ABSTRACT

Areias, João Sousa, Modeling the Production Planning and Scheduling Activities and Data in Warp Knitting, Dyeing and Finishing. (Under the direction of Dr. Jeffrey Joines and Dr. George Hodge).

Production planning and scheduling plays a fundamental role inside any manufacturing organization, and is a core competence since it interacts with all the functional areas of the organization. Production planning and scheduling is the basic tile of the first information systems upon which enterprise resource planning has been built on. Nevertheless, despite the importance of this function, companies often fail to see the importance of planning and scheduling as well as study the best possible solutions for the function, one such industry is warp knitting. Using the IDEF0 and IDEF1X modeling methodologies, a model for representing the activities and the data involved in the production planning and scheduling of a warp-knitting, dyeing and finishing company has been developed. The models were validated by gathering information from visits made to companies operating in the area of the model. The models may be used as a starting point for an information management solution in production planning and scheduling in the warp knitting, dyeing and finishing industry, as well as determining all the areas that impact a scheduling solution.

MODELING THE PRODUCTION PLANNING AND SCHEDULING ACTIVITIES AND DATA IN WARP KNITTING, DYEING AND FINISHING

BY
JOÃO S. AREIAS

A THESIS SUBMITTED TO THE
GRADUATE FACULTY OF
NORTH CAROLINA STATE UNIVERSITY
IN PARTIAL FULFILLMENT OF THE
DEGREE OF MASTER OF SCIENCE

TEXTILE ENGINEERING

RALEIGH
2002

APPROVED BY

DR. JEFFREY A. JOINES (CO-CHAIR OF ADVISORY COMMITTEE)	DR. GEORGE HODGE (CO-CHAIR OF ADVISORY COMMITTEE)

DR. GARY SMITH

DEDICATION

To my Mother Zulmira and my Grandmother Gilda.

BIOGRAPHY

João Carlos de Sousa Areias was born in Portugal, on May 17th, 1973. He started his bachelors degree in 1991 in the Universidade do Minho and during his studies he did professional training in companies in Portugal (ASA, and BASF), Switzerland (Zellweger Uster), and Germany (Spinweberei Uhingen). He started working in Quality Management in 1997, where he was responsible for implementing ISO 9000 in two textile companies. From 1998 to 1999, he enrolled in several professional training programs both in Quality Management and in education methodologies. After completion of his bachelors degree in 1999, he started his Masters degree in Industrial Engineering and completed it in 2000. In the Fall of 2000 he enrolled in the MS in Textile Engineering program at NCSU. He initiated his Masters in Information System Management in 2001 in the Universidade do Minho. During 2002 he worked in an import company and as an independent consultant.

ACKNOWLEDGMENTS

To my Mother, my Father, my Brother and my Sister, I would like to thank them for their unconditional love, support, and concern, as well as to my family for always being there when I needed them.

To the members of my Advisory Committee, Dr. Joines, Dr. Hodge, and Dr. Smith, for their unconditional support, guidance, understanding, and friendship.

To Carol, for her strength, concern and encouragement during the time I needed it most.

To all the wonderful friends (Han Dong, Brian and Mindy, Justin, Yi, Won, and Christian) that I have encountered during my studies at NCSU, I would like to say thank you for their trust, truthfulness and precious sharing.

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Chapter 1. Introduction

The work presented will focus on the planning and scheduling activities involved in the warp knitting process. Two models will be developed; one representing the activities involved in this process and another representing the data structure involved in the several activities. The models will include the activities involved in the warp knitting and the dyeing and finishing processes of the knitted goods.

The IDEF1X diagrams have the objective of complementing the IDEF0 diagrams, by providing information on the data that is involved in the several activities that compose the Production Planning and Scheduling areas.

1.1. Contents Overview

In order to reach the goal of presenting the activities and data involved in the production planning and scheduling activities of a warp knitted fabrics company, this work will start with an overview in Chapter 2 of the processes to be modeled, and information will be included regarding the most important parameters. Once a clear perspective of the process is attained, this work will analyze the Production Planning (Section 3.1) and the Production Scheduling (Section 3.2) activities. Section 3.1 provides an overview of the concepts, objectives, and activities involved in Production Planning. This section also makes the correlation between what is demanded from the model as an example of good practice methodologies.

