 158

unpredictable."[77] Another factor for a prediction concerning the workload is that nobody is able to say exactly how much the actual economical crisis affects the retail business.

An estimation of future situations can be understood as forecast which is defined as empirical established prediction about future demands concerning factors of production respectively future demands of finished goods. A time-line of past demands is the basis for the estimation of future demands.[78] This means, an analysis of historical data has to be done for being able to give a good estimation for the future. But as we can see, there are several influences that make a prediction of future situations very difficult.

Such a forecast will be the basis for further decisions that the responsible person for labour optimization has to make. This means, that the "manager can use an estimate of the workload to determine how many resources are required, e.g. people, machines, vehicles and warehouse space. On a daily basis, the quantities of machines, vehicles and space do not change. A medium-term plan should guarantee that sufficient capacity is available. However, the number of operators working in the distribution center can change every day. If the manager tunes the number of operators to match the expected workload, then an excellent utilization rate can be achieved."[79]

The medium-term plan mentioned above can be understood as weekly plan, which "provides a rough estimate of the workload. It helps to plan variables such as days off or maintenance."[80] More detailed is a daily plan, which is "established (at least) one day in advance. By then we have the latest information on the expected workload which we can use to make a reliable capacity plan. The daily planning is used, for example, to hire temporary staff or to plan the overtime of the operators."[81] Even if we have the information regarding the actual number of orders available one day in advance, this may be not early enough, because the number of required resources has to be determined – for instance – a week in advance. For being able to plan the capacity more accurately, three more things have to be considered.

3.3.1.1   Workload forecasting

Up to now labour management systems "do not provide a forecast of the workload, instead they assume that all orders are known in advance. This requires that the orders arrive at least one day in advance. However, in many distribution centers the orders arrive on the

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[77] [Berg2007], p. 157
[78] Cf. [Koet2008], p. 273
[79] [Berg2007], p. 158
[80] [Berg2007], p. 158
[81] [Berg2007], p. 158

night before or even during the day that they are shipped. Within such short response times, it is no longer possible to modify the labor capacity. Accordingly we need a forecast of the workload rather than the actual orders to plan the labor capacity in operations with short response times."[82] For being able to estimate the workload of future situations, we have to do an intensive analysis of historical data, for achieving information regarding seasonal fluctuations of the workload for example – out of the comparison of at least two years to each other.

3.3.1.2 Workload fluctuations during day

As the workload fluctuates during a week or month, we can assume that the workload even fluctuates during a day. For this reason the "systems should consider fluctuations in the workload during the day. If there is a peak workload in the morning, then several part-time operators are required only in the morning. Thus, the systems have to consider the timing of the activities."[83] So while developing a labour management tool, we have to keep this fact in mind. Therefore we have to provide an opportunity to analyse the historical data not only to determine the seasonal, monthly and weekly fluctuations, but also to find out the typical in-day fluctuations.

3.3.1.3 Operator Skills

Every operator working within a distribution centre has got different skills and as a result "not every operator is capable of performing all activities. For instance, only a few operators are certified to drive a narrow-aisle truck. In particular, temporary staff usually have had only basic training and as such are limited to straightforward tasks. Therefore it is important to be able to link the skills of the available operators to the required activities. The system then has to make a schedule and decide on which activities each operator works during the day."[84] In addition to this, not only the operator skills have to be considered, but also the productivity of each operator while working within a certain area of the warehouse. So if we are able to choose the operators for a certain area, we will for sure allocate the operators which are performing best.

Moreover, we have to consider that there may be fluctuations regarding an operator's performance throughout the day[85], so a performance measurement regarding whole days will not be sufficient. For this reason we have to think about a more detailed performance

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[82] [Berg2007], p. 159
[83] [Berg2007], p. 159
[84] [Berg2007], p. 159
[85] Cf. [Jung2008], p. 206

measurement, which we will have to link with the information concerning the skills of an operator.

3.3.2 Resource planning

The result of the capacity planning was the expected workload for a future situation. Now we have to determine the number of operators required within a certain warehouse area. To define resource planning precisely, it "is a function that computes the required number of resources for all warehouse processes in a specific time period, e.g. a day or a week. This prevents underutilization, which occurs when there are more operators than necessary. Likewise it reduces expensive overtime or late orders which may be the case when there are too few members of staff."[86] For performing a resource calculation, the following steps have to be done.

The main problem regarding labour management is that we do not know the customer demands and therefore the exact customer orders in advance. For this reason "a practical approach might be to first determine a forecast based on historical data and actual orders, using inventory control techniques […]. These techniques extrapolate historical order patterns. Subsequently, the Supply and Sell functions can evaluate the calculated forecast and modify it with regard to anticipated orders, special promotions etc. In particular, we should decide which level of detail is required for the forecast. Generally it is not necessary to forecast each individual product, but rather to determine an estimate per relevant product group and order type."[87]

After having estimated the order volume, "the second step is to convert the orders into tasks. If we receive the exact orders upfront, then we know precisely which products and quantities need to be processed. If, however we base the capacity plan on a calculated forecast per product group, then we must derive the necessary tasks from historical data. The WMS records which tasks were performed to fulfill the orders in the past. We may derive how often the various tasks were performed on average to fulfill an order line in the product group. We may use these parameters to compute the amounts of each task."[88]

Thereafter we have to calculate "the required process time. For each type of task we determined a standard time […]. If we multiply the calculated number of tasks by these standard times, then we obtain the total process time."[89] As we know by now, how much time it takes to execute all tasks, we have to "compute the number of resources required to

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[86] [Berg2007], p. 159
[87] [Berg2007], p. 160
[88] [Berg2007], p. 160
[89] [Berg2007], p. 161

perform the tasks. We find the number of resources by dividing the calculated process times by the capacity per resource"[90].

3.3.3 Workload balancing

Another aspect of labour management was mentioned before. If there are too little operators available and therefore being unable to deal with the amount of work that has to be done on one day, it has to be done even on the next day. "In the previous section we estimated the workload for the distribution center and calculated the required number of operators. However, this number may change dramatically between days and even during the day the workload may vary."[91] But not "all orders need to be performed on the indicated day. By advancing or postponing orders, we may be able to balance the workload. This helps to prevent (expensive) overtime on busy days or underutilization of resources on quiet days. Hence, the systems should understand which orders must be and which can optionally be fulfilled on a particular day."[92] Even if workload balancing is an issue that has to do with labour management, within this master thesis it will not be regarded because this would lead too far into detail.

To recapitulate this chapter, an estimation of future situations can be understood as forecast which is defined as empirical established prediction about future demands concerning factors of production respectively future demands of finished goods. A time-line of past demands is the basis for the estimation of future demands.[93] But before starting with an analysis of historical data, we have to review which warehouse processes are going to be considered and which factors are the relevant influencing ones. Moreover we will have to think about, which base unit may be the most appropriate for the considered processes for being able to compare the performance of an operator to the estimated workload.

4 Analysing warehouse processes

Labour management is a very important tool in modern warehousing business because it helps to improve the manpower cost-efficiency and therefore can be a valuable strategic advantage compared to competitors. The target of this master thesis is not to create a concept for a labour management tool for the whole distribution centre but just for several main processes. For this reason we are going to pick out and analyze three of them to get to know the essential influencing factors of the processes and moreover some critical factors

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[90] [Berg2007], p. 161
[91] [Berg2007], p. 161 et seq.
[92] [Berg2007], p. 159
[93] Cf. [Koet2008], p. 273

which may affect the accuracy of the results – when calculating the manpower requirements in accordance with the expected workload using a labour management tool – in a negative way. In addition to this, we will have to define a base unit for each of the chosen processes to achieve the most appropriate calculation results regarding the future workload respectively performance values.

As mentioned before, the target of using a labour management tool is optimising respectively reducing the number of resources to be applied to each of the considered processes. But this tool must not affect the reliability of any of the warehouse processes regarding the consistency of the material flow negatively. This means, if the number of operators working within a certain area is not able to cope with the amount of work for a day, this will result in overtime, which is very expensive. Orders will remain open at the end of the day that have to be fulfilled the next day.[94] Unmentionable that the problem of open orders may be carried on and on, if on the following day there is enough work to be done for the number of operators working within a single process and for this reason some new orders remain open. On the opposite, if there are too many operators working within a single warehouse area some of them will hardly have any work to do. The outcome will beyond doubt be a superb logistical performance at the expense of increasing manpower costs. Thus it will be a challenge to choose the right parameters while developing the concept for a labour management tool, so that a significant manpower cost reduction takes place without a negative influence on the logistical performance.

The main question we have to clear before starting with developing a concept is, how detailed such a tool should be. For our further considerations we assume that the labour management tool to be created should be able to calculate the number of operators needed on basis of single shifts – a certain period of time in advance. As we do not know the amount of work that will have to be done by then, we have to build a forecast by using the results of the analysis of historical data regarding the crucial input factors.

As far as this master thesis is concerned, we are going to analyse the warehouse processes "picking", "receiving" and "decanting". The picking process is of vital importance for the order fulfilment.[95] Therefore this process gets the highest priority and is treated first. But before analysing any of the processes from the theoretical point of view we have to give an idea of how a material flow within a distribution centre can be structured by giving an

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[94] Cf. [Berg2007], p. 159
[95] Cf. [Koet2008], p. 456

example which describes the material flow of the distribution centre which is operated by the John Lewis partnership and located at the Magna Park at Milton Keynes (UK).

4.1   John Lewis distribution centre at Milton Keynes

The distribution centre of John Lewis Partnership is located at Magna Park in Milton Keynes (UK), which is about 60 miles in the north of London. This location allows the distribution centre to become the function of a central distribution warehouse for the whole John Lewis retail business. Moreover the distribution centre is the biggest warehouse that the Knapp AG has ever built and has a ground area of 650.000 square feet (equals approximately 67.000 square metres). The planning of this warehouse started back in 2006, the start-up for the basic warehouse processes was in May 2009. At the end of January 2010 the distribution centre was still in the ramp-up phase because there are not all planned processes implemented within the distribution centre. Due to this matter of fact we do not have much valuable historical data concerning the workload and the performance of single operators, so the forecasting of the future workload and the calculation of the number of operators required to compete with a certain expected workload won't be that easy.

To be able to create a concept for a labour management tool for this distribution centre we have on the one hand to get an idea of the material flow within the considered warehouse and on the other hand to give a description of the processes that have to be considered within this master thesis – picking, receiving and decanting – by way of example. As mentioned before, there are not all planned processes implemented at the warehouse yet, so within the picking area we are going to concentrate on the "bin to bin picking" process.

4.2   Example of a material flow

To start with the description of the material flow, we have to state that we just concentrate the description of the material flow on the bin to bin picking process and the replenishment that has only to be done for this process.

The starting point of the material flow within the distribution centre is the receiving area, where 24 dock doors for trucks are available for goods receipt. There are mainly two sorts of packages that arrive at the receiving area, on the one hand loose cartons and on the other hand cartons which are already palletised. Loose cartons have to be palletised for the following process steps. If a package with a new article arrives at the warehouse, this article has to be SKU maintained. This means that a photo has to be taken and a size measurement has to be done to be able to calculate the volume of an item. This information is important to be able to know how many of this item will fit into one single tote.

If the received goods are fast movers, they are delivered directly to the decanting process; otherwise they are stored in the VNA (very narrow aisle) storage area and delivered to the decanting process when all same day turnaround goods have been decanted. The decanting process is a unique process at this distribution centre where the palletised goods are removed from the cartons and put into standardised totes which are used with the conveyor technique within this distribution centre. The main benefit of this process is that the cartons are removed centrally. Moreover we have to mention, that every conveyable item within the distribution centre has to pass the decanting process, so this process is a very important and central process, which means this process has more targets regarding the material flow. But as far as this master thesis is concerned, we just concentrate on fulfilling the shop orders.

After the decanting process is finished, the bins with the goods are transported to the picking storage area called "miniload", where only the standardised bins can be stored. The miniload area consists of two different automated systems, an AS/RS (automated storage and retrieval system) and an OSR (order storage and retrieval) system. Out of this storage area, the goods are transported to the picking area if required, where the so called "bin to bin picking" is done to fulfil the shop orders. Within the picking area, the goods are picked from the source tote, which goes back to the storage area afterwards, into a target tote.

The target tote is transported to the sorting OSR, where the single totes are grouped according to their destination. On the way to the sorting OSR, the totes are checked if they have the correct weight and if the totes are not overloaded, so to say the contents are not over a certain line which could cause at least damages within the sorting OSR. Having passed this check, the totes are labelled.

According to the time, that the goods for a certain tour are needed within the shipping area, the totes for a certain shop leave the sorting OSR and are transported to the so called "dollytiser" that stacks up to ten standardised bins on a dolly and secures them for the transport automatically. After that the dollies are transported to the shipping area where they are loaded onto the truck, which delivers the goods to the shop.

4.3   Warehouse process "picking"

In this chapter we are going to analyse the warehouse process "picking" in detail. But before we have to define what picking is and explain why it has such an importance in warehousing business. Thereafter we can go further into detail and consider the single modes of picking. In addition to this, we are going give a concrete example how the picking process is implemented within a warehouse and moreover we have to separate this process into single

tasks, which have to be performed for picking a single order line. This information will help us while identifying the critical issues regarding the picking process, which may affect the results of a labour management tool, and furthermore this information will help when defining the crucial input factors for a labour management tool, which helps to predict the number of operators that are required for the picking process within a particular shift.

4.3.1 Definition of picking

A very simple but accurate description of picking defines the process as "selecting the correct item in the correct quantity from storage to satisfy customer requirements."[96] To fulfil customer requirements means that a customer demand, which is represented by a customer order, is the basic information for starting the picking process. The customer order delivers the information about which articles need to be removed in which quantity from the storage area. So the "goods are selected from order picking stock in the required quantities and at the required time to meet the customer orders. Picking often involves break bulk operations, when goods are received from suppliers in whole pallet quantities, but are ordered by customers in less than pallet quantities. However, if a particular product is required in a sufficiently large quantity, for example a whole pallet load, it is picked directly from reserve storage."[97] To fulfil a customer order, following tasks have typically to be done: "making goods available in storage units, picking the required quantities of goods, consolidating the picked goods according to the picking sequence, transport of the picking unit to shipping, and return of part-picked storage units to storage."[98]

After having removed all the products from the storage area for a complete customer order, all items belonging to this order are composed together and being prepared for shipping to the customer.[99] In most cases picking is done manually, because the human hand is the most flexible picking tool.[100]

4.3.2 Importance of picking

Just as mentioned before, the picking process is the most essential warehouse process[101] because "order picking is the function that warehouse professionals consider to be the most critical in their distribution operations. It is at the center of the flow of products from suppliers to customers. In fact, it is where customer expectations are actually filled."[102] So if

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[96] [ToSm1998], p. 804
[97] [RuOxCr2000], p. 237
[98] [Schö2004], p. 770
[99] Cf. [Koet2008], p. 456
[100] Cf. [Koet2008], p. 52
[101] Cf. [Koet2008], p. 456
[102] [ToSm1998], p. 803

any problem occurs during this process, the customer will possibly be able to recognize this matter of fact in the worst case.

This may happen if the replenishment of goods for some frames at a department store is missing because the truck could not wait for delayed goods due to fixed time frames for delivery at the stores. If the goods are shipped directly to the customer, who got a certain confirmed delivery date and the goods are late, the customer will be very dissatisfied about that. For this reason the customer wishes get the highest priority, therefore "order picking is important for achieving high levels of customer service; it traditionally also takes a high proportion of the total warehouse staff complement and is expensive. The good design and management of picking systems and operations are consequently vital to effective warehouse performance."[103]

4.3.3 Modes of picking

According to the definitions, the picking process helps to fulfil the customer demands by allocating the required items in the right quantity to a customer order. A customer order consists of several order lines and each order line represents the quantity of one requested item. For this reason the amount of order lines to be picked can be considered as one important influencing factor for the picking process. But if we are only using the number of order lines that have been done by a single operator within a certain period of time as basis for our further calculations, this may lead to big inaccuracies due to the fact, that a single order line may consist either of only one item or of hundreds of pieces. Hence there are big differences regarding the number of order lines an operator is able to handle within a certain period of time.

Therefore we have to find another way to measure the amount of work that was done within a certain period. But before defining an adequate base unit for the picking process, we will have to analyse the picking process and the different picking modes which can be applied to the picking process. On the one hand we have to distinguish, if the operator moves to the goods or if the goods are delivered to the operator's station, and on the other hand, if the operator picks goods for each order separately or even picks the goods belonging to different orders at once. We have to describe these different types of picking because we would like to know, if the different modes of picking have an essential influence on which data has to be used when doing labour management for the picking process. Moreover we have to provide some information about picking waves.

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[103] [RuOxCr2000], p. 237

4.3.3.1   Single order picking

This mode of picking can also be found as "discrete order picking" within the literature and describes the picking mode, where "orders are picked one after the other"[104]. To be more precise, "one person picks one order, one line (product) at a time"[105]. But even if there is one order handled just after another, there are several different specifications possible. "The simplest form of this is where one picker in one circuit of the picking area collects the items for one order. This may be appropriate when one order will typically fill the capacity of the picking trolley or truck. An extension of this is when more than one order is picked per circuit, but each of the orders is accumulated into a separate container so that at the end of the picking circuit each order is discrete."[106]

Due to its simplicity, the discrete order picking has several advantages, especially when used in combination with "paper-based systems, as only one picking document must be managed. As a result, the risk of picking errors of omission is reduced"[107]. Moreover "there is only one order-scheduling window during a shift. This means that orders are not scheduled and may be picked at any time on a particular day"[108]. This allows to allocate the orders variably throughout the shift, so "in a service window environment, it provides the fastest response to the customer"[109]. But "it is the least productive procedure. Because the picker must complete the total order, travel time is likely to be excessive compared to other methods."[110]

4.3.3.2   Batch picking

If the picking process is operated according to the picking mode "batch picking", one operator "picks a group of orders (batch) at the same time, one line at a time. When a product appears on more than one order, the total quantity required for all the orders combined is picked at one time, and then segregated by order. The segregation may take place while picking into totes (small items in small quantities) or transported to a designated area where they are sorted and grouped by individual order."[111] "This sortation may be undertaken either manually or using automated sortation equipment."[112]

If a large number of orders has to be picked, the batch picking mode is applied to the picking process because "for small orders it is not always economic to pick only one order

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[104] [Schö2004], p. 770
[105] [Tomp2004], p. 200
[106] [RuCrBa2006], p.303
[107] [Tomp2004], p. 200
[108] [Tomp2004], p. 200
[109] [Tomp2004], p. 200
[110] [Tomp2004], p. 200
[111] [Tomp2004], p. 201
[112] [RuCrBa2006], p. 303

per circuit"[113]. So just having a large amount of small orders to pick, we would like to handle more orders at the same time because this provides "a significant effect on picking productivity for case and broken case picking. In fact, the more orders a picker can effectively manage at once, the greater the productivity gain. Of course, there is a point of diminishing returns. The best candidates for batch picking are orders with a few (one to four) lines and small cube. Once again, the reason for productivity improvement is the reduction of travel time. Instead of travelling throughout the warehouse to pick a single order, the picker completes several orders with a single trip. It is critical, however, that measures be taken to minimize the risk of picking and sorting errors. Computer control systems and automatic sortation are very effective."[114]

4.3.3.3   Wave picking

Another approach for achieving higher picking productivity is "wave picking", which "is similar to discrete picking in that one picker picks one line at a time. The difference is that a selected group of orders are scheduled for picking during a specific planning period. There is more than one order scheduling period during each shift. This means that orders may be scheduled for picking at specific times of the day. Typically this is done to coordinate the picking and shipping functions."[115] This coordination is required for example due to fixed tour plans, so the orders have to leave the warehouse at a point of time which is exactly defined. According to this, the picking activities for the single destinations have to be started a certain period of time in advance for being finished on time.

4.3.3.4   Man-to-goods

If the mode of the picking process is "man-to-goods", the operator moves within the storage area. A pick list provided to the operator working within the picking area tells him/her, which articles have to be removed from the storage area in which quantity and have to be put into a target tote according to a customer order. The best-known example for the picking principle "man-to-goods" is shopping in a supermarket with self-service.[116]

Corresponding to the definition given above, the operator has to move within the storage area, where the required articles are provided for the picking process. But we have to distinguish between two alternatives: The first possibility – to use the example regarding the supermarket again – the operator uses a carriage for being able to collect all the goods belonging to one customer order at once. This means that if the operator has picked one

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[113] [RuCrBa2006], p. 303
[114] [Tomp2004], p. 201
[115] [Tomp2004], p. 201
[116] Cf. [Koet2008], p. 344

article, he/she can move directly to the storage location of the next required article. After having picked all required items, the operator goes back to his/her station and puts the goods into the target tote. The second opportunity is that the operator moves to the storage location of one required article, grabs the desired number of items and goes back to his/her station for putting the item(s) into the target tote. If the process is implemented using this method, the operator has to move back to the station for each single order line which consumes an enormous amount of way time. But the way time is only one of the time consumptions which have to be considered for the picking process.

To illustrate the definition given above, we are going to imagine the sequence of the single steps that have to be performed when picking goods according to the picking principle "man-to-goods", if the operator returns to his/her station after each pick. The starting point of the process is, when the operator still being at his/her station takes the pick list, which has one or more order lines on it, each of which representing one defined article and the desired quantity. After having read one single order line, the operator moves to the storage location of the required article and grabs the quantity of goods needed to fulfil the actual order from the source location. Afterwards the operator moves back to his/her station and puts the picked goods into the target tote. In addition to this, the operator has to confirm the picking activity onto the pick list. Having finished one order line, the whole procedure has to be repeated for each order line. The sequence of the single tasks is shown in Figure 2.

| read issue quantity | going to storage position | grab item from source tote | going back to station | put item into target tote | confirm picking activity |
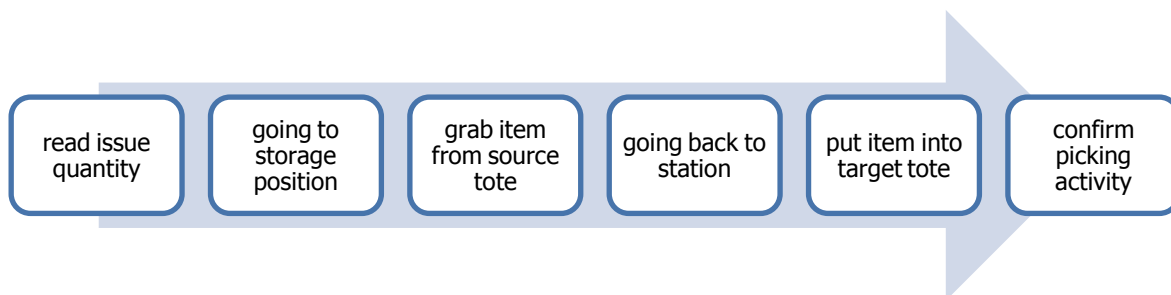
Figure 2: Sequence of tasks for picking according "man-to-goods"

Up to now we got to know which sequence of tasks has to be performed for picking a single order line. As mentioned above, the way time is only one part of the time consumptions. For this reason we have to find out the others. In addition to this, we will have to find a solution for how to measure the performance of an operator containing the way times. As the performance can be defined as base unit per time or time per base unit, we will need the time consumption of the picking process. Corresponding to the literature, the pick time for

each order consists of base time, pick time, way time and dead time, which are defined as follows[117]:

- o Base time: time needed for organizational activities before respectively after picking an order line, e.g. reading the documents concerning the picking quantity, sorting the documents, etc.

- o Way time: time between picking station and storage location of the goods and back to the picking station

- o Pick time: time for removing one piece of one article from of the storage location and putting it into a receptacle

- o Dead time: time needed for searching the storage location

When looking at the different given time consumptions regarding the picking process, we may take for granted that there are not big fluctuations when considering the base time, pick time and dead time. But due to the different distances covered, we can essentially assume that the way times vary, which is a critical factor when doing labour management. Due to the lack of knowledge which articles will be desired the following day, we certainly do not know the storage location of all the required articles in advance. For this reason we do not know either, which distances have to be covered by an operator, therefore we are unable to calculate the exact way times. So we will have to find a solution for being able to reduce the fluctuations regarding the way time for our analysis in retrospect which will also provide the possibility to apply the different way times for future situations. But simply calculating a mean of all way times would lead to inaccurate results and is therefore considered inappropriate. Thus we have to think about a more accurate solution.

Based on the consideration of one line of storage racks with a picking station in the front of it, the warehouse management system helps to optimize the storage location of each article due to the turnover ratio, which means fast-moving items are placed in a storage location near the picking station while slow-moving items are stored with a greater distance to the workstation. If we would calculate a mean of these way times, this would also be inaccurate because we can assume that there are more frequently used articles required from the customer with shorter ways than infrequently used ones with long ways. For this reason we are going to divide the racks into several zones, which we are going to call "way time zones". So each of this zone represents a certain turnover ratio and we are able to calculate a mean way time for each of these zones.

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[117] Cf. [FHWN2005], p. 8

Moreover we can find out the percentage of the usage of each way time zone needed to fulfil all orders of a day. This will allow us to estimate the way times in an appropriate accuracy, because even when doing labour management for a certain process, we will not be able to plan every second of every operator. For being able to use this considerations within a labour management tool, we have in addition to assume that each operator is able to grab each number of items which is required for an order line at once, so the operator has to go to the storage location and back to the picking station only once.

Like mentioned before, as far as the grab times are concerned, we are going to assume, that the operator has to grab each item individually even if the items are that small that he/she will be able to grab them together. Furthermore we have to keep in mind that the grab time for each item is different because e.g. a pack of napkins is less damageable than a teapot made of china. But determining a mean for the grab time over a whole day will be a good approximation.

