AN ENHANCED REQUIREMENTS EXTRACTION APPLICATION FOR ADVANCED PLANNING SYSTEMS: A CASE STUDY FOR PLASTIC INJECTION FACTORY PLANNING

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AN ENHANCED REQUIREMENTS EXTRACTION APPLICATION FOR ADVANCED PLANNING SYSTEMS: A CASE STUDY FOR PLASTIC INJECTION FACTORY PLANNING

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ABSTRACT

AN ENHANCED REQUIREMENTS EXTRACTION APPLICATION FOR ADVANCED PLANNING SYSTEMS: A CASE STUDY FOR PLASTIC INJECTION FACTORY PLANNING

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This study proposes a generic approach to reduce execution time of an integrated material requirements planning system for a plastic injection production factory that has a high mix of product variety, different product structures and varying customer demands. First, a survey study is conducted on sixty-four production companies located in Aegean Region of Turkey with regard to their planning methodologies. Then, together with a through literature review on the topic, an integrated method is proposed to reduce the execution time of requirement extraction process. This method is applied to a plastic injection company and tested under real production conditions. The test results indicate an increased performance on several managerial criteria. In addition, a full factorial experimental design that includes four factors with two levels is generated for the proposed method. It is analyzed by the ANOVA method. Results indicate that maximum number of levels in a bill of materials and average number of components in a bill of materials have significant impact on the calculation time.

Keywords: production planning, plastic injection production, requirement extraction, industrial survey.

ÖZ

İLERİ PLANLAMA SİSTEMLERİ İÇİN GELİŞMİŞ BİR İHTİYAÇLAR ELDE ETME UYGULAMASI: PLASTİK ENJEKSİYON FABRİKASI PLANLAMASI İÇİN BİR VAKA ÇALIŞMASI

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Bu çalışma, değişen müşteri taleplerine, yüksek ürün çeşitliliğine ve değişik ürün yapılarına sahip bir plastik enjeksiyon fabrikasının entegre olarak planlanmasına yönelik gereksinim planlama işlemleri için gereken süreyi azaltmaya yönelik bir yaklaşım önermektedir. Çalışmada Türkiye'nin Ege Bölgesinde bulunan 64 firmanın planlama metodolojileri incelenmiştir. İncelemeden edinilen bilgiler, yapılan literatür araştırmasından edinilen sonuçlar ile birleştirilerek gereksinim çıkarma sürecini kısaltmaya ve kolaylaştırmaya yönelik entegre bir yaklaşım önermektedir. Sonrasında bu yaklaşım bir plastik enjeksiyon firmasında uygulanıp gerçek ortamda test etmektedir. Test sonuçları, yönetimsel kriterlerde performans artışı göstermektedir. Bunlarla birlikte, metodun dört ana faktörüne göre iki seviyeli tam faktöryel deney tasarımı yapılıp ANOVA metoduyla analiz edilmiştir. Sonuçlara göre bu faktörlerden olan maksimum ürün ağacı seviyesi ve ortalama ürün ağacı birleşeni sayısı, hesaplama sürelerinde en büyük etkiye sahiptir.

Anahtar Kelimeler: üretim planlama, plastik enjeksiyon üretimi, gereksinim çıkarma.

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LIST OF ABBREVATIONS

APS:	ADVANCED PRODUCTION SYSTEMS, ADVANCED PLANNING AND SCHEDULING SYSTEMS
ATO:	SSEBMLE-TO-ORDER
ATP:	AVAILABLE TO PROMISE
ATS:	ASSEMBLE-TO-STOCK
BOM:	BILL OF MATERIALS
CDR:	COMPOSITE DISPATCHING RULES
CP:	CONSTRAINT PROGRAMMING
CRP:	CAPACITY REQUIREMENTS PLANNING
DR:	DISPATHCING RULES
DS:	DIRECT SHIPMENT
ERP:	ENTERPRISE RESOURCE PLANNING
KNB:	KANBAN
MES:	MANUFACTURING EXECUTION SYSTEM
MILP:	MIXED INTEGER LINEAR PROGRAMMING
MPC:	MANUFACTURING PLANNING AND CONTROL
MPS:	MASTER PRODUCTION SCHEDULE
MRP:	MATERIALS REQUIREMENTS PLANNING
MRP-II:	MANUFACTURING RESOURCE PLANNING
MTO:	MAKE-TO-ORDER
MTS:	MAKE-TO-STOCK
RCCP:	ROUGH CUT CAPACITY PLANNING
SCP:	SUPPLY CHAIN PLANNING
SR:	SEQUENCING RULES

CHAPTER 1: INTRODUCTION

1.1 Introduction

This chapter starts with the research motivation of this thesis in Section 1.2 and continues with introduction of traditional Manufacturing Planning and Control (MPC) systems in Section 1.3. Then, major components of such systems are presented in Section 1.4. In Section 1.5, Advanced Planning System (APS) is introduced as an alternative to MPC. The problem definition of the thesis is provided in Section 1.6. Section 1.7 ends with a general overview of this study.

1.2 Research Motivation

Generally, planning plays a major role in the success and profitability of a company. By the advancement of the business intelligence technologies, the planning systems in companies evolved from simple, limited and manual shop floor schedules into more advanced automated systems that include resource, demand, production and even shipment considerations (Tyagi et al., 2013). Although these planning topics are commonly researched in industrial engineering literature, applications of these studies are limited in the real life (Tyagi et al., 2013). Most researchers limit and test their planning models for less than 10 machines and 40 jobs for complexity considerations (Chapter 2). However, real-life applications have greater sets of machines and jobs. Also, in the industry, number of companies ranging from small workshops to large manufacturing plants has difficulties to adopt planning systems into their daily manufacturing processes due to considerable computation times, excess needs of parameter inputs for initialization, varying characteristics of demand and production parameters (Tyagi et al., 2013). Even for the companies that are able to adopt a manufacturing planning system, implementations are limited and unable to provide users with a full scope and vision of decision parameters of whole company (Tyagi et al., 2013).

Research motivation of this thesis is originated from ineffective and frequent executions of Materials Requirements Planning (MRP) runs in medium-volume manufacturers based around the cities of Izmir, Manisa, Istanbul and Aydın in Turkey. A survey that is conducted for these manufacturers, totally 64, for this thesis study reports the related issues in MRP runs, particularly under varying demand characteristics (Chapter 3). Such demand variations could be both in demand order sizes and numbers during a planning horizon (Kabak and Ornek, 2005). These changes propagate at higher levels in BOMs so that they could lead to additional stock carriages or lower service levels due to inability of meeting orders from inventories. This situation is described as MRP Nervousness (Kabak and Ornek, 2005).

Also, the survey results from the companies report that an MRP run takes about 20 to 65 minutes. To overcome such issues in industry, this study aims to develop a faster MRP running module that would allow frequent and flexible runs of MRP system as well as increase the overall performance of planning.

The following sections provide a through overview of the traditional manufacturing systems, processes that form the basis of these systems, and new methods of advanced planning systems that provide both alternatives and complements for these traditional systems.

1.3 Traditional Manufacturing Planning and Control (MPC) Systems

Vollmann et al. (1997) state that main function of a Manufacturing Planning and Control System (MPC) is to support managers to make decisions and manage operations by providing information on flow of materials, utilization of capacity (for workers and equipment), coordination of internal activities with suppliers and communication with customers about market requirements (Vollmann et al., 1997; p.2). In order to carry out these activities, Vollmann et al. (1997) frame three main modules (or phases) for MPC with different levels of detail and focus. These modules are directly connected to strategic game plan of the company that implements the MPC. Figure 1 gives a detailed framework of these modules including the capacity management and information requirements.

Front end phase sets the objectives for the MPC including Demand Management, Production Planning, Master Production Scheduling (MPS) and Resource Planning and Rough-Cut Capacity Planning (RCCP) activities. These activities provide an overall manufacturing plan for a company and creates long-term and mid-term plans.

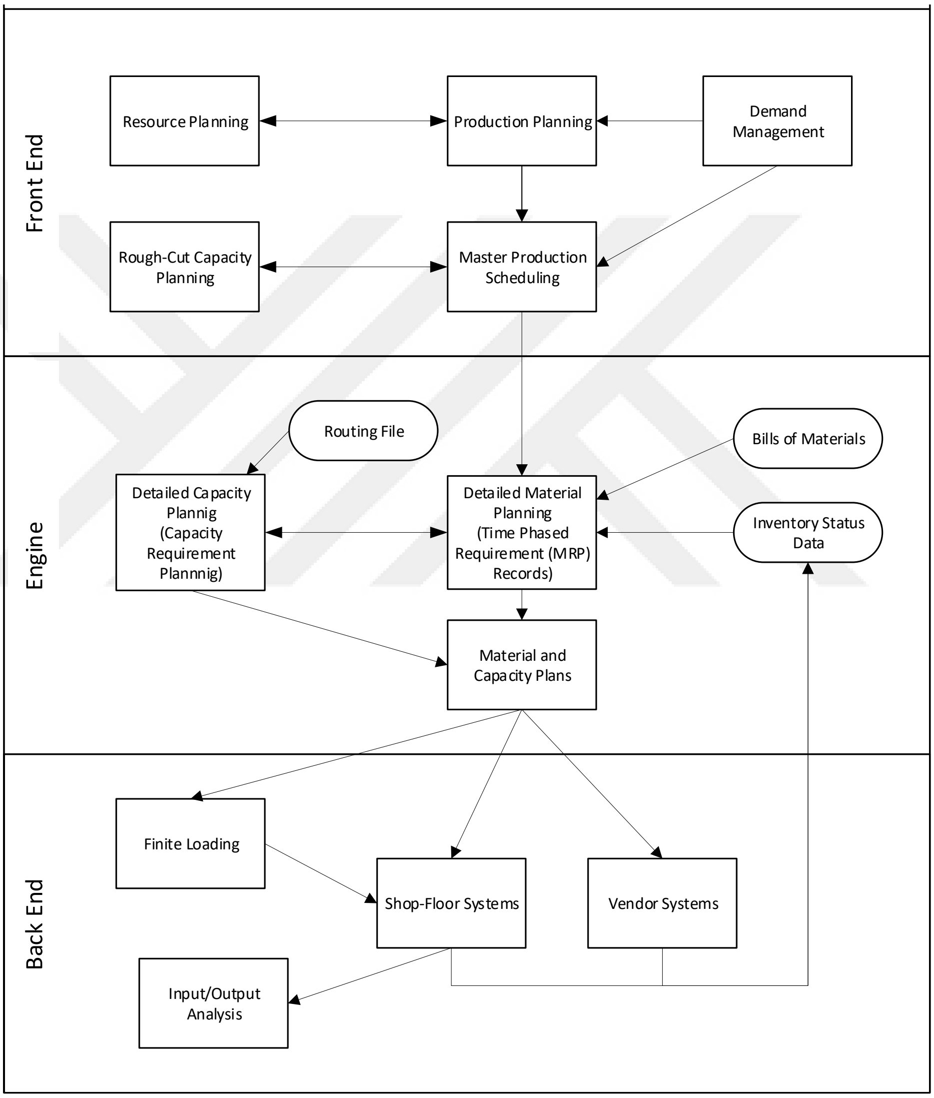

Figure 1. MPC Framework with Integrated Capacity Elements (Source: Vollmann et al., 1997; p.15, 122).

Second phase, Engine, includes the systems for obtaining the detailed material and capacity plans. These systems cover Detailed Material Planning (Time-phased Material Requirements Planning (MRP) records) that uses bills of material information and inventory status data together with Detailed Capacity Planning (Capacity Requirements Planning (CRP) records) that contains the routing information. These activities provide short-term plans for manufacturing (Vollmann et al. 1997; p.14, 121).

The last phase, Back End, depicts the execution systems that include Finite Capacity Loading, Scheduling and Control of Shop-Floor and Vendors Systems and also Input/Output analyses of these systems for evaluation and improvements. Similar to the Engine module, Back End focuses on aspects of short-term planning. All of these modules require a synchronized and integrated information flow in order to fulfill each task of the traditional manufacturing planning systems (Vollmann et al., 1997; p.6).

1.4 Major Components of Traditional Planning Systems

In the traditional planning systems, there are three main components and capacity counterparts that frame the manufacturing planning processes in each phase. In Front End, MPS together with RCCP provides mid-term objectives of a company. In the Engine, detailed Material and Capacity Planning derives customer orders into time phased requirement plans. Finally, in the Back End, Shop Floor Scheduling together with Finite Capacity Loading covers the executions of the higher-level plans in the shop floor (Vollmann et al. 1997; p.123).

1.4.1 Master Production Scheduling (MPS)

MPS links the customer demands with the factory planning through the general planning of the end products. It is considered as an anticipated build schedule for production of these end products (Vollmann et al., 1997; p.206). Together with RCCP, the planner manages to visualize the potential capacity bottlenecks and other production constraints for a certain demand structure. MPS takes into consideration of end products. For this reason, the output of this component does not completely detail both material and capacity requirements of the actual production system. In general, an altered version of the bill of materials (i.e. Planning Bill of Materials) that focuses only to the end products is used in the construction of the MPS in order to simplify the process further (Vollmann et al., 1997; p.227).

As a mid-term planning process, MPS takes weekly or monthly time buckets (Vollmann et al. 1997; p.236). Customer orders and forecasts are main inputs of MPS. In mid-term planning, MPS supports the planner to realize the bottlenecks and even provides Available to Promise (ATP) data to provide an insight for the demand management (Vollmann et al., 1997; p.236). In the short-term planning, MPS provides the input data for detailed material and capacity requirements planning, therefore accuracy of MPS yields more effective short-term planning of the production. However, since the time buckets are considered as weeks and months in MPS, the reaction of MPS to daily demand changes is rather ineffective (Vollmann et al., 1997; p.247).

1.4.2 Material Requirements Planning (MRP)

MRP refers to main set of techniques to convert MPS records into detailed time-based requirement records that can be used to schedule the production and to procure the required materials for the production. There are three main inputs for MRP according to Vollmann et al. (1997; p. 14):

1- Time-phased set of MPS records: The MPS output that contains the due dates, quantities and required end products.

2- Bill of Materials: In order to explode the given set of records, bill of materials (BOM) is needed for each end product and its components. BOM is the set of data that consists of the required direct components in order to produce the product.

3- Inventory Status: In order to calculate the actual production or procurement requirement of a component, the quantity of that component in stock should be known.

In addition to these main inputs, Nahmias (2013) provides two more required inputs, these are defined as lead times of procured items and lot sizing decisions of the products. These two inputs increase the accuracy of the detailed material requirements. The former one creates an offset of production plans according to lead times of the procured items, and the latter one creates a set of rules in order to standardize the production lot sizes to be used in explosion (Nahmias, 2013; p.382).

After these inputs are obtained, explosion calculations are executed. These calculations translate the planned orders obtained from MPS into detailed component requirements using single level BOMs for each BOM level of the end product. In order to reach the Net Requirement of the component, data from inventory level of respective component is subtracted from Gross Requirements of the component. By the lot sizing decisions, these Net Requirements are transformed into planned order releases, and lead time offsetting determines the planned order release timing for these requirements according to lead time of the components.

Figure 2 gives the pseudocode for the general explosion algorithm used in MRP (Kabak and Ornek, 2005). This process is repeated at each level of the BOM. The final MRP data provides the planned orders that can be directly scheduled. Also, these planned orders together with routing files can be inserted into detailed capacity planning procedure (or Capacity Requirements Planning (CRP)) to control the capacity required for the production. Combined with MRP, the term used for this kind of requirement planning module is MRPII. Vollmann et al. (1997) state that the term is not used to indicate Material Resource Planning but Manufacturing Resource Planning.

Although it is highlighted by Vollmann et al. (1997), capacity planning cannot be excluded in planning process. Therefore, MRPII is proved more viable for the practitioners in making daily decisions (Tyagi et al., 2013).

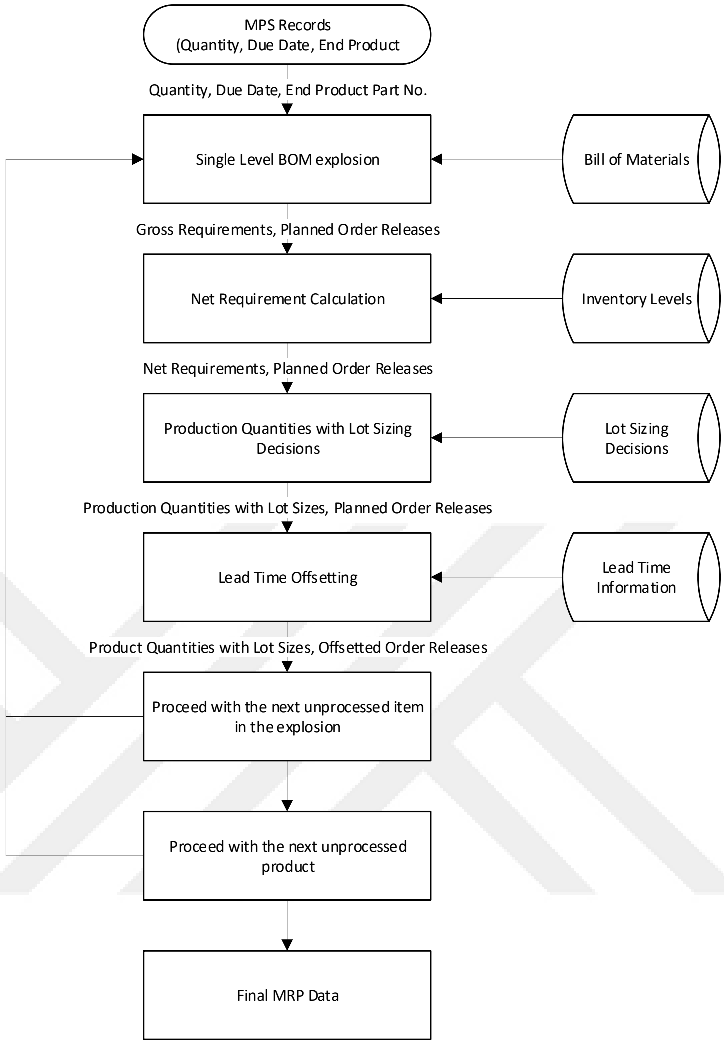

Figure 2. Pseudocode for MRP Explosion Algorithm (Source: Kabak and Ornek, 2005).

1.4.3 Shop Floor Scheduling (Factory Planning)

In general, Shop Floor Scheduling translates planned order releases into a set of tasks and due dates associated with those tasks (Nahmias, 2013; p.422). Shop floor scheduling is frequently updated since the planned order releases are constantly revised according to demand changes. Nahmias states 7 main objectives for the shop management:

1- Meeting the due dates.

2- Minimizing the average flow time through the system

3- Minimizing work-in-process inventory

4- Providing high machine/worker utilization

5- Providing accurate job status information.

6- Reducing setup times.

7- Minimizing the production and worker costs (Nahmias, 2013; p.422).

Nahmias (2013) states that optimizing all these objectives is impossible because of the contradictions present among them. These objectives can be grouped into a high-level customer service aim (1-2) and high-level production efficiency (3-7) (Nahmias, 2013; p.423). In order to compare each objective, the company has to evaluate these objectives in quality and cost basis.

Vollmann et al. (1997; p.528) group scheduling research into two main approaches. The first approach, static scheduling, consists of fixed set of jobs to be scheduled until they are completed, and the second one, dynamic scheduling, deals with ongoing process in which new jobs are being added over time. Each approach can be handled with deterministic or stochastic models.

Static scheduling approach can be dealt with optimization models since optimal model requires deterministic data inputs. However, these models can only be applied to relatively small-scale problems because of the NP hardness of the problem (Tyagi et al. 2013). In the case of larger problems, several heuristic models are used. The classical approach consists of using Dispatching Rules (DR) (or Sequencing Rules (SR)) to sequence jobs for a given number of machines according to these rules. Pinedo (2008) summarizes these elementary rules as given in Table 1. These dispatching rules can be used in both static and dynamic approaches and form the basis of both optimal and heuristic models of scheduling algorithms.

In most cases, using single dispatching rule is not adequate for scheduling of large problems. Therefore, Composite Dispatching Rules (CDR) that combine these elementary rules with scalar coefficients are introduced as a ranking expression. (Pinedo, 2008; p.373). In CDR, elementary rules are the functions of the attributes that are static or time dependent. These attributes are associated with either a machine or a job, and their effects on the overall ranking expression are determined by the rule that uses it in conjunction with the scaling parameter of that rule. It is determined either by experience of the builder or through statistical analysis.

Table 1. List of Common DRs (Source: Pinedo, 2008, p.373)

SIRO	Service in Random Order
ERD	Earliest Release Date First (First Come First Served)
EDD	Earliest Due Date First
MS	Minimum Slack First
SPT	Shortest Processing Time First
WSPT	Weighted Shortest Processing Time First
LPT	Longest Processing Time First
SPT-LPT	First Subset SPT, second subset LPT
CP	Critical Path (Highest Level First)
LNS	Largest Number of Successors First
SST	Shortest Setup Time First
LFJ	Least Flexible First
LAPT	Longest Alternate Processing Time First
SQ	Shortest Queue First
SQNO	Shortest Queue at the Next Operation First

Both DR and CDR are constructive heuristics that initialize with no schedule at all and construct the schedule themselves. On the other hand, improvement heuristics initialize with a complete schedule and try to obtain a better schedule by manipulation of the current schedule. Examples of these types of heuristics are simulated annealing, tabu-search, genetic algorithms, and ant colony optimization. Gen et al. (2013) draw the evolution of improvement type heuristics in his survey. In addition, Pinedo (2008) defines five more advanced general-purpose procedures for scheduling. These are beam-search that aims to eliminate branches in branch-and-bound procedure, decomposition methods that decompose large scheduling problems into smaller sub-problems and propose a feasible solution. Constraint programming aims to provide a feasible solution that satisfies all the constraints defined in the procedure, market-based and agent-based procedures that utilize the demand and supply mechanism between the machines, operations and initially resources. Multi-objective procedures that propose a pareto-optimal solution and combine previous methods (Pinedo, 2008, p. 373).

1.5 Advanced Planning and Scheduling Systems (APS)

Unlike traditional planning systems, Advanced Planning and Scheduling Systems (APS) tries to integrate the long-term, mid-term and short-term planning levels and decisions with computer aided systems. Stadtler et al. (2004) state that APS is not replacement of Enterprise Resource Planning (ERP) but on the contrary, it contains supporting blocks for efficient ERP systems. Lupeikiene et al. (2014) take the point one step further and declare that ERP systems are auxiliaries for APS. Mainly, APS tries to computerize the planning processes by visualizing information, reducing planning time and allowing easier application of optimization methods (Stadtler et al., 2004; p.86). All these advantages support the planner as for decision making and require human interference for data entry and programming.

In addition, Fleischmann et al. (2003; p.458) state that the concept is introduced by software providers to define a new type of modular planning software that is although not particularly advanced in planning concept nor in algorithms used in modules, but advanced in the implementation of these concepts into standard software that enables the utilization of them.

Further, Fleishmann et al. (2003; p.480) define that Hierarchical Planning Concept is the underlying structure of APS that divides the overall structure of the supply chain hierarchically and applies different optimization models in different levels of the hierarchy (i.e., different planning tasks.)

Rohde et al. (2004) classify the planning tasks of a company in two dimensions: planning horizon (namely long-term, mid-term, short-term) and supply chain processes (namely procurement, production, distribution, sales). These tasks are then placed in the Supply Chain Planning (SCP) Matrix, and they provide the basic framework of APS modules (Figure 3).

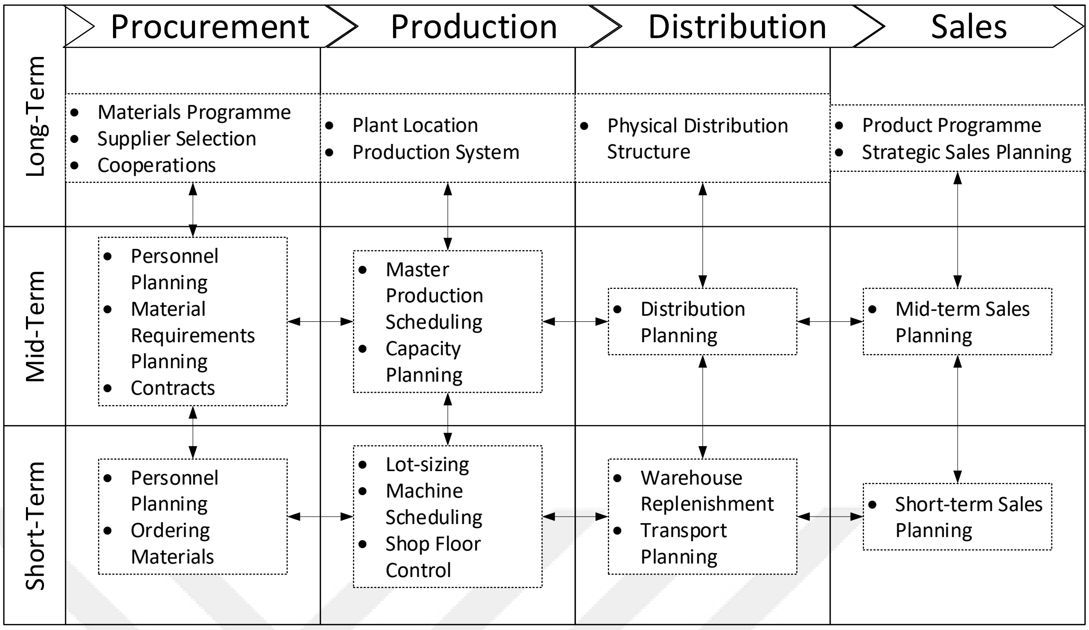

Figure 3. SCP Matrix (Source: Stadtler, 2004, p.87)

As an extension to traditional Manufacturing Planning and Control Systems (MPC) that leave both strategic planning and supply chain planning out of the scope, APS offers extended approach to these topics both within the company and in between the other supply chain companies. Figure 4 shows the collaborated APS modules of supply chain companies (Stadtler et al., 2004; p.113). This approach creates an integrated supplier-customer cooperation decreasing the information exchange delays in between the companies to milliseconds. Another advantage of such collaborated APS is that each company in the supply chain is able to calibrate its mid-term planning according to master plans of its customers and able to relay the changes to its suppliers automatically (Stadtler et al., 2004; p.113).

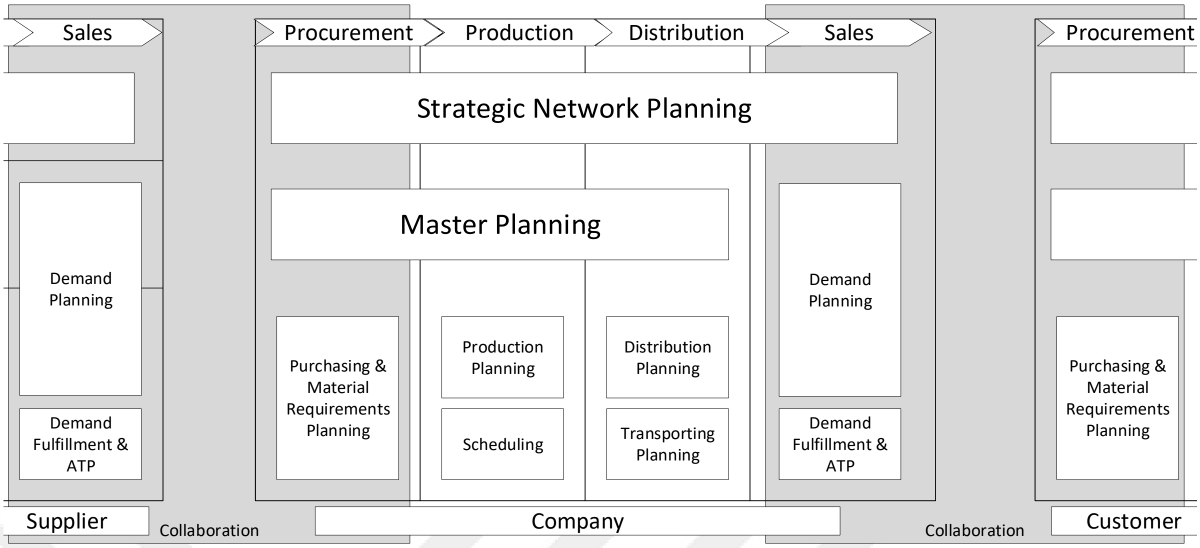

Figure 4. Collaboration between APS.

Finally, the integration between long-term, mid-term and short-term plans within the APS provides each task to be compatible with the strategic decisions of the higher management. Thus, leading to more efficient and strategic oriented mid-term and short-term processes that can be managed and controlled more easily.

1.6 Planning Levels in Production Companies

Even though previous sections provide traditional and advanced planning concepts on resource-based perspective, there is another dimension, that is dimension of time. The dimension of time provides planning levels in planning methodology.

Researchers define four main levels of production planning to be observed both separately and inter-connectedly in order to include time dimension and other managerial aspects of the planning (see Kung and Chern, 2008; Tyagi et al., 2013; Ozturk and Ornek, 2016). Time horizons and demand trends provide a wider understanding of real conditions in a production company. Both Vollmann et al. (1997) and Stadler et al. (2004) point out similar perspectives of time and the planning phases interconnected with these levels. Table 2 provides an interpretation of planning levels for planning processes defined in Vollmann et al. (1997) and Stadtler et al. (2004).

Table 2. Terminologies of Vollmann et al. (1997) and Stadtler et al. (2004).

Planning Levels	Planning Process	Vollmann et al. (1997) Terminology	Stadtler et al. (2004) Terminology
Strategic Level	Marketing Planning	Management	Long-term
	Top Management Game Plan		
	Financial Planning		
Demand Level	Resource Planning	Front End	
	Production Planning		
	Demand Management		Mid-term
Master Level	Master Production Scheduling		
	Rough-Cut Capacity Planning		
	Capacity Requirements Planning	Engine	
	Detailed Material Planning (MRP)		
Factory Level	Finite Loading	Back End	Short-term
	Input/Output		
	Shop-Floor Systems		
	Vendor Systems		

1.6.1 Strategic Level

In strategic level, main purpose is to configure the supply chain network and define the right service areas and right partners for the production (Kung et al., 2009). This level can further be expanded to include human resources and investment policies of the factory since workers and investments are one of the main long-term resources for capacity. Real production environment provides a scope of these capacity constraints with long-term forecasts and market dynamics. With a combination of past years' data and yearly forecasts, capacity bottlenecks can be observed and decisions can be made in order to prevent any shortages prior to occurrence.

1.6.2 Demand Level

Highly interconnected with strategic level, demand level mainly focuses on predicting the structure of future demands in years. Although this module is mainly researched on creating forecasts to help decision making process of inferior levels, it is based on demand structure of customers and their changes in annual horizon in order to provide insight for inventory decision making process (Kung et al., 2009).

Each customer has different trends throughout the year. The structure of demands has a main role on resource and capacity allocation of the production system. Planning horizon decision and lot sizing decisions for each customer can be implemented in this phase. By providing these parameters, changes during planning horizon and already-in-stock compensations of the orders can be managed. Instead of considering overall policies like make-to-order or make-to-stock in production, these decisions can create a generic policy for each customer at a given time.

1.6.3 Master Level

Until this level, previous levels can be considered as policy setting levels that provide parameters and metrics for the following levels. Master level focuses on satisfying demands efficiently according to capacity and resource constraints (Kung et al., 2009).

The problems for these levels are commonly based on sorting algorithms (Kung et al., 2009). However, in reality, changing customer demand sizes and due dates require to retrieve and use these sorting algorithms. Thus, simple sorting methods become incapable to react to these changes efficiently (Kung et al., 2009). In general use, MPS procedures are applied in this level and they provide the basis for the following level decision making processes.

1.6.4 Factory Level

The main research topic area for factory level is scheduling. Most of the planning research in the literature are in this level. Mainly, this level consists of dispatching orders of the master plan for the job floor and allocates capacity and resources accordingly considering the preceding constraints (Kung et al., 2009). Among all the modules, factory planning is the most important module due to its practical connections to the shop floor.

There are different approaches to this scheduling problem. Mixed Integer Linear Programming (MILP) is one of the most researched methodologies in the literature (Chapter 2). However, implementing and solving this problem is very difficult and time consuming for real life conditions due to its NP-Hard nature. On the other hand, several heuristics methods are employed to overcome this difficulty. These methods vary from generic algorithms to evolutionary approaches, and each method tries to obtain sub-optimal solutions (Chapter 2).

When scheduling the work orders in the job floor, one of the most important objectives is to limit or even eliminate the changeover times. These changeover times occur in two different types, mold setups and raw material setups. These changeover times can be foreseen during scheduling, and they change the completion time of a work order considerably.

1.7 Problem Definition

This thesis aims to provide an automated and integrated method that minimizes the time of building production schedules in a production environment that uses concepts of APS together with integration of top management decisions and strategies for daily planning processes.

The main approach to this problem is to develop an easier method for extracting the requirements for both material and operational resources. Therefore, the planning system requires significantly less computation time compared to traditional MRPs together with an automated scheduling system that provides a draft schedule according to capacity requirements and reflects top management decisions such as inventory and human resources policies.

1.8 Thesis Summary

The remainder of the thesis is organized as follows.

Chapter 2 introduces the literature review. Recent studies with regard to applications of both MPC and APS are thoroughly reviewed in this chapter.

Chapter 3 describes a general survey among 64 companies located mainly in the Aegean Region of Turkey together with varying sizes and production types.

Chapter 4 presents the problem definition of the thesis and discusses the issues in traditional planning systems together with comparing the execution times of popular commercial planning software in the market.

Chapter 5 introduces the proposed approach for requirement extraction and explains its steps.

Chapter 6 presents the case study, application of the proposed approach into the company of the interest and evaluation of the approach with regard to company performance.

Chapter 7 describes the experimental design conducted to test the proposed approach by defining main factors. Then, it represents the results of analysis of variance (ANOVA) and regression model.

Finally, Chapter 8 covers the main conclusions obtained from the thesis study and presents possible future research directions.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents a literature review to provide APS models applied in different industries and scheduling methods for the production facilities. The related literature is briefly reviewed according to objectives, methodologies, data types used, job sizes, size of machine sets and machine types together with setup time handling. Accordingly, summary table categorizing the surveyed literature is presented in Section 2.2. At the end of the chapter, concluding remarks are presented in the Section 2.3.

2.2 Literature Research

In this study, literature survey in planning systems is categorized under three groups. In the first and second groups, main research topic is on the factory level planning and scheduling. The first group of studies consists of optimization-based models is given in Subsection 2.2.1. The second group of studies includes heuristic-based models that are explained in Subsection 2.2.2. The third and final groups consist of studies on APS and consider not only factory level but also demand and master level planning in Subsection 2.2.3.