Section 3.3 provides an exposition on the importance of information technology (IT) in the textile industry. Since this research proposes a data model for a company, this section has the objective of presenting the importance of IT where the IDEF1X model may be used as a source for the development of such an integrated information system. Section 4.2 will discuss some of the efforts done in the modeling of textile processes.

Following these sections some of the characteristics of the model will be discussed in Section 4.3, namely it's integration in Enterprise Reference Architectures, as well as other considerations that the modeler should be aware in his task. Before the presentation of the models in Chapter 5 and Chapter 6, a general overview of the standards and tools used will be presented. At this point the IDEF0 diagrams are presented, followed by the models built according to the IDEF1X methodology. The thesis finishes with the conclusions and the future work proposed, in Chapter 7 and Chapter 8 respectively.

Chapter 2. Overview of Warp Knitting, Dyeing and Finishing

2.1. Overview of Warp Knitting

In the textile world, warp knitting is a modest but significant and ever growing industry. It is also the youngest industry compared with weaving or even with weft knitting. The beginning of weaving and hand knitting is not known. However, mechanical knitting was invented by Reverend William Lee in 1589, a machine used for the production of socks [33], and it took almost 200 years until Crane of Nottingham applied warp yarn guides to Lee's knitting frame (around 1775), an invention that gave birth to warp knitting [37]. Paget and William Cotton introduced improvements to the looms, in 1861 and 1864 respectively [33]. In 1849, Mattew Townsend (Leicester, England) invented the compound needle, which made the knitting machines simpler and faster [33].

Since the end of World War II the production of warp-knitted goods has experienced big increases, fostered by the usage of knitted goods in apparel [33]. According to Haig [16], this increase was due to two main reasons: the introduction of thermoplastic continuous filament yarns, and the mechanical developments in the warp knitting machine, that has increased the work speed from 300 to 3000 courses per minute.

Even though most of warp knitting production is based on continuous filament yarns, the range of products is extremely wide and ever expanding. Lingerie, light wear, shirting, sheeting, elastic fabrics for foundation garments and swimwear, domestic and automotive upholstery, curtains, drapes, laces, a large selection of geotextiles and industrial textiles are all within the range of products knitted today on warp knitting machines. This great versatility was made possible by the constant development efforts of machinery builders and yarn producers [37].

There are two basic types of warp knitting machines: Tricot and Raschel. In the past the distinction between the machine type was made based on the type of needle used. Tricot machines were equipped with bearded needles while the Raschel machines were equipped with compound needles. With the production of modern knitting machines, both the Tricot and the Raschel are equipped with compound needles. Therefore, a new type of differentiating characteristic was necessary. An accurate definition can be made by regarding the type of sinkers with which the machine is equipped and the role they play in loop formation. The sinkers used for Tricot knitting machines control the fabric throughout the knitting cycle. The fabric is held in the throats of the sinkers while the needles rise to clear and the new loops are knocked over in-between them. In Raschel knitting however, the fabric is controlled by a high take-up tension and the sinkers are only used to ensure that the fabric stays down when the needles rise [37].

From a planning and scheduling perspective, the type of knitting machine will influence the product construction specifications and will be an important factor to consider in the allocation of jobs to machines. Figure 2.1 presents a basic flowchart referencing the activities involved in the knitting process.