4.3.3.5   Goods-to-man

When using the picking principle "goods-to-man", the way times of the operator cease to exist because the goods are transported directly to the picking station either via conveyor technique or via storage technique. After having removed the required number of items of one article from the source tote, the operator has to put the picked goods into the target tote and has to confirm the picking activity. Thereafter the source tote can be removed and has to be transported back to the storage area. Moreover the removal of the goods from the source bin can be made a lot easier due to aids such as hoisting devices that can be applied to the picking station.[118]

In accordance with the definition given regarding the picking mode "goods-to-man", this mode is similar to the picking mode "man-to-goods" which was described within chapter 4.3.3.5. The main distinctive feature is the fact, that there are no way times to be considered, because the operator does not have to leave his/her station for the execution of the required picking tasks because the goods needed for fulfilling a customer order are brought to the operator's station via conveyor systems directly. This means that the tasks "going to storage location" and "going back to station" no longer exists within this picking mode while the other tasks still have to be performed. So the sequence of the single tasks to be done is as follows (see Figure 3):

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[118] Cf. [Koet2008], p. 347
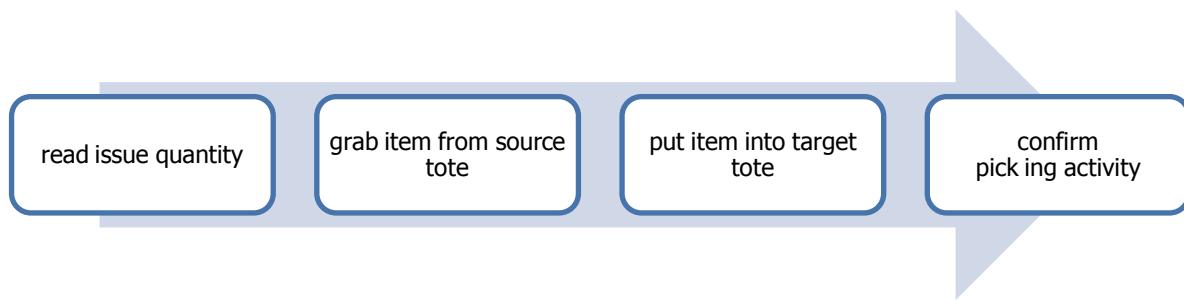
Figure 3: Sequence of tasks for picking mode "goods-to-man"

As we do not have to consider way times, if the picking mode is goods-to-man, we can assume that all the remaining times vary only within small boundaries. So we can suppose that calculating a mean value regarding the performance is accurate enough.

4.3.4 Process description

To give a practical example for a picking process, we are going to describe the "bin2bin" picking process, which is implemented within the John Lewis distribution centre at Milton Keynes. The given example will help us to determine the critical issues regarding picking processes when doing labour management.

As the name of the bin2bin picking process implies, the goods are taken from a source bin and put into a target bin. Due to the fact that the source bin is brought to the operator via conveyor technique, we can clearly say that the picking mode of this process is goods-to-man. When the picking procedure is finished, the source bin is transported back to the picking storage area, whereas the target bin (now containing the goods belonging to a customer order) is weigh checked, labelled and afterwards delivered to the sorting OSR, where it is stored until all bins for a single tour to a department store are finished. Now having an overview regarding the input and output interfaces regarding the material flow, we are now going to describe the process in detail. But before, we have to describe the conveyor technique and the workstations within the picking area in detail.

Within the bin2bin picking area there are ten picking fingers available with three picking stations per finger, so there can be at most 30 operators working simultaneously within this process. At each of the picking stations there can be up to 16 target bins filled at the same time. This big amount of target bins is needed because the bin2bin picking process uses the picking modes batch picking and in addition to this wave picking. While the picking waves are released in accordance with the tour plans, which means that the orders are consolidated and the picking procedure starts a certain period of time in advance to be ready on time, a picking batch represents a certain amount of orders with a preferably high

amount of congruent articles. This means, an operator is able to pick the articles from one source bin to several target bins, which represent different customer orders.

To achieve a maximum performance, the orders have to be collected and processed in advance to accumulate the orders which have the highest possible number of congruent articles and can for this reason be picked at the same time. So the received orders are downloaded at a certain point in time for grouping the single orders to batches and even waves. This process is done shortly after midnight to have this information available in the morning hours. Whereas a single day is separate into several picking waves in accordance with the departure times of the trucks to the planned destinations, each wave is split into single batches, each of which is allocated to a picking finger. The warehouse management system procures that the workload is evenly distributed to the single picking stations within a single picking wave. Having finished the allocation of the order batches to the single picking stations, the operators are able to start with picking.

To get a detailed description regarding the picking procedure, we have to consider the tasks that have to be done by the operator to fulfil several order lines belonging to different orders by picking the items of one single source bin. So the starting point of the picking procedure is, if a source tote is delivered to a picking station. Then the operator grabs the required number of items from the source bin and distributes the items to several target totes. The picking procedure is supported by a pick-to-light system, so the operator gets the information presented right next to the target tote how many of a certain article has to be put into which target bin. Having picked all items from one source tote, the tote is put from the station back onto the conveyor technique for being transported back to the picking storage area. Afterwards, the picking procedure can start again when the next source tote arrives at the station. As the target bins represent a part of an order or a complete order, they are just put onto the conveyor technique if all different items were picked into this target bin. Moreover the operator has to fill the spare place within his/her station with another empty target tote.

In addition to this, a standard operating procedure exists, which tells the operator for example, that he/she has to start filling the target bins with articles at the left side of the station and continuing this to the right side of the station. This regulation helps, to keep the "way times" within the picking stations short. But why are we now talking about way times, as we were telling before that the way times cease to exist when using the picking principle goods-to-man? This is, because the picking stations are this huge, that we have to consider

a small amount of way times, which leads us directly to the next issue – which critical issues we have to expect when doing labour management for the bin2bin picking process.

4.3.5 Critical issues regarding labour management

Having now given a description of the bin2bin picking process, we will now have to define a base unit for being able to measure the performance of the operators as well as the workload of this process. In addition to this, we will have to find out which factors may become the critical ones when doing labour management for this process.

As the performance of the operators and the workload of the process is actually measured by the number of single units that have been picked, we are going to adopt this unit for our considerations in the beginning because for a basic version of a labour management tool the accuracy of the data will be sufficient. If we would like to increase the level of detail regarding the method of calculation, we will have to analyse the adequacy of the base unit. But while measuring the performance and the workload of the process, we will have to consider some critical issues, such as waiting times of the operators, additional time consumptions within the picking area and performance decreases due to the picking principle. These critical factors shall now be described in detail.

The first critical issue to be described are the limitations due to the conveyor technique, because there is only one lane available for the source bins, which are transported from the picking storage area to the picking area, per picking finger. So the one lane has to supply the three picking stations, which belong to one finger. For this reason, we have to consider a certain amount of waiting times. If there are three operators, whose performance values differ widely, distributed to one finger, the slowest of these operators may block the activities of the other operators due to the limitations of the conveyor technique given above. The result will be a higher amount of waiting times than necessary and therefore a decrease in process performance. Hence the operators being allocated to one picking finger should be able to provide nearly the same performance values.

Another point that partly results from the limitation of the conveyor technique is a decrease of the picking performance at the end of a picking wave. The other part is based on the fact that the number of congruent articles regarding the orders also decreases at the end of a picking wave and for this reason the conveyor technique has to transport more and more bins. As mentioned before, the orders are evenly spread to the single fingers and picking stations. Moreover for a single picking station the WMS provides a sequence of orders which has a preferably high amount of articles in it. So for the starting period of an order batch at one finger we are able to say that a maximum of orders is fulfilled out of a minimum of

source bins. A further point that has to be considered is that if one operator at a finger still has to fulfil orders belonging to – to give an example – picking wave one, the other two operators at this finger have to wait until the last orders of wave one have been done and so the order batches from the next picking wave can be released to this finger.

To shortly sum up these critical issues, we may get a large amount of waiting times which are not caused by the operators, but which decrease the performance values anyway.

Finally we have to consider different additional time consumptions within the picking area. As mentioned before, we have to consider a small amount of way times due to the batch picking principle but due to the standard operating procedure we can assume that the values are nearly equal. Another time factor is the handling time of single items, because – for example – china products are consuming more handling time than plastic toys. But for a basic labour management tool we assume that over the whole day the handling times of the single items are equally distributed because one operator will not be picking china products the whole day. To shortly remain with the china products, the operator will have to apply some staffing to protect the material. As this material is centrally stored at each picking finger, the operator has to move to this position which consumes a certain amount of additional way time.

Even if an operator's task is not to check whether the correct goods are in the source bin, which is the job of the operators within the decanting area, but he/she may have to do some error handling due to decanting faults. This means, that some goods may still be stored in a bundle, whereas some single items of this bundle are required to fulfil the customer order. So this is a problem, which could be avoided but as long as this problem exists, it decreases the picking performance because of decanting errors being very frequent.

4.4   Warehouse process "decanting"

Within this chapter we are going to analyse the warehouse process "decanting" and give an idea about the importance of the process for all further operations within the distribution centre of John Lewis Partnership. Thereafter we are going to separate the process into its single tasks which allows us to get to know all the data required for being able to do labour management. Moreover we have to mention some of the critical issues that may affect a labour management tool.

4.4.1 Definition and importance of decanting

While the name of the process "decanting" lets us assume a very simple process, it describes a very complex and important process within the distribution centre. The main idea behind

the process is to change the loading equipment from palletised cartons to bins and at the same time remove the goods from the cartons. The empty cartons are collected centrally for disposal. Even if single cartons would be conveyable items, they still have different sizes and are more likely to cause problems within the conveyor technique. For this reason there are only used two different sizes of standardised bins within the conveyor systems and so the change of the loading equipment is required.

The decanting process is the connection between the receiving area respectively very-narrow-aisle storage area, which delivers the input for the decanting process, and the picking storage areas (e.g. "miniload"), where the output of the decanting process is delivered to via conveyor technique. For this reason the decanting process is essential for the further warehouse operations because it provides the replenishment of goods for several picking storage areas and therefore enables the picking processes to work properly.

4.4.2 Process description and single tasks

After having mentioned the aim of the decanting process and its importance for the material flow we now have to describe which single steps have to be executed by an operator to get the goods from the palletised cartons into the bins, which are used for the further warehousing operations.

At first a pallet with cartons stacked on it is brought to a decant station by a forklift truck, if the station is 'open' or available for the next piece of work. This is the starting point for an operator working within the decanting area. To start with decanting, the operator takes a carton, brings it to his/her station and opens it. Then the operator has to check, if the carton contains the correct goods. If so, the operator has to tell the system which goods he/she is going to decant and as a result the operator gets the information which kind of bin is needed for this kind of goods from the system. After that he/she takes a bin accordingly from the conveyor system which supplies the station with empty totes. Subsequently the operator gets the goods out of the carton and puts it into the bin, and then he/she has to confirm the amount of decanted goods and in some cases the size (e.g. clothes) to the system and moreover to scan the unique barcode of the tote so that the system knows which goods are in what tote. Afterwards he/she puts the bin onto the conveyor system, which transports it to the picking storage area. Then the operator puts the empty carton onto the waste conveyor, which collects the packaging material at a central point for disposal. The operator has to repeat this procedure until the pallet is empty. After that the whole procedure starts again, when a 'new' pallet is transported to the operator's station as soon as the station is

'open'. In the optimal case, the next pallet is already situated on the second pallet lift if the operator is ready with the first pallet.

If the carton size is too big and for this reason not all the articles comprised within the carton will fit into one bin, the content of one carton hast to be split and put into several bins. On the opposite, if the bundle size is very small, the operator may be able to put the content of two or more cartons into one bin. But putting the content of more than one carton into one bin is avoided in most cases, so we are able to say that mainly one carton equals one bin.

So as we just have found out, we have two different repetitive task groups to do within this process. On the one hand, grabbing the items out of an open carton and putting it into the target bin, on the other hand from opening a carton to putting the packaging material onto the waste conveyor if the carton is empty. If we put all these tasks together, the task sequence will be as follows (see Figure 4).
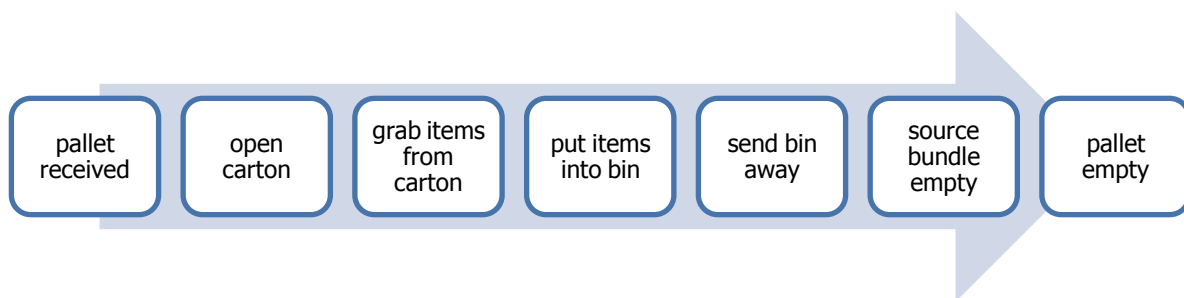
Figure 4: Sequence of tasks of "decanting"

4.4.3 Critical issues regarding labour management

Just describing the standard procedure of the decanting process, we will now have to give an idea of how to measure the performance and the workload of the decanting process. Moreover we will have to state which influencing factors may be critical when doing labour management within the decanting area.

The first critical issue is to find an appropriate base unit for measuring the performance of the decanting process because due to a wide range of products, the handling times of the goods have a wide variety. This can be illustrated by mentioning an example: a pallet with cartons containing china products like teapots will consume – due to their fragility – a larger amount of time than plastic toys. So just using the average handling time for a whole pallet will not be correct reference parameter for our further considerations. But also using the cartons as a reference will not be ideal, because the cartons have different sizes and for this reason a varying number of items in it. Just to think of an example: While of the teapot usually one teapot equals one carton, there will fit hundreds of knobs into a carton.

This example lets us assume, that a performance and workload analysis on basis of the number of items decanted will also not be accurate. So for this reason we are going to measure the performance respectively the workload on basis of single units, which for example means one single teapot and one small package of knobs. As there will still remain variances in handling times, we will have to think about considering the product group when analysing performance and workload data. In addition to this, we may have to consider the number of pallets, the number of items and the number of bins created too.

Another point to be considered is the rate of random influences like damaged packages, damaged goods and packages with wrong content. If these disruptive factors occur, they consume a certain amount of extra time due to problem handling. But this extra time consumption is not tracked by the system, so we do not have valuable information about the error rate. This is, because these problems do in fact have a negative influence on the performance of an operator but when calculating with average values, the outliers are mostly filtered out.

An additional question that arises is, to what extent the warehouse management system is able to balance the workload of the decanting process so that all operators working within the decanting area are constantly employed.

4.5 Warehouse process "receiving"

In this chapter we are going to analyse the warehouse process "receiving", which is essential for warehousing too, because without receiving any replenishment of goods, no other warehouse process will be able to work. To start with receiving, a short definition is to be given. After that the importance of this process is to be argued and thereafter, the problems of a receiving area shall be stated using the example of the John Lewis distribution centre. Afterwards we have to find out, which information is needed as input for the labour management modules for being able to estimate the number of operators required within the receiving area.

4.5.1 Definition and importance of receiving

To begin with the analysis of the receiving process we have to give a short definition which is as follows: "The receiving process is the first stage of the warehousing process and involves the actual physical receipt of the purchased goods from the transporter."[119] As the goods receipt is of vital importance for the further material flow and the further warehousing operations, we can state that receiving "is important, as it forms the basis for all the

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[119] [Voor2004], p. 56

subsequent activities of the warehouse. For example, goods need to be passed through receiving rapidly so that they are available for picking customer orders, and this must be carried out with a high degree of accuracy to ensure that the correct goods are received and located in their assigned locations."[120] So the operators working within the process have to work very accurately because "operational failures in […] these areas will quickly result in service level failures, which may be damaging to the company and may be costly to rectify."[121]

For this reason using a labour management tool for the receiving process is very critical. If there are too little operators working within the receiving area this will not only have serious consequences for the further material flow but also for the carriers, whose trucks will have to wait much longer than planned.

4.5.2 Process description and single tasks

As far as our further considerations are concerned, we assume that the deliveries of the replenishment of goods to the distribution centre are done by truck exclusively.

To get to know which basic information we need for labour management, we first need to know which tasks have to be performed for the unloading procedure for a whole truck load. For this reason we have to analyse this process in detail, like we did with the picking and the decanting process before. The starting point of our considerations is, if the trailer is in the dock and the door is open, which allows the operators to start with the unloading procedure. The separation into two tasks is, because the truck may already be at the dock but the unloading procedure has not started yet. The next three tasks are repetitive ones; they have to be performed for each single package within the delivery. First the operator has to move to the package for bringing it from the truck to the receiving area in the warehouse. This means he/she has to put the packages into the unloading zones, which are marked for each dock separately. Second he/she has to register the goods receipt either by scanning a barcode on the package or checking the documents, confirm the delivery onto them and enter this information into the system. While just scanning a barcode is a relatively short procedure, the handling of written documents is a very time consuming procedure, which reduces the performance values of an operator. Having confirmed the receipt of the goods, they can be placed onto the defined location mentioned above, where the operator of the following process is able to take the goods over. After the confirmation that the truck has been completely unloaded, the unloading procedure is done and the truck is able to leave

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[120] [RuCrBa2006], p. 18
[121] [RuCrBa2006], p. 18

the dock. The single tasks that have to be performed during the unloading procedure are shown in Figure 5.
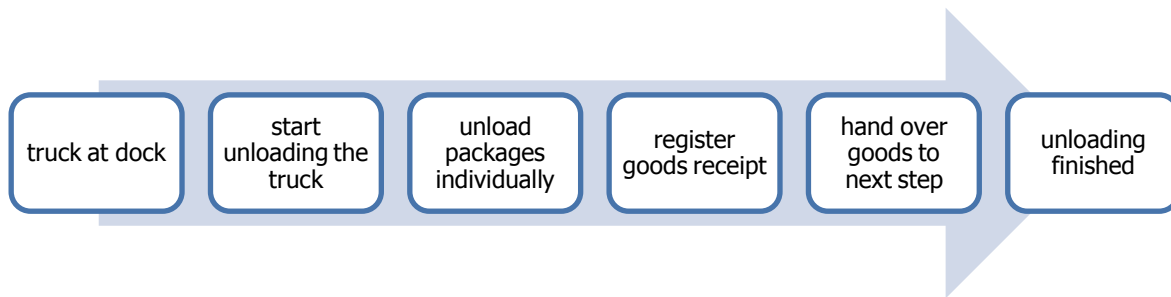
Figure 5: Sequence of tasks of "receiving"

This knowledge now enables us to give a basic idea, which data will be necessary for being able to do labour management for the receiving process. But before, we have to discuss some critical issues regarding the receiving process.

4.5.3 Critical issues regarding labour management

Before thinking of which information will be necessary for being able to do labour management for the receiving process, we have to discuss some critical issues. To get a better view of possible problems, we consider the receiving process regarding the John Lewis distribution centre.

At first we have to consider that there are several different package types to be handled, which have different handling times and moreover require a different amount of operators. We have to distinguish between cartons and pallets, but they are provided in different amounts to the warehouse. While for unloading a lorry which contains only palletised goods one operator is enough, for unloading loose cartons there are two to three operators required. Moreover we have to distinguish between two situations, on the one hand if there are only some loose cartons on the loading platform of a lorry which can be taken easily by operators and on the other hand if the cartons are stacked into a 40 feet box container, where the cartons are difficult to grab. Due to the different package sizes there can be huge fluctuations regarding the workload because if a complete container arrives there may be 20.000 units in it at once. For being able to compare the performances of the single operators to each other and moreover to make the workload planning more easy, we will have to define a common base unit. As there is a big difference between the package sizes, our first approach is to define the number of units as base unit.

Even if we get a notice in advance[122] how many trucks and how many items will arrive at the distribution centre on a certain day, on the one hand this notice may be too late, so it cannot be used for an accurate planning regarding the number of operators and on the other hand the appointment bookings may simply be wrong. Just to provide an example regarding clothing. If the procurement department of the company orders clothing for the winter season 2010 overseas in January, at the same time an appointment booking is made at the distribution centre according to the confirmed delivery date, for having the unloading capacity available. The appointment booking also contains the number of units that are expected. As it may be, the company has to reduce the order due to financial reasons, the appointment booking stays constant. So even if the number of units that can be expected on a certain day is planned well in advance, we are not able to take these amounts for real.

Another problem is also referring to the goods coming from overseas. If the goods are not appointment booked well in advance, the distribution centre gets the notice that the goods will arrive shortly at the distribution centre, when the containers with the goods arrive at the port of destination which means a time span of around 2 days. But if we would like to plan the demand regarding the operators needed so to say at least 7 days in advance, this figures are too late for being considered within the planning process. But even if a reaction on this situation was possible, there still remains the problem, if the container arrives at the distribution centre at the wrong day despite the short term appointment booking.

A further issue regarding the receiving process are some kind of special promotions. To give an example, we are talking about special promotions regarding a famous music player of a global company.[123] If this company provides a hardware update to the music player, a delivery of about 10.000 music players will arrive at the John Lewis distribution centre without any order of the John Lewis partnership. The first process affected by this matter is without doubt the receiving process, but this will also have an influence on the further processes within the warehouse.

To sum up shortly, the examples given above shall point up the big fluctuations regarding the workload within the receiving area. Due to these fluctuations doing labour management for the receiving process will be a challenge.

Yet another critical issue is how to consider the time consumption of several problems at the receiving area due to not knowing the error rate. Problems within the receiving area can for

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[122] Notice in advance: This can be an approximate advice from the customer or an exact one (ASN), which contains all important data like exact delivery time, how many packages, which kind of packages, etc.
[123] Not to mention any name but the logo contains a fruit.

instance be damaged packages, missing packages or even be problems with the documents. As these troubles consume a high amount of extra time if they occur frequently, we have to think about a possibility to consider this matter when doing labour management.

5   Concept for a labour management tool

The target of this master thesis is to create a concept for a labour management tool, which shall be integrated into a warehouse management system later on. The implementation of this tool at once would be a difficult thing to do, so the single tasks that have to be done shall be represented by single modules. Within this chapter we have to discuss, which modules are required for being able to do labour management.
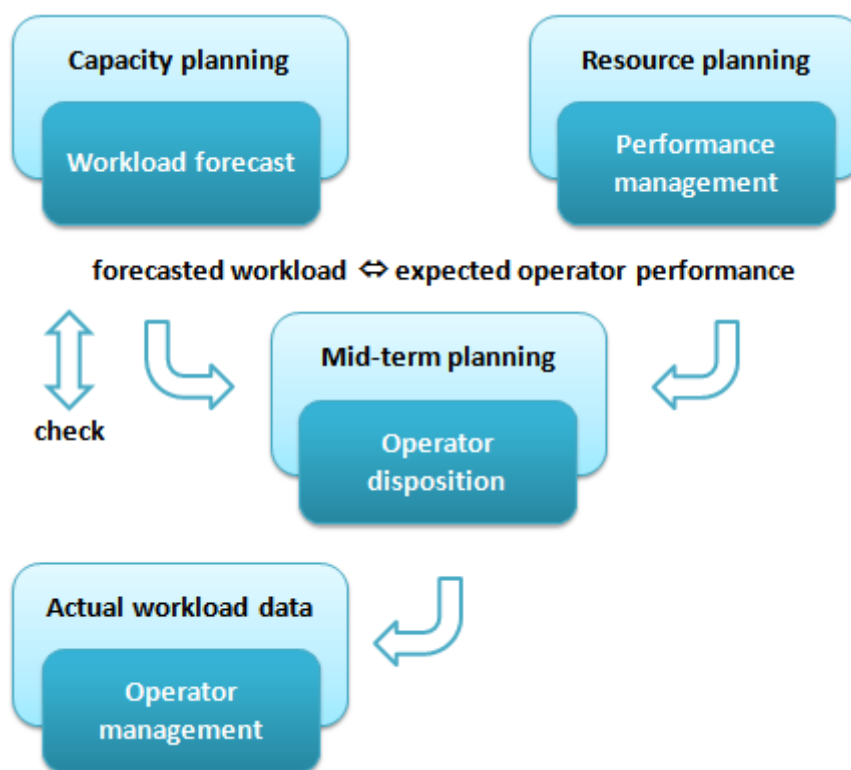
Figure 6: Modules for labour management

The main target of a labour management tool is to get the number of operators required for an estimated workload on a certain day and moreover to distribute the operators to single shifts. For this purpose, we will have to measure and analyse the performance of the operators to get an idea about the amount of work that a single operator is able to cope with on average within a certain period of time. This module is part of the resource planning described in chapter 3.3.2 and its task is to achieve operator performance information which can be used for determining the number of operators. Next we will need to know the expected workload for a whole day based on the analysis of historical data. For this reason

we have to create a module for workload forecasting, which represents the capacity planning (see chapter 3.3.1). When having the results of these two modules, we have to combine this information together, which will be the task of another module. This module shall calculate the number of operators needed and give an idea when they are allocated best within the day according to the expected workload fluctuations. Moreover we would like to provide daily information about the accuracy of the forecast and about the options to take, if there is a big difference between the forecast and the actual amount of work. These modules are now going to be described in detail.

As mentioned within the chapter regarding resource planning (see chapter 3.3.2), our further calculations should be based on time units. But from the performance measurement point of view it is completely negligible if we measure how much time is needed to handle one unit or how many units are handled within a certain period of time. So we are going to define a base unit for each process, which can be for example single units, SKUs, bundles or even store packs (cartons). This depends on the fact, which unit will deliver the most precise results. Moreover we do have indeed the net working times available within the warehouse management system plus the time, an operator is logged in at a station but the exact relation to the gross working time is missing (due to a lack of measurement of the gross working times). In addition to this, we are not able to simply apply the net time given within the literature, because this time is not necessarily appropriate due to the waiting times which are caused by the conveyor systems.

These waiting times are not considered within the literature and moreover differ for each warehouse process because of a different layout of the conveyors. So the measurement of the net working time is an important issue due to the fact that we would like to achieve precise information regarding the effective working time of an operator which finally results in an utilisation indicator. A further issue is, that the working time, which is used for the handling of problems, and the frequency of occurrence of problems are not available in the system either. But if the problems occur frequently, they decrease the performance and are for this reason indirectly measured.