2.2.1 Optimization-Based Studies

Under advanced planning and scheduling, there is an extensive research on factory planning and scheduling together with optimization models. These studies mainly focus on mixed-integer programming (MILP) and constraint programming (CP) approaches. To illustrate, Berber et al. (2007) aim to provide a MATLAB program that automatically creates the optimization model and add a new horizon constraint in order to simplify the problem minimizing the process time. They find an improved solution in reasonable time for single stage multi-purpose lines. However, the data sets are limited even though they observe and apply the model in a real-life factory. Chen et al. (2014) present a new model for short-term scheduling of multi-purpose batch plants in order to maximize the profits. The proposed model has less continuous variables and constraints that increase the efficiency of solutions.

Another approach is constraint programming-based models. These models increase the efficiency of the solution even higher, however, in the meanwhile they decrease the required computation time. Ozturk et al. (2015) present a new constraint programming model for balancing and cyclic scheduling in order to lower production lead times in mixed model assembly lines. Also, Ozturk and Ornek (2016) also combine two-phased heuristics to balance the workload of the resources on the planning level and schedule them based on constraint programming model that targets to minimize the makespan.

Gaudreault et al. (2011) focus on the real problem of scheduling in lumber industry. Their study compares two models (CP model and MILP model) with the objective of minimum tardiness. They simulate a relatively large production environment that consists of 166 product types, 12 machines with 3 different types and 525 different operations with real data of orders (from 200,000 to 900,000 units) within a 60-day horizon.

2.2.2 Heuristics-Based Studies

In order to avoid the complexity of the mathematical problems, most researchers approach the problem by using heuristics. Most heuristics are limited to factory level scheduling parameters and designed to cover specific cases and areas. Gen and Lin (2014) survey that makespan and workload variance are the main objectives of scheduling problems, and utilization of heuristics algorithms proves to be efficient in order to overcome the complex future of the scheduling problems. Cheng et al. (2011) propose two heuristics to include machine failures into a cost minimizing model to estimate machine failures while addressing optimal production and inventory allocation of a single-product, assemble-to-order system with multiple demand classes and lost sales. Eliiyi and Azizoglu (2011) propose a heuristic to balance and schedule fixed jobs with working and spread time constraints while maximizing the job-weight of the machines. The new heuristic method proves as successful with low computation time and adoptable to larger systems when it is compared to greedy heuristic methods, but slightly inefficient when it is compared to generic algorithms. Zhang et al. (2006) propose a multi-stage operation-based genetic algorithm to provide an optimal schedule in a 6 machine and multiple plant company by minimizing makespan of 4 orders with predefined sizes. Both the data and problem are hypothetical.

Although setup times are very important in scheduling, they increase the complexity of the problem and they are usually neglected by most researchers. Kerkhove and Vanhoucke (2014) consider multi-plant parallel machine scheduling problem with an emphasis on changeover times and limited technician capacities. They propose a hybrid meta-heuristic method that minimizes the weighted combination of job lateness and tardiness. Gokce et al. (2017) present ten sub-level heuristics that include specific single objectives and find optimal job schedules for each machine. Later they are combined to present an overall optimal solution for multi-level capacitated lot sizing problem with setups and linked lot sizes.

In real production environment, scheduling of job-floor depends on multiple objectives. Most of the cases, minimizing makespan, minimizing delay, minimizing production costs and balancing the workloads of the machines are the main objectives. To illustrate, Kung and Chen (2009) present a heuristic factory level planning algorithm that schedules jobs by using three tier machine-order assignment in order to minimize the delay time of orders, makespan of the products and advance time of production. Nguyen et al. (2014) propose an automatic decision-making process to assign scheduling policies by using evolutionary algorithms for multi-objective job shop scheduling problem that minimizes makespan, weighted tardiness and percentage error. Luo (2018) presents a multi-objective problem to use in production industries by using evolutionary algorithms and also minimizing makespan, delivery delay and product flow.

2.2.3 APS-Based Studies

Although most of the proposed models takes into factory level scheduling account, the connection between the other levels and factory level is researched scarcely. The researched methodologies are mainly applied to real production environments with case studies and proved as successful with regard to their objectives. To illustrate, Genin et al. (2007) focus on the effects of multi-level (namely Strategic-Level, Demand-Level and Master-Level) decisions with planning horizon on the robustness of the production plans. The indicator for robustness considered is the cost of production.

Johnsson et al. (2007) present three case studies by using specific commercial APS, and they solve sales and distribution problems. The importance of these cases is defined as the APS's ability to integrate different levels of planning. On another study, David et al. (2007) study the implementation of APS in aluminum conversion industry. The bill of material specifications (existence of up-stream BOMs and down-stream BOMs) of this industry creates difficulties for planners to effectively plan the production and procurement in the companies. Therefore, David et al. (2007) compare the use of APS in this industry with ERP systems that are already in use by the industry.

Zoryk-Schalla et al. (2003) discuss a case study for the implementation of a specific commercial APS system in a multi-plant company in a duration of 2 years. After the implementation, the results of APS generated plans are observed according to criteria defined by the implementation team. However, it is found to be unsatisfactory due to restrictions and inflexibility of the implemented model. Zhong et al. (2015) propose an RFID real time scheduling model that includes both job floor scheduling and order planning. Weights are assigned for orders and they are scheduled according to these weights to minimize tardiness. A novel approach to order-shop floor scheduling combination is researched by He et al. (2014). The model is based on minimizing cost of production, and production of each order is planned for each time by a bidding mechanism between resource agents and part (order) agents.

2.3 Concluding Remarks

The overall summary of the reviewed literature research is given in Table 3. The table reports whether or not a study includes a case study or survey, objectives, research methodology and parameters are reported for each study in the literature.

Table 3. Literature Review Summary.

Authors	**Case or Survey**		**Objectives**					**Methodology**			**Parameters**		
	Case Study	Survey	MS	T	WL	C/P	E	MILP	CP	Heuristics	Setup Handling	Max. Job Size	Max. No. of Machines
Berber et al. (2006)	X	-	X	-	-	-	-	X	-	-	SD	13	4
Chen et al. (2013)	-	-	-	-	-	X	-	X	-	-	-	11	6
Cheng et al. (2011)	-	-	-	-	-	X	-	-	-	GA	-	1	N/A
David et al. (2006)	X	-	-	-	-	-	-	-	-	-	-	-	-
Eliiyi and Azizoglu (2011)	-	-	-	-	X	-	-	-	-	PTH	-	500	10
Gaudreault et al. (2011)	X	-	-	X	-	-	-	X	X	-	-	525	12
Gen and Lin (2013)	-	X	-	-	-	-	-	-	-	EA	-	18	5
Genin et al. (2007)	-	-	-	-	-	-	-	-	-	-	-	-	-
Gokce et al. (2017)	-	-	-	-	-	-	-	-	-	GA	SI	8858	12
He et al. (2007)	X	-	-	-	-	X	-	-	-	BA	SD	16	20
Jonsson et al. (2007)	X	-	-	-	-	-	-	-	-	-	-	-	-
Kerkhove and Vanhoucke (2013)	X	-	-	X	-	-	-	-	-	GA	SD	750	75
Kung and Chen (2008)	-	-	X	X	-	-	-	-	-	GA	SI	7	5
Luo (2018)	X	-	X	X	-	-	-	-	-	EA	-	30	4
Lupeikiene et al. (2014)	-	X	-	-	-	-	-	-	-	-	-	-	-
Nguyen et al. (2014)	-	-	X	X	-	-	X	-	-	GPHH	-	200	20
Ozturk and Ornek (2016)	X	-	X	-	-	-	-	-	X	CPBH	-	39	6
Ozturk et al. (2015)	-	-	X	-	-	-	-	-	X	-	-	7	3
Tyagi et al. (2013).	-	X	-	-	-	-	-	-	-	-	-	-	-
Zhang and Gen (2006)	-	-	X	-	-	-	-	-	-	GA	SD	16	6
Zhong et al. (2015)	X	-	-	X	-	-	-	-	-	GA	SD	309	191
Zoryk-Schalla et al. (2004)	X	-	-	-	-	-	-	-	-	-	-	-	-

Objective Abbreviations: MS: Minimize Makespan, T: Minimize Tardiness or Lateness, WL: Maximize Workload, C/P: Minimize Production Cost or Maximize Profit, E: Minimize Error.
Methodology Abbreviations: MILP: Mixed Integer Linear Programming, CP: Constraint Programming
Heuristics Abbreviations: GPHH: Genetic programming-based hyperheuristic, PTH: Polynomial Time Heuristics, EA: Evolutionary Algorithms, GA: Generic Algorithms, CPBH: Constraint Programming Based Heuristics, BA: Bidding Algorithm
Setup Handling Abbreviations: SD: Sequence Dependent, SI: Sequence Independent

With regard to the case study and survey, only four studies include a survey study, however, most studies present a case study. Thus, in this thesis study, both a general survey analysis is given and also a case study for a plastic injection company is presented.

With regard to the objectives, there are many studies that takes makespan (MS) and lateness or tardiness (T) as objectives. On the other hand, there are only few studies that consider the other production system related objectives such as maximizing the workload (WL), minimizing the production cost or maximizing the profit (C/P) and minimizing the error (E). In this study, the MRP running efficiency is discussed with the production system related parameters through the analysis of the case study.

With regard to the research methodology, most studies apply heuristic approaches since the problems are examined as NP-hard problems. Only few studies consider optimization approaches such as mixed-integer programming (MILP) or constraint programming (CP).

In each study of the optimization-based group, the NP-Hardness of the problem is considered. In order to decrease complexity of the problem, small sets of machines (1-5) and relatively small size of orders (except Gaudreault et al., 2011) are chosen. In addition, the computation time required to solve these problems is in hours. On the other hand, heuristic-based group requires less computation time even with relatively larger machine and operation sizes.

With regard to the parameters, the literature is evaluated according to the setup handling and maximum number of job size. It is observed that only two studies consider sequence-independent (SI) setups, and five studies consider setup dependent setups, and most studies do not consider any setup constraints or parameters. Also, most of the studies report the maximum level of job sizes and it varies significantly, from the minimum of 1 job to maximum of 8858 jobs. Therefore, most of the studies provide solutions to highly complex and highly specific problems, however, they often neglect the most of real production conditions. Most of the studies considers very small number of machines and operations. It can be concluded that most studies discard the changeover loses and work on relatively small size problems.

APS based studies mainly focus on the application of APS models and their performances in several different industries. The main purpose of these studies is to promote or demote the application of the APS in different situations. Since the APS defined in these studies are commercial APS, the base algorithms are not defined, and there is no information about the interconnection of their modules, therefore, they are not informative to the problem defined in this thesis.

CHAPTER 3: SURVEY ON PRODUCTION COMPANIES

3.1 Introduction

This chapter starts with the presentation of a survey conducted on production companies and their planning methodologies in Section 3.2. It focuses on general characteristics of the companies with regard to planning processes. Then, concluding remarks that summarized main results are given in the following Section 3.3.

3.2 Survey on Production Companies

In order to interpret the real applications of planning methodologies, a survey is conducted among 64 real production companies located in the cities of Izmir, Manisa, Istanbul and Aydın in Turkey. The number of companies is chosen in order to cover different industries and different company sizes to represent a broader view on the topic. Following subsections provide the information about the characteristics of companies and survey queries.

3.2.1 Categorization of The Survey Population

The companies are chosen from the customer database of a Manufacturing Execution System (MES) software development company that is related to the company chosen for the case study in this thesis. Each company is visited during a specific timeline. The timeline includes last 3 years information and each visit to a company takes on average 2 hours. After obtaining the information from each production company, they are categorized according to their production sizes, main production processes, served industries and production types.

The size of the company is determined by the number of operational and separate stations in its production facilities. Small companies include up to 50 stations, medium companies contain up to 100 stations and large companies have more than

100 stations. Among the surveyed companies, the categorization according to company sizes is given in Table 4.

Table 4. Size Distribution of Surveyed Companies

Size of the Company	**# of Surveyed Companies**
Large (>100 st.)	24
Medium (>50 st.)	27
Small (<50 st.)	13
Total	**64**

Main production processes are generalized according to raw materials used in the production. Figure 5 depicts the distribution of companies according to their main production processes. Accordingly, the two most common production processes are metal processing that covers 27 companies and plastic injection that includes 13 companies in the survey. The rest of processes are wood and rubber processing. Each of them has 3 companies in the survey, this follows metal casting, textile processing, spices processing, assembly and chemical processing with 2 companies. Others include leather, meat, spirit, fodder and glass production.

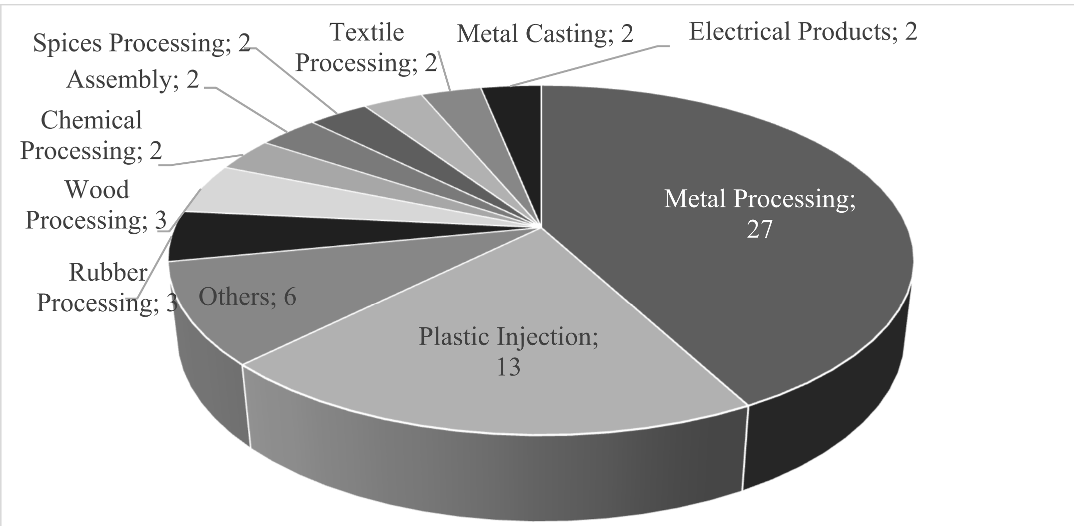

Figure 5. Main Process Distribution of Surveyed Companies

The industry categorization defines the main industry of a company that is served according to its end products. The list of main industries of these companies is given in Table 5. According to Table 5, household appliances industry has the maximum number of companies in this survey with 12 companies. This is followed by the general sub-parts and machine production industries with 8 and 7 companies. Then, automotive and food industries follow them with 6 and 4 companies. The rest of the industries includes 21 different other industries and almost half of the number of companies in the survey.

Table 5. Summary of Main Industries in the Survey

Industry	**# of Companies**	**Industry**	**# of Companies**
Household Appliances	12	Cloth and Yarn Production	1
General Sub-Parts	8	Cabling	1
Machine Production	7	Sports Textiles	1
Automotive	6	Processed Leather	1
Food	4	Dairy	1
Medical	2	Palette	1
Furniture	2	Chemical	1
Packaging	2	Food and Fodder	1
Electronics	2	Poultry	1
Motor	2	Sports Equipment	1
Window Accessories	2	Air Conditioning	1
Dye	1	Wiring	1
Bicycle Production	1	Glass	1
		Total	**64**

Production type is categorized by job type and machine utilization of each job. In a flow shop, each job is processed through machines in a sequential order. On the other hand, in a job shop, there are multiple routings exist in the shop apart from functional layouts. In this type of a shop, not all jobs require the same number of operations and sequences, while some jobs may be operated on the same machine multiple times (Nahmias, 2013; p.423). Continuous production refers to non-discrete production that raw material continuously flows into the process and it is spoiled or scrapped if not properly processed. Figure 6 gives the distribution of companies according to production types in the survey. In Figure 6, it is observed that slightly more than half of the companies (33 companies) has a flow-shop type of production, and majority of remainder companies has job-shop type of production. Only 8 companies have continuous type of production.

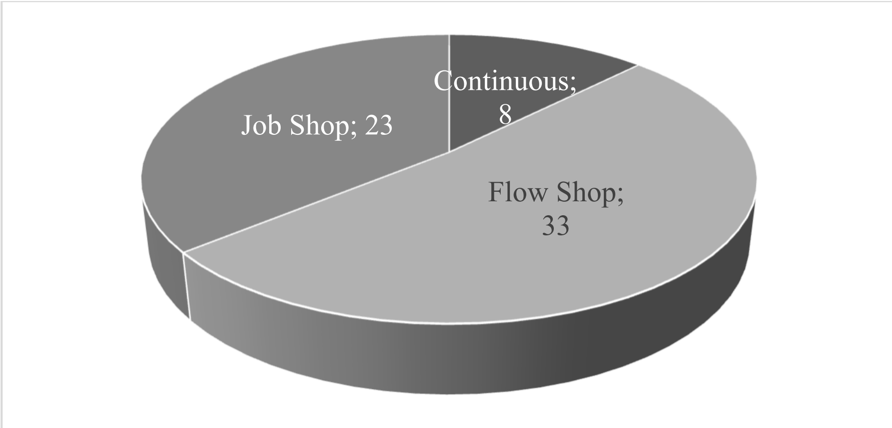

Figure 6. Production Type Distribution of the Surveyed Companies

3.2.2 Queries of the Survey

The questions of the survey intend to understand the utilization of planning systems in companies to draw conclusions. The outcomes of each question are given in the following titles.

3.2.2.1 Does the company invest in an ERP system?

All of the companies invest in an ERP system in order to comply with the accounting and financial regulations of Turkey such as the requirement to produce *Shipment Documents* with the shipment process and to convert them into *Invoices* within a week. Main ERP systems owned by the companies are mainly the ERP products of Netsis/Logo and SAP. Out of 64 companies, 47 of them have Netsis/Logo, and 12 of them have SAP.

3.2.2.2 Does the company use MRP? If yes, what is the frequency?

Only 20 of companies use an MRP module of the system. The main reason behind this is that companies do not have complicated production plans since they do not involve long levels of BOMs and high product varieties and they do not actively create new BOMs and recipes. Thus, they prefer simpler spreadsheet applications to obtain their production plans. In addition, for those companies that have complex products or processes and do not use MRP, although the execution of MRP is required for planning, they are not able to control BOMs and stock codes to produce an accurate MRP report.

3.2.2.3 How often do the customers place orders, and if they change them in process?

14 of companies that use an MRP module state that the orders are received weekly and customers do not change their orders that are in progress. Only five of companies utilizes MRP daily, however they state that they have to stop all their inventory and shipment transactions when MRP module is running. All of these companies are assembly companies with high variety of raw materials.

3.2.2.4 Does the company invest for an Advanced Planning System? If yes, does the company use it actively?

APSs are not widely invested due to their high initialization costs. Only nine companies invest on such systems but five of them had to abandon due to high reprogramming and maintenance requirements. Figure 7 gives visual information of the data.

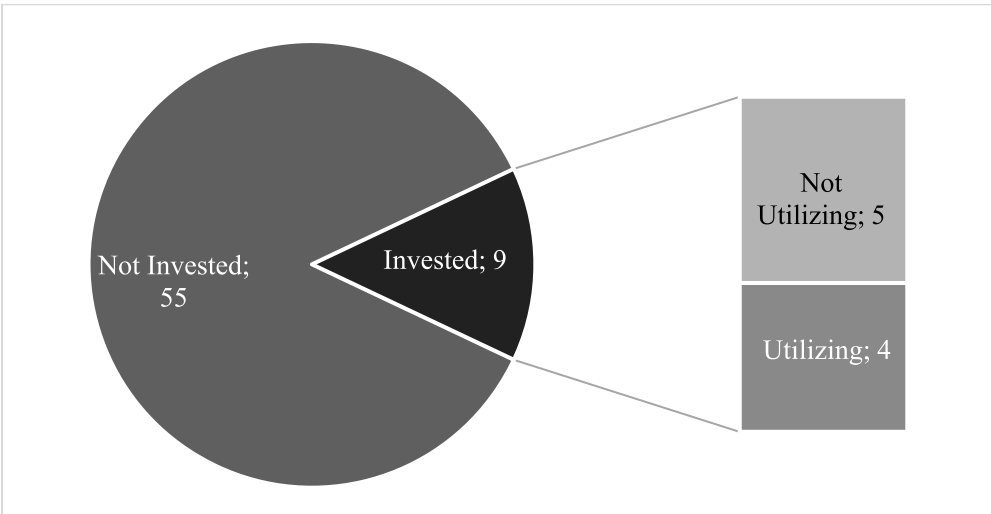

Figure 7. Investment on Advanced Planning System and Actual Utilization

3.2.2.5 Are the company inventories reliable? (Are there any inventory errors?)

41 companies state that their inventories are reliable. The rest of the companies observes inventory errors weekly hindering further the MRP utilization. All of the companies that utilize MRP modules state that their inventories are reliable.

3.2.2.6 What is the method or program that is used for planning?

Every company state that their production planning is formed by using spreadsheets application. General opinion among the companies is that it is easy to use and easy to formulate without dealing much with data entries and parameter settings. Although, most the companies highly apply integrated planning approach similar to APS, all outputs are carried on spreadsheets, and production planning and scheduling are conducted using these spreadsheets. This increases the human interaction of the processes, increasing the errors and disinformation due to lack of integration.

Apart from than these survey queries, the planning methodologies of these companies are observed. A common planning pattern is detected with regards to the planning phases and planning layers of job shop companies. This pattern coincides with the company of interest in the case study and described in Chapter 6 to provide a basis for the proposed approach in this thesis.

3.3 Concluding Remarks

In this chapter, the outcomes of the survey conducted on real-life companies are presented in order to present a better view of actual life applications of planning.

Also, the survey on production companies reveals that planning and scheduling of the production is highly dependent on the human interaction due to constant changing orders and production parameters (such as machine breakdowns and inventory errors). Just like expediters mainly used in 1950's and 1960's (Tyagi et al. 2013), there is a job distribution between these individuals according to production categories and/or customers. According to the most of the companies observed, they use an ERP system in order to comply with financial and accounting regulation however, their utilization of MRP, MPS and/or MRP-II is very low. The main reason for lack of utilization of these systems is the high parameter setting requirements and lack of automatic control mechanisms presented within the ERP systems.

The companies mainly create their own spreadsheets in order to follow the orders, dig out the material and production requirements, schedule the production and procure the required materials for production. These spreadsheets are usually not integrated to each other leaving the overall planning highly prone to human errors and unable to adopt to changes rapidly.

CHAPTER 4: PROBLEM DEFINITION

4.1 Introduction

This chapter starts with the issues in traditional MPC systems given in Section 4.2. Following with this section, the problem definition of this study is presented in Section 4.3. The defined problem is explained and discussed further in three subsections. In Section 4.3.1, requirement extraction methodology is explained. Section 4.3.2 introduces indicators and parameters of higher planning levels that provide the foundations for the sorting algorithm to be used in scheduling methodology.

4.2 Issues in Traditional Manufacturing Planning and Control (MPC) Systems

Although traditional MPCs are widely used in industry since 1980's, there are some issues for the utilization of these systems. According to Vollmann et al. (1997), main issues of these systems are contained in the process of MRP. Since MRP is one of the main processes in MPC, these issues directly affect the overall planning efficiency of the company.

Vollmann et al. (1997) indicate that *processing frequency* contains two main issues that affect the accuracy of requirement plans. First one is the decision of the coverage of the records to be processed. In regeneration, all the orders are processed in each run, therefore it covers a larger scope for demands in the expanse of higher computation time. On the other hand, net changes handle only the changed orders by excluding the unchanged orders that decrease both the computation time and accuracy of the material plans. Second decision is how frequent the MRP is to run. Each MRP run costs computation time according to the amount of orders to be processed and complexity of the BOM of the products. Vollmann et al. (1997) point out that each run costs 8-24 hours of computation which causes a motivation for less frequent MRP runs. Although by the advancement of the technology, the computation time of MRP runs are decreased to 1-2 hours, a company ceases every inventory and production transaction during these runs. This creates uncertainty in work in process (WIP) inventories leading inaccurate material requirements (Vollmann et al., 1997).

Processing frequency issue is also pointed out by Nahmias (2013). It is stated that MRP uses deterministic and static demand for a certain period of time, however, in reality, the demand changes overtime and the MRP re-runs to compensate these changes into the actual production plans.

Another main issue pointed out is the *lot size* and *lead time dependencies*. Although lot sizing can be standardized in Make-to-Stock (MTS) systems which decrease the level of complexity of MRP runs, it is inapplicable in Make-to-Order (MTO) or Assemble-to-Order (ATO) systems because of the changes in lot sizes for orders. Also, the lead times regarding the lot sizes are usually not linear, thus, they create another level of uncertainty for the MRP (Nahmias, 2013).

In addition, Tyagi et al. (2013) summarize main issues in traditional MPC systems in their survey. The following points hinder the utilization of MPC in industry:

1- The MPCs currently in use, are designed for specific industry or manufacturing environment, therefore, a more generic MPC that is applicable to every industry is required.

2- The models proposed by academics are not understood and utilized by the practitioners.

3- The proposed MPC model should be interactive and act as a Decision Support System.

4- Lead times of both production and procurement processes are not addressed correctly in current MPCs. Therefore, in MPC without a strong shop floor control system is unable to provide viable information about WIP, available capacity, and uncertainty.

5- The current MPC design lacks the ability to adopt to production and demand changes, and they are designed for static environments.

6- Most of the existing MPC systems fails to develop detailed shop floor schedules that are feasible with the production plans.

The main requirement for a planning system in the industry is that it works fast and does not require much maintenance and/or human interaction (Chapter 3). For an industrial practitioner, such generic planning and scheduling model has to be adaptable to changes and uncertainties in both shop floor level and order level. Daily changes in orders and resources should be considered, and updated schedule should reflect these changes dynamically.

On the other hand, utilization of scheduling models proposed by researchers are usually very low due to the complexity of the problem and need of certain requirements to be fulfilled before use (Tyagi et al., 2013).

In order to provide an efficient production plan, another purpose is to minimize the changeover loses. The changeover loses are due to uncertainties in the orders and causes as much as 5 machine-month worth production time per month in the real-production company of interest in this thesis.

4.3 Problem Definition

This study aims to provide an integrated approach on planning phases of a production company in order to decrease the computation time required for resource extraction (an alternative to MRP explosion), to eliminate the “sleeping time” by carrying out the extraction process offline, and to provide users with decision support information for different levels in planning.

This problem is discussed with three main parts. These are the explosion methodology of the commercial MRP systems, decision support information and the need of human interaction level.

4.3.1 Explosion Methodology

MRP systems that are currently in use have several deficiencies. Two of the commonly used MRP systems in Turkey (Netsis/Logo and SAP) are considered, and both of the systems use similar algorithms to produce requirement lists causing significant execution time without taking the work in process (WIP) inventories (Tyagi et al., 2013). Both of the mentioned MRP systems have ability to bypass the inventory checks, however, they still require a reference point and sleeping time to operate.

The reason for these problems is that in both of the MRP systems each customer order is handled from top to bottom expanding the item at each level and searching for the inventory to prepare the requirement. More detailed algorithm flow is given in Figure 8.

Accordingly, based on the order information given in the order list, a commercial software first checks the inventory using the inventory database and if there is no sufficient amount, it calculates the net requirements or required quantity. If the order for the required quantity is not for an end item, it inputs the required quantity into the purchase table, otherwise, it finds the order recipe by using the recipe database and calculates the component amounts using the BOM information and adds them into a work-order table.

In general, the MRP methodology used by these brands is the computerized version of the generic methodology pointed out by Vollmann et. al (1997). These MRP systems have more calculations (increasing logarithmically) once the level on the BOM of the products gets higher. Besides, controlling the inventory at this stage adds more calculation time to the MRP operation.

Additionally, the number of orders in the system affects the computation time required for the MRP positively. Since each order is processed separately without considering the previous explosions, the number of explosions increases.

Also, since each BOM level is exploded at each level, average number of components in the BOM is another affecting factor of computation time.

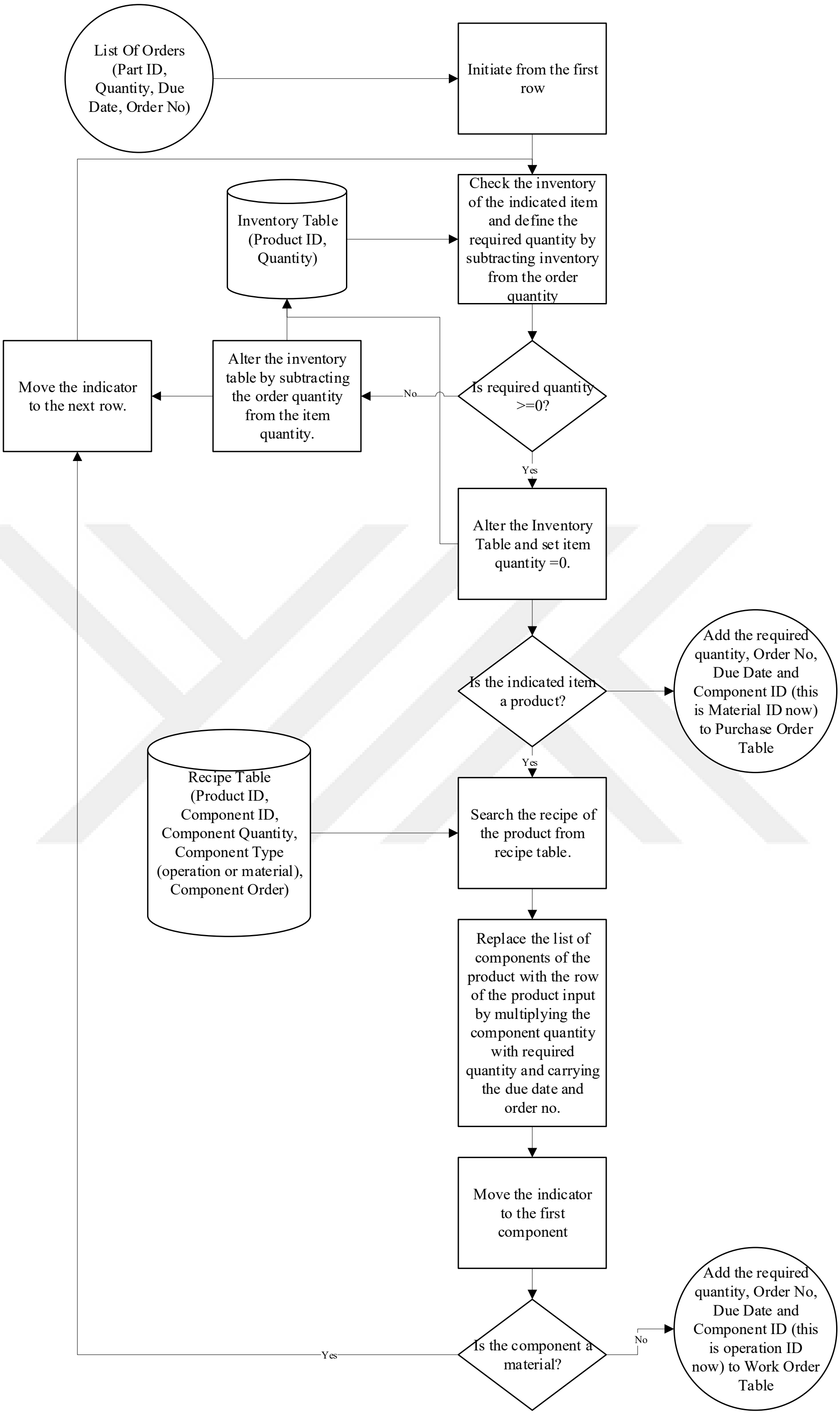

Figure 8. Basic Work Flow of Commercial MRPs

In order to test exact computation time requirements of these commercial MRPs, the same test databases are entered both in SAP and LOGO/NETSIS databases and same daily orders (that have same characteristics that are given in Table 10) are fed to the system. Table 6 compares the calculation times of these MRP systems with and without inventory checks. All other parameters (such as check minimum inventory, cumulative output orders and register inventory) are turned off in order to operate MRPs faster.

Table 6. Calculation Time of Commercial MRPs

	No Inventory Check	Inventory Check
Netsis/Logo	75 min.	94 min.
SAP	63 min.	67 min.

Both the computation time required for MRP and sleeping time requirement decrease the rate of utilization of MRP in the companies that are considered in the survey analysis (Chapter 3). In the companies that use MRP, the amount of orders to be processed are limited by time filters in order to decrease the time required for MRP, thus, they decrease the requirements and increase the changeover times in the factory level.

4.3.2 Decision Support Information

In the literature review (Chapter 2), most of the researchers focus solely on the Factory Level indicators and parameters. However, in order to simplify and increase the efficiency of the planning, Higher Planning Level information can be used. This information does not only affect the Factory Scheduling Level but also other planning phases. Information about these parameters can either be obtained from the systems with MRP, MPS, CRP, MRP-II or can be obtained intuitively with past demand, seasonal or forecasted data.

In traditional systems, obtaining this information requires the execution of the mentioned systems separately, therefore it causes more computation time. Besides, in practice, collecting all these parameters and applying them in daily decisions is a difficult task for the planners and managers. These decision support parameters can be grouped by considering the planning levels of the company, and these parameters are further discussed in Appendices (Section A-4). The impact of the proposed approach that is introduced in the next Chapter is discussed on these decision support information in Chapter 6.

4.3.3 Human Interaction on the System

As Tyagi et al. (2013) points out that human interaction required both during implementation and daily utilization is one of the problems using APS in the industry. There are two direct effects of this element. First, as the human interaction increases, data errors increase, and this affects the accuracy of planning systems. Second, as the human interaction increases, more planning time is required, this increases the personnel requirement for the tasks.

In addition, due to complexity of information to be processed, an automated planning system can increase the efficiency of overall production of the company. Heuristic methods employed according to preset policies, can decrease changeover losses in production (via scheduling task), increase the inventory efficiency (via demand planning tasks), and increase the overall customer satisfaction (via shipment planning tasks).

4.4 Concluding Remarks

This study focuses on the problem defined in Section 4.3 by considering the issues observed in literature review in Chapter 2 and in survey analyses given in Chapter 3. The approach proposed in the next Chapter is explained in order to decrease computation time for MRP explosion, to increase the integrity in between planning levels together with management level and to decrease the human interaction in conducting these planning tasks.

CHAPTER 5: PROPOSED APPROACH OF ENHANCED REQUIREMENTS EXTRACTION

5.1 Introduction

This chapter starts with introducing main concepts in constructing the requirement extraction approach and their exploitation in Section 5.2. The construction of the approach (i.e., Requirements Extraction) that is composed of EBOM construction procedure, EBOM table procedure for operation requirements and extraction procedure from an order table and their outputs are described in Section 5.3. Finally, obtaining the information from extracted resources, the scheduling methodology are presented in Section 5.4 and Section 5.5.