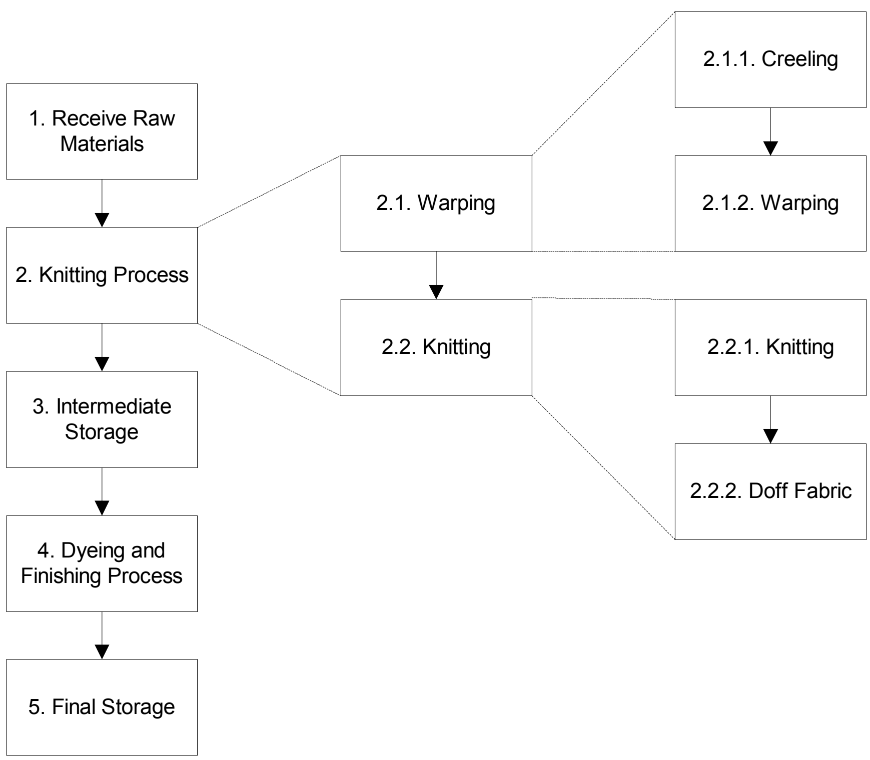


Figure 2.1: Knitting Process Activities Flowchart

2.1.1. Basic Definitions

This section provides a set of definitions to help understand the several terms that are used in the warp knitting process.

Course – a horizontal row of loops formed by the needles during one knitting cycle. In warp knitting, all the needles perform the knitting action simultaneously, such that one knitted course is formed across the whole width of the knitting machine for every turn of the main shaft [37].

Wale – a vertical column of loops formed by a single needle. The number of wales in the fabric equals the number of operating needles across the width of the machine [37].

Loop Parts – the warp knitted loop structure is made of two parts. The first one is the loop itself, which is formed by the yarn being wrapped around the needle and drawn through the previous loop. This part of the structure is called an *overlap*. The second part is the length of yarn connecting the loops, which is called an *underlap*. It is formed by the shogging movements of the ends across the needles [37].

Stitch Density – the density of loops in the fabric is defined as the total number of loops in a square area. The area is usually a square inch or centimeter and the density is obtained by multiplying the number of courses by the number of wales in that area [37].

Machine Gauge – a number of needles per unit length in the knitting machine, measured as the number of needles in one inch. This measure determines the number of wales per unit length in the knitted fabric[1]. The count of fabric courses is determined by machine settings and knitting conditions. The loops can be knitted to be long (giving a slack fabric) or small (giving a tight fabric) [37].

[1] Some warp knitted structures have the tendency to shrink widthwise when leaving the knitting zone, such that the wale count in 1 inch will be greater than the number of needles in the same length (e.g., a locknit structure knitted on 28 Needles Per Inch, will measure in some cases 36 Wales Per Inch, when taken off the knitting machine) [37].

Run-in – a yarn consumption of each guide bar, measured as the length of each yarn knitted into the fabric during 480 knitting cycles. By feeding different amounts of yarn into the knitting zone, the size of the loops is changed. A longer run-in produces a slacker fabric with big loops while a shorter run-in produces small and tight loops [37].

Rack – a working cycle of 480 knitted courses.

2.1.2. Yarn Preparation

As with so many other features, yarn preparation in warp knitting combines methods used in weaving and knitting. Although in some cases the ends of yarn can be fed directly off cones into the knitting machine, the number of cones required restricts this working method. Only when it is technologically necessary, i.e., with Jacquard and curtain machines, is the large floor space required for a creel justified. In all other cases, the yarn ends are fed off warp beams [37].

Warp beams used for warp knitting are in many cases different from those used in weaving. Since synthetic yarns are mainly used along with the moderate tensions applied to the knitting yarns, smooth operation can be ensured without sizing, so yarn preparation can be reduced to a simple winding of yarn ends onto the warp beams [37].