5.1 Module "Performance management"

One part of the basic information needed for doing labour management is collecting and analysing performance data because we need to know what amount of work an operators is able to cope with in a certain period of time on average. To start with this module we first have to define the targets of the module and the reports required. After defining this, we

have to state which input data is needed and how to analyse the performance data to get a valuable result that can be used for further calculations.

5.1.1 Targets

Within the module performance management we are aiming to get to know the average performance per operator and hour and moreover per operator type and hour. The average calculation shall be based on a 14 day moving average. Having the average values available, this will enable us to compare the average performance one operator is able to provide to another operator's average performance respectively allow us to compare the performance of several operator types to each other type. For providing the basic functionality these calculations will be sufficient, but for creating a more sophisticated performance management module some additional features will be of avail. For this reason we would like to get an overview of the skills respectively trainings of each operator, to get the information in which areas of a warehouse he/she is allowed to work. So, we will have to add some performance indicators to the module, such as the average performance per warehouse area, and some basic information regarding the operator utilisation, for instance the gross and the net working time. Furthermore the performance measurement shall be an incentive for the operators by simply letting them know that their performance is measured.

The logistical relevance of this module is on the one hand to have key performance indicators per operator available to manage a single operator's performance, for example send him/her to re-training if the performance decreases significantly. On the other hand the performance data can be used to identify potential disruptive factors regarding the material flow in a negative way which may be the worst case if operators which are providing a suboptimal performance have been allocated to single processes. Furthermore the measurement of an operator's performance can be considered as incentive for the operators to obtain or improve their performance.

5.1.2 Reports required (output)

To match the aim which was defined before, we are going to need two reports, which represent the output of the module. First we have to calculate the average performance value per operator and per hour of the day[124] for each of the considered processes and second the average performance value per operator type, also per hour of the day.

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[124] The advantage of collecting performance data on hourly basis is having this information available independently of any shift model.

5.1.3 Data required (input)

The basic input data which will be needed for doing the calculations are the operator identifier, the type of an operator, the date, calendar week, weekday and hour of the day, and the number of units/bundles/etc. that have been done within a certain period of time by a certain operator.

Having defined the basic requirements of the module, we can now think about which calculations will be needed to achieve the desired results.

5.1.4 Performance analysis

Within this chapter we are going to explain how to collect and analyse the performance data for achieving the required information which is used for the further calculations within another module.

5.1.4.1   Basic statements

Before starting to collect performance data, we have to state that this information shall be available on the basis of single hours because we would like to get performance information which is completely independent of any shift model. So for the further planning activities, which will be done by another module, the performance information can be extracted according to the shift model, which is going to be applied later on, in addition to the planned working duration and the points of time, when a certain operator type is allowed to start working.

Another point we have to consider before collecting and analysing performance data is that it will be necessary to distinguish between different types of operators that are working within a warehouse. The minimum of categorising would be a distinction between full-time and part-time workers due to the fact that part-time workers do not have any planned breaks. A further distinction will be necessary, if there is out-sourced staff, which is provided by a personnel service agency, employed in the warehouse. This further splitting is not done for performance reasons, which means that we would assume that either the company's own employees (permanent staff) or the staff provided by the agency delivers a worse performance, but for further planning reasons, because the company's own employees are allocated to the processes first and therefore we are going to need separate performance values. Just to give an example regarding the distinction between the different types of operators, as far as the distribution centre of John Lewis partnership is concerned we have to distinguish between full-time workers, either employed by John Lewis itself or provided by the agency, and part-time workers which are out-sourced staff as well.

Moreover for keeping the analysis of data simple in the beginning, we are going to start with separate performance tables for each considered warehouse process. But to get a more sophisticated performance management tool, we will have to connect this information later on.

5.1.4.2   Building performance tables

The starting point of the performance analysis is to get performance information of each single operator on an hourly basis for each considered process which means that we have to analyse what amount of work he/she has done within a certain period of time during a day. But keeping this amount of data for each day over several months and years would consume an exaggerating amount of hard disk space, so we have to condense the huge amount of data. For this reason we assume, that an operator is able to provide the same performance time-line throughout the day and even the whole week, which allows us to calculate an average performance value of each hour of the day for having the data available completely independent of any shift pattern. Hence the basic performance table per operator will have to contain the following information per operator and process: operator ID, the average performance values for each hour of the day and the data regarding the operator type.

Having the performance information available per single operator, we are now able to achieve the average performance values per operator type based on the information we have gained before. For this reason we are going to condense the information by using the operator type to get the average performance value per hour of the day and operator type.

But calculating an average performance value from the time of the entrance of an operator into business up to the actual day will lead to wrong calculations when using the average performance value. This is, because we can assume that the performance of an operator is increasing when his/her training is finished and he/she gets more and more experienced while working on the job. For this reason the hourly performance values have to be calculated by using the principle of moving average for a certain number of working days, for example for the last 14 days. The amount of days to be considered has to be prompted by the user. The principle of moving average is, when adding a new value to the data, the 'oldest' information is going to be eliminated. Using this method for calculating an average performance value will help to 'adjust' the performance values 'quickly', if for example a standard operation procedure changes resulting in a significant increase of operator performance.

Up to now, we have built basic performance tables containing the average performance values for each operator respectively operator type for each considered warehouse process

separately. So the first table provides the information, which operator was able to cope with what amount of work on average within the last 14 days on an hourly basis. As mentioned before, the target is to get an average value of how many units an operator of a certain type was able to handle within a certain hour of the day on average, which will be used as input data for the further planning activities to be done by another module.

The separate performance tables being available at the moment will provide the basis for our further calculations. To achieve a more sophisticated labour management tool, the information of the single tables has to be linked. The linkage can be used for being able to tell what skills an operator has because we can assume that an operator only is allowed to work within a certain area if he/she is trained to do so.

Due to the fact that the performance values of the single warehouse processes cannot be compared to each other if their base unit is not the same, we have to think about how to make the data comparable. For being able to compare the performance values of the operators of several warehouse areas to each other, we will first have to define a so called 'standard performance value' for each warehouse process. This standard value represents the expected respectively calculated standard performance value for a certain warehouse process. Having defined respectively determined this value we are able to compare the operator performance to the standard performance value which means we can create statements as follows: 'operator xy has achieved 112 percent of the standard performance within process 1'. When the performance information is connected by the operator identifier, we are moreover able to say 'operator xy has achieved 112 percent while working at area 1 whereas he/she is only achieving 96 percent while working at area 3'. As the percentage is calculated the same way for each warehouse process, this factor can be used for a comparison regarding the performance an operator (type) is able to provide within different warehouse areas.

5.1.5 Additional notes

The customer should think of involving a time and attendance system, which is able to provide the information of how long an operator is actually present at the warehouse and therefore allows measuring the utilisation exactly, which means we are able to determine the ratio of the log-in time (operator is at the station ready for working) to attendance time (operator at the warehouse) and moreover of the net working time (operator at the station and working) to the log-in time. As the difference between the log-in time and the net working time is called waiting time and represents the time span when the operator is ready

to work but has to wait for the next piece of work due to limitations of the conveyor technique for example.

Even if such a system is not fundamental regarding the functionality of the module, it would be a desirable enhancement with respect to a highly sophisticated performance measurement tool especially regarding the operator utilisation. So a time and attendance system will be an add-on to the performance module which we have described before. To get the required information from the system (name, ID, date, time in and out), we will have to supply an interface for getting the desired data. Moreover this kind of measurement can be important to determine further starting points regarding the utilisation of the operators.

Having now the information regarding the average performance of each type of operator available, which is one important part of the basic information needed for calculating the number of operators required, we will now have to describe the second part of important information which is needed.

5.2 Module "Workload forecast"

The second main part of information needed for doing labour management is to get an idea about the future situation concerning the workload of the warehouse processes to be considered. An analysis of historical data will provide the basis for the estimation. To start with the description of this module we have to define the targets of the module and the reports required, which finally allows us to define the input data needed and to give a proposal for calculating an estimation concerning a future workload.

5.2.1 Targets

The objective of this module is to achieve an estimation regarding the future workload situation for a certain week, day and even hour of the day. We would like to get the forecasted values at least a week in advanced but this span of time will be defined differently for each warehouse. Whereas only the forecast of the whole week will be forecasted, we have to refine this value to the single workdays and the single hour of the days by using the typical weekly workload pattern respectively the typical daily workload pattern, which has to be determined before. In addition to this, we would like to offer a data basis for providing the opportunity to do a long-term data analysis with respect to seasonal fluctuation patterns for example.

The logistical relevance of this module is to provide a solid information basis for being able to estimate the future workload situation which enables us to allocate the resources to the single processes in an optimal way.

5.2.2 Reports required (output)

The reports which are requested by the targets of the module are a workload forecast for the whole week plus the refinement on daily respectively hourly level. In addition to this, both typical workload patterns shall be shown to the user.

5.2.3 Data required (input)

The input data, which will be required for doing the calculations to match the aim given before, will be on the one hand detailed workload data from the recent past and on the other hand weekly workload data from a long period of time. Whereas the workload data of the recent past has to consist of the number of units/bundles/etc. that were processed within an hour, the date, the weekday, the calendar week and the hour of the day, the weekly workload only has to contain the sum of the workload of the whole week plus the identifier for the calendar week. Furthermore we have to implement an additional correction factor ("manual grow rate") for adjusting the weekly workload due to the knowledge about special promotions within a certain week. Moreover we are going to provide the possibility to prompt a certain workload value, which was defined by the planning department before.

5.2.4 Building the forecast

As mentioned before, the target of this module is to get a forecast regarding the expected workload for a certain process. This forecast has to be done "top down", which means we estimate the future workload of a whole week first and have to refine it to a daily and even hourly level afterwards. The basis for forecasting will be an intense analysis of historical workload data. For our further considerations we assume, that we have the workload data available for the last year in addition to the data of the actual year. For improving the quality of the forecast, we would need to compare the workload patterns of more years to each other for being able to analyse the typical seasonal patterns.

5.2.4.1   Estimate workload for a whole week

Due to the explanations above, the first task will be an estimation of the workload of a complete week. But for being able to estimate the workload for a whole week, we have to analyse the historical data of a whole year regarding the workload of complete weeks. For this reason we have to sum up the amount of work that was done within a certain week in accordance with the chosen base unit, which means that we have 52 to 53 values available for our further considerations. Moreover we will use some actual weekly workload data from the past few weeks and compare this information to the correlative historical workload data.

The starting point of our further calculations will be a factor, which will be called "calculated grow rate". This factor represents the comparison of the amount of work of the actual year

to historical workload data of the last year and tells us, if within the actual year was either less work done than within the last year or even more work. To find the calculated grow rate we have to compare the same periods of the actual and historical data, which means that we have to compare the same calendar weeks of the two data series to each other. But we have to give the user the possibility to decide, how many weeks the system has to compare in retrospect, from two to twelve weeks.

Just to give an example for illustrating the calculation method, we are at week 10 of the year 2010 actually. If the user decides that the system should compare 6 weeks, we have to check the actual workload data of week 4 to week 9 of the actual year against the historical workload data of the same calendar weeks in 2009.
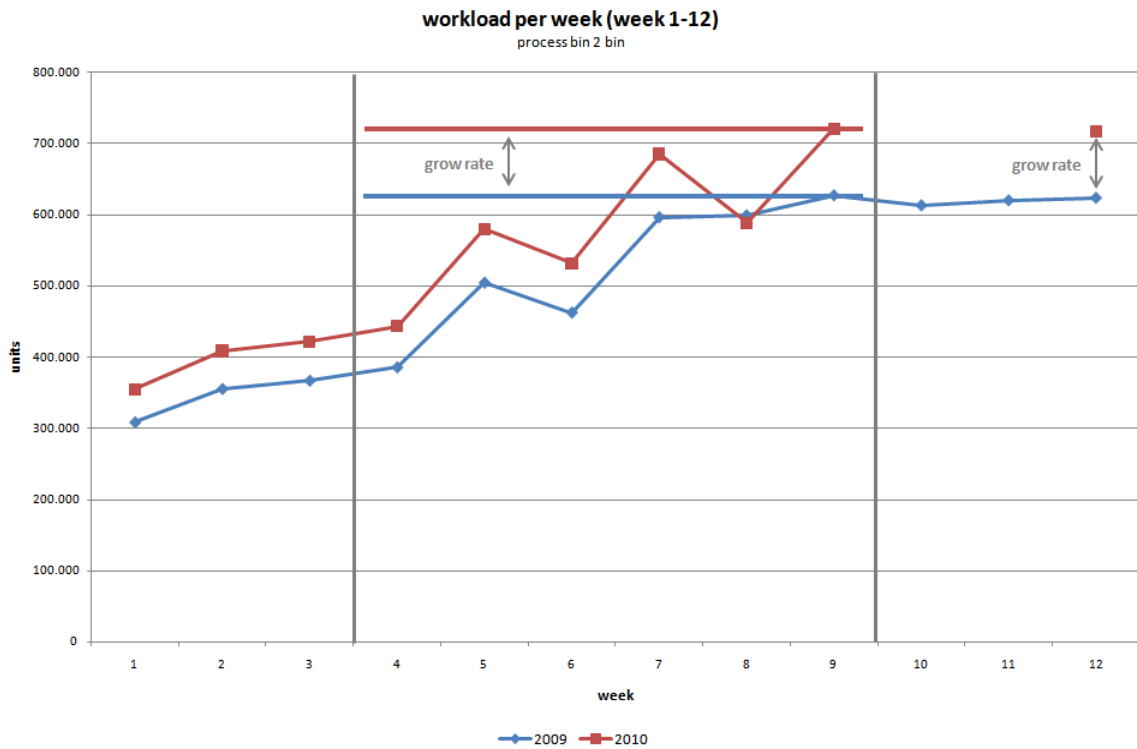
Figure 7: Determining the calculated grow rate

Within these arrays of data, the system has to scan for the maximum value of the chosen periods in 2010 and 2009. Afterwards we will have to divide the maximum value of 2010 through the maximum of 2009. The searching for the peaks using more weeks of the historical and actual data is to get a more precise grow rate due to the fact that there may be some small postponements regarding the workload peaks within this period.

$$calculated\ grow\ rate = \frac{maximum\ of\ considered\ period\ 2010}{maximum\ of\ considered\ period\ 2009}$$

Equation 1: Computation of calculated grow rate

The calculated grow rate represents the percentages of growth respectively decrease regarding the workload after a comparison of the two series of data. If the value is greater than one, there was an increase concerning the amount of work, and if the value is less than one, the workload has decreased in comparison to the last year.

As we now know the calculated grow rate, this will be a basis for forecasting the weekly amount of workload. To illustrate the forecasting method that has to be implemented within this module, we have to continue the example given above. So let's assume we are now in the mid of week 10 of 2010, the last 6 weeks have been analysed to get the calculated grow rate, which will help us with forecasting the amount of work within week 12. But why are we doing a forecast for week 12, if we are just in week 10? This is – to extend our example – because we would like to know the number of operators required at least 7 days in advance and for this reason we need the expected workload, which has to be provided by this module, at the same time. To obtain the expected workload for the whole week 12 in 2010, we have to multiply the workload of the same week in 2009 with the calculated grow rate.

$$workload\ week\ 12\_2010 = workload\ week\ 12\_2009 * calculated\ grow\ rate$$

Equation 2: Forecasting the workload of a whole week

Moreover we will have to add an additional scaling factor, called "manual grow rate", to the calculation which allows making adjustments to either reduce or increase the expected workload manually for a whole week due to the knowledge about for example special sales promotions[125], decisions of the resource planning department or even due to the effects of the economical crisis. To give an example, we got to know the amount of work to be done within week 12 by multiplying the according historical value with the calculated grow rate as stated above. If the resources planning department gets to know, that there will be a special sales promotion within week 12 and for this reason the planned workload has to be increased additionally by 5 percent, the manual grow rate will be 1.05. To adjust the originally estimated workload according to the decision of the resource planning department, we will have to multiply the original value with the manual grow rate.

$$adjusted\ workload\ week\ 12\_2010$$
$$= forceastedworkload\ week\ 12\_2010 * manual\ grow\ rate$$

Equation 3: Adjusting forecast using manual grow rate

Just to state another example, if the planning department thinks that there will be a diminution of work to the extent of 10 percent due to the effects of the economical crisis, this will result in a manual grow rate of 0.9.

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[125] Special sales promotions due to the Olympic Games, soccer world championship, etc.

After having calculated the forecast concerning the expected workload – according to our example for week 12 of 2010 – and having adjusted this value by using the manual grow rate if needed, we can now use this information to increase the level of detail and therefore calculate the expected daily workload.

In addition to calculating the weekly forecast based on historical data by using the calculated and/or the manual grow rate, we have to consider another strategy for forecasting. This means the basis for our weekly forecast is a workload value delivered by the planning department. For this reason, in dependency of the considered process, this value will be either called "sales forecast" or "order forecast" and 'overrides' the calculations that would be done concerning the weekly workload.

5.2.4.2   Identifying the typical weekly workload pattern

As we just got to know the estimated amount of work that will have to be done within a certain week, we now have to refine the results to the daily level. For this reason we will have to identify the typical weekly workload pattern first, which will help us while allocating a certain amount of the expected weekly workload to the single days. The typical weekly workload pattern contains a certain percentage for each day, which represents the ratio of average daily workload in relation to the average weekly workload. Using this typical weekly pattern based on an average calculation over the workload of several weeks can be considered as accurate due to – especially as far as the picking process is concerned – fixed tour plans to the retail stores, which are receiving replenishment of goods only on a certain days within one week. On this account we can assume, that the typical weekly workload pattern considers this "rhythm" of deliveries. Moreover we can assume that all the other processes within a warehouse have recurring patterns concerning the workload.

For discovering the typical weekly workload pattern for each single process, we are going to use the historical data of at least four weeks[126] (or even the complete last year). The starting point of our calculation will be building average workload values for each single day of the week and moreover an average workload of the whole week. We have to calculate the average workload values according to the amount of weeks that have been chosen by the user before. As we have calculated the average workload for each single day, we can put it in relation to the average workload for the complete week. The result is then a certain percentage, which characterises the amount of work that typically was done on a certain day

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[126] The amount of weeks is a variable parameter, which can be modified by the user. But there should be a limitation regarding a minimum, so this would be at least 4 weeks.

of the week. Just to give an example, we will provide the formula for the calculation of the percentage of Monday.

$$percentage\ of\ Monday = \frac{average\ workload\ of\ Monday}{average\ workload\ of\ week} * 100$$

Equation 4: Percentage of a certain weekday (example)

So to extend this example, we will be able to say, that on a Monday within the considered period of time there was typically done 15.9 percent of the weekly amount of work. Having the percentage for Monday available, we will have to finish the typical weekly workload pattern by calculating the percentages of the other weekdays in an analogue way. An example for a typical weekly workload pattern is shown in Figure 8. The Saturday was filtered within this chart, because the example data delivered 0.0 percent.
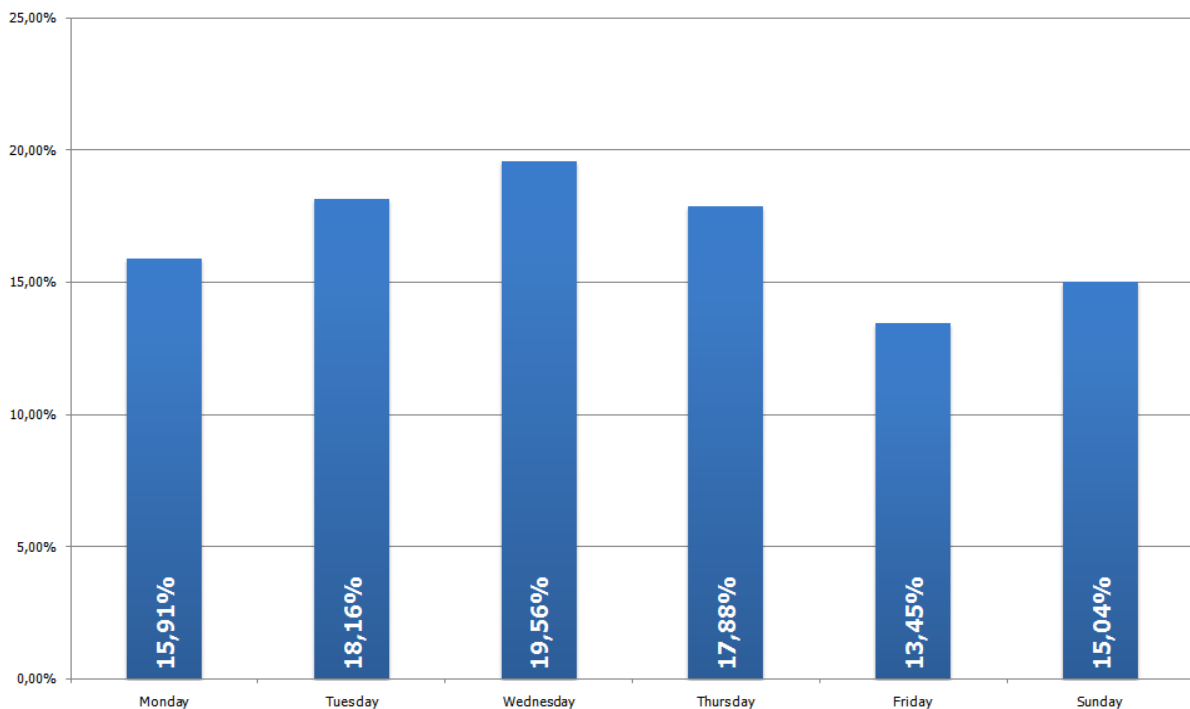
Figure 8: Typical weekly workload pattern

5.2.4.3　　Estimating the daily workload

Having the typical weekly workload pattern available, we are now able to combine it with the value of the forecasted amount of weekly workload to get the estimated daily amount of workload. Therefore we have to multiply the weekly workload with the percentage of a certain day. To remain with our example given above, the formula for the calculation of the workload for Monday is as follows:

$$estimated\ workload\ Monday = estimated\ workload\ for\ week * percentage\ of\ Monday$$

Equation 5: Estimation of daily workload (example)

This calculation has to be done for the rest of the weekdays in an analogue way. The result is a daily workload in relation to the forecasted weekly workload, which will provide the basis for further refinement.

5.2.4.4   Identifying the typical daily workload pattern

After having determined the daily workload, the next step is to find the typical daily workload pattern, which represents the typical in-day fluctuations of the workload, for being able to refine the forecast to an hourly level. Moreover the typical daily workload pattern helps us with allocating the operators throughout the day in an optimal way. This pattern has to be calculated similarly to the typical weekly workload pattern, but now representing the percentage of the hourly workload in relation to the workload of a whole day.

Whereas the first idea regarding this pattern was to build a moving average of the hourly workload over 14 days simply ignoring the different weekdays, this idea was rejected because it would lead to big inaccuracies. These would occur due to the fact of different workload patterns on each workday according to the tour plan[127], a problem which was already mentioned before. For this reason we are going to identify a typical daily workload pattern for each workday separately. This means that we have to do a separate analysis of historical workload data for each day of the week, while the amount of weeks to be considered for the typical daily workload pattern is in accordance with the amount of weeks that was considered when determining the typical weekly workload pattern.