5.2 Main Components of the Approach

This part explains the main input resources for the proposed model. Each input resource is explained in the following subsections.

5.2.1 Bill of Materials (BOM)

Vollmann et al. (1997) state that each BOM is created from the single level BOM that contains only the components of the intended product. Each subcomponent of the product may have further subcomponents creating a tree of materials when all are exploded. Therefore, BOM is the main data that MRP systems use in order to extract the required materials from a given product.

Vollmann et al. (1997) also define different types of BOM as intended BOM and planning BOM. Intended BOM expands the single level BOM and displays all the subcomponents of the product level by level. This increases the number of parts processed by any production procedure, however, it also decreases the complexity of the explosion methodology.

On the other hand, Planning BOM is used solely for MPS purposes in order to categorize the production limitations in the given orders by defining bottlenecks and/or critical production paths.

5.2.2 Routing File

Used for capacity requirement calculations, each BOM has at least one operation that combines the sub-components together. For example, in an assembly line, two or more components are assembled together to form a single product through the assembly operation.

Commercial MRP systems use routing files in MRP-II in order to calculate capacity of work stations. The main component of these routing files are operations that combine the subcomponents in the BOM together to form a product.

5.2.3 Operations and Products

The operations generally contain more than one resource. For example, for plastic injection, operation resources are plastic injection mold, plastic injection machine and operator. Each of these resources has specific parameters that affect the duration of the operation (i.e. cycle time). Since each product has its own mold in plastic injection, and each mold can be operated in specific machines, each product operation has its own machine allocation.

One of the main top-management level decisions is integrated in this point. The operation offset is defined as the slack time required for the product of the operation to be ready for next level of process. The reason behind this parameter is the time requirements for quality checks and other logical issues. For example, a subcontracting part may require 2 days to complete prior the start of the next operation. This information can be entered into the system through ERP or as a manual table.

5.3 Requirements Extraction Approach

In this part, the proposed approach and its components for requirement extraction in planning systems are described by highlighting main differences when it is compared to traditional planning systems.

In order to create a more efficient and faster extraction methodology, a cumulated expansion table is created (Enhanced BOM) in the model. This table expands all the products that are defined in the system and keeps them ready for extraction process. By this way, the extraction algorithm does not consume calculation time to expand each level and directly displays the completely expanded list in one operation unit. Figure 9 displays the flow of processes in the proposed approach and their connections to outer database tables. Following sections explain the algorithms used under the operations defined in this figure.

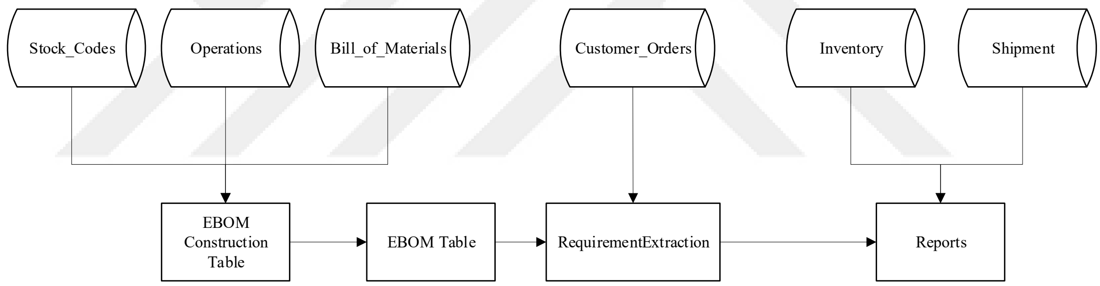

Figure 9. Flow Chart of the Proposed Approach

The proposed approach is constructed using Microsoft Power Query and outer tables are stored in Microsoft SQL Database. The approach can be adapted to any other database table by using respective queries of the applied database. The decision for using Microsoft Power Query is solely for visualization issues, and does not affect neither the computation parameters nor any other functional parameters in the approach.

5.3.1 Enhanced BOM Methodology

The requirement extraction model presented in this thesis uses an Enhanced Bill of Materials (EBOM) table that combines the components of both BOM and routing file. The idea behind this enhancement is to provide a simplified database table for extraction to decrease the computation time of MRP. It supports extracting not only the material requirements but also the operational requirements. EBOM table is a database table that consists of multi-level material and operation information of a given product. Extracting operational requirements together with material requirements enables capacity planning without need of an additional application.

5.3.2 Construction of EBOM

Construction of EBOM database table requires the single level bill of materials together with stock codes and routing files from the ERP system or any spreadsheet containing the required contents. BOM table contains the single level BOM of a given product, stock code tables contain the category, cycle time (or lead time for procurement materials), and final operation (or supplier) of each material. The routing file contains the operation required for the product, duration of the operation,

Figure 10 gives the attributes of the tables required to construct the EBOM table.

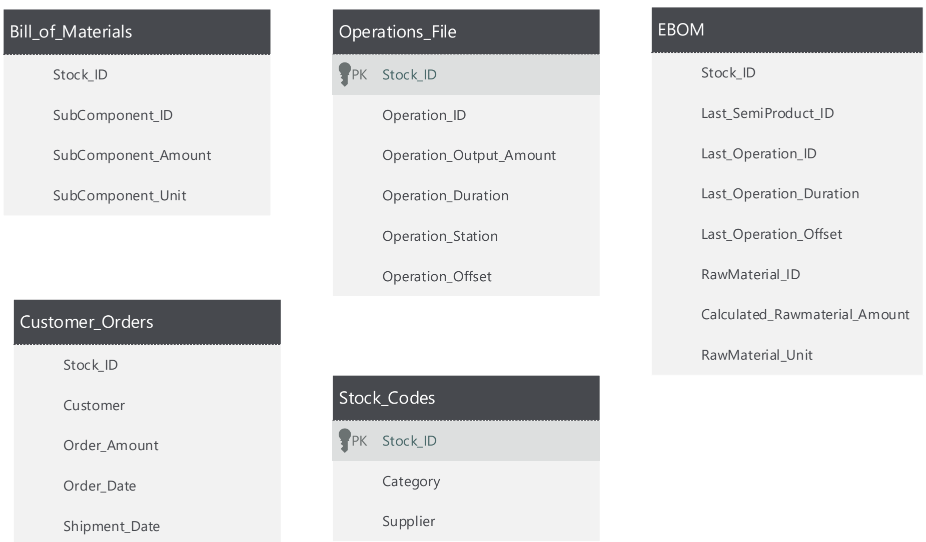

Figure 10. Tables of EBOM Procedures

5.3.3 Construction Methodology

In constructing the EBOM table, the main methodology is to create a three-level BOM that contains the product code, semi-product code and the raw material code together with the operation combining the raw materials into semi-products and their required amounts calculated from top to bottom.

The construction procedure uses iterative joint procedures to list each subcomponent of a product, operation that subcomponent is produced and the raw materials consumed during the operation. The iterative join procedures are used for each level (or each semi-product) in the BOM of the product, and each bottom-level operation is carried to the next step. By this way, the final table consists of all the operations used in the product and the raw materials required for each semi-product. Figure 11 depicts the flowchart of the construction methodology that presents each steps of the methodology. The steps of the methodology are explained in the following subsection.

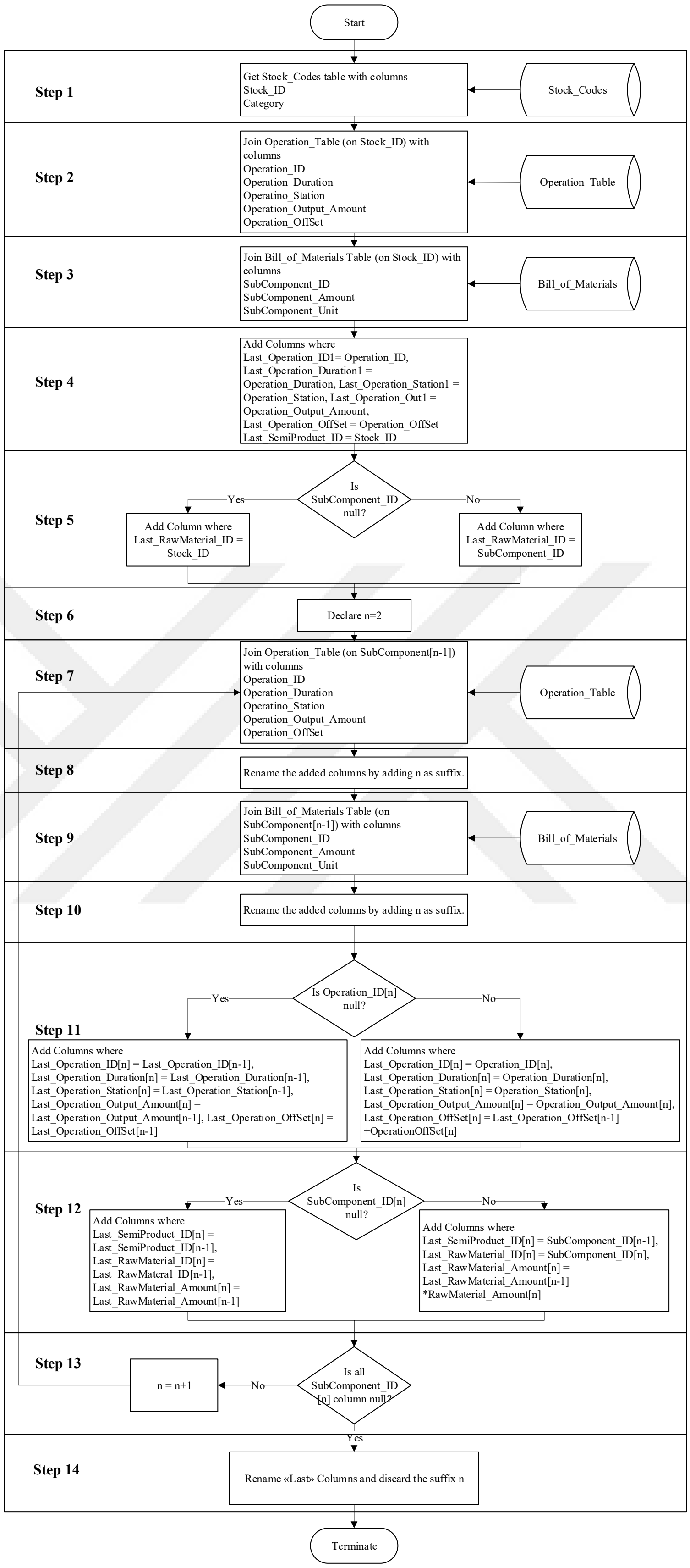

Figure 11. Flow Chart of EBOM Construction Procedure

5.3.4 Steps of the EBOM Construction Procedure

The steps of the EBOM construction procedure can be categorized into two parts. The first part consists of only the single level of the BOM and its stock codes. The related steps, step 1 to step 7, construct the first part given in the following.

Step 1. Prepare the Stock_Codes, Bill_of_Materials and Operation_Table tables.

Step 2. Join Stock_Codes table with Operation_Table table on Stock_ID. (Left-outer Join) and expand the Operation_Table.

Step 3. Join the output of Step 2 with Bill_of_Materials Table on Stock_ID. (Left-outer Join) and expand the Bill_Of_Materials table.

Step 4. Carry the Operation_ID to Last_Operation_ID1, Operation_Duration to Last_Operation_Duration1, Operation_Station to Last_Operation_Station1, Operation_Output_Amount to Last_Operation_Out1, Operation_Offset to Last_Operation_OffSet Stock_ID to Last_SemiProduct_ID, SubComponent_Amount into Calculated_LastRM_Amount1.

Step 5. Check if SubComponent_ID is null, if not carry the SubComponent_ID to RawMaterial_ID1, else carry the Stock_Code to the field.

Step 6. Declare n=2

Since only single level of the BOM of the stock codes is considered up to this point, the following steps initiate a while loop and check whether these are subcomponents in the n^{th} level in whole table and iterate the joint procedures accordingly.

Step 7. Join the output table of previous step with Operation_File on SubComponent_ID1 (Left-outer Join) and expand.

Step 8. Rename the added columns by adding suffix n (where n>1) at the end of each attribute indicating the level of explosion.

Step 9. Join the output table of previous step with Bill_of_Materials table on SubComponent_ID1 (Left-outer Join) and expand.

Step 10. Rename the added columns by adding suffix n (where n>1) at the end of each attribute indicating the level of explosion.

Step 11. Check if Operation_ID[n] is null, if true, carry

Last_Operation_ID[n-1] to Last_Operation_ID[n]
Last_Operation_Duration[n-1] to Last_Operation_Duration[n],
Last_Operation_Station[n-1] to Last_Operation_Station[n],
Last_Operation_Output[n-1] to Last_Operation_Output[n],
Last_Operation_OffSet[n-1] to Last_Operation_OffSet[n],

else carry

Operation_ID[n] to Last_Operation_ID[n],
Operation_Duration[n] to Last_Operation_Duration[n],
Operation_Station[n] to Last_Operation_Station[n],
Operation_Output_Amount[n] to Last_Operation_Out[n],
sum(Operation_OffSet[n], Last_Operation_OffSet[n-1]) to Last_Operation_OffSet[n]

Step 12. Check if SubComponent_ID[n] is null, if true, carry
Last_SemiProduct_ID[n-1] to Last_SemiPorduct_ID[n],
Last_RawMaterial_ID[n-1] to Last_RawMaterial_ID[n],
Last_RawMaterial_Amount[n-1] to Last_RawMaterial_Amount[n]

else carry

SubComponent_ID[n-1] to Last_SemiProduct_ID[n],
SubComponent_ID[n] to Last_RawMaterial_ID[n],
mult(LastRawMaterial_Amount[n-1], SubComponent_Amount[n]) to Last_RawMaterial_Amount[n]

Step 13. Check if all of SubComponent_ID[n] consist of null, if true, terminate the procedure else, repeat Steps 7-13.

The above procedure can be applied in any databases by using database specific logic and jargon. The output of the EBOM construction table consists of Product_ID (Stock_ID), Last_SemiProduct_ID, Last_Operation_ID and Last_RawMaterial_ID together with Last_Operation_Duration, Last_Operation_Station, Last_Operation_Output, Last_Operation_OffSet, and Last_RawMaterial_Amount.

It is important to note that there are two calculated attributes in the final output. Last_Operation_OffSet accumulates all the previous operation offsets in order to prevent starvation of any following operations. In addition, the single-level BOM consists of only the raw material amounts of the relative level. However, the lower levels of the BOM do not carry the upper level amounts. Therefore, this amount is multiplied in each level with the previous level to indicate the real requirement in the product.

5.3.5 EBOM Table

Since the construction of the EBOM_Construction table is a functional table, each time a new inventory code is created or an existing one is updated, the EBOM_Construction table updates itself, and it is ready for the extraction process. Even though EBOM_Construction table could be used in extraction process, it is more effective to create a summary table which is the EBOM table.

EBOM table displays each inventory code for semi products and raw materials together with operation information for producing the related semi products. Since the construction algorithm searches each level in the BOM of a product, each level is displayed as a semi product in the table together with its operation and raw material.

In addition to information obtained from EBOM_Construction Table, EBOM contains functional information obtained from Stock_Codes table that displays the category and supplier of the inventory codes. Also, for simplification, EBOM table contains the count of sub-components of each operation in order to provide a correct calculation of operation requirements. The flow chart of the procedure is given in Figure 12.

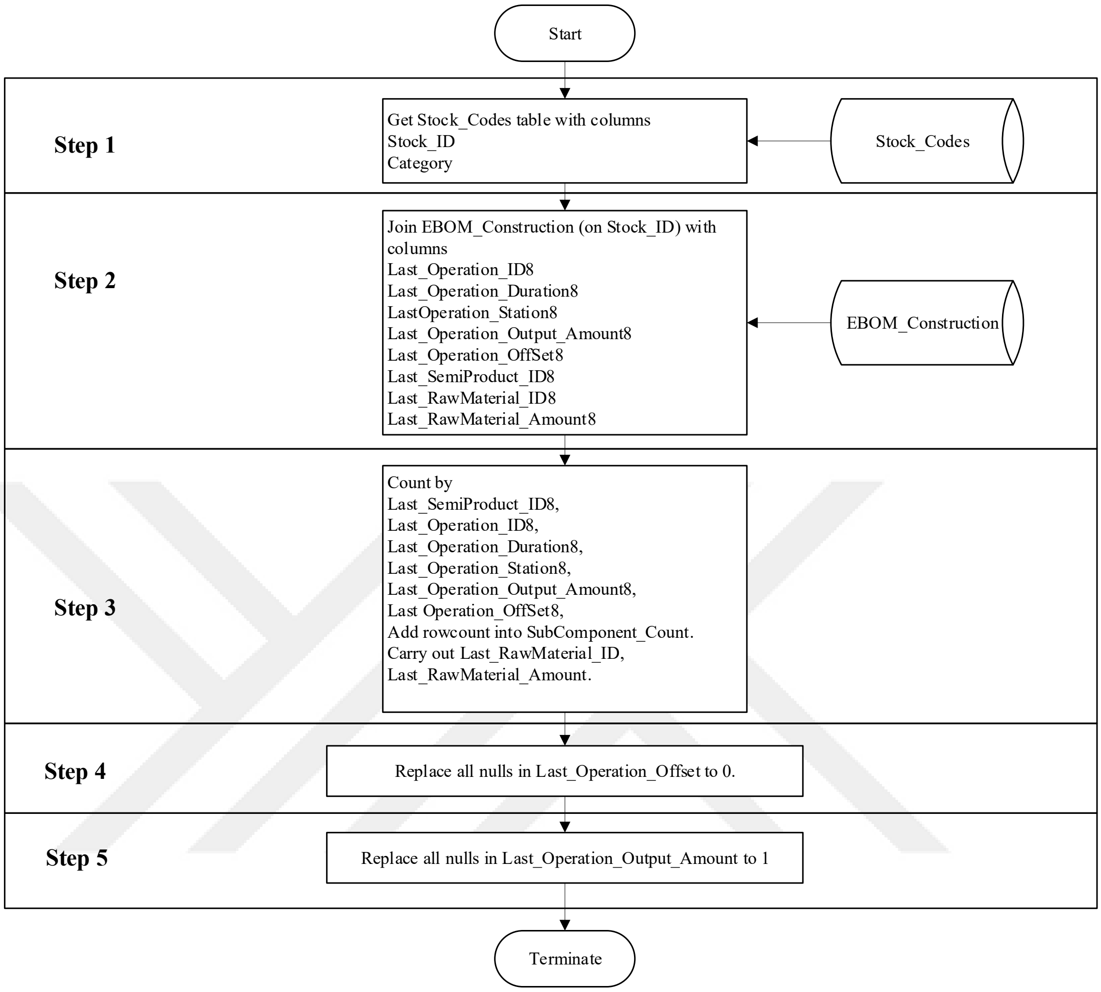

Figure 12. Flow Chart for EBOM Table.

5.3.6 Steps of the EBOM table

Step 1. Prepare the Stock_Codes and EBOM_Construction tables.

Step 2. Join Stock_Codes table with EBOM_Construction table on Stock_ID. (Left-outer Join) and expand the EBOM_Construction table considering only the final carried columns.

Step 3. Count the number of rows that have same Stock_ID, Stock_Definition, Category, Last_SemiProduct_ID, Last_Operation_ID, Last_Operation_Duration, Last_Operation_Station, Last_Operation_Output, Last_Operation_Offset values and place it in SubComponent_Count column. This step is provided in order to prevent duplicate operation duration calculations in the future procedures.

Step 4. Change all nulls in Last_Operation_OffSet column to 0.

Step 5. Change all nulls in Last_Operation_Output column to 1.

The important point in the procedure is that there may be more than one raw material in a single semi-product that is combined with the same operation in order to produce that semi-product, the operation duration. Therefore, the capacity requirement duplicates itself. By counting the raw materials in the operation, this duplicity is discarded in the future calculations.

5.3.7 Extraction from Order Table

Order table contains the customer orders with the Product_ID, Order_Amount Shipment_Date and Customer_Code of the respective orders. This table is then joined to EBOM table to provide a bulky table that contains every raw material and operations required to fulfill the demands. The output table then can be transformed into reports containing information each respective material and operation. The flow chart of the procedure is given in Figure 13 and its steps are described in the following subsection.

5.3.8 Steps for Extraction from Order Table

Step 1. Prepare the Stock_Codes, Order_Table and EBOM_Table tables.

Step 2. Join Order_Table with EBOM_Table on Stock_ID. (Left-outer Join) and expand the EBOM_Table.

Step 3. Join Order_Table with Stock_Codes table on Last_SemiProduct_ID. (Left-outer Join) and expand the Stock_Codes table.

Step 4. Join Order_Table with Stock_Codes table on Last_RawMaterial_ID. (Left-outer Join) and expand the Stock_Codes table.

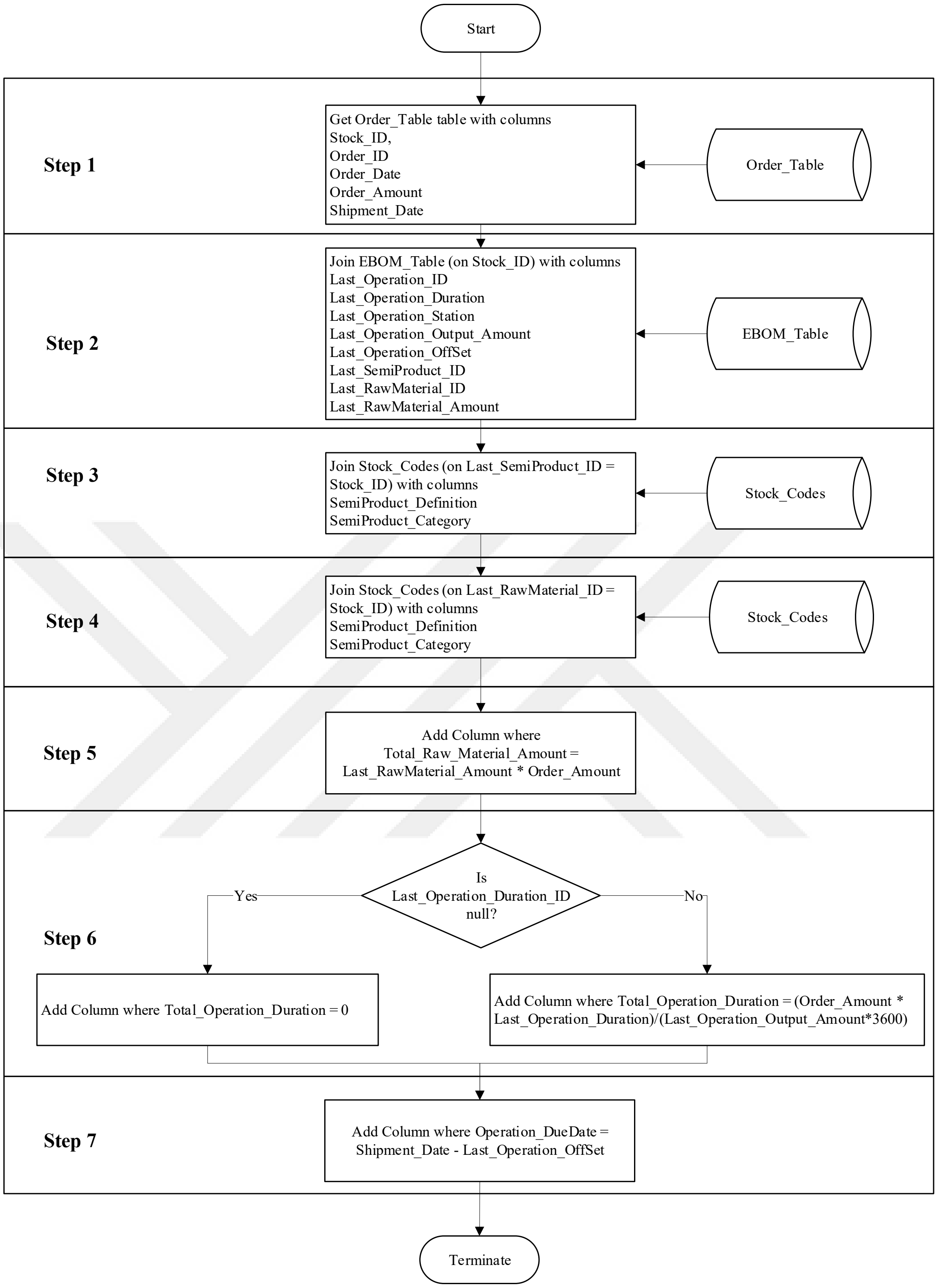

Figure 13. Flow Chart for Extraction Procedure

Step 5. Multiply the Last_RawMaterial_Amount with Order_Amount for each row and carry it to Total_RawMaterial_Amount.

Step 6. Check if the Last_Operation_Duration is null, if true, place 0, else multiply the Last_Operation_Duration with Order_Amount, divide the result by multiplication of Last_Operation_Output and SubComponent_Count. Divide the overall result by 3600 to transform it into operation hours. Place this calculation into Total_Operation_Duration.

Step 7. Subtract Last_Operation_OffSet from the Shipment_Date and carry it into Operation_DueDate.

The output table contains information of each raw material and operation together with the categories and supplier information for raw materials and operation stations for operations. This table concludes the requirement extraction process. Evaluation and parameters effecting the computation time for this process is described in Chapter 7.

5.4 Obtaining Information from Extracted Requirements

RequirementExtraction table contains the data of both material and capacity requirements. However, in this state, the table is raw and it has to be transformed into reports to display viable planning information. The reports are separated into two main groups. The first one, resource group, deals with material side of the requirements. The second one, operation group, deals with capacity requirements.

General reporting format depends on the pivoting of the information in the RequirementExtraction table. This pivoting can be applied through databases creating different pivot views from the table or as used in this thesis. Microsoft Power Pivot tool enables the user to join information from different tables while pivoting an existing table. Also, Microsoft Excel Pivot can be used to pivot data only using requirement extraction table.

In Resource Group, pivoting based on the raw materials. Using filters on RawMaterial_Category is important to view only the respective categories in the pivot table. In order to view daily requirements, the pivot columns are set to already offset Operation_DueDate, and this date data can be further be grouped to view backlogged, weekly, or even monthly requirements of that material. The supplier information can also be used to group required materials into supplier depended categories.

Since the table contains information for which semi-product and product that raw material is to be used, combination of an inventory table upon these inventory codes and raw material displays the actual need of the raw material.

Similarly, in operation group, the pivot can be based on Last_Operation_Station and Operation_DueDate. By this way, daily capacity requirements of a certain station (or station group) can be viewed and managerial parameters such as overtime shift can be decided. Operation Reports are further exploited in the scheduling model.

5.5 Scheduling Methodology

The scheduling methodology is a derivation of operation related reports according to the dispatching rules given in Table 1. With the operation requirements extracted from the customer orders, the planner can filter each operation or operation station from the operational pivot reports in order to schedule the operation station. By using predefined sorts among these reports, it reveals alternative schedules according to DRs. Each DR may require different attribute and these attributes can be calculated by using simple GROUP BY queries or if statements. Add column requirement for some of DRs is given in Table 7.

As an example, when the planner tries to plan 90 Ton injection machines, he needs to filter 90 as the last operation station and filter Mold as the last raw material from the extraction table. From this state, the planner can choose to use EDD and SPT as DR. For these DRs, the extraction table needs to be grouped by Last_RawMaterial_ID, and adding columns Earliest_DueDate = min (Operation_DueDate) and Shortest_Process_Time = min(Total_Operation_Duration).

Table 7. Add Column Requirements for DRs.

DR	Group By	Add Column Requirement
SIRO	None	RandomNumber = Number.Random
ERD	All but Raw Material Related and Order Related.	Earsliest_Release_Date = min(Order_Date)
EDD	All but Raw Material Related and Order Related.	Earliest_Due_Date = min(Operation_DueDate)
MS	All but Raw Material Related and Order Related.	Minimum_Slack = (Operation_DueDate-Total_Operation_Duration-Date.date)
SPT	All but Raw Material Related and Order Related.	Shortest_Processing_Time = min(Operation_Duration)
WSPT	All but Raw Material Related and Order Related.	WShortest_Processing_Time = min(Total_Operation_Duration)*Operation_Weight*
LPT	All but Raw Material Related and Order Related.	Longest_Processing_Time = max(Operation_Duration)
LFJ	All but Raw Material Related and Order Related.	Least_Flexible = min (Shipment_Date-Operation_DueDate-Total_Operation_Duration)

The sorting query requires sort by Earliest_DueDate (from earliest to latest) then sort by Shortest_Process_Time (from smallest to biggest) and then sort by Last_RawMaterial_ID. This sort query gives the planner the sorted list of all semi-product requirements with its last operation station as 90 tons and with earliest due date and shortest process time on the top. From this list, the planner picks the requirements to be satisfied and allocates them in the schedule. The output table of the report is given in the Table 8.

Up to this point inventories are not mentioned; however, it is a very important aspect in the planning of the production batches. Joining an inventory table together with the extraction table where Stock_ID, Last_SemiProduct_ID and RawMaterial_ID with inventory_id (from the inventory table) provides information about the inventory amounts of the related stock code. Since the planner is able to see the inventory amounts of the product, semi-product and raw material, during scheduling, he will be able to define production batches more accurately. Besides, in planning of the assembly processes, the planner will be able to realize the readiness of the raw materials and build the schedule accordingly. Table 9 gives an example to an assembly operation report with inventory amounts for semi product and raw material added from the plastic injection company chosen for the case study.

Table 8. Output of Scheduling Example

ORDERNO	ORDERCODE	ORDERAMOUNT	ORDERDATE	SHIPMENTDATE	Last_RawMaterial_	Last_RawMaterial_Def	Last_RawMaterial_Ca	Total_RawMaterial_Amou	Total_Operation_Duration	Operation_DueDat	Earliest_DueDate	Shortest_Process_Time
B29091742154513	VBZ42154513	36000	17.09.2019	17.09.2019	VBZ99609963	HAR.RAF/DUBELI KALIBI	MOLD	4500	18,75	16.09.2019	16.09.2019	3,12
B29092142154513	VBZ42154513	9000	17.09.2019	21.09.2019	VBZ99609963	HAR.RAF/DUBELI KALIBI	MOLD	1125	4,69	20.09.2019	16.09.2019	3,12
B29092542154513	VBZ42154513	12000	17.09.2019	25.09.2019	VBZ99609963	HAR.RAF/DUBELI KALIBI	MOLD	1500	6,25	24.09.2019	16.09.2019	3,12
B29092842154513	VBZ42154513	21000	17.09.2019	28.09.2019	VBZ99609963	HAR.RAF/DUBELI KALIBI	MOLD	2625	10,94	27.09.2019	16.09.2019	3,12
B29100242154513	VBZ42154513	48000	17.09.2019	2.10.2019	VBZ99609963	HAR.RAF/DUBELI KALIBI	MOLD	6000	25	1.10.2019	16.09.2019	3,12
B29100542154513	VBZ42154513	30000	17.09.2019	5.10.2019	VBZ99609963	HAR.RAF/DUBELI KALIBI	MOLD	3750	15,62	4.10.2019	16.09.2019	3,12
B29101042154513	VBZ42154513	24000	17.09.2019	10.10.2019	VBZ99609963	HAR.RAF/DUBELI KALIBI	MOLD	3000	12,5	9.10.2019	16.09.2019	3,12
B29101442154513	VBZ42154513	24000	17.09.2019	14.10.2019	VBZ99609963	HAR.RAF/DUBELI KALIBI	MOLD	3000	12,5	13.10.2019	16.09.2019	3,12
B29101942154513	VBZ42154513	6000	17.09.2019	19.10.2019	VBZ99609963	HAR.RAF/DUBELI KALIBI	MOLD	750	3,12	18.10.2019	16.09.2019	3,12
B19091842163050	VBZ42163050	2000	17.09.2019	18.09.2019	VBZ99600737	DOD AYAK ANKASTRE KALIBI	MOLD	500	2,08	17.09.2019	17.09.2019	2,08
B19092342163050	VBZ42163050	2000	17.09.2019	23.09.2019	VBZ99600737	DOD AYAK ANKASTRE KALIBI	MOLD	500	2,08	22.09.2019	17.09.2019	2,08
B19092742163050	VBZ42163050	2000	17.09.2019	27.09.2019	VBZ99600737	DOD AYAK ANKASTRE KALIBI	MOLD	500	2,08	26.09.2019	17.09.2019	2,08
B19100442163050	VBZ42163050	2000	17.09.2019	4.10.2019	VBZ99600737	DOD AYAK ANKASTRE KALIBI	MOLD	500	2,08	3.10.2019	17.09.2019	2,08
B19101042163050	VBZ42163050	2000	17.09.2019	10.10.2019	VBZ99600737	DOD AYAK ANKASTRE KALIBI	MOLD	500	2,08	9.10.2019	17.09.2019	2,08
B19101642163050	VBZ42163050	2000	17.09.2019	16.10.2019	VBZ99600737	DOD AYAK ANKASTRE KALIBI	MOLD	500	2,08	15.10.2019	17.09.2019	2,08
B19102442163050	VBZ42163050	2000	17.09.2019	24.10.2019	VBZ99600737	DOD AYAK ANKASTRE KALIBI	MOLD	500	2,08	23.10.2019	17.09.2019	2,08
B29091842033244	VBZ42033244	45000	17.09.2019	18.09.2019	VBZ99600341	SOG.HAVA KANAL TAPASI/640 KALIBI	MOLD	2812,5	3,91	17.09.2019	17.09.2019	3,47
B29092342033244	VBZ42033244	40000	17.09.2019	23.09.2019	VBZ99600341	SOG.HAVA KANAL TAPASI/640 KALIBI	MOLD	2500	3,47	22.09.2019	17.09.2019	3,47
B29093042033244	VBZ42033244	75000	17.09.2019	30.09.2019	VBZ99600341	SOG.HAVA KANAL TAPASI/640 KALIBI	MOLD	4687,5	6,51	29.09.2019	17.09.2019	3,47
B29100742033244	VBZ42033244	70000	17.09.2019	7.10.2019	VBZ99600341	SOG.HAVA KANAL TAPASI/640 KALIBI	MOLD	4375	6,08	6.10.2019	17.09.2019	3,47
B29101442033244	VBZ42033244	60000	17.09.2019	14.10.2019	VBZ99600341	SOG.HAVA KANAL TAPASI/640 KALIBI	MOLD	3750	5,21	13.10.2019	17.09.2019	3,47
MT90920SQ25N025	MTSSQ25N025G01	1250	17.09.2019	20.09.2019	MTSKSQ25N025K	V_SHAFT_T_FIX493T KALIBI	MOLD	625	1,74	19.09.2019	19.09.2019	0,62
MT90923SQ25N025	MTSSQ25N025G01	1900	17.09.2019	23.09.2019	MTSKSQ25N025K	V_SHAFT_T_FIX493T KALIBI	MOLD	950	2,64	22.09.2019	19.09.2019	0,62
MT90930SQ25N025	MTSSQ25N025G01	2100	17.09.2019	30.09.2019	MTSKSQ25N025K	V_SHAFT_T_FIX493T KALIBI	MOLD	1050	2,92	29.09.2019	19.09.2019	0,62
MT91010SQ25N025	MTSSQ25N025G01	2400	17.09.2019	10.10.2019	MTSKSQ25N025K	V_SHAFT_T_FIX493T KALIBI	MOLD	1200	3,33	9.10.2019	19.09.2019	0,62
MT91011SQ25N025	MTSSQ25N025G01	450	17.09.2019	11.10.2019	MTSKSQ25N025K	V_SHAFT_T_FIX493T KALIBI	MOLD	225	0,62	10.10.2019	19.09.2019	0,62
MT91017SQ25N025	MTSSQ25N025G01	2400	17.09.2019	17.10.2019	MTSKSQ25N025K	V_SHAFT_T_FIX493T KALIBI	MOLD	1200	3,33	16.10.2019	19.09.2019	0,62
MT91018SQ25N025	MTSSQ25N025G01	2400	17.09.2019	18.10.2019	MTSKSQ25N025K	V_SHAFT_T_FIX493T KALIBI	MOLD	1200	3,33	17.10.2019	19.09.2019	0,62
00000EN10006964	VBZ42195530	5000	17.09.2019	20.09.2019	VBZ99613438	KAPI KOLU VMOVE PLS ENJ ITICI DIL KALIB	MOLD	1250	4,34	19.09.2019	19.09.2019	4,34
00000EN10007082	VBZ42195530	5000	17.09.2019	20.09.2019	VBZ99613438	KAPI KOLU VMOVE PLS ENJ ITICI DIL KALIB	MOLD	1250	4,34	19.09.2019	19.09.2019	4,34