The quality of the warp beam has a crucial effect on the quality of the knitted fabric. In warp knitting, the frequent use of synthetic yarns as well as the loop formation enhance variations in the yarn. Differences in yarn thickness, tension, twist and other factors can result in faulty fabric. In most cases, warping mistakes are hard or impossible to correct during the knitting process [37].

Most knitting firms utilize warping equipment of some sort and prepare some – if not all – of their warp beams independently. Although yarn producers can supply prepared warps, some of the knitters prefer to remain independent. For reasons of economy (transportation costs) and quality, it is customary to acquire the standard types of yarns on beams and to warp effect yarns in the plant. Two methods of warping can be used to prepare the warps for the knitting machines: indirect and direct warping [37]. Indirect warping can be described as a method in which the yarns from the yarn packages are wound onto an intermediate cylinder (mill), in several parallel groups with a specified density, and then are back wound onto the warp beam. Direct warping can be defined as a procedure in which the ends of yarn are wrapped in one operation from the yarn packages onto the warp beam.

According to the warping method, different information requirements are necessary. Table 2.1 provides the necessary data for each warping method.

Table 2.1: Information Requirements for Warping

Information Requirement	Direct Warping	Indirect Warping
Yarn ends density	R	R
Number of revolutions	R	R
Warp length	R	R
Number of sections	NA	R
Yarn ends per section	NA	O

R – Required; O – Optional; NA – Not Applicable

Other devices may be required to be used in the warping process, some of these devices are as follows:

- Oiling devices, in order to produce some of the products in warp knitting, the warp yarn may need to be oiled. Variables include the oil type and the processing temperature;
- Static electricity elimination devices;
- Optical scanners;
- Optical stop motion mechanisms.

Warping of pattern yarns on pattern beams for multi-guide bar Raschel (or Tricot) machines is a different operation which requires different equipment. The low number of yarn ends across the width of the beam and the great number of beams on the beam support restrict the size of the pattern beam. Light-weight shafts (with no flanges) on which the yarn ends are wrapped are used. The low consumption of pattern yarns in the knitting machine allows even to such small amounts of yarn many hours of work (in some cases a few hundred hours). The changing procedure of a pattern beam on the knitting machine is very simple and takes only a few minutes [37].

2.1.3. Knitting Specifications

This section will present some of the specifications required in the knitting process. A brief description of each specification and the way this information is represented will be described in the following subsections.

2.1.3.1. Design Specifications

It is sometimes possible to describe the threading arrangement by quoting the sequence. For example: guide bar 1 fully threaded, guide bar 2 is threaded 2 in, 2 out and guide bar 3 is 1 out, 2 in, 1 out. When the sequence is long and many guide bars are involved, a threading diagram is drawn. Each horizontal row represents a guide bar and the dots indicate an empty guide eye [37].

When manufacturing a tulle structure, the wales are deflected by half a needle space every three courses, due to the lapping movement of the structure. This deflection makes it somewhat difficult to design for this ground structure on technical paper with vertical dots or lines. Different design papers, which indicate the ground structure, can be used [37].

The pattern is set up in older Tricot machines by chain links mounted to the surface of the pattern drum. The links are made to fit a certain machine gauge, and information of the gauge and the height of the link in needle spaces are stamped onto the link.

In the Raschel machine, the link type is dependent on the type of patterning mechanism used. Machines equipped with a “normal” pattern drum, operating directly against the push rod, use regular “N”-type links (like Tricot machines) with height steps each equaling one needle space. Other machines, equipped with an “H” patterning drum, which shogs the guides via a lever, use different links (“H”) with height steps of only half a needle space. The lever doubles the movement so that the guides move as required in steps of full needle spaces. Machines using a bottom and top pattern drum combination, use “H” links on the bottom drum and “E” links on the top one. “E” links are of the same length as “H” links (30 mm), while the height steps are of full needle spaces. “H” and “E” links should never be mixed. The number of links used to control the bars over one knitted course, vary from machine to machine and patterning mechanism to patterning mechanism. Some Raschel machines use two links per course, high-speed machines use four links per course and multibar machines use only one link per knitted course [37].