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[127] The tour plan affects mainly the picking area.
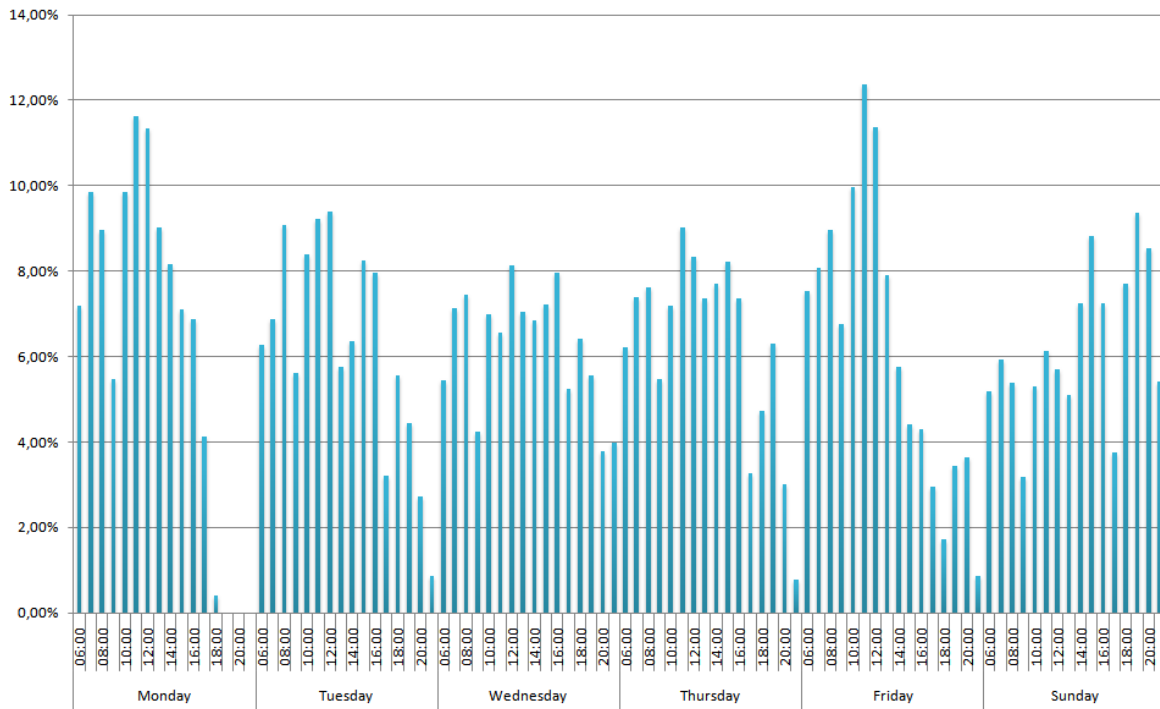
Figure 9: Comparison of the typical daily workload

So the typical daily workload pattern is a relation of the average workload of a certain hour to the average workload of a certain day. This means – to extend our Monday example – that we have to calculate the average workload value from 6 AM to 7 AM regarding the same hour on every Monday within the period to be considered for the typical daily workload pattern. Moreover we put this value in relation to the average workload for whole of Monday, which means we get a certain percentage that represents the amount of work that was typically done within this certain hour in relation to the daily workload.

$$percentage\ hourly\ workload = \frac{average\ workload\ between\ 6\ and\ 7\ AM}{average\ workload\ of\ day} * 100$$

Equation 6: Percentage of hourly workload in relation to daily workload (example)

To get the typical daily workload pattern, this calculation has to be done for all hours of a day and for each workday separately. The results of these calculations allow us to estimate the hourly workload on basis of the expected daily workload. An example for a typical daily workload pattern is shown within Figure 10.
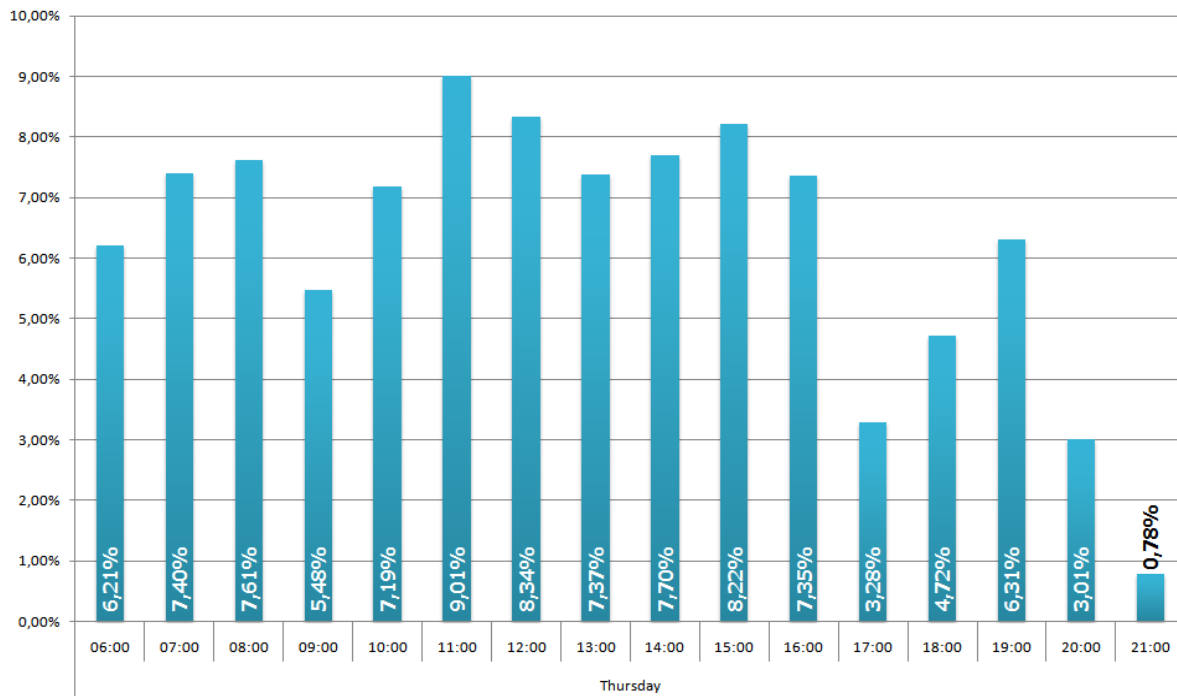
Figure 10: Example for a typical daily workload pattern

5.2.4.5   Estimating the hourly workload

Calculating the hourly workload for a certain day is the maximum level of detail we are going to provide with this tool. By using the typical daily workload pattern, we are able to get the estimated hourly workload for a certain day. For this reason we have to multiply the percentage of an hour with the expected workload for the whole day.

$$estimated\ workload\ hour = estimated\ workload\ day * percentage\ of\ hour$$

Equation 7: Estimation of hourly workload

Just to give an example to explain the calculation in detail, to get the estimated workload for Monday between 6 AM and 7 AM, we have to multiply the estimated workload for Monday with the percentage of the hour between 6 AM and 7 AM. To get the hourly workload for the whole week, we have to repeat this calculation for each hour of a day and for each day of the week. We are going to use the expected workload on basis of single hours for an optimal allocation of the different types of operators throughout the day. For this reason the results of this module are provided to the module "operator disposition", which has to be described next.

5.3   Module "Operator disposition"

As mentioned before we will get the number of operators required out of a comparison of the expected workload to the average performance of an operator multiplied with a certain factor, which finally represents the number of operators required. For this reason the results

of the modules "performance management" and "workload forecast" have to be combined and therefore provide the basis for our further calculations. Our target is not only to get the number of operators needed for a certain warehouse process for a whole day, but also to get an idea when to allocate the operators best throughout the day according to the expected workload fluctuations.

5.3.1 Targets

The target of this module is to achieve a weekly plan regarding the number of operators which is required within a certain shift in accordance with the expected workload. In addition to this, we have to provide this information early enough for either creating a shift plan or handing over the results to a shared personnel agency.

The logistical relevance of this module is to provide the right number of operators of the right operator type to the right processes at the right time for supporting the material flow in an optimal way. Moreover this should help to maximise the utilisation of single operators for being able to reduce dissipation the resource 'operator'. This means we are going to avoid operators just standing around and having no work to do because there are too many working at the same time.

5.3.2 Report required (output)

This module is expected to deliver a weekly plan, which tells the resource planner which amount of operators is required within what period of time per single shift for each type of operator within the considered warehouse.

5.3.3 Data required (input)

The input data for this module are the results of the modules "performance management" and "workload forecast". Due to this fact, we can use on the one hand the average performance values per operator type and on the other hand the estimation regarding the workload for our further calculations. But before doing any calculations, the shift pattern that is used within the warehouse has to be prompted by the user.

5.3.4 Basic statements

As stated before, the target of this module is to get the number of operators required for a certain process and when to employ them best on shift level. But before starting with any of the calculations, we will have to retain some basics in order to keep our further considerations simple at the moment. If we are able to provide the basic functionality of the module and if the module is working properly, we will be able to think about increasing the level of detail.

5.3.4.1   Types of operators

As mentioned before we have to consider that there are several different types of operators within a warehouse. Their main distinctive feature will be the standard working time, so for this reason we will have to distinguish between full-time workers and part-time workers, which are typically employed for less than the standard amount of time. Moreover we have to make a difference between a company's own personnel, which are always in and therefore have to be allocated to the processes with priority, and outsourced staff, which is provided by a personnel service agency.

As far as our further considerations are concerned, we will provide an example for a better understanding of the further remarks regarding the calculation method. For this reason we are going to use the following mix of personnel: full-time workers, which are employed by a company itself, plus full-time workers and part-time workers (for 20 hours a week), which are provided by a personnel service agency. So we are going to assume, that these part-time workers are usually working for five days a week, which means that they are working for four hours a day. Therefore the time span of four hours represents the minimum amount of time that an operator can be distributed throughout the day.

Finally we have to emphasise the sequence, in which the operators have to be allocated to the processes and to be distributed throughout the day. At first we are going to allocate the company's own personnel. If there are more operators needed for being able to cope with the expected workload, we are going to add outsourced personnel, which are provided by a personnel service agency, to the processes in accordance with the expected demand. Moreover we have to define, that the full-time workers of the agency are allocated second, if additional full-time workers are required. Additional part-time workers will be the last ones to be allocated to the processes.

5.3.4.2   Applying a shift pattern

Another point that has to be stated before doing any calculations is that we are going to calculate the number of operators required on shift level. Due to the fact that the performance and the workload forecast data is provided on hourly basis independent of any shift pattern, we will have to apply a shift model within this module first. The shift model enables us to extract the appropriate performance values from the performance matrix and to compare them to the associated workload forecast data of the daily pattern. The shift model to be used for planning has to be defined by the user of this module before doing any further planning activities.

But as there is a huge amount of different shift models available, for being able to explain the calculation scheme in detail, we have to give an example regarding the shift model. For this reason we are just thinking about a warehouse that is actually operated by two shifts, an early shift from 6 AM to 2 PM and a late shift from 2 PM to 10 PM. Moreover the warehouse is operated throughout the whole week, so we have to consider Saturday and Sunday too. This means that the possible starting times, which are to be considered for the calculations, are 6 AM and 2 PM for the full-time workers. But to extend the example given above regarding the types of operators (see chapter 5.3.4.1), we also have to find possible starting times for the part-time workers, which are normally in for 20 hours a week and therefore usually working for four hours a day, too.

As far as the early shift is concerned, there would be a lot of different starting times between 6 AM an 10 PM possible, even if we define that the time span of the early shift limits the working time of the part-time workers, which means they also have to leave at 2 PM. Due to reducing the complexity of the calculations, we are going to limit the number of possible starting times of the part-time workers, which means that within the early shift they are allowed to start either at 6 AM or at 10 AM. This simplification represents the "smallest unit" of working time that can be distributed throughout the day again and is provided by the part-time workers, which are just working for four hours a day. For this reason this "group" of four hours will be used for the further calculations regarding the estimated workload and the performance information.

5.3.5 Calculating number of operators and time of demand

After having identified the types of operators to be considered and having defined the shift pattern to be used, we are going to use this information to find the number of operators required for each type of operator separately. Moreover we have to determine how to employ the operators best throughout the whole day. The ideal version would be to consider every single hour of the day separately, but for the moment we will just simplify the calculations to groups of four hours and increase the level of detail afterwards, if the module is working properly while doing the basic calculations.

To explain the calculation method, which we are going to use within this module, in detail, we will only have an eye on the early shift at the moment. For being able to compare the expected workload to the performance values, we will have to extract the data of the corresponding tables according to the applied shift pattern respectively to the standardised starting times. Having this data available, this information will provide the basis for calculating the number of operators required. The sequence of the single calculation steps to

be described corresponds to the sequence that was defined regarding the allocation order of the single types of operators.

5.3.5.1   Workload grouping

The workload grouping is one element of the basic calculations within this module, whose result is needed for the operator disposition. The target is to get a balanced value regarding the expected workload for a group of four hours, which represents the smallest amount of time within a shift where an operator can be allocated to. As the workload fluctuates within these groups of four hours, we are going to calculate an average workload value over the groups of four hours. This means that we will have to compute the average value of the forecasted amount of workload between 6 AM and 10 AM and between 10 AM and 2 PM first. By calculating an average value regarding the workload we assume, that the amount of work which is above the average value can be either anticipated or postponed.

But simply calculating an average value would lead to a wrong result due to the planned breaks of some operators, which are not considered when applying the shift pattern. So for this reason we define, that we calculate the average value by using just the three highest workload values within a workload group of four hours, which enables us to 'filter' respectively 'ignore' the minimum value. To give an example by using the warehouse of John Lewis partnership at Milton Keynes, where a break takes place for the operators between 09:30 and 10:00 AM each day. If we do not filter this minimum amount of workload within this hour of the day, this would reduce the average value of the concerned workload group significantly and therefore lead to a wrong number of operators required.

After having calculated the average workload values of the early shift we have to compare these values to each other to find out which one has the higher value and to locate the period of time when the higher value occurs. To be able to speak easily about these two values, we will define them as minimum and maximum average workload. For our further considerations we assume that the maximum average workload is located between 10 AM and 2 PM. The average workload value represents the number of units that is estimated to be done on average within a certain workload group.

Example for typical daily workload pattern (Wednesday 6AM to 2PM)
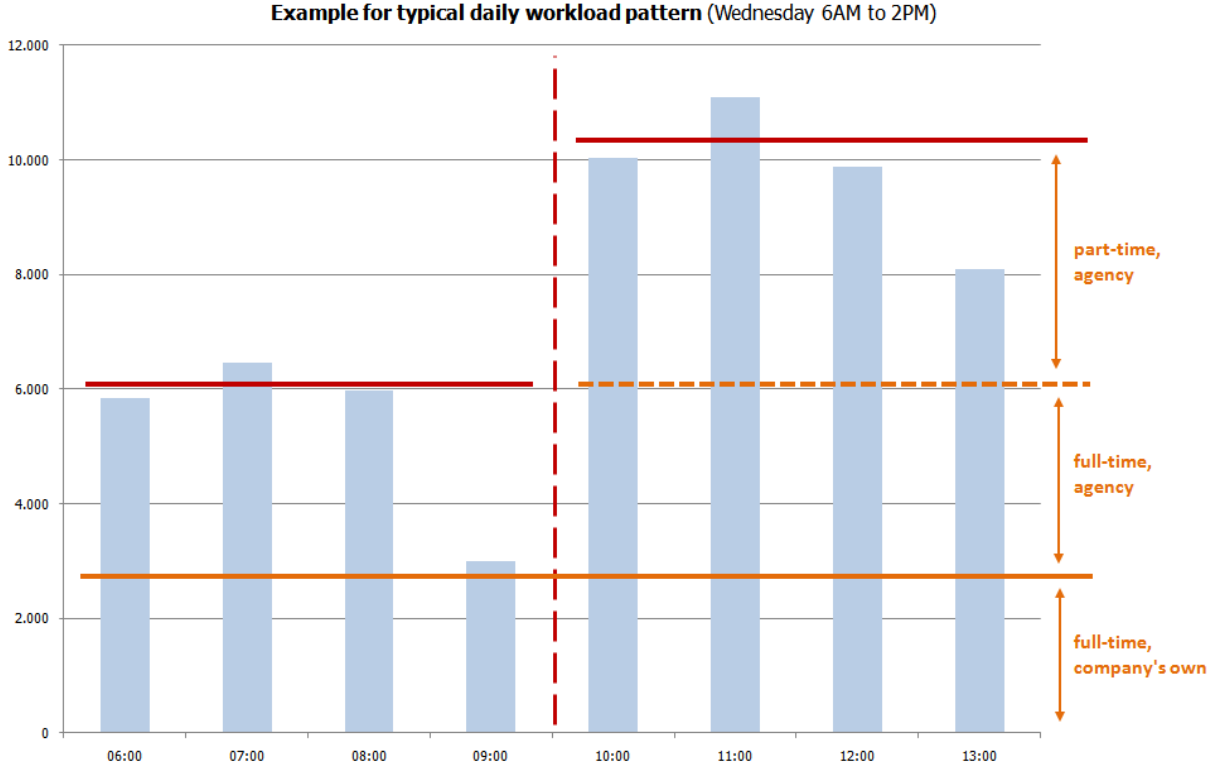
Figure 11: Operator disposition

As mentioned before, we have 3 different types of operators to allocate. On the one hand the full-time workers which are employed by a company itself and therefore have to be allocated first and on the other hand the full-time and part-time workers provided by the agency. Simply spoken, up to the minimum level of average workload we are going to allocate the full-time workers, whereas the workload difference between minimum and maximum average workload has to be covered by part-time workers. But the essential question is now, how to get the number of operators required for this scenario, as the number of the company's own personnel is fixed and therefore cannot be adjusted to the expected workload. For being able to get the number of operators, which are required additionally according to the expected workload, we have to find out the average performance values for every type of operators related to the shift pattern respectively their allowed starting times.

5.3.5.2   Performance grouping

According to the grouping of the workload, we will have to build an average value of performances for each type of operator as well. For calculating the average value for a full-time operator, the performance data contained within the performance matrix from 6 AM to 2 PM provides the basis. The calculation of the average performance value for a part-time operator is slightly different. As we have located the period of time of the maximum average

workload from 10 AM to 2 PM, we collect the performance data for the part-time workers accordingly. So the average performance value for part-time workers has to be calculated from 10 AM to 2 PM. The average performance value regarding operator performance provides the information, how many units per hour an operator is able to cope with on average for this certain period of time.

5.3.5.3   Performance of company's own full-time workers

Having the average performance information for each type of operator available, we can now start with our calculations regarding the early shift. As mentioned before, the number of full-time operators, which are employed by a company itself, is fixed and therefore these operators are always in and have to be considered first while doing the allocation. The number of operators of the company's own personnel has to be prompted by the person, who is planning the resources by using this module. As we know the number of operators, we have to multiply this number with the average performance value of the regarded operator type within the early shift.

$$
\begin{aligned}
number\ of\ units\ &(full\ time, own) \\
&= average\ performance(full\ time, own) \\
&* number\ of\ operators(full\ time, own)
\end{aligned}
$$

Equation 8: Performance provided by company's own personnel

The result of the calculation tells us the amount of work, the company's own personnel is able to cope with on average within an hour of the day and provides the basis for our further calculations.

5.3.5.4   Adding additional full-time workers

The result of the chapter before provides the basis for our further calculations. For the allocation of supplementary full-time operators, we have to subtract this value from the minimum average workload.

$$
\begin{aligned}
number\ of\ units\ &(full\ time, agency) \\
&= minimum\ average\ workload - number\ of\ units\ (full\ time, own)
\end{aligned}
$$

Equation 9: Number of units that have to be done by additional full-time workers

At first we assume that the result (number of units (full time)) of this calculation is positive, which means that we are able to allocate more full time operators. To do this, we have to divide this difference through the average performance which is provided by the full-time workers of the agency.

$$
number\ of\ operators\ (full\ time, agency) = \frac{number\ of\ units\ (full\ time, agency)}{average\ performance\ (full\ time, agency)}
$$

Equation 10: Number of additional full-time workers (agency)

The result of this division has to be round up and represents the number of full-time operators which are needed additionally from the agency. If the result of the subtraction (Equation 9) were negative, it would not make sense to add more full-time workers to this process.

Having this result available, the next task is to sum up the number of units that the full-time workers are able to cope with for being able to find out the number of part-time workers needed.

5.3.5.5   Allocating part-time workers

After having determined the number of full-time operators, we have to sum up the average performance values according to the type of operator and compare the results to the maximum average workload.

$$
\begin{aligned}
number\ of\ units&(part\ time, agency)\\
&= maximum\ average\ workload - number\ of\ operators\ (full\ time, own)\\
&\quad * average\ performance\ (full\ time, own)\\
&\quad - number\ of\ operators\ (full\ time, agency)\\
&\quad * average\ performance\ (full\ time, agency)
\end{aligned}
$$

Equation 11: Number of units that need to be done by additional part-time workers

Building the difference out of this comparison, this is the amount that has to be done by the part-time workers. This value has to be divided by the average performance value of part-time workers for this period of time, which is in our case between 10 AM and 2 PM and results in the number of part-time workers needed within this period.

$$
number\ of\ operators\ (part\ time, agency) = \frac{number\ of\ units(part\ time, agency)}{average\ performance\ (part\ time, agency)}
$$

Equation 12: Number of part-time workers (agency) required

To get an integer number of operators required we have to round up the result. When using this formula we have to assure to use the appropriate average performance values to match the period of time regarding the workload group.

The calculations stated above would be more accurate, but due to the fact that the concept is not a perfect solution yet and moreover to provide some spare capacity, we simply use the difference between the maximum and the minimum average workload for determining the number of part-time workers.

$$number\ of\ operators\ (part\ time, agency) \\ = \frac{(maximum\ average\ workload - minimum\ average\ workload)}{performance\ type\ 3}$$

Equation 13: Determining the number of part-time workers (simplification)

5.3.5.6   Determining the reserve capacity per shift

To bring the calculations down to a round figure, we have to check the accuracy of the calculation results. This means that we would like to check the amount of reserve capacity that remains within each single shift. The results of this check should deliver the resource planner an idea, how much spare capacity is left when using the calculated number of operators in comparison to the forecasted workload values. Moreover the spare capacity has to be 'translated' into the amount of spare man-hours.

For achieving the spare capacity value, we have to compare the expected operator performance within a certain shift to the forecasted workload of a whole shift. This means that our first task is to sum up the forecasted hourly workload in accordance with the single shifts.

$$sum\ forecasted\ workload\ per\ shift = \sum_{shift} hourly\ workload$$

Equation 14: Sum of forecasted workload per shift

The second piece of information is the amount of units that is expected to be done by the number of operators which was calculated before. For this reason these numbers have to be combined with the average performance values for this shift and with the typical working hours per operator type.

$$performance\ expected\ per\ shift \\ = \sum_{operator\ type} average\ performance\ operator\ type \\ * number\ of\ operators\ of\ type * typical\ working\ hours\ of\ type$$

Equation 15: Sum of expected performance per shift

Having these two values available we get the spare capacity by calculating the difference in between.

$$Reserve\ capacity\ per\ shift = performance\ expected - sum\ forecasted\ workload$$

Equation 16: Determining the reserve capacity per shift

As the result of Equation 16 delivers the value regarding the spare capacity in accordance with the chosen base unit, which is not very significant for the person who is planning by means of the module, we have to translate this value into man-hours. We are doing so by

dividing this result by the performance which is provided on average by a single operator within this shift.

5.4 Module "Operator management"

As the number of operators required was planned at a certain amount of time in advance on basis of a forecasted value concerning the workload, the chance that the actual number of units to be processed matches the forecasted one is low. Even if there may not be a big difference between the forecasted and the actual value, the responsible person has to be informed about this matter of fact. Moreover this module shall be able to give the responsible person an overview about the possible scenarios.

5.4.1 Target

The aim of this module is to create information for the responsible person in the morning, where he/she shall be informed if there is a discrepancy between the forecasted and the actual amount of workload. The calculation shall be based on actual data, which is available in the morning hours of the day.

The logistical relevance of this module is that because of being very short term, there is no further adjustment regarding the number of operators possible. For this reason we have to distribute the operators to the labour managed processes which are currently available at the warehouse.

5.4.2 Reports required (output)

The report that has to be provided to the responsible person has to contain the information, if there is a divergence between the forecasted and the actual data including the amount and the tendency of divergence. In addition to the divergence, the module has to calculate the possible scenarios and to report the possibilities to the responsible person as information basis for deciding which solution for this is going to be preferred. Furthermore the report has to compare all the workloads of the labour managed processes to each other, if there are reserve pool employees available who can be sent to other processes.

5.4.3 Data required (input)

There will be several data required for being able to calculate the scenarios. The basis for checking if there is any discrepancy between the forecasted and the actual values is the corresponding data regarding the workload. In addition to this we will need the average performance data for the considered period of time.

5.4.4 Possible scenarios

To explain why this tool is important, we will have to think about the following example: The number of operators was calculated on basis of a forecast, which stated 160.000 units for a certain day. But in the morning, when we get the actual number of orders and therefore the actual number of units to be handled, we find out, that there will be 180.000 units to be handled on this particular day. So there is simply spoken a lack of operators for 20.000 units. For this reason we will have to work out three possible scenarios, if the number of operators cannot be increased for what reason ever:

- o If the operators work at their usual performance level, there will be a certain amount of units to be handled left at the end of the day. These units are not allowed to be left for the next day, so the operators have to do (expensive) overtime. The amount of additional time required is to be calculated by the module, based on the average performance value.

- o The operators which are in, have to increase the performance and work faster, so that they can go home as planned and moreover no work is left for the next shift respectively day. The required increase of performance on average per operator has to be calculated by the module.

- o Leave the "additional" units for the next shift respectively day. Provide a hint to the responsible person that this might cause serious problems on the following day because in worst case there will be additional work due to a slightly wrong forecast again. For this scenario is no calculation necessary.

So the results of these scenarios will provide the basis for the responsible person's decision.

Another problem is the opposite situation because if there is less work to do than forecasted, the operators will just stand around. As we get to know this matter of fact in the morning of the actual day, we are not able to adjust the number of operators for the early shift. If an adjustment is possible for the late shift, this has to be discussed with the shared personnel agency.

6   Implementation of a database prototype

Within this chapter we have to describe shortly the preparations that have been done before starting with the implementation of the database prototype into a testing environment. At first we have to consider which input data is required for being able to generate the desired output data to match the aims of the single modules.

6.1 Defining a database model

Before starting with defining a database model, we will have to achieve some basic information regarding the basic elements that a database consists of. Having this information available, we will be able to define some basic elements which will be implemented within the database prototype afterwards.

6.1.1 Basic elements of a database

One type of the basic elements of a database is a table, which provides the input data for several further database operations. So the first elements we will have to define are tables which are necessary for providing the required data because a table "does resemble a file from a conceptual point of view"[128]. For doing further operations by using the provided data we will have to do some queries within database. If the query remains the same and has to be done more often, "wouldn't it be better to permanently save that query in the database? That's the function of a relational view. A view is a virtual table based on a […] query. The query can contain columns, computed columns, aliases and aggregate functions from one or more tables."[129] In addition to this, a view is dynamic which means its operations are recalculated if a view is used.

For being able to identify a row within a table clearly, we are going to use primary keys. "In general terms, the primary key (PK) is an attribute (or a combination of attributes) that uniquely identifies any given row."[130] Moreover the primary keys enable us to connect the information of a table to another by using so called foreign keys. "A foreign key (FK) is an attribute whose values match the primary key values in the related table."[131] So "each row will have a unique identity, and foreign key values can properly reference primary key values."[132]

When having defined the relations between the tables, we can display a so called entity relationship diagram, whose task is to show the relations between the single entities (tables). "The relational model is the current database implementation standard. In the relational model, the end user perceives the data as being stored in tables. Tables are related to each other by means of common values in common attributes. The entity

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[128] [RoCoCr2008], p. 70
[129] [RoCoCr2008], p. 352
[130] [RoCoCr2008], p. 76
[131] [RoCoCr2008], p. 81
[132] [RoCoCr2008], p. 82

relationship (ER) model is a popular graphical tool for data modelling that complements the relational model."[133]

As we have just provided short information regarding which elements are needed to build a small database, we now have to define these basic elements for our labour management tool.

6.1.2 Defining tables

To start with the data model we have to define some basic tables, which are going to provide the basic information for our further calculations. So the tables represent the input data which is needed to achieve the targets of the single modules.