Table 9. Assembly Operations Report with Inventory Added

Yam Op	(Birden Çok Öğe	VBZ	VKF	VCM	MTS	VBM	VEH	VCK	VFR
Sipariş	0	285511	285559	285591	285589	285579	285545	285543	285402
siptür	(Birden Çok Öğe								

Toplam Ham Top Mik							TarihGrup								StockRaw	Stock Semi
Fab	Stok Kodu	Stok Adı	Yam Kodu	Yam Adı	Ham Kodu	Ham Adı	Backlog	23.09.2019	24.09.2019	25.09.2019	26.09.2019	27.09.2019	28.09.2019	> 30.09.2019		
VBM	VBM42052033	UST SEPET TEKER GR-2-RAL 7046	VBM42052033	UST SEPET TEKER GR-2-RAL 7046	VBM42021072	UST SEPET TEKERLEKLERI-RAL 7046	36000	36000	36000	36000	36000	3[illegible]	27.09.2019 (TarihGrup)		55000	216000
VBM	VBM42052033	UST SEPET TEKER GR-2-RAL 7046	VBM42052033	UST SEPET TEKER GR-2-RAL 7046	VBM42051585	SEPET TEKER TUT.PARÇA-2-RAL 7046	36000	36000	36000	36000	36000	3[illegible]	Sütun: 27.09.2019		238320	216000
VBM	VBM42052035	ALT SEPET TEKER GR-2-RAL 7046	VBM42052035	ALT SEPET TEKER GR-2-RAL 7046	VBM42051585	SEPET TEKER TUT.PARÇA-2-RAL 7046	72000	24000	24000	48000	48000	24000	48000		238320	312000
VBM	VBM42052035	ALT SEPET TEKER GR-2-RAL 7046	VBM42052035	ALT SEPET TEKER GR-2-RAL 7046	VBM42021029	ALT SEPET TEKERLEKLERI-RAL 7046	72000	24000	24000	48000	48000	24000	48000		300100	312000
VBM	VBM42053228	ALT SEPET TEKER GR/45 RAL-7046	VBM42053228	ALT SEPET TEKER GR/45 RAL-7046	VBM42051585	SEPET TEKER TUT.PARÇA-2-RAL 7046	19000	7000							238320	94000
VBM	VBM42053228	ALT SEPET TEKER GR/45 RAL-7046	VBM42053228	ALT SEPET TEKER GR/45 RAL-7046	VBM42053229	ALT SEPET TEKERLEKLERI/45 RAL 7046	19000	7000							0	94000
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121378	KP SRGF/GRAM/CT11(DS 6401-60)	VBM42058763	GSV-1/CLAROS								324	172	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121378	KP SRGF/GRAM/CT11(DS 6401-60)	VBM42058778	ISIK TASIYICI-2(YIKAMA AD.)/CLAROS								324	5630	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121378	KP SRGF/GRAM/CT11(DS 6401-60)	VBM42062961	ISIK TASIYICI-1/2(PROGRAM)/CLAROS								648	1200	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121378	KP SRGF/GRAM/CT11(DS 6401-60)	VBM42063701	LED PERDESI-1/CLAROS								648	3350	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121378	KP SRGF/GRAM/CT11(DS 6401-60)	VBM42063702	LED PERDESI-2/CLAROS								324	36985	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121378	KP SRGF/GRAM/CT11(DS 6401-60)	VBM47010820	AL FOLYO-24								324	6500	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121378	KP SRGF/GRAM/CT11(DS 6401-60)	VBM47011423	YENI AL FOLYO-7								648	7020	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121378	KP SRGF/GRAM/CT11(DS 6401-60)	VBM42119866	ON/OFF BUTONU/CLAROS/SRGF(GRAM)								324	0	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121378	KP SRGF/GRAM/CT11(DS 6401-60)	VBM42123194	KP BSK/GRAM/CT11(DS 6401-60)								324	0	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42058762	TUTAMAK/CLAROS								324	985	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42058775	BUTON SHAFTI(SEFFAF)/CLAROS								324	0	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42058776	BUTON SHAFTI(BASLA-BEKLE)/CLAROS								324	0	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42174472	PROGRAM KART KUTUSU/YH-T SERISI								324	3025	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121378	KP SRGF/GRAM/CT11(DS 6401-60)								324	0	0
VBM	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121379	KPG SRGF/GRAM/CT11(DS 6401-60)	VBM42121380	PROGRAM BUTON-1/CLAROS/SRGF(GRAM)								324	0	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++	VBM42058778	ISIK TASIYICI-2(YIKAMA AD.)/CLAROS								162	5630	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++	VBM42058780	DISPLAY CAMI-1/CLAROS								162	0	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++	VBM42062961	ISIK TASIYICI-1/2(PROGRAM)/CLAROS								486	1200	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++	VBM42063701	LED PERDESI-1/CLAROS								486	3350	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++	VBM42063702	LED PERDESI-2/CLAROS								162	36985	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++	VBM42065981	ON/OFF BUTONU/CLAROS/DS BYL								162	681	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++	VBM47010820	AL FOLYO-24								162	6500	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++	VBM47011423	YENI AL FOLYO-7								324	7020	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++	VBM42065779	GSV-2/CLAROS/DS BYL								162	681	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++	VBM42188712	KP BSK/FRANKE/CT13(FDWF 612 XS A++)								162	0	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A+	VBM42058775	BUTON SHAFTI(SEFFAF)/CLAROS								486	0	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A+	VBM42058776	BUTON SHAFTI(BASLA-BEKLE)/CLAROS								162	0	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A+	VBM42082734	PROGRAM BUTON-1/CLAROS/DS BYL								162	4244	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A+	VBM42084215	TUTAMAK/CLAROS/SIYAH								162	411	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A+	VBM42174472	PROGRAM KART KUTUSU/YH-T SERISI								162	3025	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A+	VBM42065976	OPSIYON BUTON-1/CLAROS/DS BYL								162	440	0
VBM	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A++)	VBM42188715	KPG SRGF/FRANKE/CT13(FDWF 612 XS A+	VBM42188714	KP SRGF/FRANKE/CT13(FDWF 612 XS A++)								162	0	0
VBM	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM32004312	ROTARY SWITCH								72	3456	0
VBM	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM37006201	VIDA PT3,5X9YSB(F.LI VE T.LI)								216	20000	0
VBM	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM42143326	PCB KUTUSU-C1X GOVDE 3 LEDLI								72	7200	0
VBM	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM42021304	ELEKTRONIK BUTON SHAFTI-1/SILVA								72	7836	0
VBM	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM42021305	ELEKTRONIK BUTON SHAFTI-2/SILVA								72	3800	0
VBM	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM42151296	KPG SRGF/HELKAMA/SLX13(HAP4504)	VBM42021306	ISIK TASIYICI-1/SILVA								72	4150	0

5.6 Concluding Remarks

This chapter explains the proposed requirement extraction methodology to have an enhanced MRP execution module. It consists of EBOM construction procedure and extraction information procedure from the order table. Also, obtaining information from extraction resources is explained at length and the proposed module is integrated with the scheduling methodology. By using the pivoting abilities of MS Excel, and MS Power Pivot, the information obtained from the requirement extraction table can be reported in different alternative ways. Next chapter describes the application of the proposed approach on the plastic injection company that is selected as a representative flexible jo-shop company to have high mix product portfolios, varying BOM structures and demand profiles.

CHAPTER 6: A CASE STUDY ON PLASTIC INJECTION FACTORY PLANNING

6.1 Introduction

The production plant taken as a case study for this study is a plastic injection production plant that is a one of the largest plastic part subcontractors of global household appliances and electronics companies in Manisa, Turkey. The customers have different product groups and process requirements together with different ordering habits and ordering frequencies.

This chapters starts by introducing the production processes of the company in Section 6.2 and the demand characteristics of the customers of the company are given in Section 6.3. Section 6.4 provides information about the planning processes conducted within the company. After introducing these processes, the application of the proposed approach in the company is explained in Section 6.5. The results of this application are represented in Section 6.6. Concluding remarks and managerial evaluation of the application are given in Section 6.7.

6.2 Production Processes

The case study company has 63 injection machines with different clamping forces, 5 silk printing lines, 2 hot-stamp stations, 1 stamp print machine, 3 assembly lines, 8 assembly cells, and 1 manual painting line that is utilized in the production processes of different types of products. Factory is operated with over 500 workers in three-eight hours shifts and is operational 6 days a week throughout the year. It can be categorized as a middle-sized company with flexible job-shop production type (Pinedo, 2008, p.15). The following subsections provide detailed information about production processes and customer demand characteristics of the company.

There are four main processes in this production environment. These are: plastic injection process, painting process, printing process and assembly process. These processes are defined and required by the type of the product produced. Each of these processes is commonly interconnected with each other and they need to be planned separately for different work stations.

6.2.1 Plastic Injection Process

Even though the most basic of all processes is plastic injection, it is complicated by the number of machines and molds. The input of this process is granulized plastic raw material that is procured from the suppliers. This raw material is then injected into plastic injection molds within the plastic injection machine, and it produces plastic part that is either shipped directly to the customers or stocked for further processes.

Main loses of the factory occur in this process. The quality of the products directly affects the succeeding processes. In addition, the company uses over 800 different molds, allocates them on 63 machines, and different types and colors of raw materials (6 different types and 16 different colors total) cause one to eight hours of setup times during changeovers.

The process requires one operator for each machine during production, but during changeovers, a group consisting of four technicians is needed (one raw material technician to prepare and provides raw material for the next production, one mold technician to change the mold, one master technician to apply different machine setups and one quality technician to check the setup and approve the eligibility of the part produced).

The interconnections among machines, molds, raw materials and workers are predefined. Each mold has some predefined parameters that allocate specific machine group and raw materials.

6.2.2 Painting Process

After the injection, some parts are needed to be painted in order to be ready for the shipment or further process. This process is commonly subcontracted to other companies, or can be carried out with the company's manual painting line, or subcontracted to other companies. The painted parts are either shipped to customers or stocked for further process. The painting line of the company is processed with three operators.

6.2.3 Printing Process

The main customization of the products occurs in this process. Printing operation is done using either silk printing lines (for products that require more than one print on them), hot-stamp stations or stamp print machine. Although hot-stamp stations and stamp print machine requires one operator each, silk print lines require at least three operators up to eight operators according to the complexity of the printing process. Between the production runs of different products, a setup is required but it can be neglected.

This process can be applied on a plain plastic injection part, painted part or even printed plastics. Since it is the main customization future of the products, most of the time the process is defined directly by orders, and no extra inventory is intended to be created.

6.2.4 Assembly Process

The final process of the product is assembly process. The inputs may be injected parts, painted parts, printed parts, pre-assembled parts and procured parts, and these inputs are assembled through different subprocesses. The complexity of this process is due to the amount of inputs, and readiness of these inputs mainly defines the ability to initialize the production run. The changeover losses are negligible during this process.

While the operator requirement for most of the assembly cells is only one, the assembly lines require minimum of five operators up to nine operators to function. Since this process uses mostly customized parts, and the output products are further customized during process, they are shipped directly to the customer and no extra stock is intended to be created.

Overall, the main flow of the processes is given in the Figure 14. From this flow chart, it is easy to see that plastic injection process is the fundamental production of the company and other processes need the products of plastic injection in order to process.

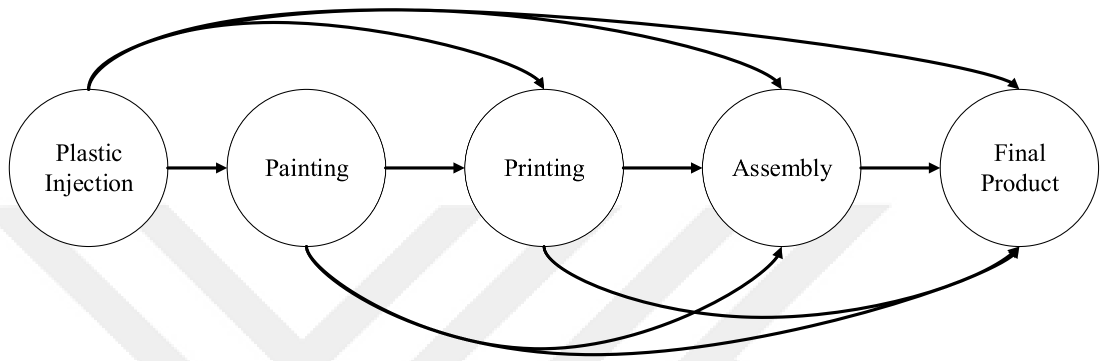

Figure 14. Process Flow Chart of Example Company

6.3 Customer Demands

Each customer demand has different types of products from the subcontractor. In addition, their order acceptance policies are different. There are two types of order acceptance policies among the customers: Kanban (KNB) and Direct Shipment (DS).

As the name implies, Kanban (KNB) acceptance requires subcontractor to follow the customer's production lines and ships the products according to their customer line entry times. Therefore, any delays or line entry changes in the customer production lines define the quantity and delivery date of the products. These entry dates could be accepted as orders and entered into subcontractor's planning system. However, the changes in the customer's own production plans should be observed closely not to cause starvation of the lines. Most of the customers only accepts products within two days of line entry time. Late products are accepted with penalties because of the loses in the customer's lines.

On the other hand, Direct Shipment (DS) orders are defined by the customers. Their quantity and/or delivery dates are again changeable according to customer's plans. In this method, subcontractor receives a daily order list from the customers and allowed to ship products within two days of the actual order due date. More detailed information about customers' demands of the company of interest is given in the Table 10. The company receives over 2,500-part orders daily, for 750 products on scope of seven days to a month, and these orders can be changed according to production plans.

In Table 10, 'order horizon' refers to the days between the latest visible order date and the current date. For example, as for the refrigerator factory, product ordered for the following month can be visible, whereas, with regard to the washing machine factory, only the orders within a week are visible. 'Number of orders in the order list' refers to number of orders with different products and different dates. Therefore, for example, when a product is ordered for five consecutive dates, it is considered as five different orders. 'Average order quantity' is the average lot size for every order in the order list. 'Number of different products in the list' refers to the number of different products (regardless of date) in the order list. For example, drying machine factory places orders for 15 different products and these products are planned to be used in 95 different production in the following 7 days.

Therefore, in overall, the company of interest has to process more than 3500 orders daily for more than 750 products. The company has an ERP system that is used for financial and accounting matters, however, did not utilize MRP. Most of the planning and scheduling work is performed through spreadsheets and almost completely dependent on human interaction. Having with 5 planners and 4 more expeditors, the company has a crisis, spending from 1 to 3 percent of its monthly revenue on penalties inserted by the customer leads only 83% on-time shipment rate. The company did not invest on an APS and is not able to define neither each BOM nor each operation recipe of the demanded products into the system.

Table 10. Customer Demand Details

Customer	Shipment Acceptance Policy		Final Operation of Ordered Product				Order List Horizon	# of Orders in the Order List	Average Order Quantity	# of Different Products in the List
	KNB	DS	PI	PA	PR	AS	(days)	(#)	(#)	(#)
Refrigerator Factory	x	x	x	x	x	x	45	2300	850	450
Washing Machine Factory	x			x	x	x	7	450	250	160
Air Conditioner Factory	x		x	x		x	15	75	800	15
Dishwasher Factory	x	x		x	x	x	30	150	4000	80
Drying Machine Factory	x	x	x	x	x	x	7	95	180	15
Oven Factory		x	x				30	9	600	1
Electronics Factory		x	x				30	30	1600	6
Air Conditioner (2) Factory		x	x			x	30	600	2500	26

KNB: Kanban Orders

DS: Direct Shipment Orders

PI: Plastic Injection Part

PA: Painted Part

PR: Printed Part

AS: Assembled Part

6.4 Planning System Phases in The Case Study Company

Similar to other flexible job shop companies, the case study company follows similar phases to plan its production. Although each phase is executed separately, they are crucially interconnected and have to be handled together with other parts.

Main flow of planning phases is given in Figure 15. Although these phases can ideally all be automatically processed with an integrated planning system, company of interest depends solely on the daily routines of its employees based on spreadsheets. Each planning phase is explained in the following subsections.

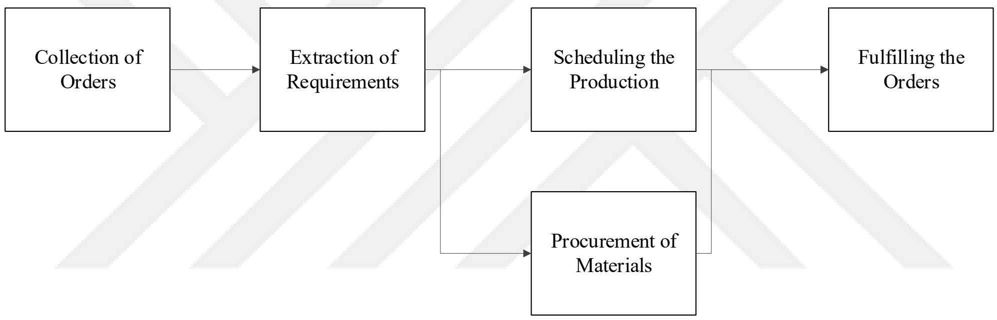

Figure 15. Planning System Phases

6.4.1 Collection of Orders

Customer orders or demands are the main inputs for this phase. Although it may seem simple, most of the planning systems requires a reference point to further process the orders. In reality, these orders can be collected in different times and with uncertainties of due dates and order sizes require a more complex handling for the system.

This phase requires the knowledge of customer, product, quantity and due date. Ideally, this data should be inserted into the system each time the order is received. In addition, the customers do not always provide a reference order number, so the system should define a reference number in order to follow the order in further stages.

In most of the MRP based production planning systems, these orders are directly fed to the system in particular time. The chosen time is usually weekends or 'sleeping hours' when the company transactions are at the minimum. In addition, last-minute or late orders cannot be included in the system and are processed until the next initialization of MRP. Since the company does not execute MRP, the orders are collected by the planners or expeditors, and further processes are carried out in separate spreadsheets without any integration.

Simple workflow of this phase is given in Figure 16. Although it is a simple process, customers tend to send their orders in different formats and their ordering times may be different. To progress these orders, similar to most of the companies, the company of interest use MS Excel macros to convert them into standard format.

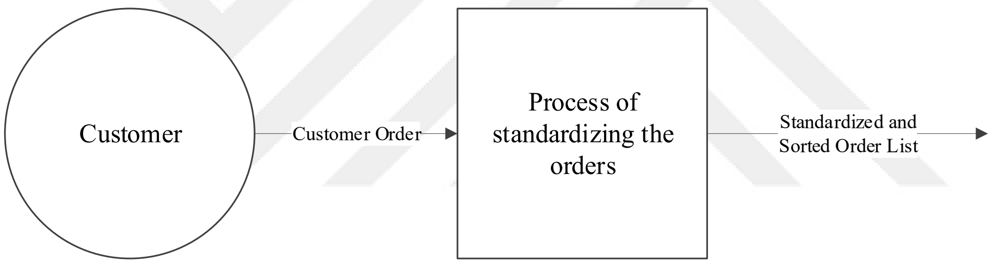

Figure 16. Collection of Orders Flow

6.4.2 Extraction of Requirements

As the orders are fed to the system, the requirement extraction process begins. The utilization of MRP systems starts here. The orders are transformed into procurement orders and work orders by using BOM and operation recipes. This transformation takes several hours according to levels of the BOM and during this time, MRP system does not allow any stock, production and order transactions into the system. This is the reason why companies using MRP choose to utilize it during 'sleeping hours'. If the company does not use MRP, it is a very complex and confusing process and most of the errors are done in this phase. Because the companies are unable to extract full lists of requirements, they are unable to see the accumulation of the requirements in wide range, and they are prone to inefficiencies in the scheduling phase.

Levels in the BOMs or operation recipes are very important in this section. Because most of the companies uses multi-level BOMs and/or operation recipes, alternating this level through manual calculations is very hard. The companies that do not use MRP systems usually spend hundreds of hours each month in this phase in order to extract their required material lists.

Lists of procurement orders and work orders are the outputs of this phase. After these lists are prepared, they are passed on to the next phase in order to be processed and scheduled. Another important input here is the inventory of procurement items and produced subcomponents. MRP systems tend to evaluate these inventories according to due date of the orders, however because the system is blind to work in process items, it is unable to produce correct requirements. The process flow of this phase is given in Figure 17.

The company subject to this case study does not utilize MRP. Instead, the BOMs are carried in between the spreadsheets and planners manually try to define both the material and operation requirements of the gathered orders. With the amount of customer orders, this particular process takes at least 5 hours daily for a single customer. Since each planner handles one to two customers, overtime becomes obvious. In addition, the process is carried out completely and manually, and it increases the human faults. This results in inaccurate requirement calculations and increasing shipment costs due to emergency situations.

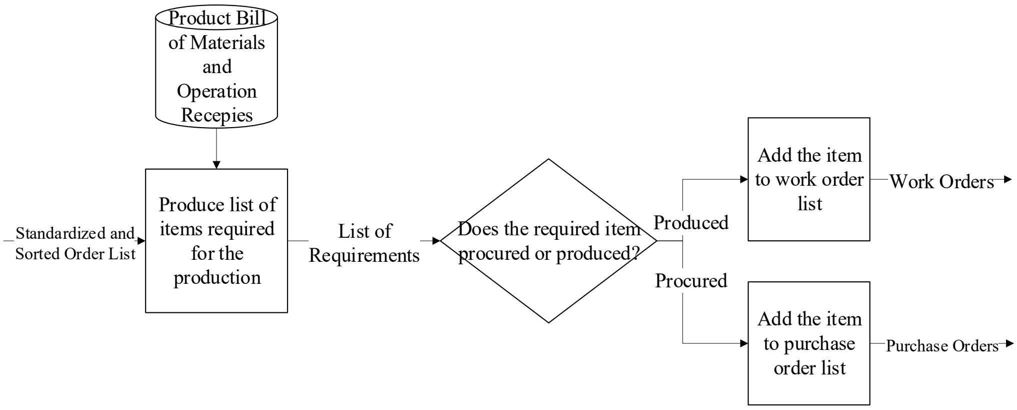

Figure 17. Extraction of Requirement Flow

6.4.3 Procurement of Materials

Once the required materials for production is listed, they can be directly ordered from the suppliers. Knowledge of minimum inventory levels and order sizes are required to manage the inventory costs efficiently. The changes in customer orders needs to be applied to procurement order changes rapidly in order not to starve the production. Most of the MRP systems directs the output to the suppliers automatically, but due to the reasons mentioned above on WIP materials, human interaction is also required in this phase.

Some of the MRP systems provide a reservation system which causes more problems with rapidly changing of orders. When a new order arrives, and the required materials are already reserved for previous orders, the system does not recognize that the actual requirement can be satisfied with materials in stock. Therefore, the system suggests that order could not be satisfied due to lack of materials although they are in stock.

This phase is also interconnected with scheduling phase because most of the operations require raw materials, that are procured prior to start of the process. Most of the ERP systems provide lead time parameter checks and MRP systems control the lead times of each purchase order before letting the operation to start. Figure 18 displays the flow chart of the phase.

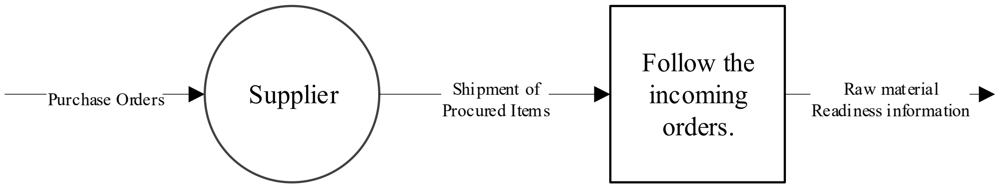

Figure 18. Procurement Process Flow.

In the company, since MRP is not executed and the requirement calculations are completely done by manual spreadsheets, the inventory costs are very high and there is a 12% of unused procured items in the inventory. When investigated further, the main reason is revealed for this loses as lack of time for inventory checks and inefficient procurement planning in the company. Quantity check for incoming orders is not conducted distinctly, therefore excessive amount of procurement items can be accepted and due to lack of procurement order system.

6.4.4 Scheduling the Production

After the work order lists are created, they are needed to be allocated on the workstations on the job floor. This is the most complex phase of the overall planning due to massive number of parameters including workstation types, process times, changeover times, capacity parameters and tooling parameters.

If it is done manually, an individual is unable to process each of these parameters and is bound to make mistakes or inefficient schedules. For simplicity, the companies that are not using advanced scheduling systems tend to narrow down the work orders into shorter lists according to their due dates excluding each work order that is due after few days. Such method prevents the individual to see a wider planning horizon, thus, it creates more changeover and inability to adopt to order changes quickly. Most of the capacity and material loses occur in this stage.

As in the company, expeditors are used to follow production schedules for certain customers. Lack of information in between them usually results in excessive production for one customer while not being able to meet other customers orders. In addition, because the planners are not aware of other customer orders, they are not able to work in harmony for creating an integrated shop floor schedule. This results in starvations at high levels of production which ends up as a penalty or an 'emergency' situation.

On the other hand, if the scheduling is performed automatically by the utilization of an advanced scheduling system, human interaction with the scheduling is minimized. However, such systems are currently beyond the affordable investment limits of the companies, and the parameters needed to be set for such systems are very complex. Among the reviewed companies, only five of them did investment for such a system however, they are unable to use the system due to its complexity and returned to manual planning.

CRP, MPS and MRP-II create an alternative hybrid way for the problems in this phase, but as stated before, the capabilities of these methods are limited to advisory level, and again human interaction and focus is required for efficient scheduling.

General process flow of the production scheduling phase is given in Figure 19. Scheduling of the production highly depends on the procurement of materials phase and information from the shop floor, because without procured materials, the production cannot start, and any delays or shortages in the production are collected to reschedule the production.

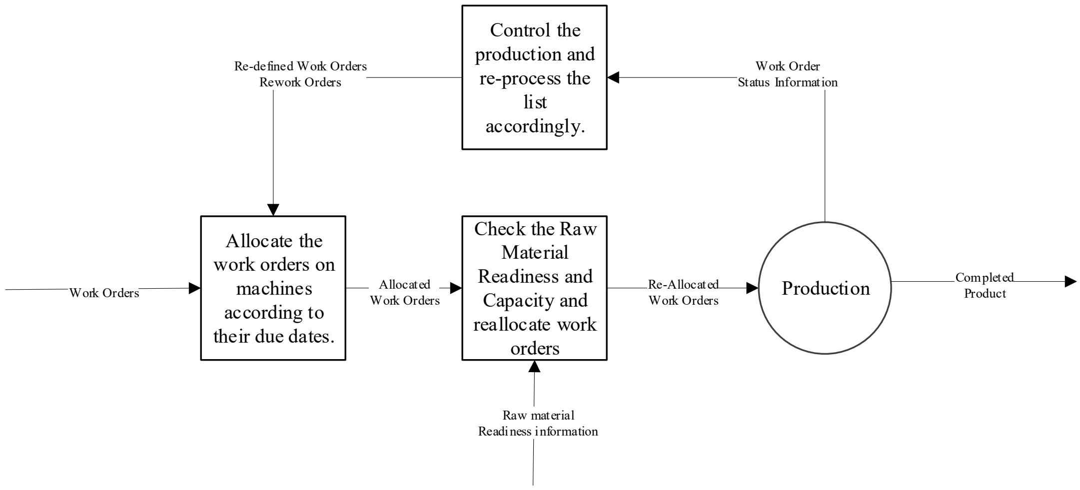

Figure 19. Scheduling the Production Flow.

6.4.5 Fulfilling the Orders

By the previous phases, the orders are received, processed and final products are prepared for shipment. In an integrated system, this phase requires minimal attention because together with work orders and procurement orders, shipment orders are created and processed. One of the main issues of this phase is that although the shipment orders are bound to due dates of the customer orders, there are constraints on how these orders are shipped. Customer can set acceptance dates which defines the slack between the actual shipment date and order due date. Another application is shipment appointments. The customer defines a time for the shipment and orders to be shipped, offsetting the due dates of the orders. The simple process flow of this phase is given in Figure 20.

The company has a trouble in this phase. Since there is a short time in between the completion of the product and shipment, the quality checks cannot be executed properly which results in customer returns for defects and/or late shipment which results in penalties.

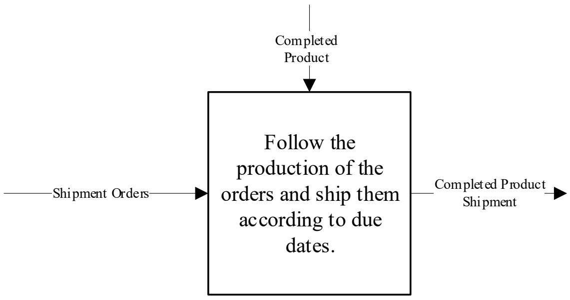

Figure 20. Fulfilling the Orders Flow

6.5 Application of the Proposed Approach in the Case Study Company

Overall flow of the planning processes in the company is given in Figure 21 where the interconnections between the phases are visible. This process flow is similar to framework given by Vollmann et al. (1997) that is introduced in Figure 1. However, in all of the processes, the company completely depends on the manual work, and uses unintegrated spreadsheets. In addition, with the disintegration of expeditor type follow ups, each planner is unaware of other customer demands and productions. This kind of production planning proves inefficient and time consuming. Without any backup plans or backup staff, the company is unable to adopt changes in customer orders and in-company dynamics.

The application of the model in the case study begins in January 2018. With the problems mentioned in the previous chapter, the management embraced a more standardized and scientific methodology for the planning processes. By the end of July

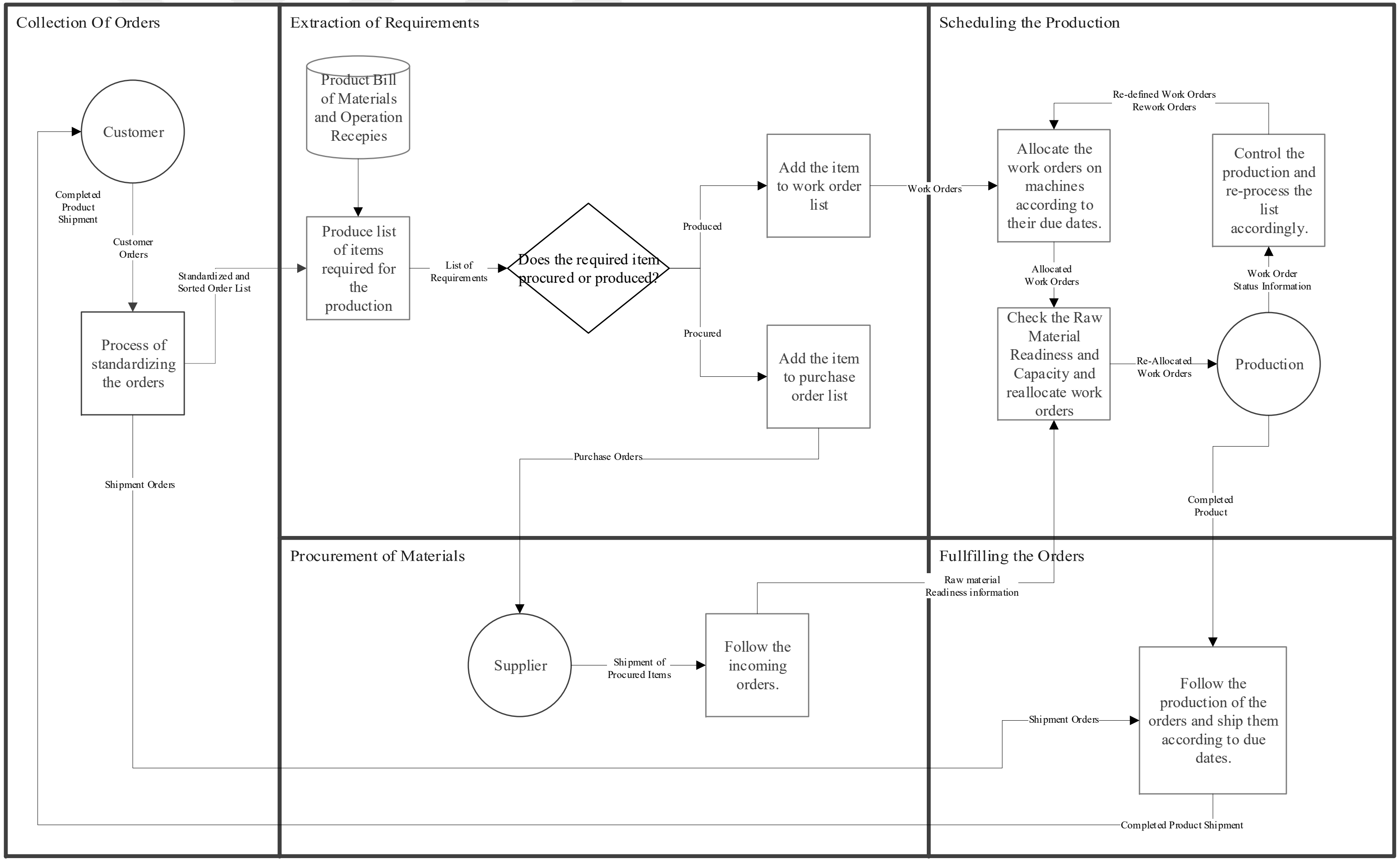

Figure 21. General Flow Chart of Planning Phases

2018, the company fully implements the new model and starts to plan all material and operational requirements with the new methodology.