Accurate information translating the design information to the chain links required should be provided to the operator, in the specification sheet, in order to enable the correct setting up of the design in the knitting machine.

2.1.3.2. Yarn Count and Machine Gauge

In conventional knitting, the yarn thickness that can be used on a knitting machine is limited by the size of the needle’s hook and the space between the needle and the knock over tricks (or sinkers). While a yarn which is too fine for the machine gauge only forms a mesh-like structure, a yarn which is too thick will be chopped up by the needle descending into knock over or in other cases will cause damage to the needle itself [37].

2.2. Overview of Dyeing and Finishing of Knitted Goods

This section presents an overview of the processes that take place between the knitting phase and the final storage of the knitted goods, included in these processes, are the pre-treatment, the dyeing, and the finishing operations to which the knitted goods are subjected, as seen in Figure 2.2.

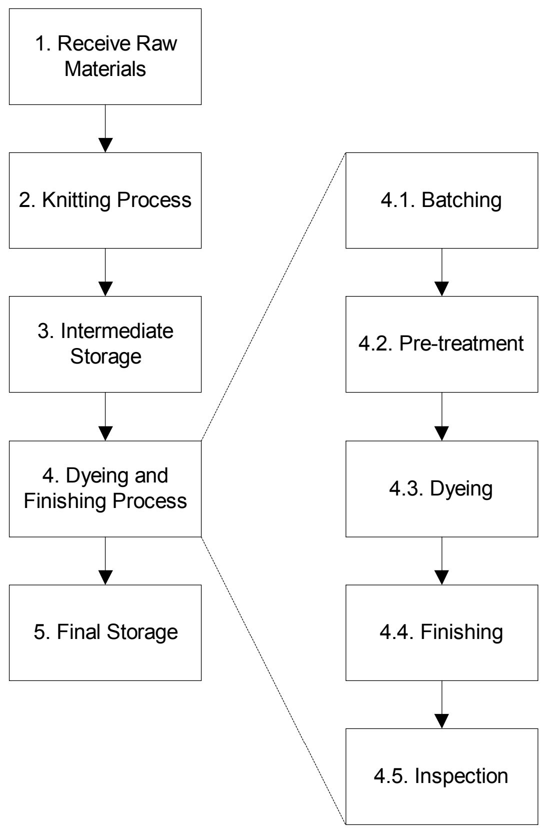


Figure 2.2 Processes Involved in Dyeing and Finishing

The procedures involved in the pretreatment, dyeing and finishing processes, vary greatly with the type of fiber to be treated, the end purpose of the product, the available dyes in the dyehouse, and the equipment availability. It would be an extremely lengthy task to try mapping all the processes possible, or even the most common ones, and define the main parameters and data required. Instead, there will be a brief introduction on the several phases involved in the processes, and the main control parameters used in each phase.

Although there are countless similarities between the dyeing (pre-treatment included) and finishing of warp and weft knitted goods based mainly on the type of treatment, and the machines used. Relatively small changes are usually necessary in the equipment used in order to allow for the correct treatment of warp knitted goods. Warp-knitting contrasts with weft-knitting based on the production direction of the loops since warp-knitted loops are produced with limited width dimension along the length of the fabric and weft-knitted loops are produced across the width of the knitted fabric.

2.2.1. Pre-treatment of Knitted Goods

Pretreatment includes all processes for the improvement of wetting capacity and absorption, dye take-up capacity, purity of the textile material, to increase the degree of whiteness and for better material development (i.e. relaxing and structure development). The raw material contains natural impurities such as grease, pigments or mineral substances and artificial or accidentally applied substances, mineral oil specks caused during knitting, etc. all these impurities must be removed because they impair subsequent finishing. At the same time, tension and material non-uniformity arising from prior knitting processes should be removed [39]. Correct pretreatment is therefore dependent upon [39]:

- The substrate (natural or synthetic fibers),
- Making up form (e.g. fabric, knitted material),
- The procedure (e.g. scouring, alkali treatment, bleaching),
- The machines (continuous, discontinuous, semi-continuous),
- The chemicals (e.g. enzymes, wetting, washing, complexing, stabilizing, reducing, oxidizing, anti-foaming agents).