6.1.2.1   Performance management

At first we are going to define the tables, which will be needed for the performance management. To get the average performance value per operator and even per operator type, we first have to define which operator belongs to what operator type. For this reason we are going to define the tables "operator data" and "operator type". Whereas the table "operator type" consists of a unique operator type identifier (primary key[134]) and the description of the operator type, the table "operator data" keeps a minimum of data for being able to identify an operator clearly. This means we have to store a unique identifier per operator, the operator's name and the matching operator type identifier (foreign key) within this table. In addition to this, we need another table ("basic performance data"), where the historical data regarding an operator's performance is stored. The columns being required are the operator identifier (foreign key), the time stamp (consists of date and hour of the day), the calendar week, a number representing the weekday and the quantity that was done by this particular operator. The aim of this table is the ability to create statements like the following: "operator 791xxx of the type 3 has done 421 units on February, 26th, 2010 in hour 6." Having now the basic information complete, we could now define the basic information which is required by the other modules. Even if our goal is to achieve an average performance value per operator and per operator type, we would like to have the data calculated just when using the module. So we are going to store them temporarily in a view, which is defined later on.

6.1.2.2   Workload forecast

The main information needed for this module is extensive historical workload data for being able to extract the typical workload patterns in addition to the sum of the weekly workload

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[133] [RoCoCr2008], p. 62

[134] A unique identifier for each entry in the table and can be used as foreign key within another table.

over several years. As this would be an exaggerating amount of data that has to be stored, we only are going to store the data of the recent past and condense the rest of the information by building weekly workload sums for being able to determine seasonal fluctuations and trends. For this reason we are going to create two tables, on the one hand "weekly workload", which stores the sum of the weekly workload plus the calendar week, and on the other hand "historical workload data", which is implemented for storing the amount of units that have been done, the actual date, the actual hour and moreover the calendar week and the weekday. This basic information is sufficient for being able to determine the typical workload patterns in addition to the weekly forecast, which is based on the historical data.

6.1.2.3   Operator disposition

As we have defined before, we have to apply a shift model for being able to calculate the number of operators required and when to employ them best on basis of single shifts. For this reason we are going to need a table "shift pattern", which consists of the columns for a unique shift identifier, a shift description plus the starting and the end time of the shift. In addition to the shift, we have defined so called "starting time groups", which are standardised starting times for the part time workers. So we have to provide this information within a separate table, which consists of a unique starting time group identifier, the according shift ID, a description as well as the starting and the end time. Moreover we have to define, when an operator of a certain type is allowed to start, for this reason we will have to combine the operator type, the starting time group and the shift. As we have to collect this information from different tables, we will do this by using a view.

Furthermore we are going to need the average forecasted workload value and the average performance value per starting time group, so the results of these calculations will also be stored within a view. Having this information available, it will be the task of another view to determine the number of operators required and the starting time group when they should start best.

6.1.2.4   Additional information

In addition to the input data that is already provided by the tables being defined before, we have to create some extra tables for having some supplementary data available. For being able to collect the weekly data belonging to a certain calendar week, we have defined a table "calendar week", whose unique identifier consists of six digits – the first four digits for the year and the last two digits for the week. The unique identifier will be used in several tables

as a foreign key. For similar reasons we have created a table "weekday", which will enable us to apply some data on a certain day of the week.

In addition to this, we have to provide the information about the number of company's own operators which will be working on a certain day within a certain shift. For this reason we have to create a table, which provides this information. Furthermore we have to define a table to provide the sales/order forecast.

6.1.3 Defining views

A view can be considered as a dynamic table within a database and the calculations are done newly if the view is chosen. Due to the dynamic behaviour, the view is preferred to a table, so the results of a view are only stored within a table if the calculations of the view have a poor performance.

6.1.3.1   Performance management

To achieve the targets of this module we have to calculate the average performance per operator and the average performance per operator type. Moreover we have to provide the information on hourly basis. So the first view to be created is the average performance value per operator which means we have to compare the same hour of several days together for being able to calculate a mean. The result of this view enables us to say, "Operator 791xxx has done 449 units on average in hour 7". Having the results for all operators available, we have to add the information regarding the operator type. This provides the basis for the second view to be created, whose aim is to provide an average performance value per operator type. For this reason we compare the average values of single operators of the same types concerning a certain hour to each other of the same type to achieve an average value. So the statement that can be done by using the results of the second view is like "operators of type 2 are able to cope with 456 units within hour 10".

6.1.3.2   Workload forecast

For being able to estimate and refine the forecast to a single hour of a day, we have to create two views, whose task is to determine the typical workload pattern. At first we have to find out the weekly workload pattern, which means we have to calculate average workload values considering several weeks comparing the average daily workload to the average weekly workload. The daily workload pattern has to be calculated in an analogue way, comparing the average workload of a certain hour to the average workload of the considered day.

The second main task of the module is to use the historical data for being able to estimate a future situation. At first a view has to calculate the estimated weekly workload by using the calculated and the manual grow rate. Having the estimated weekly workload available, the typical weekly workload pattern shall be used to refine this result to single days. Afterwards it is the task of another view, to combine the estimated workload of a certain day with the typical daily workload pattern for achieving the future workload values for single hours of a day.

6.1.3.3   Operator disposition

As mentioned before, to achieve the possible starting times for an operator type we will have to combine several data together, which means we have to combine shift information, starting time group information and operator type information together. The result of this view shall provide the possibility to say, "Operator type 1 is allowed to start in starting group 3, which is part of shift 2. This means operators of type 1 are allowed to start at 2PM and their day usually ends at 10PM."

Having the data regarding the starting times and the working hours per operator type available, we are now able to use this information for a view, whose task is to extract the performance data accordingly and to calculate average performance values per operator type and shift (if operator is a full-time worker) respectively per starting time group (if operator is part-time worker). For being able to achieve the number of operators needed, we have to calculate the average workload values per starting time groups, which will be the task of another view.

After having done the preparations regarding the basic data for a weekly plan, it will be the task of another view to combine this information together in regard to the requirements which were defined within the concept. For being able to do so, we will have to allocate the company's own operators first which means we have to consider this data which is provided within a separate table. The target of this view is to achieve a weekly plan for being able to say for example: "On Monday we are going to need 5 additional full-time operators for the late shift and moreover 10 part-time workers starting at 2PM." If we have this information available for the whole week, we are able to state we have achieved the objective which was defined within the conceptual phase.

We have only defined the basic ideas regarding tables and views at the moment because based on this little piece of information we started developing and improving the prototype "live", which means the implementation was done directly within the database environment.

6.2 Transferring the model into a database

Having defined the basic tables and views for a prototype on paper, we are now able to implement the ideas into a testing environment of a database. For this reason we are going to use the software "Toad for Oracle Professional" provided by Quest Software. At first we implemented the tables, which we have defined before, and afterwards we created the single views, which are used for storing the results of the required calculations. During the implementation process we had to change our basic ideas a bit due to two reasons: There were a bit more tables necessary than expected and moreover for not being an expert in programming of views, there can be found more views within the prototype than were initially defined. The detailed documentation of the implemented prototype can be found in chapter 7.

7 Documentation of the prototype

To start with the documentation of the implemented prototype, we first have to provide some information about the tables, such as what the purpose of a table is and which data is stored within the tables. Thereafter we have to describe the main views we have generated to get the required information out of the tables to match the targets for the single modules given within chapter 5. In addition to this we have to show the entity relationship diagram which shows the constraints between the used tables.

7.1 Tables

In this chapter we have to provide the relevant information regarding the tables which are used within the database prototype. For this reason we have to give the details of each table, such as which columns are defined for a table and if we have constraints to columns of other tables. Moreover we are going to structure the chapter referring to the single modules which have been defined within chapter 5. But during the implementation process we have discovered that we need some additional information which resulted in several additional tables, which are described within chapter 7.1.5. When defining a table, we have at least to characterise the column name, data of which data type is allowed to be inserted, if the column is a primary key and finally if the fields are allowed to be empty.

7.1.1 Operator data

Even if the first module to be implemented would be the performance management module, we have to provide some basic information regarding the operators and the different types of operators, which are working within the warehouse to be considered, before.

To start with providing this information, we have to give some information which characterises an operator type clearly. For this reason we apply a unique number to each type of operator, provide an optional type description, define the typical daily working hours and moreover give the information, in which order the different types have to be allocated to the labour managed process.

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
OPR_TYPE_ID	INTEGER	Y	N
OPR_TYPE_DESC	VARCHAR2 (100)	N	Y
OPR_WORKTIME	INTEGER	N	N
OPR_ALLOC_PRIO	INTEGER	N	N

Table 1: OPR_TYPE

For the prototype at hand we have inserted the three types of operators, which have been mentioned in chapter 5.3.4.1.

After having characterised the types of operators, the next step is to define a table, which contains the essential operator data. The information provided at the moment is the minimum requirement to identify an operator and which type of operator he/she is belonging to and has to be extended if more detailed information is needed for each operator. The minimum requirements are a unique operator ID, the name of the operator and type of operator has to be applied. The column for the operator type ID (OPR_TYPE_ID) is a foreign key pointing to Table 1: OPR_TYPE (OPR_TYPE ID).

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
OPR_ID	INTEGER	Y	N
OPR_NAME	VARCHAR2 (200)	N	N
OPR_TYPE_ID	INTEGER	N	N

Table 2: OPR_DATA

For being able to test the prototype, we have manually inserted random operator data, two of each operator type.

7.1.2 Performance data

For being able to calculate an average performance value for each operator and finally for each type of operator, we have to provide the underlying data in only one table. So within this table we have to store the basic performance data per operator. According to our definitions given before, we would like to have the performance data available on an hourly level, so we have to collect the number of units a single operator has done within one hour of the day. In addition to this, we have implemented the actual date, a number for

representing a certain day of the week and even the number of the calendar week. This table contains three foreign key constraints:

- o   Operator ID (OPR_ID) is a foreign key of Table 2: OPR_DATA

- o   Calendar week (CAL_WEEK) is a foreign key of Table 8: CAL_WEEK (CW_ID)

- o   Actual weekday (ACT_WEEKDAY) is a foreign key of Table 9: WEEKDAY_DATA (WEEKDAY_ID)

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
OPR_ID	INTEGER	N	N
ACT_DATE	DATE	N	N
ACT_HOUR	CHAR (5)	N	N
CAL_WEEK	INTEGER	N	N
ACT_WEEKDAY	INTEGER	N	N
QTY_UNITS_DONE	INTEGER	N	Y

Table 3: PM_PERF_DATA

The tables calendar week and weekday data are described within chapter 7.1.5. Due to a lack of real performance data we have generated a table with random performance data for being able to test the prototype. But the basis for the random calculation were average performance values taken from the bin 2 bin picking process at the distribution centre of the John Lewis partnership.

7.1.3 Workload history

The two tables provided regarding the workload history are going to deliver the basic information for being able to forecast the future workload of the considered processes. Therefore we have to store the data in two different tables. First we keep the hourly workload data for a certain amount of weeks for being able to determine the typical weekly and daily workload fluctuations. When the detailed data is not needed any more (outside of the period under consideration), the information has to be condensed to the weekly amount of work due to not requiring an exaggerating amount of disk space.

As mentioned before, to start with we have to store detailed historical workload data, which means we have to store the information on which day and within which hour what amount of work has been done. In addition to this, we have applied the information regarding the calendar week and the number representing the actual day. This table contains two foreign key constraints:

- o   Calendar week (CW_ID) is a foreign key of Table 8: CAL_WEEK (CW_ID)

o Actual weekday (ACT_WEEKDAY) is a foreign key of Table 9: WEEKDAY_DATA
(WEEKDAY_ID)

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
ACT_DATE	DATE	N	N
ACT_HOUR	CHAR (5)	N	N
CW_ID	INTEGER	N	N
ACT_WEEKDAY	INTEGER	N	N
QTY_UNITS_DONE	INTEGER	N	Y

Table 4: WL_DATA_HISTA

The data that has been inserted into this table was extracted from a Microsoft Access database file which contains the workload information of the bin 2 bin picking process of the John Lewis distribution centre in Milton Keynes.

As mentioned above, if we do not need the detailed data any more, we condense the data by summing up the weekly amount of workload and storing it into a separate table. This table only provides the information, in which calendar week what amount of work was done within a whole week. The calendar week (CAL_WEEK) is a foreign key constraint of Table 8: CAL_WEEK (CW_ID).

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
CAL_WEEK	INTEGER	N	N
QTY_UNITS_WEEK	INTEGER	N	N

Table 5: WL_WEEKLY_HISTA

We have inserted some hybrid data into this table. One part of the data was also extracted of the database file mentioned above; the other part was generated randomly by using a Microsoft Excel spreadsheet.

7.1.4 Shift pattern and starting time groups

For being able to extract the workload and performance data from the corresponding tables in accordance with the shift pattern, we have to provide the details regarding the shifts to the database. This means we have to generate a unique number for a shift, describe the shift optionally and give the information when a shift starts and ends.

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
SHIFT_ID	INTEGER	Y	N
SHIFT_DESC	VARCHAR2 (50)	N	Y
SHIFT_START	CHAR (5)	N	N
SHIFT_END	CHAR (5)	N	N

Table 6: OD_SHIFT_PATTERN

To be able to allocate the part time workers best, we have defined standardised starting times for this type of operator within the chapter 5.3.4.2. So we had to make these times available within the database too. Each of the starting group gets a unique ID, the shift ID (SHIFT_ID) is a foreign key constraint of Table 6: OD_SHIFT_PATTERN (SHIFT_ID), an optional starting group description plus starting and end time of the starting group.

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
ST_GROUP_ID	INTEGER	Y	N
SHIFT_ID	INTEGER	N	N
ST_DESC	VARCHAR2 (50)	N	Y
ST_START	CHAR (5)	N	N
ST_END	CHAR (5)	N	N

Table 7: OD_STARTING_TIMES

The data of these two tables has been generated manually in accordance with the concept for the module operator disposition given in chapter 5.3.

7.1.5 Additional information

In addition to the tables we have defined above, we need some basic information for being able to analyse the given data – in accordance with the concept given before – properly and to get a solid input for our further calculations. Due to the fact that some of the calculations are referring to whole weeks respectively single weekdays, we have to provide this data for securing that two sets of data can be compared easily when using the calendar week for example.

To start with the information regarding the calendar week, first we generated a unique calendar week ID, which consists of six digits. While the first four digits represent the year, the last two digits stand for the calendar week. So the unique ID for the week 12 of the year 2010 will be 201012. In addition to the ID, there can be optionally entered a description for the calendar week plus the year and the week separately.

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
CW_ID	INTEGER	Y	N
CW_DESCRIPTION	VARCHAR2 (100)	N	Y
CW_YEAR	INTEGER	N	Y
CW_WEEK	INTEGER	N	Y

Table 8: CAL_WEEK

For being able to compare for example the workload of the same day of several weeks easily to each other, we have defined a table which represents the single days of the week. For this reason we created a weekday ID (from 1 for Monday to 7 for Sunday) with the corresponding description.

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
WEEKDAY_ID	INTEGER	Y	N
WEEKDAY_DESCRIPTION	VARCHAR2 (20)	N	N

Table 9: WEEKDAY_DATA

Further essential information for the prototype is related to the module for workload forecasting. For this reason we have to provide the information about the actual calendar week, which week shall be forecasted and how many weeks of the recent history have to be considered when calculating the grow rate. In addition to this, we have to provide a manual grow rate to adjust the forecasted workload value. Initially the time for determining the grow rate is 6 and the manual grow rate is 1. This table contains two foreign key constraints: The actual week and the week for the forecast are a foreign key of Table 8: CAL_WEEK. The data has to be inserted manually.

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
ACT_WEEK	INTEGER	N	N
FC_WEEK	INTEGER	N	N
GROWTH_TIME	INTEGER	N	N
MAN_GROW_RATE	INTEGER	N	N

Table 10: FC_INFO

During the implementation of the prototype, we figured out that we will have to tell the system when the day normally starts respectively ends for being able to determine the correct workload pattern regarding a whole week and even a whole day. So for this reason we built a small table, where we inserted these two required values manually.

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
DAY_START	CHAR (5)	N	N
DAY_END	CHAR (5)	N	N

Table 11: X_DAY_HOUR

A very important input for the module "operator disposition" is the number of a company's own personnel, which is always in. So for this reason we have to provide the information, which number of a company's own operators is working within which shift on which day. The table has two foreign key constraints:

- Actual Day (ACT_DAY) is a foreign key constraint of Table 9: WEEKDAY_DATA (WEEKDAY_ID)

- Shift ID (SHIFT_ID) is a foreign key constraint of Table 6: OD_SHIFT_PATTERN (SHIFT_ID)

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
ACT_DAY	INTEGER	N	N
SHIFT_ID	INTEGER	N	N
NUM_OWN	INTEGER	N	N

Table 12: X_NUM_OWN_OPR

The data for this table was chosen randomly and manually prompted.

For being able to provide the possibility to directly enter the number of expected units in accordance with a sales forecast for example, we have created the table X_SALES_FORECAST, which contains only one data field, whose value is by standard zero. This is important, because in this case we are going to ignore this table while forecasting.

COLUMN NAME	DATA TYPE	PRIMARY KEY	NULL
SALES_FC	INTEGER	N	N

Table 13: X_SALES_FORECAST

The data for this table has to be prompted by the user manually. If this information shall not be used, the value of the sales forecast has to be zero. Even if the name of the table suggests this can only be used for inserting the sales forecast value when doing labour management for the picking process, we can use this table for the confirmed amount of goods when doing labour management for the receiving area.

7.2 ER model

After giving the information regarding the single tables and the constraints between the tables, which are used within the prototype, we now have to show the entity relationship model, which visualises the relations between the single entities (tables).
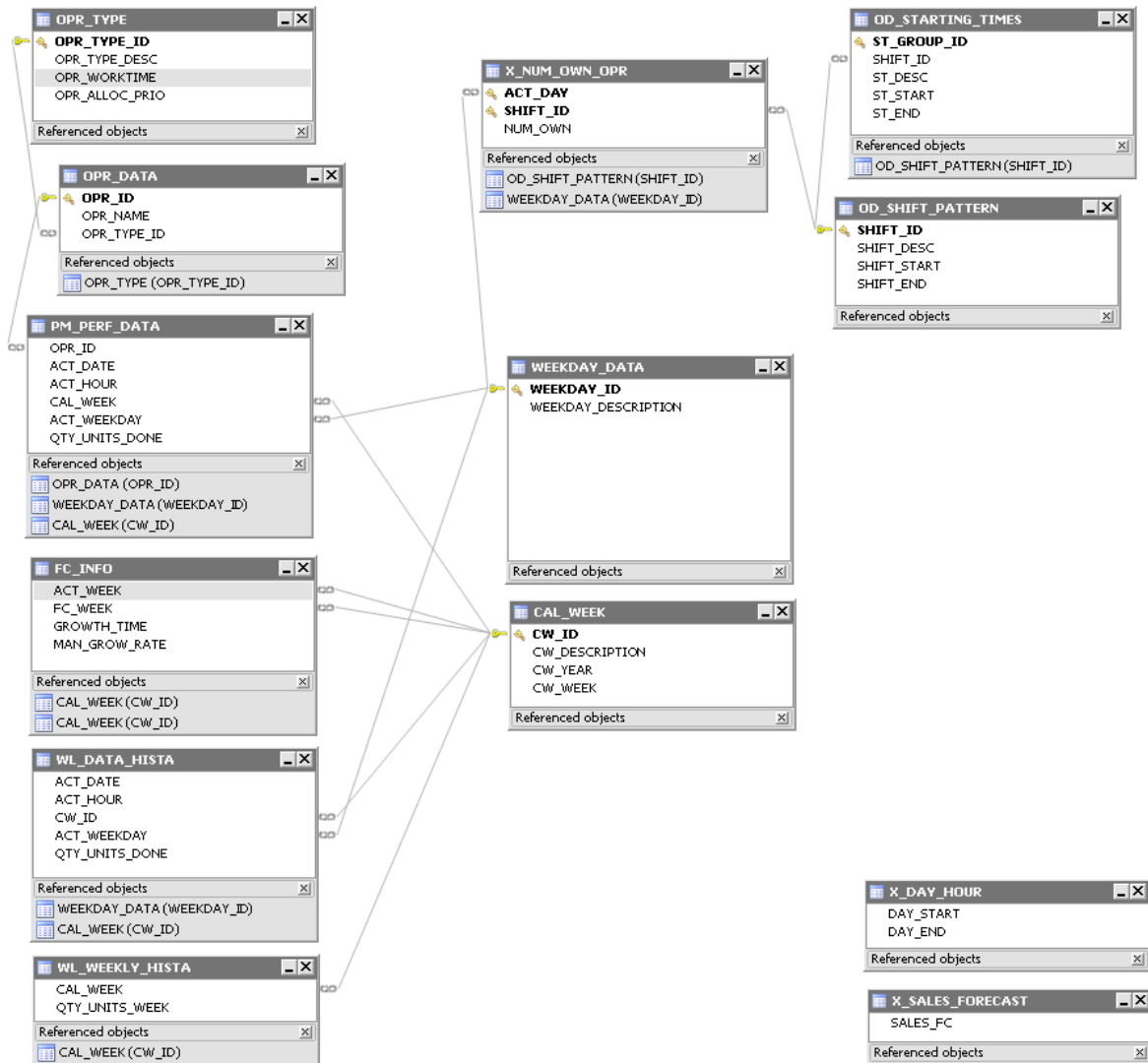
Figure 12: ER-Diagram

But there are two tables within the ER diagram (X_DAY_HOUR and X_SALES_FORECAST) without any constraint to any of the other tables. This is because they have only been implemented for providing basic information to the views.

7.3 Views

Within this chapter we are going to describe the main views, which we have created to achieve the targets that we had defined before for the single labour management modules within chapter 5. The documentation will be structured in accordance with the concept regarding the single modules.

7.3.1 Performance management

The basic data for performance management is stored within the table PM_PERF_DATA and consists of the performance values of each operator per hour over several weeks. So we have to condense the information by calculating average performance values in two stages for being able to use the data for labour management. In accordance with the concept for the performance management module, we have to calculate an average performance value for each hour of the day while using the data for several weeks.

```sql
SELECT PM_PERF_DATA.OPR_ID,PM_PERF_DATA.ACT_HOUR,
ROUND(AVG(PM_PERF_DATA.QTY_UNITS_DONE),0) AS AVG_QTY, OPR_DATA.OPR_TYPE_ID
FROM PM_PERF_DATA,OPR_DATA
WHERE PM_PERF_DATA.OPR_ID = OPR_DATA.OPR_ID
GROUP BY PM_PERF_DATA.OPR_ID,PM_PERF_DATA.ACT_HOUR, OPR_DATA.OPR_TYPE_ID
ORDER BY PM_PERF_DATA.OPR_ID,PM_PERF_DATA.ACT_HOUR
```

SQL code 1: PM01_OPR_AVG_PERF

For being able to get the average performance value per operator and hour from the basic data from the table PM_PERF_DATA, we are using the average function of SQL. Furthermore we have added the operator type to this view, which we can find within the table OPR_DATA, which enables us to calculate the average performance value per operator type within the next stage. The given syntax adds the operator type ID, if the operator ID within the two tables is equal.

Based on the results of the view PM01_OPR_AVG_PERF, we are now able to calculate the average performance value for each type of operator per hour of the day (PM02_TYPE_AVG_PERF).

```sql
SELECT OPR_TYPE_ID, ACT_HOUR, ROUND(AVG(AVG_QTY),0) AS AVG_QTY_TYPE
FROM PM01_OPR_AVG_PERF
WHERE OPR_ID = OPR_ID AND ACT_HOUR = ACT_HOUR
GROUP BY OPR_TYPE_ID, ACT_HOUR
ORDER BY OPR_TYPE_ID, ACT_HOUR
```

SQL code 2: PM02_TYPE_AVG_PERF

The average performance value required is calculated by using the average function of SQL again, which computes, according to the syntax used, the average performance value where the operator IDs and the actual hour of the day are equal. The result is now having an average performance value for each type of operator per single hour of the day.

7.3.2 Workload forecasting

To start with forecasting the future workload, we have to do an analysis of past data to determine the typical weekly and daily workload pattern first. Then we have to define, which

period has to be forecasted and the data of which period has to be analysed. After that we have to calculate the grow rate, which enables us to estimate the weekly workload, which has to be refined on daily respectively hourly level by using the typical workload patterns.

7.3.2.1 Weekly workload pattern

To be able to determine the typical weekly workload pattern, we have to do some preparations regarding the data first. Our target is to get a certain percentage, which is the result of the ratio of the average workload of a certain day to the average weekly workload. As the workload values are provided on hourly basis within the table WL_DATA_HISTA, we first have to sum up the workload regarding single days (view WL03_DAILY_SUM) and of whole weeks (WL01_WEEKLY_SUM). Having these results available, we can use these results to calculate the average workload value for all of the considered weeks (view WL02_WEEKLY_AVG). In addition to this, we have to calculate the average workload value for each single day too (view WL04_DAILY_AVG), but within this view we add the average weekly workload to each line as a preparation for the next calculation.

By now we have the basic data (view WL04_DAILY_AVG) for calculating the typical weekly workload pattern complete, which we now determine within the view WL05_WEEKLY_PATTERN. To achieve the percentage of the average workload of each day in relation to the average workload of the whole week, we have to calculate as follows (example given for Monday):

$$percentage\ of\ day = \frac{average\ weekly\ workload}{average\ daily\ workload} * 100$$

Equation 17: Percentage for weekly workload pattern

```sql
SELECT ACT_WEEKDAY, AVG_DAY, AVG_WEEK,
ROUND(((AVG_DAY/AVG_WEEK)*100),2) AS PERC_DAY
FROM WL04_DAILY_AVG
```

SQL code 3: WL05_WEEKLY_PATTERN

The results of this view are all the percentages for each single day, which tell us how much work is done on which day on average. For being able to check the calculations, we provide the columns for the average workload of a day and the average weekly workload.

7.3.2.2 Daily workload pattern

For being able to achieve the typical daily workload pattern, we need the average workload values of each single hour of the day first, which is the task of the view WL07_HOURLY_PATTERN. The result of the view is an average workload for each hour of the day and for each day of the week.