The application project starts with standardizing the inventory cards BOM. Each inventory card is supplied with respective category (product, raw material, or procured item etc.) and the BOMs of each respective inventory code are revised to reflect correct properties together with Production and Quality departments. In addition, operations of each product type inventory card are revised and standardized.

Second step of the project is to prepare a standardization procedure for the customer orders. As of May 2018, all the orders transferred into ERP system and shipment orders starts to be issued. Also, procurement order system is improved and order acceptance policies are implemented to check each incoming procurement order both for quality and quantity. No forward orders are accepted, and every accepted order is labeled and entered into ERP system.

For the planning crew, distribution of work is revised to impose an integrated system. Expeditors are discarded, and each planner is given a process instead of controlling each process related to a customer. In other words, instead of planning procurement, production, and shipment of a single customer, the planner becomes explicitly responsible from either procurement requirements of all customers, injection production of all customers or assembly lines for all customers. All of the planners are educated for all aspects of the planning, increasing the interchangeability and decreasing the dependency on a single person for a process to be controlled.

After managerial reconstruction is completed, the model is applied. The output reports are grouped into processes and integrated with inventory and shipment tables obtained from the ERP databases. Since the model is a fully integrated system, each of the reports are given as separate pivot tables in single spreadsheet file for compatibility considerations. In the beginning, in order to simplify the reports, all overdue orders are grouped as “Backlog Orders” and all orders due after ten days of the execution of the model is considered as “Long Orders”. These reports are prepared to be automatic and takes less than five minutes to prepare. In addition, some derivative reports are prepared for management. All the prepared reports are given with explanations in the following sections.

Common point in these reports is the ‘Last Shipment ID’ table. This table shows a reference point for each customer that their order lists prepared after this ID. Therefore, the shipments that are have higher number than these IDs can be decreased from the orders.

Another common point is that the inventory table is connected to these tables to display the inventory quantities of each referred to as stock code. Therefore, these quantities can be decreased from the requirements when planning the work orders or purchasing orders.

6.5.1 Injection Requirement Reports

In Injection Requirement Reports, the data is grouped into type of the required machine, mold, injection stock code (or Semi-Product in most of the cases), and finally the Product Code (i.e. Final Product). By this way, cumulative requirements can be obtained by using the feature of the pivot table, and instead of managing each final product, common semi-product can be planned.

The planner is able to observe cumulative requirement of each mold, thus in scheduling phase she or he is able to adapt to changes in the customer orders more easily and decrease the mold changes on a machine to increase the efficiency of the production.

There are two types of reports for injection requirement reports, the first one is the quantitative and the second one is the time relative report. By this way, the planner is able to automatically see the cumulative and exclusive capacities of both molds and machines, therefore, is able to schedule the work orders according to due dates.

Figure 22 and Figure 23 give screenshots for these reports from the application. The columns of the report consist of dates (with a horizon of 10 days including Backlog Orders plus the Long Orders).

Category:	Mold		Ref. Fact.	A/C Fact. (1)	W.H Fact	A/C Fact. (2)	Dish W. Fact	Elect. Fact.	Dry. M. Factr.	Oven Fact.
Operation	PLOP0001	Last Shipment ID	285511	285559	285591	285589	285579	285545	285543	285402

Op. Stat	Mold Code	Mold Name	Semi-Product Code	Semi-Product Name	Final Product Code	Final Product Name	Date Group Backlog	23.09.2019	24.09.2019	25.09.2019	26.09.2019	27.09.2019	28.09.2019	Long Orders	Semi-Product Inventory	Final Product Inventory	Shipment Qty. (From Last Shipment)
90	VBS99600341	SOG.HAVA KANAL TAPASI/640 KALIBI	VBS42033244	SOG.HAVA KANAL TAPASI/640(KAR BY	VBS42033244	SOG.HAVA KANAL TAPASI/640(KAR BYZ)			45000					200000	79720	79720	0
90	VBS99600737	DOD AYAK ANKASTRE KALIBI	VBS42163050	DOD AYAK / ANK(KAR) RV1	VBS42163050	DOD AYAK / ANK(KAR) RV1								8000	860	860	0
90	VBS99602692	SAKLAMA KABI RAY DUBELI/465 KALIBI	VBS42040299	SAKLAMA KABI RAY DUBELI/465	VBS42111078	SEBZ. GR.910-SAG(SEF,WH-GRI)				172	848	656	336	4096	3500	210	0
90	VBS99602692	SAKLAMA KABI RAY DUBELI/465 KALIBI	VBS42040299	SAKLAMA KABI RAY DUBELI/465	VBS42111079	SEBZ. GR.910-SOL(SEF-WH-GRI)				288	848	656	336	4096	3500	210	0
90	VBS99602692	SAKLAMA KABI RAY DUBELI/465 KALIBI	VBS42040299	SAKLAMA KABI RAY DUBELI/465	VBS42127401	CHI.RA.GR/3702(SEF-NAT)								1736	3500	0	0
90	VBS99602692	SAKLAMA KABI RAY DUBELI/465 KALIBI	VBS42040299	SAKLAMA KABI RAY DUBELI/465	VBS42040299	SAKLAMA KABI RAY DUBELI/465	7								3500	3500	0
90	VBS99604135	KAPI ICI LED SOKET KUT.SAG-SOL910 K	VBS42073865	KAPI ICI LED SOKET KUTU-910-SOL	VBS42073865	KAPI ICI LED SOKET KUTU-910-SOL MILKY	123	27		244		243		659	366	366	125
90	VBS99604135	KAPI ICI LED SOKET KUT.SAG-SOL910 K	VBS42073893	KAPI ICI LED SOKET KUTU-910-SAG(	VBS42073893	KAPI ICI LED SOKET KUTU-910-SAG(MILKY)	123	26		244		243		659	50	50	50
90	VBS99604509	BURC 345 CE II KALIBI	VBS42000926	BURC/345CE(NAT)	VBS42117773	A/K KEPI A.GR/640GK(HG,HJ205)RV1/STP						35		127	20500	35	0
90	VBS99604509	BURC 345 CE II KALIBI	VBS42000926	BURC/345CE(NAT)	VBS42117789	A/K KEPI A.GR/640GK(KAR BYZ)RV1/STP								108	20500	0	0
90	VBS99604509	BURC 345 CE II KALIBI	VBS42000926	BURC/345CE(NAT)	VBS42000926	BURC/345CE(NAT)					10000				20500	20500	0
90	VBS99604509	BURC 345 CE II KALIBI	VBS42000926	BURC/345CE(NAT)	VBS37024361	*STOPER DESTEK SACI GR.(KLASIK)SERVIS	10								20500	0	0
90	VBS99604509	BURC 345 CE II KALIBI	VBS42000926	BURC/345CE(NAT)	VBS37024362	*STOPER DESTEK SACI GR.(GK)SERVIS	20								20500	0	0
90	VBS99604509	BURC 345 CE II KALIBI	VBS42001533	BURC/345CE(GRI)	VBS42180180	A/K KEPI A.GR/640GK VSG RV1/STP						27		158	13160	0	0
90	VBS99604509	BURC 345 CE II KALIBI	VBS42001533	BURC/345CE(GRI)	VBS42001533	BURC/345CE(GRI)		10000							13160	13160	0
90	VBS99604509	BURC 345 CE II KALIBI	VBS42001533	BURC/345CE(GRI)	VBS42097895	*A/K KEPI A.GR/540P(GRI)YENI RV1	1								13160	0	0
90	VBS99604509	BURC 345 CE II KALIBI	VBS42014611	BURC/345CE(LXG)	VBS42014611	BURC/345CE(LXG)		5000							20465	20465	0
90	VBS99609963	HAR.RAF/DUBELI KALIBI	VBS42154513	HAR.RAF DUBELI	VBS42154513	HAR.RAF DUBELI	21000		15000			27000		123000	13450	13450	9780
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179867	ISIK TASIYICI F1/K80-90(KM)	VCK42198747	KON.PAN.GR.AYA OF1A(ASLCPP8)			136						925	0	0
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179868	ISIK TASIYICI F2/K80-90(KM)	VCK42193486	KON.PAN.GR.AKAI UF2A (ASC 83 V)						1950			3277	0	0
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179868	ISIK TASIYICI F2/K80-90(KM)	VCK42195416	KON.PAN.GR.DIKOM OF2A (DKDR8)							165		3277	0	0
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179868	ISIK TASIYICI F2/K80-90(KM)	VCK42206715	KON.PAN.GR.ELECTRA OF2A (TDC8112B)			156						3277	0	0
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179868	ISIK TASIYICI F2/K80-90(KM)	VCK42212389	KON.PAN.GR.AKAI UF2A (ASC 85 GV)								650	3277	0	0
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179868	ISIK TASIYICI F2/K80-90(KM)	VCK42212384	KON.PAN.GR.AKAI UF2A (ASC 84 FV)								1350	3277	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42151347	KON.PAN.GR.KUNFT GF1A(KWM2485)		224							7936	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42151344	KON.PAN.GR.KUNFT GF1A(KWM1721)	448								7936	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42192231	KON.PAN.GR.OCEAN OF2B(WFO 1061 L FP)	4								7936	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCK42195416	KON.PAN.GR.DIKOM OF2A (DKDR8)							165		7936	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	428								7936	7936	3072
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42163577	KON.PAN.GR.REGAL UF4B(PRESTIJ 8101 TY)	1								7936	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42103118	PR.AY.GR/K10-80-F/G.BYZ-K.BYZ-P6A	2								7936	0	2
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42140039	KON.PAN GR.REGAL UF4(PRATICA 711 T)	1								7936	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42213661	KON.PAN.GR.VESTEL GF1B(W-D0150)	1								7936	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42212288	KON.PAN.GR.OCEAN OF4A(OCD 803 ED Z A++)			54						7936	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42122012	PR.AYAR DUG.KAPAK/K80-CLS M.BAT(	VCM42214531	KON.PAN.GR.UNIVERSAL PLUS OF4A(UP1170S)								180	5100	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42122012	PR.AYAR DUG.KAPAK/K80-CLS M.BAT(	VCM42214539	KON.PAN.GR.UNIVERSAL PLUS OF4A(UP1280S)								324	5100	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42123219	PR.AYAR DUG.KAPAK/K80-MTKRM M.B/	VCM42189862	KON.PAN.GR.REGAL UFGB(EKOJET 10123 TY)		200							1573	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42123219	PR.AYAR DUG.KAPAK/K80-MTKRM M.B/	VCM42163571	KON.PAN.GR.REGAL UF4(PRESTIJ 10121 TY)		190							1573	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42123219	PR.AYAR DUG.KAPAK/K80-MTKRM M.B/	VCM42205272	KON.PAN.GR.FAVORIT XF2A(MSU 8002)-REV	155								1573	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42123219	PR.AYAR DUG.KAPAK/K80-MTKRM M.B/	VCM42209124	KON.PAN.GR.BERG OF4E(AWB-0710B)		55							1573	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42112761	PR.AYAR DUG.KAPAK/K80-SYH (PB)	VCM42137556	KON.PAN.GR.ELECTRA OF2A(W1249CF2B)	1								1624	0	0
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42123217	PR.AYAR DUG.KAPAK/K80-KAPLAMALII	VCM42107979	PR.AYAR DUG.KAPAK/K80-KROM	1476		5000						5120	0	0
120	VCM99605845	ISIK TASIYICI F1/K80-90/K1	VCM42082609	ISIK TASIYICI F1/K80-90	VCM42162365	KON.PAN.GR.HIGH ONE OF1A(WM805A++WVET)						4500			10010	0	0
120	VCM99605845	ISIK TASIYICI F1/K80-90/K1	VCM42082609	ISIK TASIYICI F1/K80-90	VCM42193008	KON.PAN.GR.AYA OF1A(LF6102)					1464				10010	0	0

Figure 22. Quantitative Injection Requirement Report

Category:	Mold		Ref. Fact.	A/C Fact. (1)	W.M Fact	A/C Fact. (2)	Dish W. Fact	Elect. Fact.	Dry. M. Factr.	Oven Fact.
Last Operation	PLOP0001	Last Shipment ID	285511	285559	285591	285589	285579	285545	285543	285402

							Date_Group							
Op. Station	Mold_Code	Mold_Name	Semi-Prd. Code	Semi-Prd. Name	Final Prd. Cod	Final Prd. Name	Backlog	23.09.2019	24.09.2019	25.09.2019	26.09.2019	27.09.2019	28.09.2019	Long Orders
90	VBS99600341	SOG.HAVA KANAL TAPASI/640 KALIBI	VBS42033244	SOG.HAVA KANAL TAPASI/640(KAR BYZ)	VBS42033244	SOG.HAVA KANAL TAPASI/640(KAR BYZ)			15,63					69,44
90	VBS99600737	DOD AYAK ANKASTRE KALIBI	VBS42163050	DOD AYAK / ANK(KAR) RV1	VBS42163050	DOD AYAK / ANK(KAR) RV1								25,00
90	VBS99602692	SAKLAMA KABI RAY DUBELI/465 KALIBI	VBS42040299	SAKLAMA KABI RAY DUBELI/465	VBS42111078	SEBZ. GR.910-SAG(SEF,WH-GRI)				0,07	0,37	0,28	0,15	1,78
90	VBS99602692	SAKLAMA KABI RAY DUBELI/465 KALIBI	VBS42040299	SAKLAMA KABI RAY DUBELI/465	VBS42111079	SEBZ. GR.910-SOL(SEF-WH-GRI)				0,13	0,37	0,28	0,15	1,78
90	VBS99602692	SAKLAMA KABI RAY DUBELI/465 KALIBI	VBS42040299	SAKLAMA KABI RAY DUBELI/465	VBS42127401	CHI.RA.GR/3702(SEF-NAT)								0,75
90	VBS99602692	SAKLAMA KABI RAY DUBELI/465 KALIBI	VBS42040299	SAKLAMA KABI RAY DUBELI/465	VBS42040299	SAKLAMA KABI RAY DUBELI/465	0,00							
90	VBS99604135	KAPI ICI LED SOKET KUT.SAG-SOL910 F	VBS42073865	KAPI ICI LED SOKET KUTU-910-SOL MILK	VBS42073865	KAPI ICI LED SOKET KUTU-910-SOL MILKY	0,32	0,07		0,64		0,64		1,74
90	VBS99604135	KAPI ICI LED SOKET KUT.SAG-SOL910 F	VBS42073893	KAPI ICI LED SOKET KUTU-910-SAG(MILK	VBS42073893	KAPI ICI LED SOKET KUTU-910-SAG(MILKY)	0,32	0,07		0,64		0,64		1,74
90	VBS99604509	BURC 345 CE II KALIBI	VBS42000926	BURC/345CE(NAT)	VBS42117773	A/K KEPI A.GR/640GK(HG,HJ205)RV1/STP						0,01		0,05
90	VBS99604509	BURC 345 CE II KALIBI	VBS42000926	BURC/345CE(NAT)	VBS42117789	A/K KEPI A.GR/640GK(KAR BYZ)RV1/STP								0,04
90	VBS99604509	BURC 345 CE II KALIBI	VBS42000926	BURC/345CE(NAT)	VBS42000926	BURC/345CE(NAT)					3,82			
90	VBS99604509	BURC 345 CE II KALIBI	VBS42000926	BURC/345CE(NAT)	VBS37024361	*STOPER DESTEK SACI GR.(KLASIK)SERVIS	0,00							
90	VBS99604509	BURC 345 CE II KALIBI	VBS42000926	BURC/345CE(NAT)	VBS37024362	*STOPER DESTEK SACI GR.(GK)SERVIS	0,01							
90	VBS99604509	BURC 345 CE II KALIBI	VBS42001533	BURC/345CE(GRI)	VBS42180180	A/K KEPI A.GR/640GK VSG RV1/STP						0,01		0,06
90	VBS99604509	BURC 345 CE II KALIBI	VBS42001533	BURC/345CE(GRI)	VBS42001533	BURC/345CE(GRI)		3,82						
90	VBS99604509	BURC 345 CE II KALIBI	VBS42001533	BURC/345CE(GRI)	VBS42097895	*A/K KEPI A.GR/540P(GRI)YENI RV1	0,00							
90	VBS99604509	BURC 345 CE II KALIBI	VBS42014611	BURC/345CE(LXG)	VBS42014611	BURC/345CE(LXG)		1,91						
90	VBS99609963	HAR.RAF/DUBELI KALIBI	VBS42154513	HAR.RAF DUBELI	VBS42154513	HAR.RAF DUBELI	21,88		15,63			28,13		128,13
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179867	ISIK TASIYICI F1/K80-90(KM)	VCK42198747	KON.PAN.GR.AYA OF1A(ASLCPP8)			0,57					
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179868	ISIK TASIYICI F2/K80-90(KM)	VCK42193486	KON.PAN.GR.AKAI UF2A (ASC 83 V)						8,13		
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179868	ISIK TASIYICI F2/K80-90(KM)	VCK42195416	KON.PAN.GR.DIKOM OF2A (DKDR8)							0,69	
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179868	ISIK TASIYICI F2/K80-90(KM)	VCK42206715	KON.PAN.GR.ELECTRA OF2A (TDC8112B)			0,65					
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179868	ISIK TASIYICI F2/K80-90(KM)	VCK42212389	KON.PAN.GR.AKAI UF2A (ASC 85 GV)								2,71
90	VCK99615338	ISIK TASIYICI F1-F2 K80/90 (KM)	VCK42179868	ISIK TASIYICI F2/K80-90(KM)	VCK42212384	KON.PAN.GR.AKAI UF2A (ASC 84 PV)								5,63
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42151347	KON.PAN.GR.KUNFT GF1A(KWM2485)		0,54						
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42151344	KON.PAN.GR.KUNFT GF1A(KWM1721)	1,09							
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42192231	KON.PAN.GR.OCEAN OF2B(WFO 1061 L FP)	0,01							
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCK42195416	KON.PAN.GR.DIKOM OF2A (DKDR8)							0,40	
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	1,04							
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42163577	KON.PAN.GR.REGAL UF4B(PRESTIJ 8101 TY)	0,00							
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42103118	PR.AY.GR/K10-80-F/G.BYZ-K.BYZ-P6A	0,00							
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42140039	KON.PAN GR.REGAL UF4(PRATICA 711 T)	0,00							
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCM42213661	KON.PAN.GR.VESTEL GF1B(W-D015O)	0,00							
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42082604	PR.AYAR DUG.KAPAK/K80-BYZ	VCK42212288	KON.PAN.GR.OCEAN OF4A(OCD 803 ED Z A++)			0,13					
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42122012	PR.AYAR DUG.KAPAK/K80-CLS M.BATCH	VCK42214531	KON.PAN.GR.UNIVERSAL PLUS OF4A(UP1170S)								0,44
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42122012	PR.AYAR DUG.KAPAK/K80-CLS M.BATCH	VCK42214539	KON.PAN.GR.UNIVERSAL PLUS OF4A(UP1280S)								0,79
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42123219	PR.AYAR DUG.KAPAK/K80-MTKRM M.BATCH	VCM42189862	KON.PAN.GR.REGAL UFGB(EKOJET 10123 TY)		0,49						
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42123219	PR.AYAR DUG.KAPAK/K80-MTKRM M.BATCH	VCM42163571	KON.PAN.GR.REGAL UF4(PRESTIJ 10121 TY)		0,46						
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42123219	PR.AYAR DUG.KAPAK/K80-MTKRM M.BATCH	VCM42205272	KON.PAN.GR.FAVORIT XF2A(MSU 8002)-REV	0,38							
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42123219	PR.AYAR DUG.KAPAK/K80-MTKRM M.BATCH	VCM42209124	KON.PAN.GR.BERG OF4E(AWE-0710B)		0,13						
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42112761	PR.AYAR DUG.KAPAK/K80-SYH (PB)	VCM42137556	KON.PAN.GR.ELECTRA OF2A(W1249CF2B)	0,00							
120	VCM99605842	PROG.AY.DUG.KAPAK/K80/K1	VCM42123217	PR.AYAR DUG.KAPAK/K80-KAPLAMALIK	VCM42107979	PR.AYAR DUG.KAPAK/K80-KROM	3,59		12,15					
120	VCM99605845	ISIK TASIYICI F1/K80-90/K1	VCM42082609	ISIK TASIYICI F1/K80-90	VCM42162365	KON.PAN.GR.HIGH ONE OF1A(WM805A++WVET)						6,25		
120	VCM99605845	ISIK TASIYICI F1/K80-90/K1	VCM42082609	ISIK TASIYICI F1/K80-90	VCM42193008	KON.PAN.GR.AYA OF1A(LF6102)					2,03			

Figure 23. Time Related Injection Requirement Report

6.5.1 Assembly Requirement Reports

Similar to the injection requirement reports, assembly reports are considered both quantitively, and relative to worker time. However, in assembly reports, it is easier to handle requirements top to bottom instead of bottom up unlike the reports on Injection Requirements. The reason for this change is that in assembly, each component shall be prepared prior to assembly, therefore, inventories of both the completed product and its components are visible to planner for the quantitative report. An example report for the quantitative assembly requirement is given in Figure 25.

In the time related report for the assembly requirements, the components are hidden from the planners in order to visualize the real capacity requirements for the production. The data is grouped by the operation code given related to assembly line or cells and the total capacity requirements can be gathered accordingly. Figure 24 gives an example to this kind of report. Similar reports can be obtained for painting and printing operations.

.			Date_Group							
Last Operation	Final Prd. Code	Final Prd. Name	Backlog	23.09.2019	24.09.2019	25.09.2019	26.09.2019	27.09.2019	28.09.2019	Long Orders
PLOP0004	VBS42189100	U/K/A KEP GR/473DUZYENI-MAND(KAR)	24,87	19,15			3,18			55,73
PLOP0004	VBS42189112	U/K/A KEP GR/473DUZYENI-MAND(CLS)	9,65	1,73	1,76		1,70			48,45
PLOP0004	VBS42189115	U/K/A KEP GR/473DUZYENI-MAND(HJ205)	8,72				0,87			0,90
PLOP0004	VBS42192978	U/K PANO GR/473M(SYH)			0,45					13,20
PLOP0004	VBS42031371	A/K/U KEP GR/140K-P-KLT-ALT-L(KAR)								7,40
PLOP0004	VBS42099882	A/K/U KEP GR/345V-S(KAR)							0,85	
PLOP0004	VBS42106292	A/K/A-U/K/A KEP GR/140K-P(HG,HJ 205)								0,67
PLOP0004	VBS42106307	A/K/U-U/K/U KEP GR/140K-P(HG,HJ 205)								1,55
PLOP0004	VBS42053912	U/K/A KEP GR/366V-MAND(CLS)								1,95
PLOP0004	VBS42055827	A/K/U KEP GR/345DM-P(CLS)								1,81
PLOP0004	VBS42004800	A/K/U KEP GR/345V-P(CLS)								1,98
PLOP0004	VBS42037855	U/K/A KEP GR/260V-P(SIYAH)								10,88
PLOP0004	VBS42189095	U/K/A KEP GR/492DUZYENI-MAND-MIK(KAR)	35,62							17,05
PLOP0004	VBS42189096	U/K/A KEP GR/492DUZYENI-MAND-MIK(CLS)			9,54	24,35		4,68	1,38	20,36
PLOP0004	VBS42191426	U/K/A KEP GR/140K-S-KLT-CE-UST(KAR)-RV1								1,19
PLOP0004	VBS42032601	A/K/U KEP GR/140V-KLT-ALT-L(KAR)								0,80
PLOP0004	VBS42033749	U/K/A KEP GR/260V-P-KLT-UST-L(KAR)								0,66
PLOP0004	VBS42031402	A/K KEPI U.GR/455F(KAR BYZ)								7,44
PLOP0004	VBS42033799	U/K KEPI A.GR/455F(KAR BYZ)								8,72
PLOP0004	VBS42155136	A/K/U KEP GR/473ERA-P(HG,HJ205)				0,16				0,48
PLOP0004	VBS42200591	U/K/A KEP GR/319GK-FLN-STP-P(KAR)	5,45	3,24						21,79
PLOP0004	VBS42200608	A/K/U KEP GR/319GK-FLN-P(KAR)	4,42	2,63						17,68
PLOP0004	VBS42200593	U/K/A KEP GR/319GK-FLN-STP-P(CLS)	2,80		0,74					5,74
PLOP0004	VBS42200609	A/K/U KEP GR/319GK-FLN-P(CLS)	2,27		0,60					4,54
PLOP0004	VBS42205056	U/K/A KEP GR/270FLN-STP-P(KAR)RV1			1,44	12,46	19,14	37,56	8,67	41,35
PLOP0004	VBS42205057	A/K/U KEP GR/270FLN-P(KAR)RV1				7,29	12,66	27,23	5,73	29,74
PLOP0004	VBS42200586	U/K/A KEP GR/319GK-F-STP-P(CLS)								1,33
PLOP0004	VBS42200606	A/K/U KEP GR/319GK-F-P(CLS)								1,08
PLOP0004	VBS42206672	A/K/U KEP GR/130V-P(KAR)	29,94	13,61		12,44	5,74	0,49	4,76	41,13
PLOP0004	VBS42203562	U/K PANO GR/473M(RTRKIRBYL)	6,15							
PLOP0004	VBS42205369	A/K/A KEP GR/130K-STP-P(VSG)		0,46	5,69	6,95	7,06	24,71	12,53	45,44
PLOP0004	VBS42205381	A/K/U-U/K/U KEP GR/130K-P(CLS)		0,19	2,53	10,99	1,75	20,03	6,51	9,72
PLOP0004	VBS42206670	A/K/U KEP GR/130V-P(CLS)				0,97	1,75	0,97	1,46	9,24
PLOP0004	VBS42205372	A/K/A-U/K/A KEP GR/130K-P(CLS)		0,09	0,53	4,62		8,71		
PLOP0004	VBS42205379	A/K/A-U/K/A KEP GR/130K-P(VSG)	1,69					1,87		1,96
PLOP0004	VBS42200445	A/K/U KEP GR/473ERA-P(SYH)			0,32					12,83
PLOP0004	VBS37024361	*STOPER DESTEK SACI GR.(KLASIK)SERVI:	0,06							
PLOP0004	VBS42189120	U/K/A KEP GR/473DUZYENI-MAND(RTRKIRBY	12,35							
PLOP0004	VBS42138762	A/K/U KEP GR/345DM-P(HJ205)								2,99
PLOP0004	VBS42063234	A/K KEPI U.GR/640GK(LXG)RV1	0,02							
PLOP0004	VBS37024362	*STOPER DESTEK SACI GR.(GK)SERVIS	0,11							
PLOP0004	VBS42211685	U/K PANO GR/345V-P-BOMBELI(HJ205)								2,57
PLOP0004	VBS42097895	*A/K KEPI A.GR/540P(GRI)YENI RV1	0,04							
PLOP0004	VBS42205388	A/K/U-U/K/U KEP GR/130K-P-SOL(CLS)	0,66							
PLOP0004	VBS42205380	A/K/A-U/K/A KEP GR/130K-P(VSG)SOL	0,60							
PLOP0005	VCM42027955	KAPI GR(O-C)	0,51							

Figure 24. Time Related Assembly Requirements Report

Last Operation:	(Multiple Objects)	Ref. Fact.	A/C Fact. (1)	W.M Fact	A/C Fact. (2)	Dish W. Fact	Elect. Fact.	Dry. M. Factr.	Oven Fact.
Order Code	0	285511	285559	285591	285589	285579	285545	285543	285402

Cust.Code	Last Operation	Final Product Code	Final Product Name	Component Code	Component Name	Date_Group Backlog	23.09.2019	24.09.2019	25.09.2019	26.09.2019	27.09.2019	28.09.2019	Component Inv.	Final Inv.	Shipment Qty.
VBS	PLOP0004	VBZ42189100	U/K/A KEP GR/473DUSYENI-MAND(KAR)	VBZ37025272	VIDA,P,RYSB,30x20,F,ST,A3B,O	861	663			110			10000	704	400
VBS	PLOP0004	VBZ42189100	U/K/A KEP GR/473DUSYENI-MAND(KAR)	VBZ37025273	VIDA,P,RYSB,30x10,C,ST,A3B	861	663			110			0	704	400
VBS	PLOP0004	VBZ42189100	U/K/A KEP GR/473DUSYENI-MAND(KAR)	VBZ42130570	KAPI MANDALI 473(NAT)	861	663			110			1000	704	400
VBS	PLOP0004	VBZ42189100	U/K/A KEP GR/473DUSYENI-MAND(KAR)	VBZ42189111	U/K/A KEPI/473DUZYENI(KAR)	861	663			110			1517	704	400
VBS	PLOP0004	VBZ42189100	U/K/A KEP GR/473DUSYENI-MAND(KAR)	VBZ45000564	BANT SUNGER(19MM*6*R YPS)TESA 50523/0	77	60			10			765	704	400
VBS	PLOP0004	VBZ42189100	U/K/A KEP GR/473DUSYENI-MAND(KAR)	VBZ45000577	BANT HAVA(25MM*R) 5225/00 BN10	0	0			0			2	704	400
VBS	PLOP0004	VBZ42189100	U/K/A KEP GR/473DUSYENI-MAND(KAR)	VBZ47010668	BANT SUNGER(10*T5*R)(PU)	112	86			14			3840	704	400
VBS	PLOP0004	VBZ42189112	U/K/A KEP GR/473DUSYENI-MAND(CLS)	VBZ37024182	KAPI MANDAL STOPERI /473	334	60	61		59			6500	0	455
VBS	PLOP0004	VBZ42189112	U/K/A KEP GR/473DUSYENI-MAND(CLS)	VBZ37025272	VIDA,P,RYSB,30x20,F,ST,A3B,O	334	60	61		59			10000	0	455
VBS	PLOP0004	VBZ42189112	U/K/A KEP GR/473DUSYENI-MAND(CLS)	VBZ37025273	VIDA,P,RYSB,30x10,C,ST,A3B	334	60	61		59			0	0	455
VBS	PLOP0004	VBZ42189112	U/K/A KEP GR/473DUSYENI-MAND(CLS)	VBZ42139437	KAPI MANDALI 473(GRI)	334	60	61		59			5000	0	455
VBS	PLOP0004	VBZ42189112	U/K/A KEP GR/473DUSYENI-MAND(CLS)	VBZ42189113	U/K/A KEPI/473DUZYENI(CLS)	334	60	61		59			4991	0	455
VBS	PLOP0004	VBZ42189112	U/K/A KEP GR/473DUSYENI-MAND(CLS)	VBZ45000564	BANT SUNGER(19MM*6*R YPS)TESA 50523/0	30	5	5		5			765	0	455
VBS	PLOP0004	VBZ42189112	U/K/A KEP GR/473DUSYENI-MAND(CLS)	VBZ45000577	BANT HAVA(25MM*R) 5225/00 BN10	0	0	0		0			2	0	455
VBS	PLOP0004	VBZ42189112	U/K/A KEP GR/473DUSYENI-MAND(CLS)	VBZ47010668	BANT SUNGER(10*T5*R)(PU)	43	8	8		8			3840	0	455
VBS	PLOP0004	VBZ42189115	U/K/A KEP GR/473DUSYENI-MAND(HJ205)	VBZ37024182	KAPI MANDAL STOPERI /473	302				30			6500	0	310
VBS	PLOP0004	VBZ42189115	U/K/A KEP GR/473DUSYENI-MAND(HJ205)	VBZ37025272	VIDA,P,RYSB,30x20,F,ST,A3B,O	302				30			10000	0	310
VBS	PLOP0004	VBZ42189115	U/K/A KEP GR/473DUSYENI-MAND(HJ205)	VBZ37025273	VIDA,P,RYSB,30x10,C,ST,A3B	302				30			0	0	310
VBS	PLOP0004	VBZ42189115	U/K/A KEP GR/473DUSYENI-MAND(HJ205)	VBZ42130570	KAPI MANDALI 473(NAT)	302				30			1000	0	310
VBS	PLOP0004	VBZ42189115	U/K/A KEP GR/473DUSYENI-MAND(HJ205)	VBZ42189116	U/K/A KEPI/473DUZYENI(HJ205)	302				30			367	0	310
VBS	PLOP0004	VBZ42189115	U/K/A KEP GR/473DUSYENI-MAND(HJ205)	VBZ45000564	BANT SUNGER(19MM*6*R YPS)TESA 50523/0	27				3			765	0	310
VBS	PLOP0004	VBZ42189115	U/K/A KEP GR/473DUSYENI-MAND(HJ205)	VBZ45000577	BANT HAVA(25MM*R) 5225/00 BN10	0				0			2	0	310
VBS	PLOP0004	VBZ42189115	U/K/A KEP GR/473DUSYENI-MAND(HJ205)	VBZ47010668	BANT SUNGER(10*T5*R)(PU)	39				4			3840	0	310
VBS	PLOP0004	VBZ42192978	U/K PANO GR/473M(SYH)	VBZ42014608	BURC/540CE(LXG)			60					5100	36	0
VBS	PLOP0004	VBZ42192978	U/K PANO GR/473M(SYH)	VBZ42164478	U/K PANO/473M(SIYAH)			30					495	36	0
VBS	PLOP0004	VBZ42192978	U/K PANO GR/473M(SYH)	VBZ45000577	BANT HAVA(25MM*R) 5225/00 BN10			0					2	36	0
VBS	PLOP0004	VBZ42192978	U/K PANO GR/473M(SYH)	VBZ47010668	BANT SUNGER(10*T5*R)(PU)			4					3840	36	0
VBS	PLOP0004	VBZ42031371	A/K/U KEP GR/140K-P-KLT-ALT-L(KAR)	VBZ42031583	BURC/540CE(KAR)								30000	0	0
VBS	PLOP0004	VBZ42004800	A/K/U KEP GR/345V-P(CLS)	VBZ42128087	BURC/345P(GRI) RV1								15000	0	0
VBS	PLOP0004	VBZ42004800	A/K/U KEP GR/345V-P(CLS)	VBZ42182265	BURC TAPASI CENTIKLI (CLS)								37260	0	0
VBS	PLOP0004	VBZ42004800	A/K/U KEP GR/345V-P(CLS)	VBZ45000577	BANT HAVA(25MM*R) 5225/00 BN10								2	0	0
VBS	PLOP0004	VBZ42004800	A/K/U KEP GR/345V-P(CLS)	VBZ42112582	A/K/U KEP/345V(CLS)								2036	0	0
VBS	PLOP0004	VBZ42037855	U/K/A KEP GR/260V-P(SIYAH)	VBZ42128088	BURC/345P(LXG) RV1								7500	0	0
VBS	PLOP0004	VBZ42037855	U/K/A KEP GR/260V-P(SIYAH)	VBZ45000577	BANT HAVA(25MM*R) 5225/00 BN10								2	0	0
VBS	PLOP0004	VBZ42037855	U/K/A KEP GR/260V-P(SIYAH)	VBZ42070993	KAPI KEPI/260V(SIYAH)								184	0	0
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ37024182	KAPI MANDAL STOPERI /473	1034							6500	0	1039
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ37025272	VIDA,P,RYSB,30x20,F,ST,A3B,O	1034							10000	0	1039
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ37025273	VIDA,P,RYSB,30x10,C,ST,A3B	1034							0	0	1039
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ42130570	KAPI MANDALI 473(NAT)	1034							1000	0	1039
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ42189111	U/K/A KEPI/473DUZYENI(KAR)	1034							1517	0	1039
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ45000564	BANT SUNGER(19MM*6*R YPS)TESA 50523/0	93							765	0	1039
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ45000577	BANT HAVA(25MM*R) 5225/00 BN10	0							2	0	1039
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ47016698	BANT SUNGER(T2*10*10) EPDM SN 14	1034							4800	0	1039
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ42185385	MIKNATIS KAPAK 70CM(KAR)	1034							0	0	1039
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ47010668	BANT SUNGER(10*T5*R)(PU)	134							3840	0	1039
VBS	PLOP0004	VBZ42189095	U/K/A KEP GR/492DUSYENI-MAND-MIK(KAR)	VBZ47017049	MIKNATIS/590(Y35,40X15X10MM)/P	2068							1134	0	1039

Figure 25. Quantitative Assembly Requirement Report

6.5.2 Procurement and Subcontract Requirement Reports

Similar to previous reports, all raw materials can be reported and tracked through procurement reports. In the case study, these reports are divided into subcategories such as injection raw materials, which are further grouped by the raw material types, sub-parts, which are grouped by the supplier and subcontracted parts which requires inventory information in three levels (Component – Subcontracted Semi-product and Final Product) in order to increase the traceability in the planning.