Pretreatment is a combination of several processes that are selected and controlled according to the dependency of the factors listed above. The most common pretreatment processes for knitted goods are: washing, bleaching, optical brightening, fixing, mercerizing, and shrinking [39].

Washing is the process in which heavy or slight soiling is removed and transferred to the water in the form of a solution or dispersion. Washing has the effect of cleaning surfaces [39]. Bleaching is the chemical treatment of textiles in order to lighten or remove by means of suitable bleaching agents the tinting contained in the grey fabrics due to growth (natural fibres) or production (man-made fibres) [39].

Optical brighteners are substances that may be considered as dyes that instead of absorbing visible radiations, absorb the radiations in the ultraviolet spectrum (wave lengths below 400 nm) and emit radiations in the visible spectrum. When in the fibers, these substances will camouflage the yellowish color, giving a white appearance due to the activity of reflectance [1].

Mercerization is a treatment made with a concentrated solution of caustic soda, on the cotton fibers, with the objective of modifying the structure, increase the shine and the resistance, and improve the dye stuff absorption and the dyeability. On the other hand, there is a fixation of the knitted good structure, increasing the dimensional stability [1].

The shrinking process is an anticipation of shrinkage caused by mechanical and/or hydrothermal finishing processes of non-shrink finish [39]. Also, in order to facilitate the knitting process, the yarns are lubricated in order to reduce the draft, which consequently reduces the tension and yarn breaks. The products used for this objective are usually removed by a simple wash with a soaping agent [1].

2.2.1.1. Pre-treatment Parameters

Table 2.2 provides a set of parameters that apply to several types of pre-treatment processes.

Table 2.2: Pre-treatment Parameters

Treatment Name	Parameters
Washing	• Chemistry; • Liquor ratio; • Mechanics; • Temperature; • Time.
Bleaching	• Chemistry; • Degree of whiteness; • Liquor ratio; • Substrate; • Temperature; • Time.
Mercerization	• Chemistry (caustic soda concentration); • Tension (Impregnation tension, and stabilization tension); • Time (impregnation); • Temperature; • Previous processes.
Shrinking	• Mechanics; • Humidity; • Temperature (heat); • Time.

2.2.2. Dyeing of Knitted Goods

In the case of dyeing and finishing of knitted goods, generally the following sequence of operations is performed.

1. Greige inspection of the fabrics;
2. Preparation of the fabric prior to scouring – batching;
3. Scouring and bleaching, either using conventional winch (open or closed) or HTHP[2] machines from various make;
4. Tensionless horizontal dryers or hot room dryers;
5. Compacting machines that compact the fabric to reduce shrinkages of the fabric after dyeing.

The dyeing process consists on the application of the dye to the textile substrate by a technological process, mainly consisting of deposition or adsorption and fixation (both processes being carried out simultaneously or in succession) [39].

It is necessary to understand the impact of greige inspection before dyeing and finishing. Greige inspection enables the processor to verify if the fabric that has been sent for processing is fault free and determine if it is worthwhile to process. Sometimes such defects as horizontal lines (course wise) are seen at regular intervals, while sometimes the fabric exhibits pinholes or vertical lines splitting the fabric structure. Also, fabric could be stained either due to bad handling, poor oiling, or knitting machine heads (oil stains associated with dust are difficult to remove). Fabrics knitted with carded yarns should not be processed as they exhibit poor properties at the time of dyeing. Carded yarns contain greater number of dead and immature fibers as compared to combed yarns and therefore, combed yarn would be preferable. One must also include inspection of all the dyes and chemicals on a regular routine in order to get required results, in particular, the importance of water, free

[2] HTHP – High-Temperature High-Pressure

from mineral salts needs to be overemphasized. Many times these aspects are overlooked due to urgency of processing and this could prove expensive [11]. Dyeing parameters are dependent on the fiber to be dyed. From the type of fiber the dye selection and consequently the dyeing process is selected as seen in Table 2.3.