Now having the results of the view WL06_HOURLY_AVG available, we combine them with the average daily workload, we have calculated before (view WL04_DAILY_AVG), to get the percentage representing the ratio of an average hourly workload to the corresponding workload of a day.

$$percentage\ of\ hour = \frac{average\ workload\ hour}{average\ workload\ day} * 100$$

Equation 18: Percentage for daily workload pattern

```
SELECT WL06_HOURLY_AVG.ACT_WEEKDAY, WL06_HOURLY_AVG.ACT_HOUR,
WL06_HOURLY_AVG.AVG_HOUR, WL04_DAILY_AVG.AVG_DAY,
ROUND(((WL06_HOURLY_AVG.AVG_HOUR/WL04_DAILY_AVG.AVG_DAY)*100),2) AS PERC_HOUR
FROM WL06_HOURLY_AVG, WL04_DAILY_AVG
WHERE WL06_HOURLY_AVG.ACT_WEEKDAY = WL04_DAILY_AVG.ACT_WEEKDAY
GROUP BY WL06_HOURLY_AVG.ACT_WEEKDAY, WL06_HOURLY_AVG.ACT_HOUR,
WL06_HOURLY_AVG.AVG_HOUR, WL04_DAILY_AVG.AVG_DAY
ORDER BY WL06_HOURLY_AVG.ACT_WEEKDAY, WL06_HOURLY_AVG.ACT_HOUR
```

SQL code 4: WL07_HOURLY_PATTERN

For being able to check the results randomly, we provide the columns containing the average hourly workload and the average daily workload in addition to the columns which contain the results, here the actual weekday, the actual hour and the percentage, which represents the amount of work that has been done on average within an hour in relation to the average workload of the day.

As we have finished the calculation of typical workload patterns, the next task required to match the target for this module is to do the workload forecasting on weekly, daily and hourly level.

7.3.2.3   Periods to be considered

The second main part of this module is to forecast a future workload situation. To start with forecasting, we have to determine which periods have to be considered and moreover to calculate the grow rate first. To start with the periods to be considered, we have created the view FC01_TIME_PERIOD, which uses the information from the tables FC_INFO and CAL_WEEK to compute the period of time, where we have to look for the peak of the weekly workload, in accordance with the GROWTH_TIME, which tells us how many weeks we have to consider when searching for workload peaks. The basic information for the calculation of the single periods is available within the table FC_INFO, where the data regarding the actual week, the week to be forecasted and the number of weeks to be considered is stored.

```
SELECT FC_INFO.ACT_WEEK,FC_INFO.FC_WEEK,
(FC_INFO.FC_WEEK-100) AS FC_WEEK_LY,
(FC_INFO.ACT_WEEK-FC_INFO.GROWTH_TIME) AS ACT_SP,
(FC_INFO.ACT_WEEK-1) AS ACT_EP,
(CAL_WEEK.CW_ID-100-FC_INFO.GROWTH_TIME) AS LY_SP,
(CAL_WEEK.CW_ID-100-1) AS LY_EP
FROM FC_INFO,CAL_WEEK
WHERE FC_INFO.ACT_WEEK = CAL_WEEK.CW_ID
```

SQL code 5: FC01_TIME_PERIOD

To get the week, which provides the basis for the forecasted workload and which is according to our definition the same week but of the last year, we have to reduce the number of the actual week by hundred. Just remember that we are using a 6 digit number for the calendar week, where the first four digits represent the year and the last two digits the calendar week. So the formula would be as follows:

$$forecasted\ week\ last\ year = forcasted\ week - 100$$

Equation 19: Determining calendar week, which provides the basis value for forecasting

In addition to this, we need the information which periods of the actual and of the last year have to be scanned for workload peaks. For this reason we have to calculate the starting and end point of this period. We get the week of the starting point by subtracting the growth time from the actual week and the week of the end point by reducing the actual value by one. This is, because we always take the most actual complete weeks as a basis for our calculations. The formulas are as follows:

$$starting\ point = actual\ week - growth\ time$$

Equation 20: Starting point for analysis of grow factor within actual year

$$end\ point = actual\ week - 1$$

Equation 21: End point for analysis of grow factor within actual year

According to these calculations, we get the period under observation from the last year, but we have to add a subtraction of 100 to the right side of the formulas.

As the view works perfectly if we are only considering weeks which are belonging to the same year, we will have to implement some extra code for being able to compare the weekly workloads over the turn of the year.

7.3.2.4   Calculated grow rate

The task of the two views FC02_GROW_RATE1 (actual year) and FC03_GROW_RATE2 (last year) is, to look for the workload peaks within the periods calculated before. This means the views scan for the maximum workload, where the calendar week is between the starting and

the end point. The result is the maximum value regarding the workload of the actual respectively the last year.

```
SELECT FC02_GROW_RATE1.MAX_WEEK_ACT_YEAR,FC03_GROW_RATE2.MAX_WEEK_LAST_YEAR,
ROUND(FC02_GROW_RATE1.MAX_WEEK_ACT_YEAR/FC03_GROW_RATE2.MAX_WEEK_LAST_YEAR,2)
AS CALC_GROW_RATE
FROM FC02_GROW_RATE1, FC03_GROW_RATE2
```

SQL code 6: FC04_GROW_RATE3

For determining the grow rate, we have implemented the view FC04_GROW_RATE3, which combines the results of the two views FC02_GROW_RATE1 and FC03_GROW_RATE2 created before. To get the grow rate, we divide the maximum workload value of the actual year by the workload value of the last year.

$$calculated\ grow\ rate = \frac{maximum\ workload\ actual\ year}{maximum\ workload\ last\ year}$$

Equation 22: Determining the calculated grow rate

The result represents the calculated grow rate, which is the basis for the calculation of the forecast for the whole week.

7.3.2.5   Forecasting of the workload

The calculations regarding the forecast are done in 3 stages. At first we calculate the forecast regarding the weekly workload, after that the daily workload and finally the estimated hourly workload.

So the first task is to get the estimated weekly workload. Achieving this result is the task of the view FC05_FORECAST_WEEK. The view uses the forecasted week last year, which is a result of the view FC01_TIME_PERIOD to extract the weekly workload data from the table WL_WEEKLY_HISTA where the codes for the calendar week are identical. The value found within the table has to be multiplied with the calculated grow rate (from view FC04_GROW_RATE3). For a further adjustment, the result is multiplied with the manual grow rate (from table FC_INFO).

$$forecast\ week = forecasted\ week\ last\ year * calc\ grow\ rate * man\ grow\ rate$$

Equation 23: Forecasting the workload for a whole week

In addition to the forecasted amount of workload, the week where the basis data for the forecast was found and the two grow rates are shown within the result of this view.

```
SELECT FC01_TIME_PERIOD.FC_WEEK_LY,FC04_GROW_RATE3.CALC_GROW_RATE,
CASE
WHEN X_SALES_FORECAST.SALES_FC = 0
THEN ROUND((WL_WEEKLY_HISTA.QTY_UNITS_WEEK*FC04_GROW_RATE3.CALC_GROW_RATE)*
FC_INFO.MAN_GROW_RATE,0)
ELSE X_SALES_FORECAST.SALES_FC
END AS FC_QTY_WEEK, FC_INFO.MAN_GROW_RATE
FROM FC01_TIME_PERIOD, FC04_GROW_RATE3, WL_WEEKLY_HISTA, FC_INFO, X_SALES_FORECAST
WHERE FC01_TIME_PERIOD.FC_WEEK_LY = WL_WEEKLY_HISTA.CAL_WEEK
```

SQL code 7: FC05_FORECAST_WEEK

Within the table structure we have provided the possibility to prompt the sales figures for a certain week. If the value in table X_SALES_FORECAST is zero, the historical data provides the basis for the forecast. When the user of the labour management tool enters the sales figures into the data field, this value 'overrides' the forecasting method.

Having forecasted the workload for the whole week, we can now use this result and the typical weekly workload pattern, which we have determined earlier, to compute the daily workload, which is the task of the view FC06_FORECAST_DAY. So for achieving the workload for a certain day of the week, we have to multiply the workload of the whole week (result of view FC05_FORECAST_WEEK) with the percentage concerning this day (from view WL05_WEEKLY_PATTERN). So if we give the example for Monday, the formula is as follows:

$$workload\ forecast\ Monday = workload\ of\ whole\ week * percentage\ of\ Monday$$

Equation 24: Estimating workload of a single day (example)

But to get the correct values, we have to divide the percentage by hundred because they have been multiplied by the same factor as the percentages have been calculated.

```
SELECT WL05_WEEKLY_PATTERN.ACT_WEEKDAY, FC05_FORECAST_WEEK.FC_QTY_WEEK,
WL05_WEEKLY_PATTERN.PERC_DAY,
ROUND(FC05_FORECAST_WEEK.FC_QTY_WEEK*(WL05_WEEKLY_PATTERN.PERC_DAY/100),0)
AS FC_QTY_DAY
FROM WL05_WEEKLY_PATTERN, FC05_FORECAST_WEEK
```

SQL code 8: FC06_FORECAST_DAY

For being able to check the calculations of the prototype, we do not only provide the actual day of the week with the corresponding workload forecast but also the quantity of the whole week plus the percentage of a day.

By having the results regarding the daily workload available, we are able to calculate the hourly workload within the view FC07_FORECAST_HOUR. To achieve the workload for each single hour within a whole week, we combine the workload forecast for a whole day (the

result of FC06_FORECAST_DAY) with the typical daily workload pattern (from view WL07_HOURLY_PATTERN), which we have calculated earlier. To get the workload for a certain hour of the day, we multiply the workload of the day with the percentage of a certain hour. To give an example, the formula is as follows:

$$Forecasted\ workload\ Monday\ 6AM$$
$$= Forecasted\ workload\ of\ Monday * percentage\ of\ Monday\ 6AM$$

Equation 25: Formula for hourly workload forecast (example)

To get the correct values, the percentages have to be divided by hundred because they have been multiplied by the same factor as the percentages have been calculated.

```
SELECT FC06_FORECAST_DAY.ACT_WEEKDAY,WL07_HOURLY_PATTERN.ACT_HOUR,
FC06_FORECAST_DAY.FC_QTY_DAY, WL07_HOURLY_PATTERN.PERC_HOUR,
ROUND(FC06_FORECAST_DAY.FC_QTY_DAY*(WL07_HOURLY_PATTERN.PERC_HOUR/100),0)
AS FC_QTY_HOUR
FROM WL07_HOURLY_PATTERN,FC06_FORECAST_DAY
WHERE WL07_HOURLY_PATTERN.ACT_WEEKDAY = FC06_FORECAST_DAY.ACT_WEEKDAY
ORDER BY FC06_FORECAST_DAY.ACT_WEEKDAY,WL07_HOURLY_PATTERN.ACT_HOUR
```

SQL code 9: FC07_FORECAST_HOUR

In addition to the columns for the actual weekday, the actual hour and the corresponding forecasted workload, we provide the forecasted quantity for the whole day plus the percentage, for being able to check the calculations.

7.3.3 Operator disposition

The target of this module is to get the number of operators required for a certain expected workload. To achieve this, we have to do some different tasks, which have to be allocated to several views.

7.3.3.1   Starting times per operator type

The first task is to collect the information regarding the starting time groups, which shall provide the data regarding the possible starting and working times of the different operator types, for being able to add the shift pattern to the forecasted workload values and to the performance data. For this reason we are going to combine the information of the tables OD_STARTING_TIMES, OPR_TYPE and OD_SHIFT_PATTERN. As the full-time operators (type 1 and 2) are by definition only allowed to start within the starting time group 1 and 3, we have to find some criteria to extract the correct starting times, starting time group ID, the matching shift ID and the standard working time in accordance with the operator type. So we can use the fact that the starting time groups of the full-time operators are identified by uneven numbers for the case handling.

If an operator normally works 8 hours a day and the starting time group ID is uneven, the operator is allowed to start and we can insert the starting time which is stored for the starting time group. As the end time regarding the shift can be found within the table OD_STARTING_TIMES in another row, we have to extract the end time from the table OD_SHIFT_PATTERN. When the number of the starting time group ID is even, the operator is not allowed to start and so we do not have to add data to the view for these starting groups.

On the contrary, the part-time workers (operator type 3) are allowed to start within every starting time group, so we can add the matching starting respectively end time from the table OD_STARTING_TIMES for every starting time group.

```sql
SELECT OPR_TYPE.OPR_TYPE_ID,OD_STARTING_TIMES.SHIFT_ID,
OD_STARTING_TIMES.ST_GROUP_ID,OPR_TYPE.OPR_WORKTIME,
(CASE
WHEN OPR_TYPE.OPR_WORKTIME = 8 AND MOD(OD_STARTING_TIMES.ST_GROUP_ID,2) = 1
THEN 'Y'
WHEN OPR_TYPE.OPR_WORKTIME = 8 AND MOD(OD_STARTING_TIMES.ST_GROUP_ID,2) = 0
THEN 'N'
WHEN OPR_TYPE.OPR_WORKTIME = 4 THEN 'Y'
END) AS START_OK,
(CASE
WHEN OPR_TYPE.OPR_WORKTIME = 8 AND MOD(OD_STARTING_TIMES.ST_GROUP_ID,2) = 1
THEN OD_STARTING_TIMES.ST_START
WHEN OPR_TYPE.OPR_WORKTIME = 8 AND MOD(OD_STARTING_TIMES.ST_GROUP_ID,2) = 0
THEN NULL
WHEN OPR_TYPE.OPR_WORKTIME = 4 THEN ST_START
END) AS OD_OPR_START,
(CASE
WHEN OPR_TYPE.OPR_WORKTIME = 8 AND MOD(OD_STARTING_TIMES.ST_GROUP_ID,2) = 1 AND
OD_STARTING_TIMES.SHIFT_ID = OD_SHIFT_PATTERN.SHIFT_ID
THEN OD_SHIFT_PATTERN.SHIFT_END
WHEN OPR_TYPE.OPR_WORKTIME = 4 THEN OD_STARTING_TIMES.ST_END
END) AS OD_OPR_END
FROM OD_STARTING_TIMES, OPR_TYPE, OD_SHIFT_PATTERN
WHERE OD_STARTING_TIMES.SHIFT_ID = OD_SHIFT_PATTERN.SHIFT_ID
ORDER BY OPR_TYPE.OPR_TYPE_ID,OD_STARTING_TIMES.ST_GROUP_ID,
OD_STARTING_TIMES.SHIFT_ID
```

SQL code 10: OD01_ST_OPR

The results of this view can now be used, to extract the forecasted workload data and the performance data in accordance with the working hours.

7.3.3.2   Average performance per operator type

Having the results regarding the allowed starting times per operator type and the corresponding time spans available, our next task is to find the average performance of each type of operators in accordance with their starting respectively end time (provided by view OD01_ST_OPR). To start with, we have to combine the average performance values of each type of operator from the view PM02_TYPE_AVG_PERF with the matching starting time group ID from the view OD01_ST_OPR. The starting time group ID is matching to the data of the performance values, if the operator type ID within these two views is equal and moreover if the actual hour of the performance data is between the starting time and the end type of a certain operator type.

```
SELECT DISTINCT PM02_TYPE_AVG_PERF.OPR_TYPE_ID,PM02_TYPE_AVG_PERF.ACT_HOUR,
PM02_TYPE_AVG_PERF.AVG_QTY_TYPE, OD01_ST_OPR.ST_GROUP_ID
FROM PM02_TYPE_AVG_PERF,OD01_ST_OPR
WHERE PM02_TYPE_AVG_PERF.OPR_TYPE_ID = OD01_ST_OPR.OPR_TYPE_ID AND
PM02_TYPE_AVG_PERF.ACT_HOUR
BETWEEN (OD01_ST_OPR.OD_OPR_START) AND (OD01_ST_OPR.OD_OPR_END)
ORDER BY PM02_TYPE_AVG_PERF.OPR_TYPE_ID,PM02_TYPE_AVG_PERF.ACT_HOUR
```

SQL code 11: OD02_ST_GROUPING

So the result of the view OD02_ST_GROUPING is the average performance value per each type of operator combined with the appropriate starting time group ID, which will be used within the next view (OD03_ST_AVG_PERF) to calculate the average performance per operator type within the time span of the starting time group, a type of operator is allowed to start working.

```
SELECT OPR_TYPE_ID,ST_GROUP_ID,ROUND(AVG(AVG_QTY_TYPE),0) AS AVG_PERF_TYPE_ST
FROM OD02_ST_GROUPING
WHERE OPR_TYPE_ID = OPR_TYPE_ID AND ST_GROUP_ID = ST_GROUP_ID
GROUP BY OPR_TYPE_ID,ST_GROUP_ID
ORDER BY OPR_TYPE_ID,ST_GROUP_ID
```

SQL code 12: OD03_ST_AVG_PERF

This means that for starting group 1 and operator types 1 and 2 the average performance value consists of 8 single values, while for operator type 3 there are only 4 hours considered for an average performance value. As a result, we get only two different performance values for the full-time operators and four values for the part-time operators. But as we may need the performance values of the full-time workers for the two other starting time groups, we have implemented two views (OD04_ST_AVG_PERF_SG and OD05_ST_AVG_PERF_GROUP) which 'duplicate' the performance values. This means that the performance value of starting

time group 1 is duplicated to group 2; the value of group 3 is copied to group 4 accordingly. The result is, having four performance values for each type of operator available.

As we cannot use the results of the view OD05_ST_AVG_PERF_GROUP directly, we have created some views (identifiers from OD06_... to OD10_...), whose task it is to transform these performance matrix. The target was to achieve a performance matrix, where the performance values are grouped by the starting time group ID and provides a column for each type of operator. This is obviously not the best method to store performance data due to a lack of flexibility regarding expansion, but we need the performance data within the same row of a view for our further calculations. Having finished these calculations we have grouped the performance values in accordance with the starting times.

7.3.3.3   Grouping of forecasted workload

The next task, that had to be implemented, was to group the forecasted workload values according to the starting time groups too. But this task was again split to several views. To get the basis for the calculation, we have to add the shift ID and the starting time group ID to the forecasted workload values, which is be done by the view OD11_FC_ADD_SG. The view adds the required information of the table OD_STARTING_TIMES to the results of the view FC07_FORECAST_HOUR, if the hour of the forecast is between the starting and end time of a certain starting time group.

```
SELECT FC07_FORECAST_HOUR.ACT_WEEKDAY, FC07_FORECAST_HOUR.ACT_HOUR,
FC07_FORECAST_HOUR.FC_QTY_HOUR, OD_STARTING_TIMES.ST_GROUP_ID,
OD_STARTING_TIMES.SHIFT_ID
FROM FC07_FORECAST_HOUR, OD_STARTING_TIMES
WHERE FC07_FORECAST_HOUR.ACT_HOUR BETWEEN
OD_STARTING_TIMES.ST_START AND OD_STARTING_TIMES.ST_END
```

SQL code 13: OD11_FC_ADD_SG

Adding the starting time group and the shift ID to the forecasted workload values, we now have to calculate the average workload value for each of the starting time groups. For this reason we are using the three highest values per starting group. This is done for not influencing the average value in a negative way due to planned breaks of the operators, which are not regarded within the shift model. To get the three highest values per starting time group, we have applied a 'trick' to the view. As we have four workload values available per group, we first sum them up, then subtract the minimum value and divide the result by three.

$$Average\ workload\ = \frac{(sum\ of\ workload - minimum\ of\ workload)}{3}$$

Equation 26: Average workload per starting time group

The result of this calculation is rounded up to get a whole number of units.

```sql
SELECT ACT_WEEKDAY, SHIFT_ID, ST_GROUP_ID,
CASE
WHEN (CEIL((SUM(FC_QTY_HOUR)-MIN(FC_QTY_HOUR))/3) = 0) THEN MEDIAN(FC_QTY_HOUR)
ELSE (CEIL((SUM(FC_QTY_HOUR)-MIN(FC_QTY_HOUR))/3))
END AS FC_QTY_HOUR_D_ST
FROM OD11_FC_ADD_SG
WHERE ACT_WEEKDAY = ACT_WEEKDAY AND ST_GROUP_ID = ST_GROUP_ID
GROUP BY ACT_WEEKDAY, ST_GROUP_ID, SHIFT_ID
ORDER BY ACT_WEEKDAY, SHIFT_ID, ST_GROUP_ID
```

SQL code 14: OD12_FC_WL_GROUP

The results of the view OD12_FC_WL_GROUP are used within the view OD13_FC_MAX_SHIFT to determine which one is the maximum average workload value of a shift. So we have to compare the average workload values, which belong to the same shift and moreover to the same day.

```sql
SELECT ACT_WEEKDAY,SHIFT_ID, MAX(FC_QTY_HOUR_D_ST) AS WL_GR_MAX
FROM OD12_FC_WL_GROUP
WHERE ACT_WEEKDAY = ACT_WEEKDAY AND SHIFT_ID = SHIFT_ID
GROUP BY ACT_WEEKDAY, SHIFT_ID
ORDER BY ACT_WEEKDAY, SHIFT_ID
```

SQL code 15: OD13_FC_MAX_SHIFT

Within the view OD14_FC_WEEK_CPL, we just use the results of view OD12_FC_WL_GROUP and extend every line with the matching maximum average workload (from view OD13_FC_MAX_SHIFT) for each single shift of the week. This enables us to compare the average workload value for a certain starting group to the maximum average workload value. If the two values are equal, we have found a maximum within a shift, if the two values differ, we have found the minimum. The results are stored within a separate column.

```sql
SELECT OD12_FC_WL_GROUP.ACT_WEEKDAY,OD12_FC_WL_GROUP.SHIFT_ID,
OD12_FC_WL_GROUP.ST_GROUP_ID,OD12_FC_WL_GROUP.FC_QTY_HOUR_D_ST,
OD13_FC_MAX_SHIFT.WL_GR_MAX,
CASE
WHEN (OD12_FC_WL_GROUP.FC_QTY_HOUR_D_ST=OD13_FC_MAX_SHIFT.WL_GR_MAX)
THEN 'max' ELSE 'min'
END AS AVG_WL
FROM OD12_FC_WL_GROUP, OD13_FC_MAX_SHIFT
WHERE OD12_FC_WL_GROUP.ACT_WEEKDAY = OD13_FC_MAX_SHIFT.ACT_WEEKDAY
AND OD12_FC_WL_GROUP.SHIFT_ID = OD13_FC_MAX_SHIFT.SHIFT_ID
```

SQL code 16: OD14_FC_WEEK_CPL

7.3.3.4   Adding performance values and starting time groups

Based on these results, within the view OD15_ADD_OPR_PERF_SG we are going to add the performance values of the full-time operators (from view OD10_ST_AVG_PERF_OPR), the number of the company's own operators and within which shift they are working (data from table X_NUM_OWN_OPR) and moreover the possible starting time groups of the operators, which are provided by the agency. We are adding this information to the lines, where the comparison of the workload values resulted in 'minimum' because when using the information of these rows, we can calculate the difference between the maximum and the minimum average workload value easily.

The first part to be added is the performance of the company's own personnel (type 1) in accordance with the starting time groups and the number of how many of these operators is working within a certain shift (number from table X_NUM_OWN_OPR). The performance of the operator type 2 is added to the view in an analogue way, if the starting time groups are matching. But to get the correct starting time groups to the rows containing 'minimum', we have to do some 'tricky' case handling.

As the IDs of the starting time groups, where the full-time operators are allowed to start, are by definition uneven numbers, we can adjust the given starting group ID within the 'minimum' row by using the modulo operator of SQL. If the starting time group ID within this row is an even number, the modulo operator delivers zero if using two as divisor. In this case we have to reduce the starting group ID by one; otherwise we can simply 'copy' the group ID to the column SG_ADD_TYPE2.

Finding the correct starting group ID for the part-time operators (type 3) is a little different, even if we can also use the modulo operator. As we have to allocate the part-time workers, when the maximum workload occurs within a shift, we have to determine the matching group IDs. But we are still using the 'minimum' rows to collect the information. So if the result of the modulo operator is one, the starting time group where the minimum average workload is located has an uneven number (which is by definition always the first starting time group of a shift) and for this reason we have to increase the group ID by one, because the maximum average workload can be found within the other starting time group of a shift, whose ID has an even number. If the result of the modulo operator is zero, we have to decrease the group ID by one.

```
SELECT OD14_FC_WEEK_CPL.ACT_WEEKDAY,OD14_FC_WEEK_CPL.SHIFT_ID,
OD14_FC_WEEK_CPL.ST_GROUP_ID,OD14_FC_WEEK_CPL.FC_QTY_HOUR_D_ST,
OD14_FC_WEEK_CPL.WL_GR_MAX,OD14_FC_WEEK_CPL.AVG_WL,
CASE
WHEN OD10_ST_AVG_PERF_OPR.ST_GROUP_ID = OD14_FC_WEEK_CPL.ST_GROUP_ID
THEN OD10_ST_AVG_PERF_OPR.PT1
END AS PERF_TYPE1,X_NUM_OWN_OPR.NUM_OWN,
CASE
WHEN OD10_ST_AVG_PERF_OPR.ST_GROUP_ID = OD14_FC_WEEK_CPL.ST_GROUP_ID
THEN OD10_ST_AVG_PERF_OPR.PT2
END AS PERF_TYPE2,
CASE
WHEN OD14_FC_WEEK_CPL.AVG_WL = 'min' AND MOD(OD14_FC_WEEK_CPL.ST_GROUP_ID,2) = 0
THEN OD14_FC_WEEK_CPL.ST_GROUP_ID-1
WHEN OD14_FC_WEEK_CPL.AVG_WL = 'min' THEN OD14_FC_WEEK_CPL.ST_GROUP_ID
END AS SG_ADD_TYPE2,
CASE
WHEN OD14_FC_WEEK_CPL.AVG_WL = 'min' AND MOD(OD14_FC_WEEK_CPL.ST_GROUP_ID,2) = 1
THEN OD14_FC_WEEK_CPL.ST_GROUP_ID+1
WHEN OD14_FC_WEEK_CPL.AVG_WL = 'min' AND MOD(OD14_FC_WEEK_CPL.ST_GROUP_ID,2) = 0
THEN OD14_FC_WEEK_CPL.ST_GROUP_ID-1
END AS SG_ADD_TYPE3
FROM OD10_ST_AVG_PERF_OPR,OD14_FC_WEEK_CPL LEFT JOIN X_NUM_OWN_OPR
ON OD14_FC_WEEK_CPL.ACT_WEEKDAY = X_NUM_OWN_OPR.ACT_DAY
AND OD14_FC_WEEK_CPL.SHIFT_ID = X_NUM_OWN_OPR.SHIFT_ID
WHERE OD14_FC_WEEK_CPL.ST_GROUP_ID = OD10_ST_AVG_PERF_OPR.ST_GROUP_ID
ORDER BY OD14_FC_WEEK_CPL.ACT_WEEKDAY,OD14_FC_WEEK_CPL.SHIFT_ID,
OD14_FC_WEEK_CPL.ST_GROUP_ID
```

SQL code 17: OD15_ADD_OPR_PERF_SG

7.3.3.5   Determining number of additional full-time operators

Now having the performance values of all the full-time operators plus the number of a company's own personnel and the shift, to which they are allocated, available within the view OD15_ADD_OPR_PERF_SG, we are now able to determine if there are additional full-time workers needed and how many are required. To achieve this target, we use the data of the 'minimum' rows again.