6.5.3 Executive Reports

In addition to reports for planning staff, every execution of the extraction system provides executive reports that supports decision making on worker management and subcontracting decisions.

For example, Figure 26 displays the accumulated assembly capacity requirements and Figure 27 displays the cumulative injection capacity requirements for the customer orders. These tables are obtained from the time related reports and repivoted to display daily machine and personnel requirements respectively. In the short-term planning (for 10 days) the management can decide on the extended shifts and/or personnel replacement in between the lines and machines. These reports provide managers and planners the bottlenecks or excess capacities prior to occurrence and gives flexibility in decision making.

Operation	Backlog	23.09.2019	24.09.2019	25.09.2019	26.09.2019	27.09.2019	28.09.2019	Overall Total	Workers	Worker Req.	Average Capacity
Ref. Assy.	34	13	17	9	14	16	12	114	19	16	86%
Air Cond. Assy.	10	2	4	2	10	13	9	51	15	7	49%
Drying M. P. Assy.	39	13	7	15	14	22	13	122	18	17	97%
D.W. Panel Assy.	16	9	8	10	10	8	6	67	8	10	119%
W.M. Door Assy.	36	66	37	74	73	56	50	393	22	56	255%
W.M. Panel Assy.	29	30	48	17	25	64	52	265	46	38	82%
Air Cond. 2 Assy.	0	1	0	6	5	0	0	12	4	2	43%
Sub Total	164	134	120	132	151	179	143	1024	132	146	111%

Figure 26. Cumulative Capacity Report for Assembly Lines

Op. Station	Backlog	23.09.2019	24.09.2019	25.09.2019	26.09.2019	27.09.2019	28.09.2019	Overall Total	Machine Inv.	Avg.Req. Per Day	Average Capacity
90	1	0	2	0	0	2	1	7	2	1	48%
120	3	3	2	1	1	1	1	12	3	2	55%
160	6	6	2	3	3	4	2	27	3	4	127%
200	1	1	0	1	1	1	1	5	3	1	24%
280	3	2	2	2	2	2	3	16	1	2	234%
320	1	1	1	2	1	2	1	11	6	2	26%
380	6	6	6	5	5	3	4	34	11	5	44%
470	15	12	10	14	18	16	14	100	16	14	89%
600	7	6	4	6	5	7	7	42	10	6	60%
700	8	3	4	1	1	2	1	20	4	3	73%
900	3	1	1	1	2	2	1	12	2	2	86%
1200	0	0	0	0	0	0	0	0	1	0	5%
1400	0	0	0	0	0	0	0	0	1	0	0%
Sub Total	54	41	35	38	40	41	37	286	63	41	65%

Figure 27. Cumulative Capacity Report for Injection Machines

In addition, the application of the model provided the company to have direct control over the job floor scheduling, prepared by the planners, by displaying number of critical machines, the number of machines that work for over inventory, and the overall capacity of the company. By connecting the inventory database and machine schedule spreadsheet to the model, the managers are able to understand the dynamics even better and manage the employees, inventory and the budget easily. Figure 29 displays the machine schedule evaluation obtained by the model.

Overall, in each execution of the extraction model, an executive summary is also provided. This summary contains crucial information about the backlog machine requirements, the number of critical machines, most dense production days, and capacity fulfillment of the relative department. The summary also gives insight about the inventory status of the planned work orders. Figure 28 displays an example to this executive summary.

Backlog Machine Requirement	54
Backlog Critical Machines	38
5 Days Critical Machines	50
Injection Capacity Fullfilment	65%
Most Dense Production Day	23.09.2019
Backlog Assy Hour Requirement	164
Assy. Average Capacity Fullfilment	111%
Most Dense Production Day	27.09.2019

Planned Production Inventories	Count W/O
No Requirement	3
15 Days Inventory	27
10 Days Inventory	24
5 Days Inventory	35
2 Days Inventory	36
InSuff. Inventory	103
Total	**228**

Figure 28. Executive Summary Report

WORK ORDER	MACHINE NAME	CODE	PART NAME	PROD. CATEGOR	W/O QTY.	LABELED	PRODUCED	LEFT	QTY/HR	HOURS LEFT	QTY/DAY	.	PRD. INV	TOTAL INV.	INV. CONTR	..	BACKLOG REQ	5 DAY REQ.	10 DAY REQ.	TOTAL REQ.
IE1900000008393	A01 470B ROBOT	VBZ42164174	DOND.ORTA SEPET ARKA/276(KAR BYZ)	ASSY.	10000	1160	1442	8558	72,00	118,86	1584		216	5977	InSuff. Inv		7202	14722	87622	87622
IE1900000008025	A02 470B	VBZ42130573	U/K PANO/473M(KAR)	ASSY.	15000	14312	13512	1488	160,00	9,30	3520		5040	2400	5 Days Inv.		3925	5326	23556	23556
IE1900000008470	A02 470B	VBZ42130573	U/K PANO/473M(KAR)	ASSY.	10000			10000	160,00	62,50	3520		5040	2400	5 Days Inv.		3925	5326	23556	23556
IE1900000008604	A03 470B ROBOT	VBZ42121571	SEBZ./1001(SEF-NAT)	MIX	1000	648	424	576	72,00	8,00	1584		9884	11738	10 Days Inv.		0	5985	13230	13230
IE1900000008457	A03 470B ROBOT	VBZ42127865	AROMA KUTU(SEF-NATUREL)	ASSY.	1000	0		1000	261,82	3,82	5760		0	0	InSuff. Inv		58	73	871	871
IE1900000008458	A03 470B ROBOT	VBZ42127944	SISELIK/1400 ANK(SEF-NAT)	MIX	8500			8500	144,00	59,03	3168		1228	1228	2 Days Inv.		85	1797	9976	9976
IE1900000008549	A03 470B ROBOT	VBZ42004514	SISELIK/1400 ANK(SEF-MAVI)	MIX	1000			1000	144,00	6,94	3168		1497	1497	15 Days Inv.		0	0	2225	2225
IE1900000008550	A03 470B ROBOT	VBZ42024710	SISELIK/1400 ANK(SEF-WH.GRI)	MIX	1200			1200	144,00	8,33	3168		5084	5084	15 Days Inv.		0	249	6479	6479
IE1900000008262	A04 470B ROBOT	VBZ42121573	SISELIK/1001(SEF-NAT)	SHIPMENT	10000	9312	8119	1881	160,00	11,76	3520		7754	8906	10 Days Inv.		0	5539	12784	12784
IE1900000008471	A04 470B ROBOT	VBZ42125031	SISELIK/1001(SEF WH GRI)	MIX	2500			2500	160,00	15,63	3520		160	160	15 Days Inv.		0	0	2305	2305
IE1900000008514	A04 470B ROBOT	VBZ40003431	HAR.RAF/345(SEF-MAVI)	MIX	900			900	135,85	6,63	2989		0	0	InSuff. Inv		0	0	814	814
IE1900000008515	A04 470B ROBOT	VBZ42024764	HAR.RAF/345(SEF-WH GRI)	MIX	100			100	135,85	0,74	2989		350	350	15 Days Inv.		0	40	373	373
IE1900000008516	A04 470B ROBOT	VBZ42127647	HAR.RAF/345(SEF-NAT)	MIX	2000			2000	135,85	14,72	2989		558	558	15 Days Inv.		0	0	2240	2240
IE1900000008098	A05 600A	VBZ42164174	DOND.ORTA SEPET ARKA/276(KAR BYZ)	ASSY.	10000	6875	7499	2501	72,00	34,74	1584		216	5977	InSuff. Inv		7202	14722	87622	87622
IE1900000008472	A05 600A	VBZ42164174	DOND.ORTA SEPET ARKA/276(KAR BYZ)	ASSY.	10000			10000	72,00	138,89	1584		216	5977	InSuff. Inv		7202	14722	87622	87622
IE1900000008603	A06 600B ROBOT	VBZ42128542	SOG.SEBZ. ON 270(SEF-NAT)	MIX	850	480	37	813	144,00	5,65	3168		606	139	15 Days Inv.		323	323	1051	1051
IE1900000008520	A06 600B ROBOT	VBZ42111687	ORTA SEPET KAPAGI/272(SEF.WH GRI)	MIX	50	0		50	138,46	0,36	3046		0	0	InSuff. Inv		11	11	36	36
IE1900000008521	A06 600B ROBOT	VBZ42128537	ORTA SEPET KAPAGI/272(SEF-NAT)	MIX	750			750	138,46	5,42	3046		286	286	InSuff. Inv		323	323	1051	1051
IE1900000008607	A06 600B ROBOT	VBZ42128472	DOND.KAPI RAF/465FW-ARC(SEF-NAT)	MIX	6000			6000	130,91	45,83	2880		1740	1740	10 Days Inv.		210	1288	7410	7410
IE1900000008252	A07 700B ROBOT	VBZ42177566	DOND.ORTA SEPET KAP./252(SEF NAT)	MIX	20000	1412	1238	18762	138,46	135,50	3046		2817	4537	InSuff. Inv		4836	10724	67213	67213
IE1900000008253	A08 700B ROBOT	VBZ42164144	FLAP.KAPAK/252 (SEF-WHGRI)	MIX	5500	900	401	5099	130,91	38,95	2880		900	1360	10 Days Inv.		0	0	11760	11760
IE1900000008449	A9 600B ROBOT	VBZ42128392	SISELIK/456FW-ARC(NAT)	MIX	5500	3424	3272	2228	114,29	19,50	2514		5257	6328	15 Days Inv.		847	2197	7515	7515
IE1900000008450	A9 600B ROBOT	VBZ42080506	SISELIK/456FW-ARC(WHGRI)	MIX	200			200	114,29	1,75	2514		76	121	15 Days Inv.		0	0	320	320
IE1900000008451	A9 600B ROBOT	VBZ42047512	SISELIK/456FW-ARC(MAVI)	MIX	1500			1500	114,29	13,13	2514		2325	2409	15 Days Inv.		0	11	3679	3679
IE1900000008255	A10 700A ROBOT	VBZ42163962	DOND.ALT SEPET KAP/252(SEF WH GRI)	ASSY.	6000	2256	1780	4220	130,91	32,24	2880		786	880	InSuff. Inv		1496	2493	18211	18211
IE1900000008445	A10 700A ROBOT	VBZ42177554	DOND.ALT SEPET KAP/252(SEF MAVI)	ASSY.	2000			2000	130,91	15,28	2880		584	0	2 Days Inv.		0	729	2497	2497
IE1900000008370	A10 700A ROBOT	VBZ42177564	DOND.ALT SEPET KAP/252(SEF NAT)	MIX	10000			10000	130,91	76,39	2880		11252	669	5 Days Inv.		4880	8585	39228	39228
IE1900000008446	A11 470B ROBOT	VBZ42121572	P/T RAF/1001(SEF-NATUREL)	MIX	5000	1344	726	4274	156,52	27,31	3443		18100	18180	10 Days Inv.		0	12038	26528	26528
IE1900000008560	A11 470B ROBOT	VBZ42128573	DOND.KA./1451(SEF-NAT)	MIX	50			50	160,00	0,31	3520		0	0	InSuff. Inv		4	4	4	4
IE1900000008559	A11 470B ROBOT	VBZ42111086	KAPI RAF/910(SEF-WH-GRI)	MIX	5000			5000	130,91	38,19	2880		4793	136	10 Days Inv.		0	406	11964	11964
IE1900000008377	B01 380B	VBZ42137542	A/K/U KEPI/473ERA(NAT.GRI)	PAINT	15000	7112	6389	8611	144,00	59,80	3168		896	756	InSuff. Inv		2353	2838	18080	18080
IE1900000008076	B01 380B	VBZ42164480	A/K/U KEPI/473ERA(SIYAH)	PAINT	500			500	144,00	3,47	3168		34	16	10 Days Inv.		0	20	830	830
IE1900000008355	B02 380B	VBZ42205351	KAPI KEPI/130K(NAT GRI)	PAINT	5000	1800	1704	3296	160,00	20,60	3520		0	868	2 Days Inv.		68	2068	6958	6958
IE1900000008447	B02 380B	VBZ42205361	KAPI KEPI/130K(VSG)	ASSY.	5000			5000	160,00	31,25	3520		2579	968	5 Days Inv.		258	1408	9718	9718
IE1900000008551	B02 380B	VBZ42080637	KAPI KEPI/260V(KAR)	ASSY.	15000			15000	160,00	93,75	3520		500	900	2 Days Inv.		115	2425	15805	15805
IE1900000008405	B03 380B	VBZ42161622	SEBZELIK RAY SAG/373 RV1	SHIPMENT	10000	1600	3391	6609	180,00	36,72	3960		4000	4000	10 Days Inv.		0	0	25559	25559
IE1900000008406	B03 380B	VBZ42161623	SEBZELIK RAY SOL/373 RV1	SHIPMENT	10000	0	3391	6609	180,00	36,72	3960		1600	1600	5 Days Inv.		0	0	25326	25326
IE1900000008609	B03 380B	VBZ42161622	SEBZELIK RAY SAG/373 RV1	SHIPMENT	10000			10000	180,00	55,56	3960		4000	4000	10 Days Inv.		0	0	25559	25559
IE1900000008610	B03 380B	VBZ42161623	SEBZELIK RAY SOL/373 RV1	SHIPMENT	10000			10000	180,00	55,56	3960		1600	1600	5 Days Inv.		0	0	25326	25326
IE1900000008226	B04 600A ROBOT	VBZ42145609	DOND.HAVA KAN.I 373(KAR)	ASSY.	10000	2150	2214	7786	72,00	108,14	1584		2650	700	5 Days Inv.		1050	1050	19749	19749
IE1900000008097	B05 600A ROBOT	VFR42148147	LC INDUCTION PLASTIK KAIDE	SHIPMENT	8000	450	365	7635	66,67	114,53	1467		1050	1050	2 Days Inv.		213	2508	6489	6489
IE1900000008082	B05 600A ROBOT	VBZ42038312	SOG.CAM RAF PRF-ON/1700(KAR BYZ)	SHIPMENT	10000			10000	144,00	69,44	3168		0	0	InSuff. Inv		0	0	19500	19500
IE1900000007710	B06 600A ROBOT	MTSDK25Y055	SERVICE PANEL 517T	SHIPMENT	20000	7872	7765	12235	120,00	101,96	2640		192	192	5 Days Inv.		0	0	15648	15648
IE1900000008465	B07 900A ROBOT	VBZ42214659	SOG.HAVA KANALI/373(KAR BYZ) VR1 HIPS	ASSY.	5000	550	200	4800	65,45	73,33	1440		2996	933	10 Days Inv.		740	740	7255	7255
IE1900000008373	B07 900A ROBOT	VBZ42208801I	SOG.HAVA KANALI/373(KAR BYZ) VR4 HIPS	ASSY.	2000			2000	65,45	30,56	1440		2174	0	10 Days Inv.		0	0	4820	4820
IE1900000008596	B07 900A ROBOT	VCK42214035	ISTIF APARAT ÇEKMECESI-SYH	ASSY.	50	0		50	60,00	0,83	1320		31	0	15 Days Inv.		1	1	1	1
IE1900000008597	B07 900A ROBOT	VCK42214032	ISTIF APARAT ÇEKMECESI-CLX MB	PAINT	50	0		50	60,00	0,83	1320		157	0	No Req.		0	0	0	0
IE1900000008453	B08 900A ROBOT	VBZ42192083	U/TABLA 143 (KAR) HIPS (SARP PLS)	SHIPMENT	11500	4270	3993	7507	65,45	114,69	1440		280	1260	InSuff. Inv		4305	8967	8967	8967
IE1900000008454	B08 900A ROBOT	VBZ42207734	U/TABLA 143 (NAT GRI)	PAINT	2200			2200	65,45	33,61	1440		0	80	InSuff. Inv		0	0	2130	2130
IE1900000008302	B09 1400B ROBOT	VBZ42163961	DOND.ALT SEPET ARKA/252(KAR BYZ)	ASSY.	20000	1000	781	19219	116,13	165,50	2555		0	880	InSuff. Inv		5715	10757	57431	57431

Figure 29. Machine Schedule Evaluation Report

6.6 Application Results

After the application of the proposed approach in the company of interest, the company is able to obtain its requirements for its customer orders daily and able to plan it production accordingly. Overall execution time for extraction of requirements together with the preparation of reports mentioned in the previous section, takes only fifteen minutes and only 1 person to execute. Compared to the previous average of 5 hours for 5 full time planners working on the extraction daily, the impact of the approach is significant. In addition, because the approach is integrated and automated, human interaction requirement for the process is very limited, decreasing the errors due to human faults.

For decision support contribution of the system, top management of the company defines five major criteria. These are, (a) Customer Returns, (b) Penalties, (c) Overall Personnel Costs, (d) Planning Personnel Costs, and (e) On-Time Shipment Success. In addition to these, implementation of the scheduling methodology derivatively affects the following performance criteria of the production departments: (f) Number of Mold/Raw Material Changes, (g) Amount of Raw Material Scraps due to Setup, (h) Loses due to Inefficient Material Planning. All of these criteria are discussed in the following sections.

The information about these criteria is directly gathered from real data of the case study company. This real data covers a period between January 2017 to June 2019 and divided into two parts to reflect changes in the performance of the company (separated by August 2018). In order to normalize the changes in prices, Revenue Percentage of the financial data is taken into consideration instead of financial outputs.

6.6.1 Customer Returns

There are two main reasons for customer returns. First of all, quality depended returns, that are caused by the insufficient quality of the shipped product. The planning department's effect on this kind of customer return is due to time left for the Quality Department to check and control the product prior to shipment. When adequate time is allocated, quality check is adequately executed and any faulty results will be reworked prior to shipment decreasing the customer returns.

Second reason for the customer returns is directly corelated with on-time shipment success. As discussed previously, shipments are bound for certain dates and any shipment that is early or too late is considered as a return. This type of return is usually due to inability of the planning department to follow the customers own production plans and giving shipment orders of the products prior to its actual usage in the customers' plant.

The implementation of the extraction and scheduling model helps the planning department in two folds. First, the operation offset lets the planner to schedule any operation regardless of time required for the quality checks. The order becomes ready prior to shipment date and the sufficient slack time is provided for quality checks and rework processes. Secondly, every day changes are reflected to requirement lists and planners are more aware of these changes. Therefore, the shipment orders change simultaneously, preventing early order shipments.

When observed on the real data, the application of the model decreases the customer returns by forty-four percent on monthly average. This corresponds to 0,6 percent change of the average monthly revenue.

6.6.2 Penalties

Similar to customer returns, penalties are inflicted by the customers on planning and quality reasons. When the shipment occurs overdue, the customer reflects its loses due to starvation on the supplier. Also, when a quality problem is observed during the customer's production, the rework loses are directly inflicted to the supplier.

Another indicator on penalties for planning success is the distribution of quality and planning penalties. While quality penalties are indirectly reasoned by the planning, the planning penalties are directly affected by the planning department. The real data reveals that after the implementation, the penalties are decreased by forty-one percent on monthly average, corresponding to 0,4 percent change on the average monthly revenue.

Also, the distribution of the penalties for direct planning reasons are dropped drastically by 67%.

6.6.3 Overall Personnel Costs

The success of planning department directly and/or indirectly affects the Overall Personnel costs of the company by decreasing the changeovers and increasing the flexibility to adopt customer demand changes. Implementation of the model increased the ability of planners to visualize a wider scope of customer demands and ability to change inventory models according to mid and long-term demands. Therefore, the overall personnel requirements are decreased, effecting one of the largest costs of the company.

Real data reveals that after the implementation of the model, the personnel costs are decreased by six percent, corresponding to 0,9% on average monthly revenue.

6.6.4 Planning Personnel Costs

Another criterion for planning department is the time required for the planning processes of the company. This is reflected by the Planning Personnel costs. By standardizing the planning process and discarding the expeditor type of processes, the time required for planning decreased dramatically. As discussed previously, the time-consuming requirement extraction processes on spreadsheets are ceased, leaving more time for actual planning and scheduling processes for the planners.

On the real data, time requirement decrease is reflected by 30% decrease of planning personnel costs corresponding to 0,4% on the average monthly revenue. In addition, the Production Improvement division is merged into the planning department without need of extra personnel.

6.6.5 On-Time Shipment Success

As discussed previously on Customer Returns and Penalties, on-time shipment success of the company is affected directly by the planning department. This criterion also affects the Customer Satisfaction level.

The implementation of the model increased the on-time shipment success of the company from %83 to %96, carrying the company to becoming one of the preferred suppliers of the customers.

6.6.6 Number of Mold/Raw Material Changes

By providing the planners with larger scope on customer demands and increasing the effective time required for scheduling, the planners are able to define production lot sizes more efficiently, decreasing the overall model changes and increasing the inventory management success.

This criterion directly effects the number of mold and raw material changes both in each section of the production, decreasing the setup related costs. By the implementation of the model, daily mold changes are decreased by 56% and daily raw material changes decreased by 32%. This change, freed 5% of the total injection machine capacity and decreased change related mold failures by 45%.

6.6.7 Amount of Raw Material Scraps due to Setup

Another implication of the decrease in daily changeovers is the setup related scrap of raw material. As mentioned in the previous sub-section, implementation decreased the overall model changes and the setup related scrap amount decreased by %64 percent.

6.6.8 Loses due to Inefficient Material Planning

Similar to previous sub-sections, ability to realize daily changes in customer orders, increased the accuracy of scheduling of the operations by the planning department.

Together with more accurate operation schedules, the planning of the procured items, and production of product sub-components become more efficient. This efficiency is reflected to both personnel times loses due to scarcity of the raw material (starvation) and inventory costs for the procured items.

Both of the criteria decreased positively after the implementation of the model. The personnel time loses due to planning are decreased by 23% and inventory costs of procured materials are decreased by 36%.

6.7 Concluding Remarks

In the case study company, although the preparation for the application lasts for six months, the complete implementation of the model takes only one month. This duration may increase or decrease in other companies according to neatness of the bill of materials and operation connections of the stock IDs. Table 11 summaries these improvements in one table. When observed through the management point of view, the implementation doubled the EBITDA (Earnings Before Interest, Taxation, Depreciation and Amortization) of the company, making it more efficient. All the real observations are given in Appendix A.2 – Company Data (January 2017 – July 2019).

Table 11. Performance Comparison of the Case Study Company

	Average (01/17-07/18)	**Average (08/18-07/19)**	**Change**
Revenue (avg/month)	6.926.716,78 ₺	9.101.895,87 ₺	31,4%
Customer Returns Cost	1,2%	0,6%	-44,0%
Penalties Cost	0,6%	0,4%	-41,1%
Penalty Distribution (Planning/Total)	65,3%	21,4%	-67,2%
Overall Personnel Cost	14,7%	13,8%	-6,0%
Planning Personnel Cost	0,22%	0,15%	-30,4%
% of On-Time-Shipment	83%	96%	15,7%
Daily Mold Change (daily avg.)	55,40	24,30	-56,1%
Daily Raw Material change (daily avg.)	43,50	29,70	-31,7%
Amount of Raw Material Scraps Due to Setup (kg. per month)	14842,00	5344,00	-64%
Lost Personnel Hours (avg. per month)	2596,00	1993,00	-23%
EBITDA	2,75%	8,95%	325,45%

CHAPTER 7: RESULTS OF DESIGN OF EXPERIMENTS AND TEST SCENARIOS

7.1 Introduction

In this chapter, the factors that affect the computation time for Consctuction_EBOM table, EBOM_Table and Requirement_Extraction tables and preparing the Requirement_Extraction output are explained in Section 7.2. In Section 7.3, the experimental design using these factors are explained and results of Analysis of Variance (ANOVA) are presented. In Section 7.4, the regression model based on the experimental design is introduced and explained according to the performance measure.

7.2 Description of Factors That Affect The Calculation Time

Four factors are defined to have impact on the calculation time of the proposed Requirements Extraction Methodology explained in previous chapters (Chapter 5 and 6). They are described in the following subsections.

7.2.1 Maximum Bill of Materials Depth (*maxBMD*)

The Maximum Bill of Materials Depth ($maxBMD$) refers to the maximum number of operations a raw material takes until it is ready for shipment (i.e. becomes a Final Product).

This parameter affects the number of loops in the EBOM construction procedure and since the loop can only be terminated when all the final sub-components in the table are null, the procedure continues to join aforementioned tables for each row in the Construction_EBOM table.

7.2.2 Average Number of Components in Bill of Materials (*avgBCC*)

Average Number of Components in BOM ($avgBCC$) refers to the overall average number of single level components that stock codes have in their BOM.

After each insertion of relative stock codes with their BOM tables, the number of rows in the Construction_EBOM table multiplies with this average number.

7.2.3 Number of Different Stock Codes (*countSID*)

Since the Stock_Codes table is the main table the Construction_EBOM table is constructed upon, the Number of Different Stock Codes ($countSID$) increases the number of insertions with BOM table at the beginning, directly increases the number of loops in the procedure.

7.2.4 Count of Customer Orders (*countCO*)

Since the Requirement_Extraction procedure takes the Customer_Order table as base table, similar to $countSID$, Count of Customer Orders ($countCO$) affects the computation time required for resource extraction.

7.3 Experimental Design and Results of the ANOVA

The experimental design applied for testing the proposed approach is the full-factorial experimental design based on four factors, and each factor has two levels. It is defined as a 2^4 full-factorial experimental design. Accordingly, there are total 16 different scenarios. The experimental design that shows each factor and its levels is given in Table 10. Accordingly, *maxBMD* has two levels with 4 and 8 operations, *avgBCC* has on average 4 and 12 number of single level components, *countSID* contains 15000 and 25000 number of different stock codes, and *countCO* has 3500 and 7000 customer orders.

Table 12. Factor Levels of the Experiment

Factors	Levels of Factors	
maxBMD	4	8
avgBCC	4	12
countSID	15000	25000
countCO	3500	7000

By using these factor levels, Minitab Statistics Software version 16 is used to conduct Analysis of Variance (ANOVA) based on the experimental design that is given in Table 13. The factors selected are then applied to the procedures proposed by adding new stock codes, new orders, and adding new components and deleting the codes with higher BOM levels in order to reach the values for these factors. Each experiment run with separate executions, and the results of Calculation Time (*CalcTime*), that is the response parameter, are given in Table 13. All experiments run on a computer with Intel Core i7 @ 2.80Ghz with 16GB RAM that runs Windows 10.

Table 13. The Experimental Design and Calculation Time Results

StdOrder	**RunOrder**	**CenterPt**	**Blocks**	***maxBMD***	***avgBCC***	***countSID***	***countCO***	***CalcTime***
8	1	1	1	8	12	25000	3500	8.46
5	2	1	1	4	4	25000	3500	2.77
6	3	1	1	8	4	25000	3500	6.07
9	4	1	1	4	4	15000	7000	2.15
11	5	1	1	4	12	15000	7000	3.89
14	6	1	1	8	4	25000	7000	6.24
7	7	1	1	4	12	25000	3500	4.64
3	8	1	1	4	12	15000	3500	3.78
10	9	1	1	8	4	15000	7000	5.64
4	10	1	1	8	12	15000	3500	6.49
13	11	1	1	4	4	25000	7000	2.96
1	12	1	1	4	4	15000	3500	2.11
16	13	1	1	8	12	25000	7000	8.93
15	14	1	1	4	12	25000	7000	4.72
12	15	1	1	8	12	15000	7000	6.87
2	16	1	1	8	4	15000	3500	5.59

According to the experimental design, ANOVA is applied to analyze the main effects of predefined factors and effects of their interactions. The statistical results of ANOVA are given in Table 14.

Table 14. Results of ANOVA

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	635.830	635.830	158.958	*	*
maxBMD	1	464.783	464.783	464.783	*	*
avgBCC	1	126.914	126.914	126.914	*	*
countSID	1	42.746	42.746	42.746	*	*
countCO	1	0.1388	0.1388	0.1388	*	*
2-Way Interactions	6	0.9225	0.9225	0.1537	*	*
*maxBMD*avgBCC*	1	0.0018	0.0018	0.0018	*	*
*maxBMD*countSID*	1	0.2377	0.2377	0.2377	*	*
*maxBMD*countCO*	1	0.0264	0.0264	0.0264	*	*
*avgBCC*countSID*	1	0.6281	0.6281	0.6281	*	*
*avgBCC*countCO*	1	0.0218	0.0218	0.0218	*	*
*countSID*countCO*	1	0.0068	0.0068	0.0068	*	*
3-Way Interactions	4	0.4971	0.4971	0.1243	*	*
*maxBMD*avgBCC*countSID*	1	0.4658	0.4658	0.4658	*	*
*maxBMD*avgBCC*countCO*	1	0.0281	0.0281	0.0281	*	*
*maxBMD*countSID*countCO*	1	0.0005	0.0005	0.0005	*	*
*avgBCC*countSID*countCO*	1	0.0028	0.0028	0.0028	*	*
4-Way Interactions	1	0.0014	0.0014	0.0014	*	*
*maxBMD*avgBCC*countSID*countCO*	1	0.0014	0.0014	0.0014	*	*
Residual Error	0	*	*	*		
Total	15	650.040				

According to the results of ANOVA, the plot of main effects on calculation time response is given in Figure 30. Accordingly, the *maxBMD* factor has the highest direct proportional effect on the *CalcTime* with the increase of the levels from 4 to 8, this is followed by the *avgBCC*. *CalcTime* increases when the levels are increased from 4 to 12. However, the increase on *CalcTime* is less for the countSID factor, it increases when the levels are increased from 15000 to 25000. On the other hand, the increase is not significant for the factor by the countCO when levels are increased from 3500 to 7000.

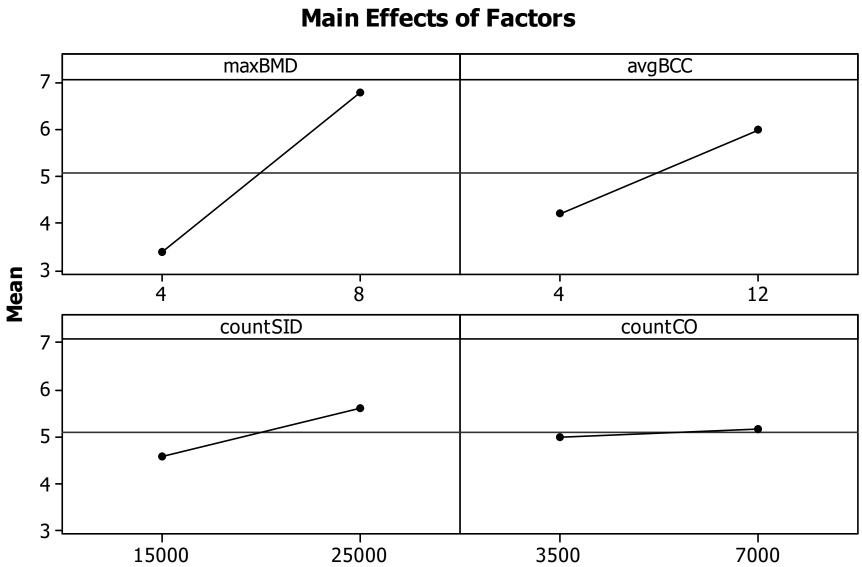

Figure 30. Main Effects of the Factors

According to the interactions plot given in Figure 31, interactions effects of the factors *maxBMD* and *avgBCC* are the highest, this is followed by the interactions impact of factors *maxBMD* and *countSID*, and then it is found as the impact of the factors between *avgBCC* and *countSID*. The interaction impact between the parameters of *countSID* and *countCO* are found as the lowest.

Further, the ANOVA results are given in a cube plot format with the means of *CalcTime* in Figure 32. Two cubic designs are represented by the two levels of *countCO* parameters, that is for 3500 and 7000.