Table 2.3: Example of Dyeing Parameters Variables

Fiber Type	Dye Stuff	Application	Dyeing Process	Characteristics
Polyester	Disperse dyes	Main range of dyes	• Beam dyeing machine for warp knitted fabrics. • Pad-roll	• HTHP process
			• Thermosol	-
Acetate	Disperse dyes	Shirting and lingerie	• Beam dyeing	• HT conditions • Carriers
		Warp-knitted fabric	• Winch dyeing	
	Acid dyes	-	• Jig dyeing	-
Polyamide	Acid dyes	Wide color gamut and good fastness properties	• Jig dyeing	-
Cotton	Reactive dyes	Wide color selection and good fastness properties	• Exhaustion	• Winch dyeing machine • Jigger
			• Padding	• Pad batch • Pad Steam

Filament yarns may be chemically or physically variable, and if variable yarn is used in knitting this can lead to the appearance of vertical bars in the warp-knitted goods due to non-uniform dye absorption [16].

Raschel laces and nets require special attention in dyeing, as well as finishing, due to the type of structure that is involved. The structure range obtained is very considerable, including all-overs, plain and embroidered nets, glove fabrics, etc., in addition to laces that range in width from ½” to 6” and are held together for ease of wet processing by draw threads or roving threads. After dyeing and finishing, the draw threads or roving threads are pulled out, unroved or dissolved out to give the lace panels required. Normally, laces are processed in the form of complete pieces ranging in width from 75” to 120”, and are broken up into panels after wet processing is completed.

2.2.2.1. Dyeing Parameters

The range of available dyeing equipment and processes is very wide, and it would be necessary a long and exhaustive list to describe for each equipment and process which parameters should be considered. Considering this fact Table 2.4 makes reference only to the general parameters that should be taken into account regardless of equipment and process.

Table 2.4: Dyeing Parameters

Process	Parameters
Dyeing	• Operating temperature; • Liquor ratio; • Processing time; • Fabric circulation speed; • Fabric weight.

2.2.3. Finishing of Knitted Goods

Before the knitted good is sent to cutting and sewing, it is necessary to proceed to an improvement of certain properties, such as surface appearance, shine, handle, wrinkle behavior, resistance, dimensional stability, etc. The finishing operations are dependent, amongst others on the fibers that compose the knitted good, the type of yarn, the type of knitting procedure, the pre-treatment operations, and the dyestuff used [1].

Two different types of finishing methods may be considered: mechanical and chemical. Mechanical methods alter the properties of the knitted goods only by mechanical action without directly using any type of chemicals. Chemical methods are based on the application of chemical substances that will react with the fibers or will act on the properties of the knitted good. This separation is usually virtual, since in the biggest part of the situations, there is a combination of mechanical and chemical methods [1]. Finishing parameters are dependent on the dyeing process used (that in turn is dependent on the fiber type and dye selection), accordingly the processes used in the finishing of the knitted goods are selected.

Some of the existing mechanical finishing processes applicable to knitted goods are:

- Drying – After wet processing treatments, the drying of the fabric is required. There is a large variety of drying systems available for knitted goods, heating alternatives range from natural gas to IR (i.e. infra red) systems, each requiring specific technology and control variables.

- Calendering – Treatment of open-width fabric with pressurized bowls or rollers on calenders to influence the surface appearance, pore density, smoothness, luster/matt effects, handle and, if required, produce additional patterning effects [39].

- Raising – This finishing process is used to create a different feel and a velvety material surface on fabrics and knitwear by loosening a large number of individual fibers from the fabric and subsequent raising (velour raising) and napping (nap raising) in order to create a dense raised surface. This also produces more fullness and softer handle [39].

- Shearing – The shearing, or cropping, of knitted fabrics is required for three different purposes: to level raised, or unraised fabrics, to cut loop-pile fabrics so as to produce velour finishes, and to level cut pile fabrics in order to give imitation fur fabric finishes [16].

- Shrinking – One of the most important care and use properties of clothing textiles is shape retention during wearing and washing. A positive influence on the dimensional stability of knitwear made from cotton is possible by means of mechanical processes such as controlled compressive shrinkage [39].