Before doing any of the calculations regarding the number of additional full-time operators, we have to check, if there are additional full-time workers needed. We can check this matter by multiplying the number of company's own personnel with the average performance of this operator type in accordance with the starting time group. If additional operators are needed, we can achieve the number by building the difference between the minimum average workload and the number of units, the company's own personnel is able to cope. Afterwards

we have to divide the result by the average performance of full-time operators provided by the agency (operator type 2).

$$\#operator\ type\ 2 = \frac{(minimum\ average\ workload - (\#op.type\ 1 * perf.type\ 1))}{performance\ type\ 2}$$

Equation 27: Calculating number of additional full-time operators

After having rounded up the result, we have the number of additional full-time operators available.

```sql
SELECT OD15_ADD_OPR_PERF_SG.ACT_WEEKDAY,OD15_ADD_OPR_PERF_SG.SHIFT_ID,
OD15_ADD_OPR_PERF_SG.ST_GROUP_ID,OD15_ADD_OPR_PERF_SG.FC_QTY_HOUR_D_ST,
OD15_ADD_OPR_PERF_SG.WL_GR_MAX,OD15_ADD_OPR_PERF_SG.AVG_WL,
OD15_ADD_OPR_PERF_SG.PERF_TYPE1,OD15_ADD_OPR_PERF_SG.NUM_OWN,
OD15_ADD_OPR_PERF_SG.PERF_TYPE2,OD15_ADD_OPR_PERF_SG.SG_ADD_TYPE2,
CASE
WHEN AVG_WL = 'min' AND FC_QTY_HOUR_D_ST>(NUM_OWN*PERF_TYPE1) AND
SG_ADD_TYPE2 >= 1
THEN CEIL((FC_QTY_HOUR_D_ST-(NUM_OWN*PERF_TYPE1))/PERF_TYPE2) ELSE 0
END AS ADD_TYPE2,OD15_ADD_OPR_PERF_SG.SG_ADD_TYPE3,
OD10_ST_AVG_PERF_OPR.PT3 AS PERF_TYPE3
FROM OD15_ADD_OPR_PERF_SG LEFT JOIN OD10_ST_AVG_PERF_OPR
ON OD15_ADD_OPR_PERF_SG.SG_ADD_TYPE3 = OD10_ST_AVG_PERF_OPR.ST_GROUP_ID
```

SQL code 18: OD16_ADD_OPR_TYPE2

Moreover we add the performance values of the part-time operators (from view OD10_ST_AVG_PERF_OPR) in accordance with the starting time group IDs, which we have determined within view OD15_ADD_OPR_PERF_SG.

7.3.3.6   Determining number of additional part-time workers

As we now have the number of additionally required full-time operators available, we can now fill the gap between the minimum and maximum average workload by adding part-time workers. While calculating the number of required part-time workers, we have to distinguish between three different cases.

If the maximum average workload is bigger than the amount of units, that the operators of type 1 and type 2 are able to cope with (number of operators multiplied with average performance value of corresponding operator type), we compute the difference between the maximum and the minimum average workload. Afterwards we divide this result by the average performance of operator type 3 (corresponding to the considered starting time group) and round up to get the whole number of additionally needed part-time workers.

$$\#\ operator\ type\ 3 = \frac{(maximum\ average\ workload - minimum\ average\ workload)}{performance\ type\ 3}$$

Equation 28: Calculating number of part-time operators required

If the minimum average workload within a shift is zero, we have to calculate the difference between the maximum average workload and the number of units, which the company's own personnel (type 1) is able to cope within this shift. Afterwards we have to divide this result by the average performance of operator type 3 and round up to get the number of the additionally required part-time operators.

If the minimum average workload value is less than the amount of units, the company's own operators are able to cope with, and the maximum average workload value is greater than the number of units provided by the operators of type 1, we have to subtract the number of units, the operators of type 1 are able to cope with, from the maximum average workload to achieve the number of units, which have to be done by the part-time workers. Afterwards we have to divide the result by the performance of operator type 3 (in accordance with the starting time group) and round up to achieve the number of part-time workers.

```sql
SELECT ACT_WEEKDAY,SHIFT_ID,ST_GROUP_ID,FC_QTY_HOUR_D_ST,WL_GR_MAX,AVG_WL,
PERF_TYPE1,NUM_OWN,PERF_TYPE2,SG_ADD_TYPE2,ADD_TYPE2,SG_ADD_TYPE3,PERF_TYPE3,
CASE
WHEN AVG_WL = 'min' AND WL_GR_MAX>((NUM_OWN*PERF_TYPE1)+(ADD_TYPE2*PERF_TYPE2))
THEN CEIL((WL_GR_MAX-FC_QTY_HOUR_D_ST)/PERF_TYPE3)
WHEN AVG_WL = 'min' AND FC_QTY_HOUR_D_ST=0
THEN CEIL(((WL_GR_MAX-FC_QTY_HOUR_D_ST)-(NUM_OWN*PERF_TYPE1))/PERF_TYPE3)
WHEN AVG_WL = 'min' AND FC_QTY_HOUR_D_ST<NUM_OWN*PERF_TYPE1
AND WL_GR_MAX>(NUM_OWN*PERF_TYPE1)
THEN CEIL((WL_GR_MAX-(NUM_OWN*PERF_TYPE1))/PERF_TYPE3) ELSE 0
END AS ADD_TYPE3
FROM OD16_ADD_OPR_TYPE2
```

SQL code 19: OD17_ADD_OPR_TYPE3

7.3.3.7 Condense the results

To condense the results of view OD17_ADD_OPR_TYPE3, we have created the view OD18_WEEKLY_PLAN. There are no more calculations done within the view, we have just reduced the amount of information, which we are going to provide to the user of the labour management tool. Finally we only deliver the information regarding the actual day of the week, the IDs of the shift of this day and in addition to this, the number of additional full-time operators needed for the shift. Moreover we give the information, how many part-time workers are needed and when they should start working to match the expected daily workload fluctuations. Furthermore we add the information, for which week the forecast was done.

7.4   Results delivered by the prototype

Having implemented the prototype, we finally have to document some main results which we have achieved by using the prototype. This has to be done to display that the functionality of the prototype matches the targets of the single modules which were defined within the conceptual phase (see chapter 5). We are going to structure the results in accordance with the single modules given before.

7.4.1 Performance measurement

Just to recapitulate the targets of this module, we have defined we would like to have the performance values available per hour of the day. This is due to the fact that our aim was to provide the performance values independently of any shift model. In addition to this the target was to get the average hourly performance on the one hand per operator and on the other hand per operator type.

OPR_ID	ACT_HOUR	AVG_QTY	OPR_TYPE_ID
791026	06:00	437	1
791026	07:00	462	1
791026	08:00	462	1
791026	09:00	462	1
791026	10:00	477	1
791026	11:00	453	1
791026	12:00	460	1
791026	13:00	442	1

Figure 13: Average performance per operator (excerpt)

As you can see within this figure, the average quantity was calculated per operator and actual hour of the day. In addition to this, we have assigned the operator type to this view which helps us with the next step of calculation. Having the average performance values available per operator available, this result was used to achieve the average performance values per operator type.

OPR_TYPE_ID	ACT_HOUR	AVG_QTY_TYPE
1	06:00	444
1	07:00	443
1	08:00	455
1	09:00	463
1	10:00	474
1	11:00	448
1	12:00	457
1	13:00	452

Figure 14: Average performance per operator type (excerpt)

These two results provide on the one hand to compare the average performances of single operators to each other and on the other hand to use the average performance per operator type for allocating the operators to the warehouse processes.

7.4.2 Workload forecasting

The main target of the module is to achieve a workload forecast for a whole week which has to be refined to the daily and even hourly level for being able to allocate the operators to the single processes in an optimal way. While the weekly value was forecasted first, it provides the basis for further refinement by using the typical weekly and daily workload pattern which hat to be calculated first. Moreover the data is still available independent of any shift model.

So the first task was to find the typical weekly workload pattern based on an analysis of historical data. As mentioned before this represents the amount of work that was done on average on a certain weekday in comparison to the average weekly workload.

ACT_WEEKDAY	AVG_DAY	AVG_WEEK	PERC_DAY
1	119567	741563	16,12
2	137797	741563	18,58
3	140866	741563	19
4	134309	741563	18,11
5	94864	741563	12,79
6	0	741563	0
7	114160	741563	15,39

Figure 15: Typical weekly workload pattern

The typical daily workload pattern was calculated in an analogue way which means that we have computed the ratio of the average hourly workload to the average daily workload.

ACT_WEEKDAY	ACT_HOUR	AVG_HOUR	AVG_DAY	PERC_HOUR
1	06:00	8696	119567	7,27
1	07:00	11899	119567	9,95
1	08:00	10826	119567	9,05
1	09:00	6592	119567	5,51
1	10:00	11906	119567	9,96
1	11:00	14031	119567	11,73
1	12:00	13684	119567	11,44
1	13:00	10897	119567	9,11

Figure 16: Typical daily workload pattern (excerpt)

Our next task within this module is to estimate the future workload on basis of historical data. For this reason we have multiplied the workload of the same week of the last year with the grow rate, which was determined before.

FC_WEEK_LY	CALC_GROW_RATE	FC_QTY_WEEK	MAN_GROW_RATE
200912	1,15	716698	1

Figure 17: Calculating the weekly forecast

Having forecasted the weekly workload we can now use the typical workload patterns to increase the level of detail of the results to single days and even to single hours. So the first step will be the refinement of the weekly workload to the single days by using the typical weekly workload pattern.

ACT_WEEKDAY	FC_QTY_WEEK	PERC_DAY	FC_QTY_DAY
1	716698	16,12	115532
2	716698	18,58	133162
3	716698	19	136173
4	716698	18,11	129794
5	716698	12,79	91666
6	716698	0	0
7	716698	15,39	110300

Figure 18: Weekly forecast refined on daily level

Based on these results we can do further refinement of the forecasted workload data to achieve the estimated hourly workload by using the typical daily workload pattern.

ACT_WEEKDAY	ACT_HOUR	FC_QTY_DAY	PERC_HOUR	FC_QTY_HOUR
1	06:00	115532	7,27	8399
1	07:00	115532	9,95	11495
1	08:00	115532	9,05	10456
1	09:00	115532	5,51	6366
1	10:00	115532	9,96	11507
1	11:00	115532	11,73	13552
1	12:00	115532	11,44	13217
1	13:00	115532	9,11	10525

Figure 19: Daily forecast refined on hourly level (excerpt)

After having processed these steps of refinement, we have estimated the daily and hourly workload, which will be one part of the basis data for the allocation of the operators throughout the whole day. The data which is provided by this module is also available independently of any shift pattern.

7.4.3 Operator disposition

Within this module several results and data were combined together. On the one hand the information regarding the shift pattern and when the single operator types are allowed to start and on the other hand the forecasted workload values and the performance values. The target of this module was to calculate the number of operators which are required within a certain shift and when to employ them best. This information had to be provided as a weekly plan for each considered process.

Before doing any calculations we have created a piece of information out of the basic shift model, which tells us which type of operator is allowed to work within which period of time.

OPR_TYPE_ID	SHIFT_ID	ST_GROUP_ID	OPR_WORKTIME	START_OK	OD_OPR_START	OD_OPR_END
1	1	1	8	Y	06:00	13:00
1	1	2	8	N		
1	2	3	8	Y	14:00	21:00
1	2	4	8	N		
2	1	1	8	Y	06:00	13:00
2	1	2	8	N		
2	2	3	8	Y	14:00	21:00
2	2	4	8	N		
3	1	1	4	Y	06:00	09:00
3	1	2	4	Y	10:00	13:00
3	2	3	4	Y	14:00	17:00
3	2	4	4	Y	18:00	21:00

Figure 20: Shift model and allowed starting times per operator type

This view provides the basis for our further calculations which have to be done within this module regarding the average performance that is usually provided per operator type. To achieve this, we have to extract the average performance values of each operator from the corresponding view in accordance with the period of time the operators of a certain type are allowed to work. The result of this calculation is the average performance value per starting time group and per operator type.

ST_GROUP_ID	PT1	PT2	PT3
1	455	450	456
2	455	450	449
3	450	453	449
4	450	453	450

Figure 21: Average performance per operator type and starting time group

The other part of information required is the average forecasted workload value per starting time group. As we have two starting time groups per shift, we have to average workload values available. For being able to determine the number of operators and the best starting time per operator type in accordance with the concept given above, we had to determine which of the two average workloads is the maximum value.

ACT_WEEKDAY	SHIFT_ID	ST_GROUP_ID	FC_QTY_HOUR_D_ST	WL_GR_MAX	AVG_WL
1	1	1	10117	12759	min
1	1	2	12759	12759	max
1	2	3	8615	8615	max
1	2	4	100	8615	min
2	1	1	9859	11990	min
2	1	2	11990	11990	max
2	2	3	10032	10032	max
2	2	4	5646	10032	min

Figure 22: Weekly forecast with average workload per starting time group

This view allows us to join the data regarding the average performance values per operator type, the number of operators that are provided by the company itself and moreover to find out within which starting time group the single operator types shall start working. Having

this information available, we are able to calculate the number of operators required. While the full result of the view can be found within the appendix (see Figure 34), the condensed version is provided within figure (see Figure 23).

FC_WEEK	ACT_WEEKDAY	SHIFT_ID	NUM_OWN	ADD_TYPE2	ADD_TYPE3	ST_TYPE_3
201012	1	1	10	13	6	10:00
201012	1	2	0	1	19	14:00
201012	2	1	10	12	5	10:00
201012	2	2	0	13	10	14:00
201012	3	1	10	12	2	10:00
201012	3	2	0	17	7	14:00
201012	4	1	10	11	4	10:00
201012	4	2	0	14	9	14:00
201012	5	1	10	8	7	10:00
201012	5	2	0	6	5	14:00
201012	7	1	10	4	0	10:00
201012	7	2	0	19	2	18:00

Figure 23: Number of additional operators required for considered week

Having now achieved a result which represents a weekly plan regarding the number of operators needed and when they should start to match the expected workload, we are now able to say this result matches the target we have defined in the beginning. This allows us to state, that the transfer of the concept into a database prototype is possible and moreover delivers the desired results. In addition to this, we have taken some sample values randomly and have checked the calculation of the prototype by using a calculator.

7.5   Implementing a graphical user interface prototype

For being able to make a presentation of the prototype to a potential customer easier, we have implemented a graphical user interface whose basis is the database structure of the prototype mentioned before. The user interface was created by using a software tool which was created by and is property of the KNAPP Systemintegration GmbH. For this reason we are not going to provide detailed information regarding this software but only give a short description regarding the purpose of the main points which are provided for the interaction with the user plus some screenshots of the results. We are going to use the structure of the concept again, but we had to add the section "master data" to the prototype which allows the user to define some decisive parameters. Moreover we have defined some additional functionality which was not considered within the database prototype. We have to mention, that the further consideration concentrate on the bin2bin picking process.

7.5.1 User menu structure

To start with the description of the graphical user interface prototype we will have to give a short overview of the menu tree, which was mainly structured in accordance with the models given within the concept. The main point "master data" was added to the menu for being able to prompt some basic input data to the labour management tool.
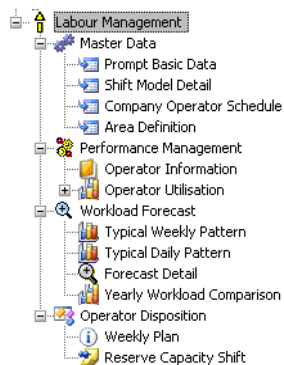
Figure 24: User menu

Giving a description regarding the menu tree, we are now going to describe the single menu points shortly.

7.5.2 Master data

The first point regarding the master data is the input mask for the forecasting details, which means the user has to prompt the actual week and the week for which the workload has to be forecasted. Moreover the user has to define the number of periods that shall be considered for determining the calculated grow rate, the manual grow rate for a further adjustment of the weekly forecast, if necessary. In addition to this a sales forecast can be entered, if such information is available to the resource planner. When a sales forecast is prompted, the calculated weekly workload forecast which was determined by using the grow rates will be ignored.

Actual week	Week to be forecasted	# periods for calc. grow rate	Manual grow rate	Sales forecast [units]
201010	201012	6	1	0

Figure 25: Define forecast basics

Secondly the user has to define the shift pattern which is used within the considered warehouse for enabling the manpower planning procedure on basis of single shifts. The possible starting times for some of the operator types have to be defined additionally. The main point is to get the information regarding the time span of the single shifts respectively the starting time groups.

Shift ID △	Shift	Start [hour]	End [hour]
▶1	Early shift (6AM - 2PM)	06:00	13:00
2	Late shift (2PM - 10PM)	14:00	21:00

Starting time group ID	Description	Starts [hour]	End [hour]
▶1	06AM - 10AM	06:00	09:00
2	10AM - 02PM	10:00	13:00

Figure 26: Shift plan and starting time groups

For being able to determine the number of operators which will be required in addition to the company's own operators, the user has to prompt the information, how many of the operators of the permanent staff will be working on which day and within which shift.

Weekday	Shift ID	Shift	# operators
▶Monday	1	Early shift (6AM - 2PM)	10
Monday	2	Late shift (2PM - 10PM)	0
Tuesday	1	Early shift (6AM - 2PM)	10
Tuesday	2	Late shift (2PM - 10PM)	0
Wednesday	1	Early shift (6AM - 2PM)	10
Wednesday	2	Late shift (2PM - 10PM)	0

Figure 27: Schedule of permanent staff

Within the menu point for the master data maintenance the possibility to prompt some area information is provided. The importance of this point will increase when the labour management tool is used for more than one warehouse process.

7.5.3 Performance management

For the module performance management are two menu items provided for being able to monitor some performance indicators regarding an operator's performance. The point "operator information" presents a general view of the operators which are working within the warehouse plus some performance indicators per operator. So this information can be considered like a performance database. The basic information which is provided at a glance tells the user the operator type, the typical working duration a day, the average performance value for a whole day plus the average log-in, net working and – if a time and attendance system is available – the attendance time. In addition to this, the performance time-line of an operator is displayed if an operator is chosen. Moreover the user is able to group the single columns and sort the data which means he/she is for example to find out the top ten operators for a certain area respectively of a certain operator type.

Operator ID △	Name	Type	Worktime [h]	Avg day [units]	Area	Ø log-in...	Ø net wo...	Ø atten...
791026	Lee Tibbles	Full-time, own personnel	8	455	Bin2Bin	7,28	6,63	8,10
791036	Aaron Robson	Full-time, own personnel	8	449	Bin2Bin	7,52	6,84	8,20
792056	Patrick O'Connell	Full-time, agency	8	452	Bin2Bin	6,74	6	7,87
792126	Simon Ayres	Full-time, agency	8	450	Bin2Bin	7,47	5,46	7,94
793003	Nicky Morley	Part-time, agency	4	459	Bin2Bin	3,74	2,92	3,97
793125	Judith Murray	Part-time, agency	4	442	Bin2Bin	2,61	2,52	4,05

Hour of day	Avg. [units]	Area
06:00	458	Bin2Bin
07:00	439	Bin2Bin
08:00	438	Bin2Bin
09:00	431	Bin2Bin
10:00	442	Bin2Bin
11:00	451	Bin2Bin
12:00	415	Bin2Bin
13:00	422	Bin2Bin

Figure 28: Operator information

The second part of information provided is "operator utilisation", which represents several charts displaying the average utilisation of operators, whereas several levels of detail can be chosen. This means the user is on the one hand able to check the utilisation of operators regarding single warehouse processes compared to the other warehouse processes and on the other hand able to compare single operator types to another type and moreover to the overall utilisation. At the moment the utilisation is a comparison between the log-in time and the net working time, but the information should be extended by the data of a time and attendance system. This information would enable us to check the log-in times against the attendance time of the operators.
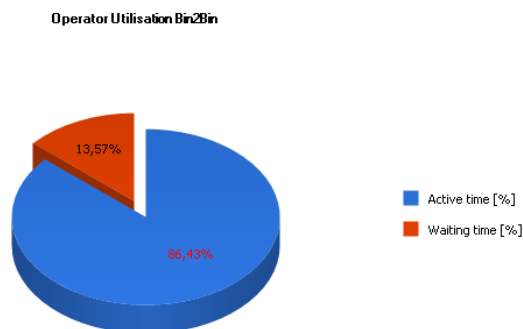
Figure 29: Example for utilisation chart

7.5.4 Workload forecast

The main point of information to be provided by this module is the weekly workload forecast including the grow rates which were used while calculating the forecast plus the detailed forecast for single days respectively hours. The details regarding the forecast of each single hour are presented when choosing a certain day.

Year	Week	Fc. qty week	Calc. grow rate	Man. grow rate
▶ 2010	12	716698	1,15	1

Weekday	Perc. day	Fc. qty day
Monday	16,12	115532
▶ Tuesday	18,58	133162
Wednesday	19	136173
Thursday	18,11	129794
Friday	12,79	91666
Saturday	0	0
Sunday	15,39	110300

Hour of day	Perc. hour	Fc. qty hour
▶ 06:00	6,27	8349
07:00	6,87	9148
08:00	9,07	12078
09:00	5,62	7484
10:00	8,40	11186
11:00	9,23	12291
12:00	9,38	12491
13:00	5,77	7683
14:00	6,36	8469
15:00	8,27	11012
16:00	7,97	10613
17:00	3,22	4288
18:00	5,56	7404
19:00	4,44	5912
20:00	2,72	3622
21:00	0,85	1132

Figure 30: Weekly forecast and forecast details

The chart which is represented by the menu item "yearly workload comparison" shall support the user in getting an idea regarding the accuracy of the forecasted values. For this reason 3 different time-lines are presented within the chart: The weekly workload data of the past year, the weekly workload of the actual year and the forecasted values of the actual year. So the user is able to compare the seasonal workload fluctuations of two years to each other and moreover 'check' the accuracy of the forecasted values to the workload of the recent past.
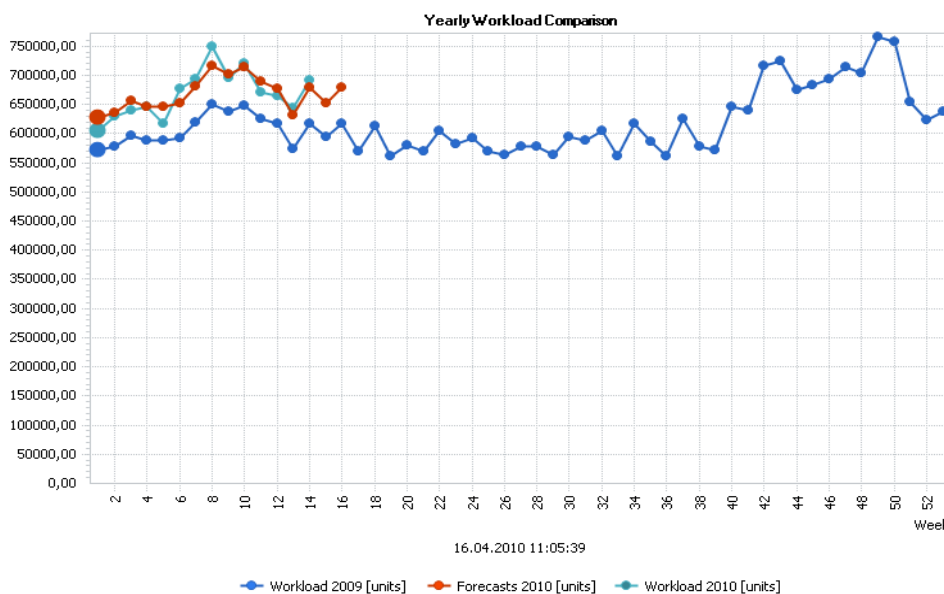
Figure 31: Weekly workload comparison

In addition to this information, the user is able to display a chart regarding the typical weekly respectively daily workload pattern. For these two menu items we are not going to provide any screenshots because the charts are similar to the charts presented within the concept.

7.5.5 Operator disposition

By using the menu item "operator disposition", the user of the labour management tool is able to access the information regarding the weekly plan and moreover the expected reserve capacity per shift for the same week.

The weekly plan is based on the corresponding view of the database prototype, which means it simply presents the same data. For being able to understand the data presented in this view easier, we have joined the description fields of the matching tables. So the user gets proper information regarding how many additional workers are required within a certain shift or at which point of time on a certain weekday.

| Year	Week	Day	Shift	# permanent staff	# full-time agency	# part-time agency	... starting at
2010	12	Monday	Early shift (6AM - 2PM)	10	13	6	10:00
2010	12	Monday	Late shift (2PM - 10PM)	0	1	19	14:00
2010	12	Tuesday	Early shift (6AM - 2PM)	10	12	5	10:00
2010	12	Tuesday	Late shift (2PM - 10PM)	0	13	10	14:00
2010	12	Wednesday	Early shift (6AM - 2PM)	10	12	2	10:00
2010	12	Wednesday	Late shift (2PM - 10PM)	0	17	7	14:00
2010	12	Thursday	Early shift (6AM - 2PM)	10	11	4	10:00
2010	12	Thursday	Late shift (2PM - 10PM)	0	14	9	14:00
2010	12	Friday	Early shift (6AM - 2PM)	10	8	7	10:00
2010	12	Friday	Late shift (2PM - 10PM)	0	6	5	14:00
2010	12	Sunday	Early shift (6AM - 2PM)	10	4	0	10:00
2010	12	Sunday	Late shift (2PM - 10PM)	0	19	2	18:00

Figure 32: Weekly plan

For being able to get an idea about the accuracy of the weekly plan given above, we provide some supplementary information regarding the spare capacity per shift to the user. This information is presented in two ways; first by simply calculating the difference between the forecasted workload and the expected workload per shift. As this value is presented original unit, it is not very representative. For this reason the result is expressed in spare man-hours per shift additionally.