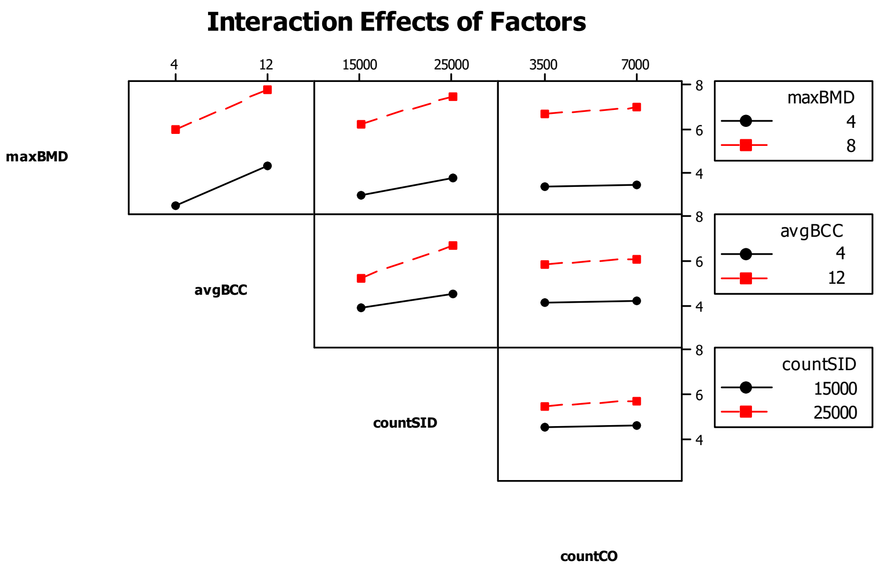

Figure 31. Interaction Effects of Factors

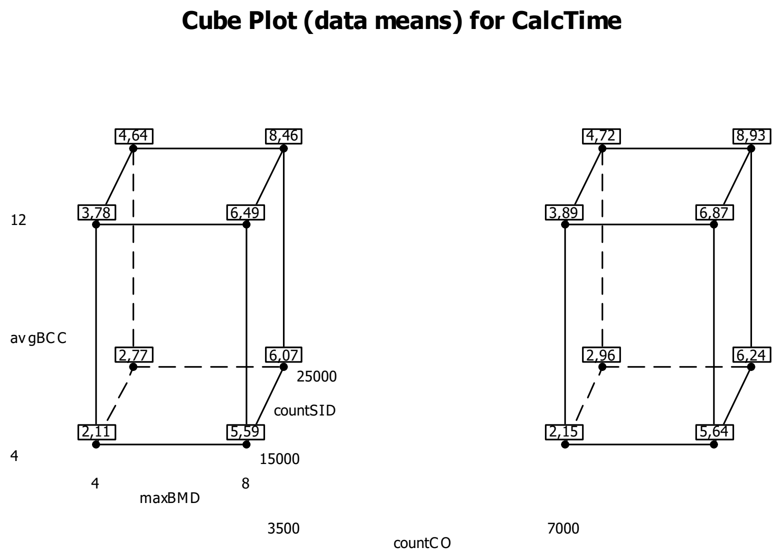

Figure 32. Cube plots of ANOVA results for *CalcTime* response.

7.4 Regression Model Based on Experimental Design

Further, the experimental design is used to calculate the regression model for the given factors. It represents the mathematical equation of the factors (*maxBMD*, *avgBCC*, *countSID* and *countCO*) selected for the experimental design for the response parameter of *CalcTime*. The calculated regression model is given in the following formula by using the Minitab Statistics Software.

$$CalcTime = -4{,}16 + 0{,}852\ maxBMD + 0{,}223\ avgBCC + 0{,}000103\ countSID + 0{,}000053\ countCO$$

Also, the results of the regression analysis is given in the following table.

Table 15. Regression Analysis: *CalcTime* versus *maxBMD, avgBCC, countSID*, *countCO*

Predictor	Coef	SE Coef	T	P	VIF
Constant	-41.594	0.5611	-7.41	0	
maxBMD	0.85219	0.04493	18.97	0	1.000
avgBCC	0.22266	0.02246	9.91	0	1.000
countSID	0.000103	1.8E-05	5.75	0	1.000
countCO	5.32E-05	5.14E-05	1.04	0.322	1.000
S = 0.359	421 R-Sq =	97.8% R-S	q(adj) =	97.00%	

From the regression analysis, R-sq value is obtained as 97.8%. It represents significant fit for the regression model. According to the results, it is observed that $maxBMD$ has the highest effect on the computation time. This is attributed to the loop used in the construction table. However, the coefficients for *countSID* and *countCO* are obtained as very small and insignificant.

7.5 Overall Evaluation of the Proposed Approach

When compared to commercial MRP programs (see Table 6 and Figure 8), the performance of the model proves to be efficient and less time consuming. Since commercial MRP programs explode each customer order separately, repetitive orders of the same inventory utilize the explosion repetitively. However, in the EBOM, each branch of the BOM is already exploded and stored in the EBOM table.

The model aims to minimize the overall time requirement of building production schedules by integrating top management decisions to daily planning processes. One of the main problems in inefficient planning is the time required for requirement extraction, where the commercial MRP systems impose a sleeping time that ceases every inventory and demand transaction for the duration of the process that the most of companies in the survey is unable to spare. This problem is solved by the EBOM methodology that decrease the computation time for requirement extraction and avoids sleeping time due to view logic of the databases. On the other hand, in order to handle operation requirements (or capacity requirements) MRP-II has to be executed, so it increases the duration of the sleeping hours. EBOM methodology extracts the operation requirements together with the material requirements in the same computation, therefore, all the information of both material and capacity is revealed by a single run of computation.

Referring to Vollmann et al. (1997), the accuracy of the MRP depends on the frequency of MRP runs. As the survey remarks, the frequency of the MRP runs depends on the sub-periodic changes in the customer orders. Although, most of the companies (including the case study company) has daily changing demand, they are unable to utilize MRP due to consideration of sleeping hours. With the EBOM methodology, the extraction can be run by in shorter time without need of ceasing daily operations in daily, hourly or even quarter-hourly frequency. Therefore, the schedules can be based on more accurate material and operation requirements.

Another problem in implementing the tradition MRP systems is the complexity and time requirement for inputs. With the proposed model, the complexity is discarded. Only the vital information of stock codes, bill-of-materials and operation information are required as the input for the system. In EBOM methodology, this information can be obtained either from a database, or even from another spreadsheet. In addition, the accuracy of the inventory does not affect the overall system performance. Besides, EBOM methodology can be implemented generally regardless of the industry that the company works as long as the aforementioned vital information is supplied. The EBOM methodology also provides an integration of higher-level decision parameters and indicators to the daily plans. With ability to detect periodic bottlenecks and capacity surpluses, the planner is able to feed management with better human-resources requirements and investment-based information. In addition, daily changes reflect simultaneously to the material requirements. The lot sizing is not preset in EBOM methodology, therefore, the planners can schedule production with more batches. The planner can define the order batches according to daily requirements and the lead time of the procured items via operation offset attribute. In addition, working on an extra MPS is no more required for querying available to promise information for the customer demands.

Another benefit of the EBOM is that it calculates the operational requirements, and thus, no extra time is required for capacity planning. In commercial MRP systems, MRP-II is required for capacity planning.

In addition, EBOM works as a database view, therefore does not require 'sleeping hours' in order to operate. On the other hand, for aforementioned reasons, commercial MRPs require 'sleeping hours', and all inventory and database functions need to be ceased under operation.

One negative trait of EBOM is that it does not include inventory, therefore, calculating the Net Requirement is left to the planner. This process can be eased by displaying inventory at the scheduling level, but still it requires human interaction and interpretation.

CHAPTER 8: CONCLUSIONS AND DISCUSSIONS

8.1 Introduction

This chapter concludes the thesis study by summarizing and discussing main outcomes of the proposed approach and its application, and it presents future research suggestions for the improvement of the study.

8.2 Conclusions and Discussions

This thesis considers a real-life problem in a plastic injection company that is unable to produce shop-floor schedules efficiently. The main problem is the need of an easy to use and easy to implement methodology to the factory level planning problem by utilizing dispatching rule based heuristic methods that decrease human interaction in planning phases without a need of an expensive advanced planning software. One of the main considerations in the problem is frequent changes in customer demands, and the approach should be flexible enough to reflect these changes into the schedules.

In order to achieve this aim, first, different methods are observed through Literature Research. It is observed that approaches offered by the researchers commonly use optimization methods and evolutionary heuristics for the problem. However, even with smaller machine and order amounts, they require high computation times and the implementation of these methods requires high-level engineering education and time.

Second approach on finding a feasible method for the problem is to observe industrial companies and their planning methods. Through a general survey conducted on 64 production companies with various served industries, the most common method is to follow the framework presented by Vollmann et al. (1997), and it depends on the commercial MRP systems for extracting the material requirements. However, only 31% of the companies executes MRP, and only 8% execute MRP in daily basis (Chapter 3). In addition, majority of the companies depends on unintegrated spreadsheets prepared manually during their planning processes that decrease the planning efficiency. Another point observed in the surveyed companies is that MRP computation time is considered a major set-back due to need of ceasing all inventory operations during the computation period. Additional considerations for the approach are given according to the highlights by Tyagi et al. (2013, p.70,71). They are listed in the following.

1- Generality: The proposed method can be applied to different production processes and different industries. Separation of bill of materials from routes provides higher customization ability for the method.

2- Understandability: The proposed method does not refer to complex optimization methods that require engineering, and it can be implemented and utilized by different personnel ranks.

3- Decision Support System: The method is constructed as a decision support system that gives both planners and managers information about the distribution of orders, utilization of capacity, frequency of inventory replenishment and order requirements.

4- Production Lead Time Precision: By the offsets added to operations, the planners are able to react to uncertain events (such as machine break-downs, demand changes etc.) more easily.

Together with these observations and considerations, the application of the proposed approach is constructed. Details of the application are given in Chapter 5. The performance evaluation of the model and the implications for application of the model into the case study company is given in Chapter 7.

Overall, this thesis study contributes to the literature under following points.

1. The problem taken into consideration is a real-life problem that companies deal with every day.

2. Data used in the Case Study is a real-life data. Among the literature search, no such large dataset is taken into consideration for proposed models before (Table 3**Hata! Başvuru kaynağı bulunamadı.**).

3. A general survey is conducted among 64 production companies visualizing the usage of MPC and APS systems among the several different industries, it highlights the need of such systems in the industry.
4. The model is applied and validated during the study, and top-management criteria affected by the model are observed.
5. An alternative method for requirement extraction methodology is validated.
6. The model proposes a general methodology to extract requirements and it can be implemented to any industry.

8.3 Future Research

This study can be further improved by the following points.

1. Inventory information is not utilized until scheduling method. If the inventories of the explosion stock ids can be obtained during extraction, the inventory check can be automated and freed from human interaction.
2. Scheduling can be further modeled to automatically form alternatives and report the comparison of these alternatives.
3. EBOM model can be further optimized to decrease computation time, by preparing a pre-table that collects data from the changes occurred in operations, bill of materials and stock ids. Currently, EBOM Construction procedure is automatically processed during extraction. Separating this process from the rest of the model decreases the computation time of overall process drastically.
4. Reports can be further developed to prepare weekly and monthly budgets for the company. For this function, Stock_Codes and Operation_Table include price information of the corresponding stocks and operations.

REFERENCES

Berber, R., Yuceer, M., Ozdemir, Z., "Automatic Generation of Production Scheduling Models in Single Stage Multi-Product Batch Plants: Some Examples", Mathematical and Computer Modelling, 46, pp. 69-79, 2007.

Chen, G., Yan, L., Shi, B., "Modeling and Optimization for Short-term Scheduling of Multipurpose Batch Plants", Chinese Journal of Chemical Engineering, 22(6), pp. 682-689, 2014.

Cheng, T. C. E., Gao, C., Shen, H., "Production Planning and Inventory Allocation of a Single-Product Assemble-To-Order System with Failure-Prone Machines", *International Journal of Production Economics*, 131 pp. 604-617, 2011.

David, F., Pierreval, H., Caux, C., "Advanced Planning and Scheduling Systems in Aluminium Conversion Industry", *International Journal of Computer Integrated Manufacturing*, vol. 19, no. 7, pp. 705-715, 2006.

Eliiyi, D. T., Azizoglu, M., "Heuristics for Operational Fixed Job Scheduling Problems with Working and Spread Time Constraints", *International Journal of Production Economics*, 132, pp. 107-121, 2011.

Fleischman, B., Meyr, H. Chapter 9: Planning Hierarchy, Modeling and Advanced Planning Systems, 457-523. de Kok, A. G., Graves, S.C., Handbooks in OR & MS, Vol.11, 2003.

Gaudreault, J., Frayret, J,. Rousseau, A., D'Amours, S., "Combined Planning and Scheduling in a Divergent Production System with Co-production: A Case Study in the Lumber Industry", *Computers & Operations Research*, 38, pp. 1238–1250, 2011.

Gen, M., Lin, L., "Multi-Objective Evolutionary Algorithm for Manufacturing Scheduling Problems: State-of-the-Art Survey", *Journal of Intelligent Manufacturing*, 25, pp. 849-866, 2014.

Genin, P., Thomas, A., Lamouri, S., “How to Manage Robust Tactical Planning with an APS (Advanced Planning Systems)”, *Journal of Intelligent Manufacturing*, 18, pp. 209-221, 2007.

Gokce M. A., Beygo, B., Emekci, T., “A Hyperheuristic Approach for Dynamic Multilevel Capacitated Lot Sizing with Linked Lot Sizes for APS Implementations”, *Journal of Yasar University*, 12/45, pp. 14–31, 2017.

He, N., Zhang, D. Z., Li, Q., “Agent-Based Hierarchical Production Planning and Scheduling Make-to-Order Manufacturing System”, *International Journal of Production Economics*, 149, pp. 117–130, 2014.

Jonsson, P., Kjellsdoter, Rudberg, M., “Applying Advanced Planning Systems for Supply Chain Planning: Three Case Studies”, *International Journal of Physical Distribution & Logistics Management*, vol. 37, no. 10, pp. 816-834, 2007.

Kabak, E. K., Ornek, M. A., “Measurement of Instability in Multi – Item MRP Systems Under Varying Operating Conditions”, sub to. Dokuz Eylül Üniversitesi, 2005.

Kabak, E. K., Ornek, M. A., “An Improved Metric for Measuring Multi-Item Multi-Level Schedule Instability Under Rolling Schedules”, *Computers & Industrial Engineering*, 56, pp. 691–707, 2009.

Kerkhove, L. P., Vanhoucke, M., “Scheduling of Unrelated Parallel Machines with Limited Server Availability on Multiple Production Locations: A Case Study in Knitted Fabrics”, *International Journal of Production Research*, 52(9), pp. 2630–2653, 2014.

Kung L. C., Chen, C. C., “Heuristic Factory Planning Algorithm for Advanced Planning and Scheduling”, *Computers &Operations Research*, 36, pp. 2513-2530, 2009.

Luo, M., “Study on Scheduling Optimization of Automatic Production Line in Production Shop Based on Multi-Objective Optimization Algorithm”, *Academic Journal of Manufacturing Engineering*, vol. 16, is. 3, pp. 147-154, 2018.

Lupeikiene, A., Dzemyda, G., Kiss, F., Caplinskas, A., “Advanced Planning and Scheduling Systems: Modelling and Implementation Challenges” *INFORMATICA*, Vol. 25, No. 4, pp. 581–616, 2014.

Nahmias, S., Production & Operations Analysis, New York, McGraw Hill Education, 6th Ed., 2013.

Nguyen, S., Zhang, M., Johnston, M., Tan, K. C., “Automatic Design of Scheduling Policies for Dynamic Multi-objective Job Shop Scheduling via Cooperative Coevolution Genetic Programming”, *IEEE Transaction on Evolutionary Computation*, vol. 18, no. 2, pp.193-208, 2014.

Ozturk, C., Ornek, M. A., “Optimization and Constraint Based Heuristic Methods for Advanced Planning and Scheduling”, *International Journal of Industrial Engineering*, 23(1), pp. 26-48, 2016.

Ozturk, C., Tunalı, S., Hnich, B., Ornek, M. A., “Cyclic Scheduling of Flexible Mixed Model Assembly Lines with Parallel Stations”, *Journal of Manufacturing Systems*, 36, pp. 147-158, 2015.

Pinedo, M.L., Scheduling Theory, Algorithms, Systems, New York, Springer Science and Business Media, LLC., 3rd Ed., 2008.

Smith, A., Milletlerin Zenginliği, İstanbul, Türkiye İş Bankası Kültür Yayınları, 7. Basım, 2013.

Stadtler, H., Kilger, C., Supply Chain Management and Advanced Planning, Berlin, Springer Berlin, 3rd Ed., 2005.

Tyagi, V., Jain, A., Jain, P. K., “Towards Integrated Manufacturing Planning and Control: A Review and Classification”, *The IUP Journal of Operations Management*, vol. 12, no. 2, pp. 57–79, 2013.

Vollmann, T.E., William L., Berry, D., Waybark, C., Manufacturing Planning and Control Systems, Irwin/McGraw-Hill, 4th Ed., 1997.

Zhang, H., Gen, M., “Effective Genetic Approach for Optimizing Advanced Planning and Scheduling in Flexible Manufacturing System”, GECCO '06 Proceedings of the 8th Annual Conference on Genetic and Evolutionary Computation, pp. 1841-1848, 2006.

Zhong, R. Y., Huang, G. Q., Lan, S., Dai, Q. Y., Zhang, T., Xu, C., “A Two-Level Advanced Production Planning and Scheduling Model for RFID-Enabled Ubiquitous Manufacturing”, *Advanced Engineering Informatics*, 29, pp. 799–812, 2015.

Zoryk-Schalla, A. J., Fransoo, J. C., de Kok, T. G., “Modeling the Planning Process in Advanced Planning Systems”, *Information & Management*, vol. 42, pp. 75–87, 2004.

APPENDICIES

A.1 – M Query Codes

A.1.1 M Query for EBOM Construction

Please note that m query does not allow while loop in joint tables. Therefore all 8 levels of bill of materials are added manually.

```
let

    Source = Excel.Workbook(File.Contents("D:\OneDrive\Masaüstü\Input.xlsx"), null, true),

    Stock_Codes_Table = Kaynak{[Item="Stock_Codes",Kind="Table"]}[Data],

    OP_Level1 = Table.NestedJoin(Stock_Codes_Table, {"Stock_ID"}, Operation_Table, {"Stock_ID"}, "Operation", JoinKind.LeftOuter),

    Expand_OP_Level1= Table.ExpandTableColumn(OP_Level1, "Operation", {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}, {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}),

    BOM_Level1 = Table.NestedJoin(Expand_OP_Level1, {"Stock_ID"}, Bill_Of_Materials, {"Stock_ID"}, "Bill_Of_Materials", JoinKind.LeftOuter),

    Expand_BOM_Level1 = Table.ExpandTableColumn(BOM_Level1, "Bill_Of_Materials", {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}, {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}),

    Rename_Level1 = Table.RenameColumns(Expand_BOM_Level1,{{"Operation_ID", "Operation_ID1"}, {"Operation_Output_Amount", "Operation_Output_Amount1"}, {"Operation_Duration", "Operation_Duration1"}, {"Operation_Station", "Operation_Station1"}, {"Operation_OffSet", "Operation_OffSet1"}, {"SubComponent_ID", "SubComponent_ID1"}, {"SubComponent_Category", "SubComponent_Category1"}, {"SubComponent_Amount", "SubComponent_Amount1"}, {"SubComponent_Unit", "SubComponent_Unit1"}}),

    Carry_LastOP_ID1 = Table.AddColumn(Rename_Level1, "Last_Operation_ID1", each [Operation_ID1]),

    Carry_LastOP_Dur1 = Table.AddColumn(Carry_LastOP_ID1, "Last_Operation_Duration1", each [Operation_Duration1]),

    Carry_LastOP_Stat1 = Table.AddColumn(Carry_LastOP_Dur1, "Last_Operation_Station1", each[Operation_Station1]),

    Carry_LastOP_Out1= Table.AddColumn(Carry_LastOP_Stat1, "Last_Operation_Output1", each[Operation_Output_Amount1]),

    Calc_LastOP_OffSet1 = Table.AddColumn(Carry_LastOP_Out1, "Last_Operation_OffSet1", each [Operation_OffSet1]),
```

Carry_LastSP_ID1 = Table.AddColumn(Calc_LastOP_OffSet1, "Last_SemiProduct_ID1", each [Stock_ID]),

Carry_LastRM_Level1 = Table.AddColumn(Carry_LastSP_ID1, "Last_RawMaterial_ID1", each if [SubComponent_ID1] = null then

[Stock_ID]

else[SubComponent_ID1]),

Calc_LastRM_Amount_Level1 = Table.AddColumn(Carry_LastRM_Level1, "Last_Raw_Material_Amount1", each [SubComponent_Amount1]),

Op_Level2 = Table.NestedJoin(Calc_LastRM_Amount_Level1, {"SubComponent_ID1"}, Operation_Table, {"Stock_ID"}, "Operation", JoinKind.LeftOuter),

Expand_OP_Level2 = Table.ExpandTableColumn(Op_Level2, "Operation", {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}, {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}),

BOM_Level2 = Table.NestedJoin(Expand_OP_Level2, {"SubComponent_ID1"}, Bill_Of_Materials, {"Stock_ID"}, "Bill_Of_Materials", JoinKind.LeftOuter),

Expand_BOM_Level2 = Table.ExpandTableColumn(BOM_Level2, "Bill_Of_Materials", {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}, {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}),

Rename_Level2 = Table.RenameColumns(Expand_BOM_Level2,{{"Operation_ID", "Operation_ID2"}, {"Operation_Output_Amount", "Operation_Output_Amount2"}, {"Operation_Duration", "Operation_Duration2"}, {"Operation_Station", "Operation_Station2"}, {"Operation_OffSet", "Operation_OffSet2"},{"SubComponent_ID", "SubComponent_ID2"}, {"SubComponent_Category", "SubComponent_Category2"}, {"SubComponent_Amount", "SubComponent_Amount2"}, {"SubComponent_Unit", "SubComponent_Unit2"}}),

Carry_LastOP_ID2 = Table.AddColumn(Rename_Level2, "Last_Operation_ID2", each if [Operation_ID2] = null then

[Last_Operation_ID1]

else[Operation_ID2]),

Carry_LastOP_Dur2 = Table.AddColumn(Carry_LastOP_ID2, "Last_Operation_Duration2", each if [Operation_Duration2] = null then

[Last_Operation_Duration1]

else[Operation_Duration2]),

Carry_LastOP_Stat2 = Table.AddColumn(Carry_LastOP_Dur2, "Last_Operation_Station2", each if [Operation_Station2] = null then

[Last_Operation_Station1]

else [Operation_Station2]),

Carry_LastOP_Out2 = Table.AddColumn(Carry_LastOP_Stat2, "Last_Operation_Output2", each if [Operation_Output_Amount2] = null then

[Last_Operation_Output1]

else [Operation_Output_Amount2]),

Calc_LastOP_OffSet2 = Table.AddColumn(Carry_LastOP_Out2, "Last_Operation_OffSet2", each if [Operation_OffSet2] = null then

[Last_Operation_OffSet1]

else[Operation_OffSet2]+[Last_Operation_OffSet1]),

Carry_LastSP_ID2 = Table.AddColumn(Calc_LastOP_OffSet2, "Last_SemiProduct_ID2", each if [SubComponent_ID2] = null then

[Last_SemiProduct_ID1]

else

[SubComponent_ID1]),

Carry_LastRM_Level2 = Table.AddColumn(Carry_LastSP_ID2, "Last_RawMaterial_ID2", each if [SubComponent_ID2] = null then

[Last_RawMaterial_ID1]

else[SubComponent_ID2]),

Calc_LastRM_Amount_Level2 = Table.AddColumn(Carry_LastRM_Level2, "Last_Raw_Material_Amount2", each if [SubComponent_ID2] = null then

[Last_Raw_Material_Amount1]

else

[Last_Raw_Material_Amount1]*[SubComponent_Amount2]),

OP_Level3 = Table.NestedJoin(Calc_LastRM_Amount_Level2, {"SubComponent_ID2"}, Operation_Table, {"Stock_ID"}, "Operation", JoinKind.LeftOuter),

Expand_OP_Level3 = Table.ExpandTableColumn(OP_Level3, "Operation", {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}, {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}),

BOM_Level3 = Table.NestedJoin(Expand_OP_Level3, {"SubComponent_ID2"}, Bill_Of_Materials, {"Stock_ID"}, "Bill_Of_Materials", JoinKind.LeftOuter),

Expand_BOM_Level3 = Table.ExpandTableColumn(BOM_Level3, "Bill_Of_Materials", {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}, {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}),

Rename_Level3 = Table.RenameColumns(Expand_BOM_Level3,{{"Operation_ID", "Operation_ID3"}, {"Operation_Output_Amount", "Operation_Output_Amount3"}, {"Operation_Duration", "Operation_Duration3"}, {"Operation_Station", "Operation_Station3"}, {"Operation_OffSet", "Operation_OffSet3"}, {"SubComponent_ID", "SubComponent_ID3"}, {"SubComponent_Category", "SubComponent_Category3"}, {"SubComponent_Amount", "SubComponent_Amount3"}, {"SubComponent_Unit", "SubComponent_Unit3"}}),

Carry_LastOP_ID3 = Table.AddColumn(Rename_Level3, "Last_Operation_ID3", each if [Operation_ID3] = null then

[Last_Operation_ID2]

else[Operation_ID3]),

Carry_LastOP_Dur3 = Table.AddColumn(Carry_LastOP_ID3, "Last_Operation_Duration3", each if [Operation_Duration3] = null then

[Last_Operation_Duration2]

else[Operation_Duration3]),

Carry_LastOP_Stat3 = Table.AddColumn(Carry_LastOP_Dur3, "Last_Operation_Station3", each if [Operation_Station3] = null then

[Last_Operation_Station2]

else [Operation_Station3]),

Carry_LastOP_Out3 = Table.AddColumn(Carry_LastOP_Stat3, "Last_Operation_Output3", each if [Operation_Output_Amount3] = null then

[Last_Operation_Output2]

else [Operation_Output_Amount3]),

Calc_LastOP_OffSet3 = Table.AddColumn(Carry_LastOP_Out3, "Last_Operation_OffSet3", each if [Operation_OffSet3] = null then

[Last_Operation_OffSet2]

else[Operation_OffSet3]+[Last_Operation_OffSet2]),

Carry_LastSP_ID3 = Table.AddColumn(Calc_LastOP_OffSet3, "Last_SemiProduct_ID3", each if [SubComponent_ID3] = null then

[Last_SemiProduct_ID2]

else

[SubComponent_ID2]),

Carry_LastRM_Level3 = Table.AddColumn(Carry_LastSP_ID3, "Last_RawMaterial_ID3", each if [SubComponent_ID3] = null then

[Last_RawMaterial_ID2]

else[SubComponent_ID3]),

Calc_LastRM_Amount_Level3 = Table.AddColumn(Carry_LastRM_Level3, "Last_Raw_Material_Amount3", each if [SubComponent_ID3] = null then

[Last_Raw_Material_Amount2]

else

[Last_Raw_Material_Amount2]*[SubComponent_Amount3]),

OP_Level4 = Table.NestedJoin(Calc_LastRM_Amount_Level3, {"SubComponent_ID3"}, Operation_Table, {"Stock_ID"}, "Operation", JoinKind.LeftOuter),

Expand_Op_Level4 = Table.ExpandTableColumn(OP_Level4, "Operation", {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}, {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}),

BOM_Level4 = Table.NestedJoin(Expand_Op_Level4, {"SubComponent_ID3"}, Bill_Of_Materials, {"Stock_ID"}, "Bill_Of_Materials", JoinKind.LeftOuter),

Expand_BOM_Level4 = Table.ExpandTableColumn(BOM_Level4, "Bill_Of_Materials", {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}, {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}),

Rename_Level4 = Table.RenameColumns(Expand_BOM_Level4,{{"Operation_ID", "Operation_ID4"}, {"Operation_Output_Amount", "Operation_Output_Amount4"}, {"Operation_Duration", "Operation_Duration4"}, {"Operation_Station", "Operation_Station4"}, {"Operation_OffSet", "Operation_OffSet4"}, {"SubComponent_ID", "SubComponent_ID4"}, {"SubComponent_Category", "SubComponent_Category4"}, {"SubComponent_Amount", "SubComponent_Amount4"}, {"SubComponent_Unit", "SubComponent_Unit4"}}),

Carry_LastOP_ID4 = Table.AddColumn(Rename_Level4, "Last_Operation_ID4", each if [Operation_ID4] = null then

[Last_Operation_ID3]

else[Operation_ID4]),

Carry_LastOP_Dur4 = Table.AddColumn(Carry_LastOP_ID4, "Last_Operation_Duration4", each if [Operation_Duration4] = null then

[Last_Operation_Duration3]

else[Operation_Duration4]),

Carry_LastOP_Stat4 = Table.AddColumn(Carry_LastOP_Dur4, "Last_Operation_Station4", each if [Operation_Station4] = null then

[Last_Operation_Station3]

else [Operation_Station4]),

Carry_LastOP_Out4 = Table.AddColumn(Carry_LastOP_Stat4, "Last_Operation_Output4", each if [Operation_Output_Amount4] = null then

[Last_Operation_Output3]

else [Operation_Output_Amount4]),

Calc_LastOP_OffSet4 = Table.AddColumn(Carry_LastOP_Out4, "Last_Operation_OffSet4", each if [Operation_OffSet4] = null then

[Last_Operation_OffSet3]

else[Operation_OffSet4]+[Last_Operation_OffSet3]),

Carry_LastSP_ID4 = Table.AddColumn(Calc_LastOP_OffSet4, "Last_SemiProduct_ID4", each if [SubComponent_ID4] = null then

[Last_SemiProduct_ID3]

else

[SubComponent_ID3]),

Carry_LastRM_Level4 = Table.AddColumn(Carry_LastSP_ID4, "Last_RawMaterial_ID4", each if [SubComponent_ID4] = null then

[Last_RawMaterial_ID3]

else[SubComponent_ID4]),

Calc_LastRM_Amount_Level4 = Table.AddColumn(Carry_LastRM_Level4, "Last_Raw_Material_Amount4", each if [SubComponent_ID4] = null then

[Last_Raw_Material_Amount3]

else

[Last_Raw_Material_Amount3]*[SubComponent_Amount4]),

OP_Level5 = Table.NestedJoin(Calc_LastRM_Amount_Level4, {"SubComponent_ID4"}, Operation_Table, {"Stock_ID"}, "Operation", JoinKind.LeftOuter),

Expand_OP_level5 = Table.ExpandTableColumn(OP_Level5, "Operation", {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}, {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}),

BOM_Level5 = Table.NestedJoin(Expand_OP_level5, {"SubComponent_ID4"}, Bill_Of_Materials, {"Stock_ID"}, "Bill_Of_Materials", JoinKind.LeftOuter),

Expand_BOM_level5 = Table.ExpandTableColumn(BOM_Level5, "Bill_Of_Materials", {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}, {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}),

Rename_Level5 = Table.RenameColumns(Expand_BOM_level5,{{"Operation_ID", "Operation_ID5"}, {"Operation_Output_Amount", "Operation_Output_Amount5"}, {"Operation_Duration", "Operation_Duration5"}, {"Operation_Station", "Operation_Station5"}, {"Operation_OffSet", "Operation_OffSet5"}, {"SubComponent_ID", "SubComponent_ID5"}, {"SubComponent_Category", "SubComponent_Category5"}, {"SubComponent_Amount", "SubComponent_Amount5"}, {"SubComponent_Unit", "SubComponent_Unit5"}}),

Carry_LastOP_ID5 = Table.AddColumn(Rename_Level5, "Last_Operation_ID5", each if [Operation_ID5] = null then

[Last_Operation_ID4]

else[Operation_ID5]),

Carry_LastOP_Dur5 = Table.AddColumn(Carry_LastOP_ID5, "Last_Operation_Duration5", each if [Operation_Duration5] = null then

```
[Last_Operation_Duration4]

else[Operation_Duration5]),

    Carry_LastOP_Stat5 = Table.AddColumn(Carry_LastOP_Dur5, "Last_Operation_Station5", each if [Operation_Station5] = null then

[Last_Operation_Station4]

else [Operation_Station5]),

    Carry_LastOP_Out5 = Table.AddColumn(Carry_LastOP_Stat5, "Last_Operation_Output5", each if [Operation_Output_Amount5] = null then

[Last_Operation_Output4]

else [Operation_Output_Amount5]),

    Calc_LastOP_OffSet5 = Table.AddColumn(Carry_LastOP_Out5, "Last_Operation_OffSet5", each if [Operation_OffSet5] = null then

[Last_Operation_OffSet4]

else[Operation_OffSet5]+[Last_Operation_OffSet4]),

    Carry_LastSP_ID5 = Table.AddColumn(Calc_LastOP_OffSet5, "Last_SemiProduct_ID5", each if [SubComponent_ID5] = null then

[Last_SemiProduct_ID4]

else

[SubComponent_ID4]),

    Carry_LastRM_Level5 = Table.AddColumn(Carry_LastSP_ID5, "Last_RawMaterial_ID5", each if [SubComponent_ID5] = null then

[Last_RawMaterial_ID4]

else[SubComponent_ID5]),

    Calc_LastRM_Amount_Level5 = Table.AddColumn(Carry_LastRM_Level5, "Last_Raw_Material_Amount5", each if [SubComponent_ID5] = null then

[Last_Raw_Material_Amount4]

else

    [Last_Raw_Material_Amount4]*[SubComponent_Amount5]),

    Op_Level6 = Table.NestedJoin(Calc_LastRM_Amount_Level5, {"SubComponent_ID5"}, Operation_Table, {"Stock_ID"}, "Operation", JoinKind.LeftOuter),

    Expand_OP_Level6 = Table.ExpandTableColumn(Op_Level6, "Operation", {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}, {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}),

    BOM_Level6 = Table.NestedJoin(Expand_OP_Level6, {"SubComponent_ID5"}, Bill_Of_Materials, {"Stock_ID"}, "Bill_Of_Materials", JoinKind.LeftOuter),
```

Expand_BOM_Level6 = Table.ExpandTableColumn(BOM_Level6, "Bill_Of_Materials", {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}, {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}),

Rename_Level6 = Table.RenameColumns(Expand_BOM_Level6,{{"Operation_ID", "Operation_ID6"}, {"Operation_Output_Amount", "Operation_Output_Amount6"}, {"Operation_Duration", "Operation_Duration6"}, {"Operation_Station", "Operation_Station6"}, {"Operation_OffSet", "Operation_OffSet6"}, {"SubComponent_ID", "SubComponent_ID6"}, {"SubComponent_Category", "SubComponent_Category6"}, {"SubComponent_Amount", "SubComponent_Amount6"}, {"SubComponent_Unit", "SubComponent_Unit6"}}),

Carry_LastOP_ID6 = Table.AddColumn(Rename_Level6, "Last_Operation_ID6", each if [Operation_ID6] = null then

[Last_Operation_ID5]

else[Operation_ID6]),

Carry_LastOP_Dur6 = Table.AddColumn(Carry_LastOP_ID6, "Last_Operation_Duration6", each if [Operation_Duration6] = null then

[Last_Operation_Duration5]

else[Operation_Duration6]),

Carry_LastOP_Stat6 = Table.AddColumn(Carry_LastOP_Dur6, "Last_Operation_Station6", each if [Operation_Station6] = null then

[Last_Operation_Station5]

else [Operation_Station6]),

Carry_LastOP_Out6 = Table.AddColumn(Carry_LastOP_Stat6, "Last_Operation_Output6", each if [Operation_Output_Amount6] = null then

[Last_Operation_Output5]

else [Operation_Output_Amount6]),

Calc_LastOP_OffSet6 = Table.AddColumn(Carry_LastOP_Out6, "Last_Operation_OffSet6", each if [Operation_OffSet6] = null then