Weekday	Shift	Σ forecasted workload [units]	Expected performance [units]	Reserve capacity [units]	Reserve man-hours [hours]
Monday	Early shift (6AM - 2PM)	85517	93976	8459	19
Monday	Late shift (2PM - 10PM)	30153	37748	7595	17
Tuesday	Early shift (6AM - 2PM)	80710	88580	7870	18
Tuesday	Late shift (2PM - 10PM)	52452	65072	12620	29
Wednesday	Early shift (6AM - 2PM)	74351	83192	8841	20
Wednesday	Late shift (2PM - 10PM)	65514	74180	8666	20
Thursday	Early shift (6AM - 2PM)	76878	83184	6306	15
Thursday	Late shift (2PM - 10PM)	54267	66900	12633	29
Friday	Early shift (6AM - 2PM)	71941	77772	5831	13
Friday	Late shift (2PM - 10PM)	24795	30724	5929	14
Saturday	Early shift (6AM - 2PM)	0			
Saturday	Late shift (2PM - 10PM)	0			
Sunday	Early shift (6AM - 2PM)	46238	50800	4562	11
Sunday	Late shift (2PM - 10PM)	64040	72456	8416	19

Figure 33: Reserve capacity according to weekly plan

We would like to emphasise that these spare capacity is based on the workload forecast information and should be considered as a buffer, if the actual workload is slightly higher than the forecast.

To summarise the documentation of the implemented prototypes shortly, we are now able to say that we were able to achieve the targets we have defined within the concept. This means that we are able to deliver the information in accordance with the aims of the single modules and the concept, which we have defined, can be transferred into a database structure.

8   Conclusion

To complete the master thesis we are going to give a short summary regarding the main points plus accentuating the central research questions again. Afterwards we have to discuss if the results of this master thesis can be used without any additional work or what kind of improvements have to be made to the status quo of the concept respectively prototype. In addition to this, we have to give a short overview which points have to be considered if the idea of offering the labour management tool to potential customers is pursued.

8.1   Benefits of labour management in warehouses

Apart from the fact that from a logistical point of view the best warehouse would be having no warehouse, a warehouse respectively distribution centre plays an important role within a supply chain. The single processes which are typically done within a warehouse can be either done manually or automated. Due to considering automated warehouses within this master thesis, we can state that the productivity of the single processes cannot be improved any more within an automated environment. But the companies, which are operating such warehouses, would like to achieve a further increase regarding the economic efficiency. For this reason, the resources which are kind of supporting the warehouse processes, come to the focal point. As there would be several starting points available, the resource 'labour' stands out due to causing the highest amount of the current costs, which is the main reason for this factor being this important. So relating to the research question, why such a tool can be this important for a warehouse, we can state that the significance is based on the high amount of costs being consumed by the resource 'labour'.

Due to improving the planning in regard to the number of operators required and the point in time of the operator demand, a tool for achieving this information is to be created. In accordance with the literature, such "Labour Management Systems" are available on the market. The result of these LMS is based on actual order data, which means the system is able to consider the actual storage locations and all the tasks that have to be processed for fulfilling all the orders. This information is combined with the standard time for each single task and so the result is a certain amount of time that has to be covered by a defined amount of operators. Even if these calculations are highly accurate, a LMS does not exactly match our aim due to being very short-term because the actual order data is available only one day in advance. But as we would like to create a mid-term planning tool, this period of time simply is too short. As we are not able to use actual order data as input for our tool, we have to estimate a future situation.

For being able to achieve the number of operators needed and when to employ them best, we have mainly to do two different tasks: capacity planning and resource planning. While the task of 'capacity planning' is to provide a forecast, which is based on historical data, regarding a future workload situation, the 'resource planning' uses this information for determining the number of operators which are required for being able to cope with the expected workload. But for doing these calculations, some performance information regarding the operator performance is required. So we can say that we have to compare the forecasted workload to the expected operator performance. The results being expected from our labour management tool is to get a weekly plan on shift level a certain period of time in advance.

8.2   Structure of labour management tool

The concept of the labour management tool which was developed within the frame of this master thesis was structured in several modules. Whereas the modules 'performance management' and 'workload forecast' are used for collecting, analysing and calculating the basic information, the module 'operator disposition' finally determines the number of operators required and when to employ them best. In addition to this, we have thought of the module 'operator management' whose task is to offer an information basis of decision-making by calculating some scenarios, if the forecasted workload information differs from the actual one. Having just defined the modules, a little more detailed description of the main modules is given.

To start describing the modules, the aim of the module 'performance management' is to achieve several performance indicators per operator, including the performance time-line of a day and the utilisation values. In addition to this, the user of the module should be able to group the information per operator type and warehouse area for analysing an operator's performance and for comparing several operators to each other. Moreover the performance indicators should be able to provide a basis for a performance-linked payment. The performance information, which represents the average amount of work an operator is able to cope with, is used for determining the number of operators needed.

Another piece of information is the result of the module ''workload forecast', whose target is to provide an estimation regarding a future workload situation on hourly basis. Due to the fact that keeping historical data on hourly level would consume an exaggerating amount of disk space, we have decided to keep only the weekly workload sum per process. For this reason, we have developed two different forecasting strategies. The first one is to prompt the sales respectively order forecast which is provided by the planning department, whereas

the second strategy compares the historical workload data to the workload data of the recent past to achieve the calculated grow rate. Additionally we have provided the possibility to prompt a manual grow rate, which provides the possibility to adjust the 'originally' forecasted workload value in accordance with the experience of the resource planner (special sales promotions, changing seasonal peaks like Easter, etc.). Having the forecast regarding the weekly workload available, this value has to be refined by using the typical weekly and daily workload patterns, which have to be determined before.

Based on the results of these two modules, the target of the module 'operator disposition' is used to achieve a weekly plan on shift level. For being able to determine the weekly plan regarding single shifts, we have to add the information regarding the shift pattern which is used within the considered warehouse. In addition to this, we have to define possible starting times for operators, which are working less than the standard working time. As we made a distinction between permanent staff and operators, which are provided by a shared personnel agency, we have to supply the information to the module, how many operators of the permanent staff are working and when. Through a comparison of the expected performance and the forecasted workload, we are able to provide the weekly plan which is required. Furthermore we provide the information regarding the spare capacity per shift to the user of this module.

The idea behind the module 'operator management' is to provide a daily check-up regarding the accuracy of the forecast. This means the forecasted workload is checked against the actual workload data for a day and three possible scenarios are calculated to give the responsive person a basis for the decisions that has to be made, if any difference between the planned and the actual values occurs. In addition to this, the actual workload of all labour managed processes are compared for being able to sort out the chance to send employees to other processes, if possible due to their skills.

On basis of the concept that was developed within the scope of this master thesis, a prototype for the modules 'performance management', 'workload forecast' and 'operator disposition' was implemented by transferring the ideas of the concept into a database structure. This was done by defining several tables, which are providing the basic data and some views, whose task is to analyse and determine the required information from the corresponding tables. The main target in regard to the implementation of the database prototype based on the given concept was to check if the modules are transferable into a database structure and moreover if the prototype based on the given concept is able to

provide the desired functionality. The purpose of additionally implementing a GUI prototype was to make a presentation of the labour management tool easier.

After having finished the implementation of the prototype and having inserted some sample data, which was provided by the industry partner, into the tables for being able to do further calculations on basis of this information. The required calculations that have been defined within the concept are processed by single views, which were grouped in accordance with the single modules. Afterwards we have compared the results which were presented by the views to the reports, which are required by the concept and are for this reason able to say, that the desired basic functionality is provided by the prototype and therefore by the concept, on which the prototype is based on. Moreover we have checked some of the calculations randomly.

For this reason we are able to say in respect of one of our research questions, how such a labour management tool has to be structured for being able to provide the expected functionality, that the concept given within the master thesis is one of the possible solutions regarding this issue.

8.3   Difficulties to be considered

But even if the labour management tool is able to provide the desired basic functionality, we have to consider some influencing factors, which may have a decisive influence on the accuracy of the results. As there is a wide range of such factors, for summarising we only emphasise the most important ones to answer the research question, 'which kind of difficulties we do have to expect when doing labour management for several warehouse processes'.

The first crucial point when doing labour management is to define the most appropriate base unit for both measuring the operator performance and the amount of work which was done within a certain period. While for some warehouse processes it may be most appropriate to choose the number of cartons or even pallets as base unit, for other processes it may be best to choose single units or a bundle, which represents the smallest indivisible package of an article. To find out the 'correct' base unit, it will be necessary to compare the workload and performance values of several different units to each other.

Another critical point regarding the influence on labour managed processes is a high amount of unexpected extra work due to special sales promotions of certain companies, simply sending goods without any order to the warehouse that have to be additionally distributed. These fluctuations are completely unexpected and can for this reason not be considered

when doing workload forecasting and therefore are disregarded when planning the demand regarding the resource 'labour'. Even if the actual calculation method provides a little amount of spare capacity per each shift, this may only be sufficient to cover a small amount of extra work but not an extremely high amount. To minimise this risk, an improvement regarding the communication to these suppliers should be thought of.

Similarly serious is the situation when there is a big difference between the forecasted workload value and the actual amount of work because of the extremely narrow timeframe for adjusting the number of operators to the 'new' situation. For this reason the workload forecast is a very sensitive part of the labour management tool and has therefore to be planned with care.

In addition to this there are several limitations regarding the performance data of the operators. As we have chosen not to calculate a standard time for a certain process task due to the fact that the handling time will differ dependent from the product group a certain article belongs to. Moreover there may be a certain amount of very time consuming error handling necessary, whose amount of time consumption is not collected within the warehouse management system. For this reason we do not know the rate of problems either. By choosing the number of a certain base unit that an operator is able to cope with over a certain period of time, we assume that the factors which are limiting the performance are for the most part comprised and therefore confining the uncertainty concerning the accuracy of the performance information.

8.4 Outlook

To bring the master thesis to a termination, we are now going to consider several possible tasks that should be thought of if the "concept of a labour management tool" is pursued to get a final labour management tool which can be sold to interested customers.

At first we would have to think about the benefit regarding the cost efficiency a potential customer may be able to achieve for deriving a market price for this tool. The estimated price will allow us to determine the effort that can be done when refactoring the current prototype. This would be necessary in this respect that an expert programmer will achieve a more performant database. In addition to this, the benefit a customer will be able to achieve will for sure be a crucial argument for the sales department.

Due to the fact of several simplifications and average calculations, the existing concept and the prototype based on it can only be considered as a "basic labour management tool". Even if the tool works steadily at this level of detail, we have to think about increasing the level of

detail. The further refinement will embrace a refinement concerning the different operator types within the considered warehouse regarding the possible starting times and even possible starting days, if a certain operator type is usually working only from Tuesday to Friday for example. Moreover we shall think of creating a more flexible shift pattern which means that we can define the number of shifts for a certain weekday and for each process separately. Beyond that we should think about reducing the time span for the calculations regarding the average workload for being able to increase the accuracy.

In addition to this we only have considered three warehouse processes within this concept and only have implemented one into the prototype. For being able to achieve the maximum economic efficiency possible, we will have to get a holistic view of the warehouse processes which means we will have to integrate all the warehouse processes into the labour management tool. Moreover this calls for a more sophisticated performance management which means we will have to implement sort of a skill matrix for being able on the one hand to achieve a central performance information including the decisive performance indicators and the area(s) of work and on the other hand to identify possible relief persons at a glance if needed due to different meanderings between the actual and the forecasted data.

Based on the seasonality of the retail business we should think of implementing a calendar into the database. Even if the concept provides the possibility to adjust the workload forecast in accordance with the resource planning department, a calendar could support e.g. to locate the Easter holidays more easy because the point in time differs from year to year whereas the Christmas season is relatively constant regarding the calendar week.

So if a customer (hopefully) decides that he/she would like to have a labour management tool implemented for one or more warehouses, we will also need an implementation timeline, which was not defined within this master thesis. Moreover we will have to assure to get a valid data pool for achieving a preferably high accuracy regarding the calculations and for this reason a significant reduction regarding the labour cost and moreover a highly satisfied customer.

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10 Appendix

10.1 SQL source codes

Within this appendix we are going to provide the SQL source codes unless they are provided in chapter 7.3.

```sql
SELECT WL_DATA_HISTA.CW_ID, SUM(WL_DATA_HISTA.QTY_UNITS_DONE) AS SUM_WEEK,
CAL_WEEK.CW_YEAR, CAL_WEEK.CW_WEEK
FROM WL_DATA_HISTA, CAL_WEEK, X_DAY_HOUR
WHERE WL_DATA_HISTA.CW_ID = CAL_WEEK.CW_ID AND WL_DATA_HISTA.ACT_HOUR
BETWEEN X_DAY_HOUR.DAY_START AND X_DAY_HOUR.DAY_END
GROUP BY WL_DATA_HISTA.CW_ID,CAL_WEEK.CW_YEAR,CAL_WEEK.CW_WEEK
```

SQL code 20: WL01_WEEKLY_SUM

```sql
SELECT ROUND(AVG(SUM_WEEK),0) AS AVG_WEEK
FROM WL01_WEEKLY_SUM
```

SQL code 21: WL02_WEEKLY_AVG

```sql
SELECT WL_DATA_HISTA.CW_ID, WL_DATA_HISTA.ACT_WEEKDAY,
SUM(QTY_UNITS_DONE) AS SUM_DAY
FROM WL_DATA_HISTA, X_DAY_HOUR
WHERE WL_DATA_HISTA.ACT_HOUR BETWEEN X_DAY_HOUR.DAY_START AND X_DAY_HOUR.DAY_END
GROUP BY CW_ID, ACT_WEEKDAY
ORDER BY CW_ID, ACT_WEEKDAY
```

SQL code 22: WL03_DAILY_SUM

```sql
SELECT WL03_DAILY_SUM.ACT_WEEKDAY, ROUND(AVG(SUM_DAY),0),
WL02_WEEKLY_AVG.AVG_WEEK
FROM WL03_DAILY_SUM, WL02_WEEKLY_AVG
WHERE ACT_WEEKDAY = ACT_WEEKDAY
GROUP BY ACT_WEEKDAY, AVG_WEEK
ORDER BY ACT_WEEKDAY
```

SQL code 23: WL04_DAILY_AVG

```
SELECT WL_DATA_HISTA.ACT_WEEKDAY, WL_DATA_HISTA.ACT_HOUR,
ROUND(AVG(QTY_UNITS_DONE),0) AS AVG_HOUR
FROM WL_DATA_HISTA, X_DAY_HOUR
WHERE ACT_WEEKDAY = ACT_WEEKDAY AND ACT_HOUR = ACT_HOUR
AND WL_DATA_HISTA.ACT_HOUR BETWEEN X_DAY_HOUR.DAY_START AND X_DAY_HOUR.DAY_END
GROUP BY ACT_WEEKDAY, ACT_HOUR
ORDER BY ACT_WEEKDAY, ACT_HOUR
```

SQL code 24: WL06_HOURLY_AVG

```
SELECT MAX(WL_WEEKLY_HISTA.QTY_UNITS_WEEK) AS MAX_WEEK_ACT_YEAR
FROM WL_WEEKLY_HISTA, FC01_TIME_PERIOD
WHERE WL_WEEKLY_HISTA.CAL_WEEK BETWEEN
FC01_TIME_PERIOD.ACT_SP AND FC01_TIME_PERIOD.ACT_EP
```

SQL code 25: FC02_GROW_RATE1

```
SELECT MAX(WL_WEEKLY_HISTA.QTY_UNITS_WEEK) AS MAX_WEEK_LAST_YEAR
FROM WL_WEEKLY_HISTA, FC01_TIME_PERIOD
WHERE WL_WEEKLY_HISTA.CAL_WEEK BETWEEN
FC01_TIME_PERIOD.LY_SP AND FC01_TIME_PERIOD.LY_EP
```

SQL code 26: FC03_GROW_RATE2

```
SELECT OPR_TYPE_ID,ST_GROUP_ID,
CASE
WHEN OPR_TYPE_ID < 3 AND MOD(ST_GROUP_ID,2)=1 THEN ST_GROUP_ID
WHEN OPR_TYPE_ID < 3 AND MOD(ST_GROUP_ID,2)=0 THEN ST_GROUP_ID-1
WHEN OPR_TYPE_ID = 3                          THEN ST_GROUP_ID
END AS ST_TYPE1_2
FROM OD01_ST_OPR
```

SQL code 27: OD04_ST_AVG_PERF_SG

```
SELECT OD04_ST_AVG_PERF_SG.OPR_TYPE_ID,OD04_ST_AVG_PERF_SG.ST_GROUP_ID,
OD04_ST_AVG_PERF_SG.ST_TYPE1_2,OD03_ST_AVG_PERF.AVG_PERF_TYPE_ST
FROM OD04_ST_AVG_PERF_SG LEFT JOIN OD03_ST_AVG_PERF
ON OD03_ST_AVG_PERF.OPR_TYPE_ID = OD04_ST_AVG_PERF_SG.OPR_TYPE_ID
AND OD04_ST_AVG_PERF_SG.ST_TYPE1_2 = OD03_ST_AVG_PERF.ST_GROUP_ID
ORDER BY OD04_ST_AVG_PERF_SG.OPR_TYPE_ID,OD04_ST_AVG_PERF_SG.ST_GROUP_ID
```

SQL code 28: OD05_ST_AVG_PERF_GROUP

```
SELECT ST_GROUP_ID, AVG_PERF_TYPE_ST AS PT1
FROM OD05_ST_AVG_PERF_GROUP
WHERE OPR_TYPE_ID = 1
ORDER BY ST_GROUP_ID
```

SQL code 29: OD06_ST_AVG_PERF_TYPE1

```
SELECT ST_GROUP_ID, AVG_PERF_TYPE_ST AS PT2
FROM OD05_ST_AVG_PERF_GROUP
WHERE OPR_TYPE_ID = 2
ORDER BY ST_GROUP_ID
```

SQL code 30: OD07_ST_AVG_PERF_TYPE2

```
SELECT ST_GROUP_ID, AVG_PERF_TYPE_ST AS PT3
FROM OD05_ST_AVG_PERF_GROUP
WHERE OPR_TYPE_ID = 3
ORDER BY ST_GROUP_ID
```

SQL code 31: OD08_ST_AVG_PERF_TYPE3

```
SELECT OD08_ST_AVG_PERF_TYPE3.ST_GROUP_ID,OD07_ST_AVG_PERF_TYPE2.PT2,
OD08_ST_AVG_PERF_TYPE3.PT3
FROM OD08_ST_AVG_PERF_TYPE3 LEFT JOIN OD07_ST_AVG_PERF_TYPE2
ON OD08_ST_AVG_PERF_TYPE3.ST_GROUP_ID = OD07_ST_AVG_PERF_TYPE2.ST_GROUP_ID
```

SQL code 32: OD09_ST_AVG_PERF_TYPES

```
SELECT OD09_ST_AVG_PERF_TYPES.ST_GROUP_ID,OD06_ST_AVG_PERF_TYPE1.PT1,
OD09_ST_AVG_PERF_TYPES.PT2,OD09_ST_AVG_PERF_TYPES.PT3
FROM OD09_ST_AVG_PERF_TYPES LEFT JOIN OD06_ST_AVG_PERF_TYPE1
ON OD09_ST_AVG_PERF_TYPES.ST_GROUP_ID = OD06_ST_AVG_PERF_TYPE1.ST_GROUP_ID
```

SQL code 33: OD10_ST_AVG_PERF_OPR

```
SELECT FC_INFO.FC_WEEK,OD17_ADD_OPR_TYPE3.ACT_WEEKDAY,OD17_ADD_OPR_TYPE3.SHIFT_ID,
OD17_ADD_OPR_TYPE3.NUM_OWN,OD17_ADD_OPR_TYPE3.ADD_TYPE2,
OD17_ADD_OPR_TYPE3.ADD_TYPE3,OD01_ST_OPR.OD_OPR_START AS ST_TYPE_3
FROM FC_INFO,OD17_ADD_OPR_TYPE3 LEFT JOIN OD01_ST_OPR
ON OD01_ST_OPR.OPR_TYPE_ID = 3 AND
OD17_ADD_OPR_TYPE3.SG_ADD_TYPE3 = OD01_ST_OPR.ST_GROUP_ID
WHERE ADD_TYPE3 > 0 OR ADD_TYPE2 > 0
```

SQL code 34: OD18_WEEKLY_PLAN

```
SELECT od11.ACT_WEEKDAY, od11.SHIFT_ID, SUM(od11.FC_QTY_HOUR) AS SHIFT_SUM
FROM OD11_FC_ADD_SG od11
WHERE od11.ACT_WEEKDAY = od11.ACT_WEEKDAY AND od11.SHIFT_ID = od11.SHIFT_ID
GROUP BY od11.ACT_WEEKDAY, od11.SHIFT_ID
ORDER BY od11.ACT_WEEKDAY
```

SQL code 35: XGUI_OD_RC1

```
SELECT od1.ACT_WEEKDAY, od1.SHIFT_ID, od1.SHIFT_SUM, NUM.PERF_TYPE1, NUM.NUM_OWN,
NUM.PERF_TYPE2, NUM.ADD_TYPE2, NUM.PERF_TYPE3, NUM.ADD_TYPE3
FROM XGUI_OD_RC1 od1
LEFT JOIN OD17_ADD_OPR_TYPE3 num
ON od1.ACT_WEEKDAY = num.ACT_WEEKDAY AND od1.SHIFT_ID = num.SHIFT_ID AND
num.ADD_TYPE2 > 0
ORDER BY od1.ACT_WEEKDAY, od1.SHIFT_ID
```

SQL code 36: XGUI_OD_RC2

```
SELECT ACT_WEEKDAY, SHIFT_ID, SHIFT_SUM,
(PERF_TYPE1*NUM_OWN*8+PERF_TYPE2*ADD_TYPE2*8+PERF_TYPE3*ADD_TYPE3*4)
AS QTY_UNITS_PROV,
((PERF_TYPE1*NUM_OWN*8+PERF_TYPE2*ADD_TYPE2*8+PERF_TYPE3*ADD_TYPE3*4)-SHIFT_SUM)
AS RESERVE_CAPA
FROM XGUI_OD_RC2
```

SQL code 37: XGUI_OD_RC3

```
SELECT xrc.ACT_WEEKDAY, wd.WEEKDAY_DESCRIPTION, xrc.SHIFT_ID, sp.SHIFT_DESC,
xrc.SHIFT_SUM, xrc.QTY_UNITS_PROV, xrc.RESERVE_CAPA,
CEIL(xrc.RESERVE_CAPA/450) AS RES_HOUR
FROM XGUI_OD_RC3 xrc
INNER JOIN WEEKDAY_DATA wd
ON wd.WEEKDAY_ID = xrc.ACT_WEEKDAY
INNER JOIN OD_SHIFT_PATTERN sp
ON sp.SHIFT_ID = xrc.SHIFT_ID
ORDER BY xrc.ACT_WEEKDAY, xrc.SHIFT_ID
```

SQL code 38: XGUI_OD_RC4

10.2 Complete weekly plan provided by database prototype

ACT_WEEKDAY	SHIFT_ID	ST_GROUP_ID	FC_QTY_HOUR_D_ST	WL_GR_MAX	AVG_WL	PERF_TYPE1	NUM_OWN	PERF_TYPE2	SG_ADD_TYPE2	ADD_TYPE2	SG_ADD_TYPE3	PERF_TYPE3	ADD_TYPE3
1	1	1	1	10117	12759 min	455	10	450	1	13	2	449	6
1	1	2	2	12759	12759 max	455	10	450		0			0
1	2	1	3	8615	8615 max	450	0	453		0			0
1	2	2	4	100	8615 min	450	0	453	3	1	3	449	19
2	1	1	1	9859	11990 min	455	10	450	1	12	2	449	5
2	1	2	2	11990	11990 max	455	10	450		0			0
2	2	1	3	10032	10032 max	450	0	453		0			0
2	2	2	4	5646	10032 min	450	0	453	3	13	3	449	10
3	1	1	1	9573	10390 min	455	10	450	1	12	2	449	2
3	1	2	2	10390	10390 max	455	10	450		0			0
3	2	1	3	10540	10540 max	450	0	453		0			0
3	2	2	4	7526	10540 min	450	0	453	3	17	3	449	7
4	1	1	1	9276	10812 min	455	10	450	1	11	2	449	4
4	1	2	2	10812	10812 max	455	10	450		0			0
4	2	1	3	10176	10176 max	450	0	453		0			0
4	2	2	4	6140	10176 min	450	0	453	3	14	3	449	9
5	1	1	1	8079	11083 min	455	10	450	1	8	2	449	7
5	1	2	2	11083	11083 max	455	10	450		0			0
5	2	1	3	4522	4522 max	450	0	453		0			0
5	2	2	4	2491	4522 min	450	0	453	3	6	3	449	5
6	1	1	1	0	0 max	455	0	450		0			0
6	1	2	2	0	0 max	455	0	450		0			0
6	2	1	3	0	0 max	450	0	453		0			0
6	2	2	4	0	0 max	450	0	453		0			0
7	1	1	1	6067	6302 min	455	10	450	1	4	2	449	0
7	1	1	2	6302	6302 max	455	10	450		0			0
7	2	2	3	8571	9413 min	450	0	453	3	19	4	450	2
7	2	2	4	9413	9413 max	450	0	453		0			0

Figure 34: Complete weekly plan for considered week