[Last_Operation_OffSet5]

else[Operation_OffSet6]+[Last_Operation_OffSet5]),

Carry_LastSP_ID6 = Table.AddColumn(Calc_LastOP_OffSet6, "Last_SemiProduct_ID6", each if [SubComponent_ID6] = null then

[Last_SemiProduct_ID5]

else

[SubComponent_ID5]),

Carry_LastRM_Level6 = Table.AddColumn(Carry_LastSP_ID6, "Last_RawMaterial_ID6", each if [SubComponent_ID6] = null then

[Last_RawMaterial_ID5]

else[SubComponent_ID6]),

Calc_LastRM_Amount_Level6 = Table.AddColumn(Carry_LastRM_Level6, "Last_Raw_Material_Amount6", each if [SubComponent_ID6] = null then

[Last_Raw_Material_Amount5]

else

[Last_Raw_Material_Amount5]*[SubComponent_Amount6]),

OP_Level7 = Table.NestedJoin(Calc_LastRM_Amount_Level6, {"SubComponent_ID6"}, Operation_Table, {"Stock_ID"}, "Operation", JoinKind.LeftOuter),

Expand_OP_Level7 = Table.ExpandTableColumn(OP_Level7, "Operation", {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}, {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}),

BOM_Level7 = Table.NestedJoin(Expand_OP_Level7, {"SubComponent_ID6"}, Bill_Of_Materials, {"Stock_ID"}, "Bill_Of_Materials", JoinKind.LeftOuter),

Expand_BOM_Level7 = Table.ExpandTableColumn(BOM_Level7, "Bill_Of_Materials", {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}, {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}),

Rename_Level7 = Table.RenameColumns(Expand_BOM_Level7,{{"Operation_ID", "Operation_ID7"}, {"Operation_Output_Amount", "Operation_Output_Amount7"}, {"Operation_Duration", "Operation_Duration7"}, {"Operation_Station", "Operation_Station7"}, {"Operation_OffSet", "Operation_OffSet7"}, {"SubComponent_ID", "SubComponent_ID7"}, {"SubComponent_Category", "SubComponent_Category7"}, {"SubComponent_Amount", "SubComponent_Amount7"}, {"SubComponent_Unit", "SubComponent_Unit7"}}),

Carry_LastOP_ID7 = Table.AddColumn(Rename_Level7, "Last_Operation_ID7", each if [Operation_ID7] = null then

[Last_Operation_ID6]

else[Operation_ID7]),

Carry_LastOP_Dur7 = Table.AddColumn(Carry_LastOP_ID7, "Last_Operation_Duration7", each if [Operation_Duration7] = null then

[Last_Operation_Duration6]

else[Operation_Duration7]),

Carry_LastOP_Stat7 = Table.AddColumn(Carry_LastOP_Dur7, "Last_Operation_Station7", each if [Operation_Station7] = null then

[Last_Operation_Station6]

else [Operation_Station7]),

Carry_LastOP_Out7 = Table.AddColumn(Carry_LastOP_Stat7, "Last_Operation_Output7", each if [Operation_Output_Amount7] = null then

[Last_Operation_Output6]

else [Operation_Output_Amount7]),

Calc_LastOP_OffSet7 = Table.AddColumn(Carry_LastOP_Out7, "Last_Operation_OffSet7", each if [Operation_OffSet7] = null then

[Last_Operation_OffSet6]

else[Operation_OffSet7]+[Last_Operation_OffSet6]),

Carry_LastSP_ID7 = Table.AddColumn(Calc_LastOP_OffSet7, "Last_SemiProduct_ID7", each if [SubComponent_ID7] = null then

[Last_SemiProduct_ID6]

else

[SubComponent_ID6]),

Carry_LastRM_Level7 = Table.AddColumn(Carry_LastSP_ID7, "Last_RawMaterial_ID7", each if [SubComponent_ID7] = null then

[Last_RawMaterial_ID6]

else[SubComponent_ID7]),

Calc_LastRM_Amount_Level7 = Table.AddColumn(Carry_LastRM_Level7, "Last_Raw_Material_Amount7", each if [SubComponent_ID7] = null then

[Last_Raw_Material_Amount6]

else

[Last_Raw_Material_Amount6]*[SubComponent_Amount7]),

OP_level8 = Table.NestedJoin(Calc_LastRM_Amount_Level7, {"SubComponent_ID7"}, Operation_Table, {"Stock_ID"}, "Operation", JoinKind.LeftOuter),

Expand_Op_Level8 = Table.ExpandTableColumn(OP_level8, "Operation", {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}, {"Operation_ID", "Operation_Output_Amount", "Operation_Duration", "Operation_Station", "Operation_OffSet"}),

BOM_Level8 = Table.NestedJoin(Expand_Op_Level8, {"SubComponent_ID7"}, Bill_Of_Materials, {"Stock_ID"}, "Bill_Of_Materials", JoinKind.LeftOuter),

Expand_Bom_Level8 = Table.ExpandTableColumn(BOM_Level8, "Bill_Of_Materials", {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}, {"SubComponent_ID", "SubComponent_Category", "SubComponent_Amount", "SubComponent_Unit"}),

Rename_Level8 = Table.RenameColumns(Expand_Bom_Level8,{{"Operation_ID", "Operation_ID8"}, {"Operation_Output_Amount", "Operation_Output_Amount8"}, {"Operation_Duration", "Operation_Duration8"}, {"Operation_Station", "Operation_Station8"}, {"Operation_OffSet", "Operation_OffSet8"}, {"SubComponent_ID", "SubComponent_ID8"}, {"SubComponent_Category", "SubComponent_Category8"}, {"SubComponent_Amount", "SubComponent_Amount8"}, {"SubComponent_Unit", "SubComponent_Unit8"}}),

Carry_LastOP_ID8 = Table.AddColumn(Rename_Level8, "Last_Operation_ID8", each if [Operation_ID8] = null then

[Last_Operation_ID7]

else[Operation_ID8]),

Carry_LastOP_Dur8 = Table.AddColumn(Carry_LastOP_ID8, "Last_Operation_Duration8", each if [Operation_Duration8] = null then

[Last_Operation_Duration7]

else[Operation_Duration8]),

Carry_LastOP_Stat8 = Table.AddColumn(Carry_LastOP_Dur8, "Last_Operation_Station8", each if [Operation_Station8] = null then

[Last_Operation_Station7]

else [Operation_Station8]),

Carry_LastOP_Out8 = Table.AddColumn(Carry_LastOP_Stat8, "Last_Operation_Output8", each if [Operation_Output_Amount8] = null then

[Last_Operation_Output7]

else [Operation_Output_Amount8]),

Calc_LastOP_OffSet8 = Table.AddColumn(Carry_LastOP_Out8, "Last_Operation_OffSet8", each if [Operation_OffSet8] = null then

[Last_Operation_OffSet7]

else[Operation_OffSet8]+[Last_Operation_OffSet7]),

Carry_LastSP_ID8 = Table.AddColumn(Calc_LastOP_OffSet8, "Last_SemiProduct_ID8", each if [SubComponent_ID8] = null then

[Last_SemiProduct_ID7]

else

[SubComponent_ID7]),

Carry_LastRM_Level8 = Table.AddColumn(Carry_LastSP_ID8, "Last_RawMaterial_ID8", each if [SubComponent_ID8] = null then

[Last_RawMaterial_ID7]

else[SubComponent_ID8]),

Calc_LastRM_Amount_Level8 = Table.AddColumn(Carry_LastRM_Level8, "Last_Raw_Material_Amount8", each if [SubComponent_ID6] = null then

[Last_Raw_Material_Amount7]

else

[Last_Raw_Material_Amount7]*[SubComponent_Amount8])

in

Calc_LastRM_Amount_Level8

A.1.2 M Query for EBOM table

let

Source = Excel.Workbook(File.Contents("D:\OneDrive\Masaüstü\Input.xlsx"), null, true),

Stock_Codes_Table = Kaynak{[Item="Stock_Codes",Kind="Table"]}[Data],

Changed_Type = Table.TransformColumnTypes(Stock_Codes_Table,{{"Stock_ID", type text}, {"Stock_Defintion", type text}, {"Category", type text}, {"Supplier", type any}}),

Removed_Columns = Table.RemoveColumns Changed Type,{"Supplier"}),

Join_EBOM_Construction= Table.NestedJoin Removed_Columns, {"Stock_ID"}, EBOM_Construction, {"Stock_ID"}, "EBOM_Construction", JoinKind.LeftOuter),

Expand_EBOM_Construction = Table.ExpandTableColumn(Join_EBOM_Construction, "EBOM_Construction", {"Last_Operation_ID8", "Last_Operation_Duration8", "Last_Operation_Station8", "Last_Operation_Output8", "Last_Operation_OffSet8", "Last_SemiProduct_ID8", "Last_RawMaterial_ID8", "Last_Raw_Material_Amount8"}, {"Last_Operation_ID8", "Last_Operation_Duration8", "Last_Operation_Station8", "Last_Operation_Output8", "Last_Operation_OffSet8", "Last_SemiProduct_ID8", "Last_RawMaterial_ID8", "Last_Raw_Material_Amount8"}),

Rename_EBOM_Cons = Table.RenameColumns (Expand_EBOM_Construction,{{"Last_Operation_ID8", "Last_Operation_ID"}, {"Last_Operation_Duration8", "Last_Operation_Duration"}, {"Last_Operation_Station8", "Last_Operation_Station"}, {"Last_Operation_Output8", "Last_Operation_Output"}, {"Last_Operation_OffSet8", "Last_Operation_OffSet"}}),

Reorder_New_Columns = Table.ReorderColumns (Rename_EBOM_Cons,{"Stock_ID", "Stock_Defintion", "Category", "Last_SemiProduct_ID8", "Last_Operation_ID", "Last_Operation_Duration", "Last_Operation_Station", "Last_Operation_Output", "Last_Operation_OffSet", "Last_RawMaterial_ID8", "Last_Raw_Material_Amount8"}),

ReName_RawMat = Table.RenameColumns Reorder_New_Columns,{{"Last_RawMaterial_ID8", "Last_RawMaterial_ID"}, {"Last_Raw_Material_Amount8", "Last_Raw_Material_Amount"}, {"Last_SemiProduct_ID8", "Last_SemiProduct_ID"}}),

Group_by_Operation = Table.Group (ReName_RawMat, {"Stock_ID", "Stock_Defintion", "Category", "Last_SemiProduct_ID", "Last_Operation_ID", "Last_Operation_Duration", "Last_Operation_Station", "Last_Operation_Output", "Last_Operation_OffSet"}, {{"SubComponent_Cout", each Table.RowCount(_), type number}, {"AllRows", each _, type table [Stock_ID=text, Stock_Defintion=text, Category=text, Last_SemiProduct_ID=text, Last_Operation_ID=text, Last_Operation_Duration=number, Last_Operation_Station=text, Last_Operation_Output=number, Last_Operation_OffSet=number, Last_RawMaterial_ID=text, Last_Raw_Material_Amount=number]}}), Expand_Raw_Materials= Table.ExpandTableColumn Group_by_Operation, "AllRows", {"Last_RawMaterial_ID", "Last_Raw_Material_Amount"}, {"Last_RawMaterial_ID", "Last_Raw_Material_Amount"}),

Replace_Nulls1 = Table.ReplaceValue (Expand_Raw_Materials,null,1,Replacer.ReplaceValue,{"Last_Operation_Output"}),

Replace_Nulls2 = Table.ReplaceValue(Replace_Nulls1, null,0,Replacer.ReplaceValue,{"Last_Operation_OffSet"})

in

Replace_Nulls2

A.1.3 M Query for RequirementExtraction

let

Source = Excel.Workbook(File.Contents("D:\OneDrive\Masaüstü\Input.xlsx"), null, true),

OrderTable_Table = Kaynak{[Item="OrderTable",Kind="Table"]}[Data],

ChangeTypes = Table.TransformColumnTypes(OrderTable_Table,{{"ORDERNO", type text}, {"ORDERCODE", type text}, {"ORDERAMOUNT", Int64.Type}, {"CUSTOMER", type text}, {"ORDERDATE", type date}, {"SHIPMENTDATE", type date}}),

Join_EBOM = Table.NestedJoin(ChangeTypes, {"ORDERCODE"}, EBOM_Table, {"Stock_ID"}, "EBOM_Table", JoinKind.LeftOuter),

Expand_EBOM = Table.ExpandTableColumn(Join_EBOM, "EBOM_Table", {"Stock_Defintion", "Category", "Last_SemiProduct_ID", "Last_Operation_ID", "Last_Operation_Duration", "Last_Operation_Station", "Last_Operation_Output", "Last_Operation_OffSet", "SubComponent_Cout", "Last_RawMaterial_ID", "Last_Raw_Material_Amount"}, {"Stock_Defintion", "Category", "Last_SemiProduct_ID", "Last_Operation_ID", "Last_Operation_Duration", "Last_Operation_Station", "Last_Operation_Output", "Last_Operation_OffSet", "SubComponent_Cout", "Last_RawMaterial_ID", "Last_Raw_Material_Amount"}),

Join_SemiProduct = Table.NestedJoin(Expand_EBOM, {"Last_SemiProduct_ID"}, Stock_Codes, {"Stock_ID"}, "Stock_Codes", JoinKind.LeftOuter),

Expand_SemiProduct = Table.ExpandTableColumn(Join_SemiProduct, "Stock_Codes", {"Stock_Defintion", "Category"}, {"Stock_Defintion.1", "Category.1"}),

Order_Columns = Table.ReorderColumns(Expand_SemiProduct,{"ORDERNO", "ORDERCODE", "ORDERAMOUNT", "CUSTOMER", "ORDERDATE", "SHIPMENTDATE", "Stock_Defintion", "Category", "Last_SemiProduct_ID", "Stock_Defintion.1", "Category.1", "Last_Operation_ID", "Last_Operation_Duration", "Last_Operation_Station", "Last_Operation_Output", "Last_Operation_OffSet", "SubComponent_Cout", "Last_RawMaterial_ID", "Last_Raw_Material_Amount"}),

Rename_Columns = Table.RenameColumns(Order_Columns,{{"Stock_Defintion.1", "Last_SemiProduct_Def"}, {"Category.1", "Last_SemiProduct_Cat"}}),

Join_RawMaterial = Table.NestedJoin(Rename_Columns, {"Last_RawMaterial_ID"}, Stock_Codes, {"Stock_ID"}, "Stock_Codes", JoinKind.LeftOuter),

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Expand_RawMaterial = Table.ExpandTableColumn(Join_RawMaterial, "Stock_Codes", {"Stock_Defintion", "Category", "Supplier"}, {"Stock_Defintion.2", "Category.2", "Supplier"}),

Order_Columns1 = Table.ReorderColumns(Expand_RawMaterial,{"ORDERNO", "ORDERCODE", "ORDERAMOUNT", "CUSTOMER", "ORDERDATE", "SHIPMENTDATE", "Stock_Defintion", "Category", "Last_SemiProduct_ID", "Last_SemiProduct_Def", "Last_SemiProduct_Cat", "Last_Operation_ID", "Last_Operation_Duration", "Last_Operation_Station", "Last_Operation_Output", "Last_Operation_OffSet", "SubComponent_Cout", "Last_RawMaterial_ID", "Stock_Defintion.2", "Category.2", "Supplier", "Last_Raw_Material_Amount"}),

Rename_Comlumns1 = Table.RenameColumns(Order_Columns1,{{"Stock_Defintion.2", "Last_RawMaterial_Def"}, {"Category.2", "Last_RawMaterial_Cat"}, {"Supplier", "Last_RawMaterial_Sup"}}),

Calc_TotalRM_Amount = Table.AddColumn(Rename_Comlumns1, "Total_RawMaterial_Amout", each [ORDERAMOUNT]*[Last_Raw_Material_Amount]),

Calc_TotalOP_Duration = Table.AddColumn(Calc_TotalRM_Amount, "Total_Operation_Duration", each if [Last_Operation_Duration] = null then

0

else

Number.Round([ORDERAMOUNT]*[Last_Operation_Duration]/([Last_Operation_Output]*[SubComponent_Cout]*3600),2)),

Calc_Operation_OffSet = Table.AddColumn(Calc_TotalOP_Duration, "Operation_DueDate", each Date.AddDays([SHIPMENTDATE], -[Last_Operation_OffSet])),

Change_Type = Table.TransformColumnTypes(Calc_Operation_OffSet,{{"Last_Operation_Duration", type number}, {"Last_Operation_Output", type number}, {"Operation_DueDate", type date}, {"Total_Operation_Duration", type number}, {"Total_RawMaterial_Amout", type number}})

in

Change_Type
```

A.2 – Company Data (January 2017 – July 2019)

Month	Revenue	Customer Returns	Penalties	Overall Personnel Costs	Planning Personnel Costs	EBITDA %
January-17	3.765.045,97 ₺	0,93%	0,45%	20,76%	0,36%	-13,65%
February-17	4.526.726,18 ₺	0,84%	0,53%	14,70%	0,31%	5,96%
March-17	7.831.921,83 ₺	0,48%	0,55%	11,76%	0,18%	6,93%
April-17	8.082.036,20 ₺	0,37%	0,76%	11,34%	0,14%	4,93%
May-17	8.461.843,83 ₺	1,73%	0,42%	10,47%	0,17%	12,07%
June-17	7.268.732,78 ₺	0,79%	0,99%	12,97%	0,20%	-8,74%
July-17	7.702.818,38 ₺	0,91%	0,78%	13,53%	0,20%	7,35%
August-17	6.608.701,04 ₺	1,22%	1,20%	16,38%	0,16%	2,76%
September-17	7.135.224,84 ₺	1,41%	0,26%	14,42%	0,15%	-0,79%
October-17	7.208.596,39 ₺	3,02%	1,13%	14,91%	0,12%	3,36%
November-17	5.991.387,40 ₺	3,26%	1,24%	15,79%	0,13%	11,90%
December-17	6.582.802,62 ₺	0,66%	0,20%	14,00%	0,21%	9,93%
January-18	5.159.750,58 ₺	0,85%	0,44%	19,85%	0,37%	-5,85%
February-18	6.991.954,51 ₺	1,15%	0,28%	16,17%	0,28%	0,35%
March-18	8.274.177,88 ₺	1,00%	0,49%	13,43%	0,26%	2,31%
April-18	7.760.895,03 ₺	1,39%	0,25%	14,63%	0,36%	8,06%
May-18	8.202.529,22 ₺	0,87%	0,57%	14,80%	0,22%	-3,80%
June-18	7.125.757,39 ₺	0,48%	0,99%	15,04%	0,20%	6,37%
July-18	8.385.465,54 ₺	0,50%	0,42%	13,48%	0,12%	2,77%
August-18	6.597.167,83 ₺	0,95%	0,65%	16,39%	0,13%	8,29%
September-18	9.069.087,05 ₺	0,52%	0,06%	12,32%	0,09%	4,01%
October-18	11.443.330,09 ₺	0,59%	0,36%	10,21%	0,08%	2,54%
November-18	11.243.864,83 ₺	1,06%	0,30%	10,16%	0,08%	10,48%
December-18	8.978.272,25 ₺	0,84%	0,40%	11,46%	0,13%	22,88%
January-19	5.737.474,04 ₺	0,96%	0,66%	20,74%	0,22%	6,55%
February-19	8.531.719,07 ₺	0,71%	0,34%	17,29%	0,16%	13,21%
March-19	9.624.403,90 ₺	0,66%	0,33%	10,95%	0,14%	10,95%
April-19	9.617.279,79 ₺	0,41%	0,31%	14,98%	0,20%	7,17%
May-19	9.995.966,87 ₺	0,48%	0,21%	13,12%	0,19%	10,39%
June-19	8.688.966,30 ₺	0,12%	0,22%	15,02%	0,22%	10,39%
July-19	10.411.648,75 ₺	0,57%	0,56%	12,92%	0,19%	6,74%

A.3 – Survey Data

Comp. Code	Main Process	Industry	Prod. Method	Size	Use Of ERP	ERP Brand	Use of MRP	Freq. of MRP	Use Of MPS	Use of APS	Invested in APS	ATO	MTO	MTS
1	Metal Processing and Assembly	Motor	FS	L	YES	SAP	YES	W	NO	NO	YES	X		X
2	Metal Processing and Assembly	Poultry	JS	L	YES	NETSİS -LOGO	YES	W	YES	NO	YES	X	X	
3	Metal Processing	Household Appliances	JS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	
4	Plastic Injection and Coating	Household Appliances	FS	S	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	
5	Plastic Injection and Assembly	Medical	FS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO			X
6	Plastic Injection and Assembly	Window	FS	M	YES	NETSİS -LOGO	YES	W	YES	NO	NO	X		X
7	Plastic Injection and Assembly	Window	FS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X		X
8	Metal Processing	Automotive	FS	S	YES	NETSİS -LOGO	YES	W	YES	YES	YES	X		
9	Metal Processing	Automotive	JS	S	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	
10	Plastic Injection and Assembly	Household Appliances	FS	M	YES	NETSİS -LOGO	YES	D	NO	NO	NO	X	X	
11	Plastic Injection and Assembly	Household Appliances	FS	S	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X	X	
12	Chemical Processing	Chemical	C	L	YES	SAP	YES	W	YES	NO	NO			X
13	Metal Processing	Sports Equipments	JS	M	YES	NETSİS -LOGO	YES	W	NO	NO	NO	X	X	
14	Rubber Processing	General sub-parts	FS	L	YES	NETSİS -LOGO	YES	W	NO	NO	YES	X	X	X
15	Metal Processing and Assembly	Air Conditionin g	JS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X		

Comp. Code	Main Process	Industry	Prod. Method	Size	Use Of ERP	ERP Brand	Use of MRP	Freq. of MRP	Use Of MPS	Use of APS	Invested in APS	ATO	MTO	MTS
16	Meat Processing	Food	C	L	YES	NETSİS -LOGO	N/A	N/A	NO	NO	NO			X
17	Metal Processing	Automotive	JS	S	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	
18	Livestock and Fodder Processing	Food and Fodder	C	L	YES	NETSİS -LOGO	N/A	N/A	NO	NO	NO			X
19	Metal Processing and Assembly	Machine Production	JS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	
20	Metal Processing	Household Appliances	FS	S	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X	X	
21	Metal Processing	Machine Production	FS	M	YES	MICRO SOFT	NO	N/A	YES	NO	NO	X		
22	Metal Processing and Assembly	Machine Production	FS	M	YES	NETSİS -LOGO	YES	W	NO	NO	NO	X	X	
23	Wood Processing	Furniture	JS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X		X
24	Dairy Processing	Dairy	C	L	YES	NETSİS -LOGO	N/A	N/A	NO	NO	NO			X
25	Rubber Processing	Automotive	FS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	
26	Metal Processing	General sub-parts	JS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	
27	Metal Processing	General sub-parts	JS	L	YES	SAP	YES	W	YES	NO	NO	X	X	
28	Wood Processing	Palette	FS	L	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO			X
29	Plastic Injection and Assembly	Medical	FS	M	YES	SAP	YES	MON THLY	YES	YES	YES			X
30	Electrical Products	Electronics	FS	L	YES	NETSİS -LOGO	YES	W	NO	NO	NO			X
31	Metal Processing	Machine Production	JS	M	YES	NETSİS -LOGO	NO	N/A	YES	NO	NO	X		
32	Plastic Injection	Household Appliances	FS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	
33	Electrical Products	Cabling	FS	S	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X	X	

Comp. Code	Main Process	Industry	Prod. Method	Size	Use Of ERP	ERP Brand	Use of MRP	Freq. of MRP	Use Of MPS	Use of APS	Invested in APS	A T O	M T O	M T S
34	Textile Processing	Sports Textiles	JS	S	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X		
35	Spirit Production	Food	C	L	YES	MICRO SOFT	N/A	N/A	NO	NO	NO			X
36	Metal Casting	General sub-parts	JS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X	X	
37	Metal Processing	General sub-parts	JS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	
38	Spices Processing	Food	C	S	YES	SAP	N/A	N/A	NO	NO	NO			X
39	Metal Processing	General sub-parts	JS	S	YES	MICRO	NO	N/A	NO	NO	NO	X	X	
40	Metal Processing and Assembly	Household Appliances	FS	L	YES	MICRO SOFT	YES	W	YES	YES	YES	X		X
41	Textile Processing	Cloth and yarn production	JS	L	YES	NETSİS -LOGO	N/A	N/A	YES	NO	NO			X
42	Plastic Injection and Assembly	Household Appliances	FS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X	X	
43	Metal Casting and Wire Extrusion	Wiring	FS	L	YES	NETSİS -LOGO	N/A	N/A	NO	NO	NO			X
44	Rubber Processing	General sub-parts and Machine Production	FS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	X
45	Metal Processing	General sub-parts	JS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO		X	
46	Wood Processing and Assembly	Furniture	JS	L	YES	SAP	YES	W	YES	NO	NO	X		X
47	Plastic Injection and Assembly	Household Appliances	FS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X	X	
48	Leather Processing	Processed Leather	JS	L	YES	NETSİS -LOGO	N/A	N/A	NO	NO	NO			X
49	Metal Processing	General sub-parts	FS	S	YES	NETSİS -LOGO	NO	N/A	YES	NO	NO			X
50	Spices Processing	Food	FS	L	YES	SAP	N/A	N/A	NO	NO	NO			X

Comp. Code	**Main Process**	**Industry**	**Prod. Method**	**Size**	**Use Of ERP**	**ERP Brand**	**Use of MRP**	**Freq. of MRP**	**Use Of MPS**	**Use of APS**	**Invested in APS**	**ATO**	**MTO**	**MTS**
51	Metal Processing	Machine Production	JS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X		
52	Metal Processing and Assembly	Bicycle Production	FS	L	YES	SAP	YES	W	YES	NO	NO			X
53	Metal Processing and Assembly	Motor	FS	S	YES	OTHER	NO	N/A	NO	NO	NO			X
54	Assembly	Household Appliances	FS	L	YES	SAP	YES	D	YES	YES	YES			X
55	Chemical Processing	Dying	C	L	YES	NETSİS -LOGO	N/A	N/A	YES	NO	NO			X
56	Metal Processing and Assembly	Machine Production	JS	M	YES	NETSİS -LOGO	NO	N/A	YES	NO	NO	X		
57	Metal Processing	Automotive	JS	L	YES	SAP	YES	W	YES	NO	NO	X	X	
58	Plastic Injection	Packaging	FS	S	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO			X
59	Metal Processing	Automotive	JS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X	X	
60	Plastic Injection and Assembly	Packaging	FS	L	YES	NETSİS -LOGO	YES	D	NO	NO	NO	X	X	X
61	Assembly	Household Appliances	FS	L	YES	SAP	YES	D	YES	NO	YES	X		X
62	Plastic Injection and Assembly	Electronics	FS	L	YES	SAP	YES	D	YES	NO	YES	X		X
63	Glass Production	Glass	C	M	YES	NETSİS -LOGO	N/A	N/A	NO	NO	NO		X	X
64	Metal Processing and Assembly	Household Appliances	FS	M	YES	NETSİS -LOGO	NO	N/A	NO	NO	NO	X	X	

A.4 – Decision Support Information

Strategic Level Indicators and Parameters

Investment Indicators: Increasing or decreasing the machine pool is one of the main components of managing overall capacity. In the yearly planning phase, increasing trends of demands on particular machine groups can be micromanaged by inventory planning, however when such machine group is already a bottleneck, increasing the machine capacity is required.

Opposingly, decreasing trends of demands may provide an excess capacity in a machine group and selling machines can be a beneficial decision. The need of increased or decreased capacity can be obtained with throughout capacity planning both in long, mid and short-term capacity reports.

Subcontracting Indicators: If the demands of capacity fluctuate throughout the year, subcontracting the production can be vital for balancing the capacity loads. Although it is rather an unprofitable solution, on the macro level, it can be employed instead of an investment decision. In addition, short-term changes in the demand characteristics enforces this method to be employed in order to allocate bottleneck stations.

Human Resources Parameters: Due to government regulations and allowances, planning of human resources should be managed both in micro level and macro level. Most of the researchers bypass this topic in planning and simply assumes unlimited resource. However, in reality, general scarcity or surplus effects the profitability of the production systems.

Yearly planning of the human resources requires the knowledge of overall capacity demand trends. In addition, conversion rates of worker hours to machine hours are very critical, and they need to be calculated and observed in the decision-making process.

Fluctuation of demands throughout the year provides hiring and lay off decisions together with overtime decisions and scheduling general annual leaves. All of which both depends and affects the capacity and therefore demands.

Demand Level Indicators and Parameters

Order Horizon Parameters: When dispatching orders to shop floor, choosing which orders to be processed is a primary concern. Combining orders of the same product daily, weekly or monthly, creates differences in setup times. Also, when a capacity bottleneck occurs, it is important to process only orders that are critical.

Master Level Indicators and Parameters

Machine Group Workload Density Indicator: Workload density of the machines and machine groups marks the first of the parameters to be used in the sorting algorithm. The bottleneck machines or groups should be prioritized and orders to be processed should be ranked higher.

In other hand, the excess capacity of the non-bottleneck machine/machine groups should be considered to balance the bottleneck capacities.

Need of Overtime/Leave Parameter: After the machine hour needs are set, another important topic comes to surface. The daily intensity of the machine hours determines the need of worker hours. When the required machine time is over the worker hours, need of overtime occurs. On the contrary, when there is surplus of worker hours, then, according to human resources policy in effect, the need of annual leave, or leave-without-pay decisions should be given.

Because the wages are in fact primal component of production cost, this decision has a huge effect on profitable production.

Mold-Machine Allocation Map: Although the machines in the job floor are similar in their groups which are defined by the machine's clamping force, there are some other parameters in the machines that highly affects the cycle time and production capability when allocated to molds. For plastic injection machines, these differences are, Screw Type, X-Y Plate Dimensions, Stroke and Shot Volume. These parameters should match requirements of the molds.

An allocation map that displays each and every possible combination helps the planning phase by giving different machine-mold combination possibilities.

A.5 – Full Factorial Design of the Experimental Design

Full Factorial Design

```
Factors:   4   Base Design:         4. 16
Runs:     16   Replicates:              1
Blocks:    1   Center pts (total):      0


All terms are free from aliasing.
Design Table (randomized)

Run  A  B  C  D
  1  +  +  +  -
  2  -  -  +  -
  3  +  -  +  -
  4  -  -  -  +
  5  -  +  -  +
  6  +  -  +  +
  7  -  +  +  -
  8  -  +  -  -
  9  +  -  -  +
 10  +  +  -  -
 11  -  -  +  +
 12  -  -  -  -
 13  +  +  +  +
 14  -  +  +  +
 15  +  +  -  +
 16  +  -  -  -
```

Factorial Fit: CalcTime versus maxBMD. avgBCC. countSID. countCO

```
Estimated Effects and Coefficients for CalcTime (coded units)

Term                              Effect      Coef
Constant                                   5,08188
maxBMD                           3,40875   1,70437
avgBCC                           1,78125   0,89062
countSID                         1,03375   0,51688
countCO                          0,18625   0,09313
maxBMD*avgBCC                    0,02125   0,01063
maxBMD*countSID                  0,24375   0,12188
maxBMD*countCO                   0,08125   0,04062
avgBCC*countSID                  0,39625   0,19812
avgBCC*countCO                   0,07375   0,03688
countSID*countCO                 0,04125   0,02062
maxBMD*avgBCC*countSID           0,34125   0,17063
maxBMD*avgBCC*countCO            0,08375   0,04187
maxBMD*countSID*countCO          0,01125   0,00563
avgBCC*countSID*countCO         -0,02625  -0,01312
maxBMD*avgBCC*countSID*countCO   0,01875   0,00937


S = *   PRESS = *


Analysis of Variance for CalcTime (coded units)
```

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	63,5830	63,5830	15,8958	*	*
maxBMD	1	46,4783	46,4783	46,4783	*	*
avgBCC	1	12,6914	12,6914	12,6914	*	*
countSID	1	4,2746	4,2746	4,2746	*	*
countCO	1	0,1388	0,1388	0,1388	*	*
2-Way Interactions	6	0,9225	0,9225	0,1537	*	*
maxBMD*avgBCC	1	0,0018	0,0018	0,0018	*	*
maxBMD*countSID	1	0,2377	0,2377	0,2377	*	*
maxBMD*countCO	1	0,0264	0,0264	0,0264	*	*
avgBCC*countSID	1	0,6281	0,6281	0,6281	*	*
avgBCC*countCO	1	0,0218	0,0218	0,0218	*	*
countSID*countCO	1	0,0068	0,0068	0,0068	*	*
3-Way Interactions	4	0,4971	0,4971	0,1243	*	*
maxBMD*avgBCC*countSID	1	0,4658	0,4658	0,4658	*	*
maxBMD*avgBCC*countCO	1	0,0281	0,0281	0,0281	*	*
maxBMD*countSID*countCO	1	0,0005	0,0005	0,0005	*	*
avgBCC*countSID*countCO	1	0,0028	0,0028	0,0028	*	*
4-Way Interactions	1	0,0014	0,0014	0,0014	*	*
maxBMD*avgBCC*countSID*countCO	1	0,0014	0,0014	0,0014	*	*
Residual Error	0	*	*	*		
Total	15	65,0040				

Obs	StdOrder	CalcTime	Fit	SE Fit	Residual	St Resid
1	8	8,46000	8,46000	*	0,00000	*
2	5	2,77000	2,77000	*	-0,00000	*
3	6	6,07000	6,07000	*	0,00000	*
4	9	2,15000	2,15000	*	0,00000	*
5	11	3,89000	3,89000	*	-0,00000	*
6	14	6,24000	6,24000	*	0,00000	*
7	7	4,64000	4,64000	*	0,00000	*
8	3	3,78000	3,78000	*	0,00000	*
9	10	5,64000	5,64000	*	-0,00000	*
10	4	6,49000	6,49000	*	0,00000	*
11	13	2,96000	2,96000	*	-0,00000	*
12	1	2,11000	2,11000	*	0,00000	*
13	16	8,93000	8,93000	*	0,00000	*
14	15	4,72000	4,72000	*	-0,00000	*
15	12	6,87000	6,87000	*	0,00000	*
16	2	5,59000	5,59000	*	0,00000	*

Estimated Coefficients for CalcTime using data in uncoded units

Term	Coef
Constant	-4,27500
maxBMD	1,26625
avgBCC	0,471250
countSID	0,000104000
countCO	-1,12143E-04
maxBMD*avgBCC	-0,0856250
maxBMD*countSID	-1,80000E-05
maxBMD*countCO	2,67857E-06
avgBCC*countSID	-9,50000E-06
avgBCC*countCO	1,08929E-05
countSID*countCO	9,85714E-09
maxBMD*avgBCC*countSID	3,56250E-06
maxBMD*avgBCC*countCO	3,12500E-07
maxBMD*countSID*countCO	-7,50000E-10
avgBCC*countSID*countCO	-1,17857E-09
maxBMD*avgBCC*countSID*countCO	1,33929E-10