Chemical finishing processes, as mentioned previously in Section 2.2.2.1 for dyeing, can be undertaken in a wide range of non specific equipment, usually the same type of machines used for dyeing, or during the mechanical finishing processes, by applying the finishing auxiliaries before or during mechanical processing. Parameters for chemical finishing will mainly depend on the material composition and chemicals to apply. For simplification reasons, the chemical treatments will not be described in Section 2.2.3.1 regarding the parameters involved in finishing operations.

2.2.3.1. Finishing Parameters

For each different operation and machine used, Table 2.5 provides a general description of the parameters involved. These parameters have to be defined in order to program the equipment and control the process.

Table 2.5: Finishing Parameters

Operation	Machine	Parameters
Drying	Stenter[3]	• Production speed; • Processing time; • Fabric length; • Fabric width; • Fabric weight.
	Drying Unit	• Rotation speed; • Processing time; • Processing temperature.
Calendering	Calender	• Rotational speed; • Temperature; • Bowl pressure; • Degree of friction; • Fabric state (wet, dry, damp) • Cloth run; • Number of passages.
Raising	Raising machine	• Rotational speed; • Material tension; • Material speed; • Raising intensity.
Shearing	Shearing machine	• Material speed; • Cylinder speed; • Shearing distance; • Shear value.
Shrinking	e.g.: Sanforizing machine	• Speed; • Humidity; • Temperature; • Degree of shrinkage.

[3] An open-width fabric-finishing machine in which the selvedges of a textile fabric are held by a pair of endless travelling chains maintaining tension.
Note 1: Attachment may be by pins (pin stenter) or clips (clip stenter).
Note 2: Such machines are used for: (a) drying; (b) heat-setting of thermoplastic material; (c) fixing of dyes and chemical finishes: (d) chain mercerizing; (e) controlling fabric width. [2]

Chapter 3. Production Planning and Scheduling

In Chapter 2, the processes involved in knitting, dyeing and finishing have been defined. Now the activities involved in production planning and scheduling will be discussed.

3.1. Overview of Production Planning Activities

As described by Podbereski [35], a good production plan will result in the full and steady utilization of equipment and human resources, in an even flow of production through all the manufacturing departments throughout the duration of the production program, in low in-process inventories and in on time deliveries.

Production planning analyzes orders, separates styles, confirms the existence in stock of the products, checks inventory levels to confirm availability, sends information to purchase department regarding when the materials should be available, and verifies machine availability in order to allow production. The activities involved require information regarding style specifications, inventory levels, parts list, equipment availability, plant capacity, and company policies regarding priority rules.

The activities and the data involved in the models developed, should be as generic as possible in order to provide valuable information regardless of the manufacturing control environment that is used by the knitting company (e.g. Just-In-Time, Manufacturing Resource Planning, or Optimized Production Timetables), this consideration should guarantee the models applicability in different production control systems and different shop floor environments.

3.1.1. The Range of The Production Plan

Planning activities differ highly on the time frame that is considered, and plans can be long, intermediate or short-range. A relationship between plans should be always considered, since intermediate-range plans derive from long-range plans, and short-range plans from intermediate-range plans. Regardless of the time frame considered, production plans should be reviewed and adjusted at regular intervals in order to maintain their accuracy regarding the forecasted and effective customer demand by end product.

Long-range plans are used for helping management formulate capacity planning strategies [32]. Intermediate-range plans, with the aggregate production plan (APP) being an example, will provide inputs to the financial plan, the marketing plan, requirements planning and detailed scheduling decisions, as seen in Figure 3.1. The aggregate plan will determine workforce levels, overtime, and inventory levels with the objective of minimizing costs. Results will be useful for [32]:

- Operating management to determine an operating budget;
- Workforce levels will be translated to the labor budget;
- Inventory levels can be used to determine requirements for storage space.

Aggregate output planning generally consists of planning a desired output (in our study, the unit of measuring output is the length of the knitted fabric) over an intermediate range of three months to one year (the further the forecast goes into the future, the less likely it is to be accurate). As in long range plans, the outputs are in the shape of product groups, in order to keep plans as accurate as possible [32].

Many aggregate planning strategies are available to the manager. These strategies involve the manipulation of inventory, production rate, manpower needs, capacity, and other controllable variables as seen in Figure 3.1 [32].

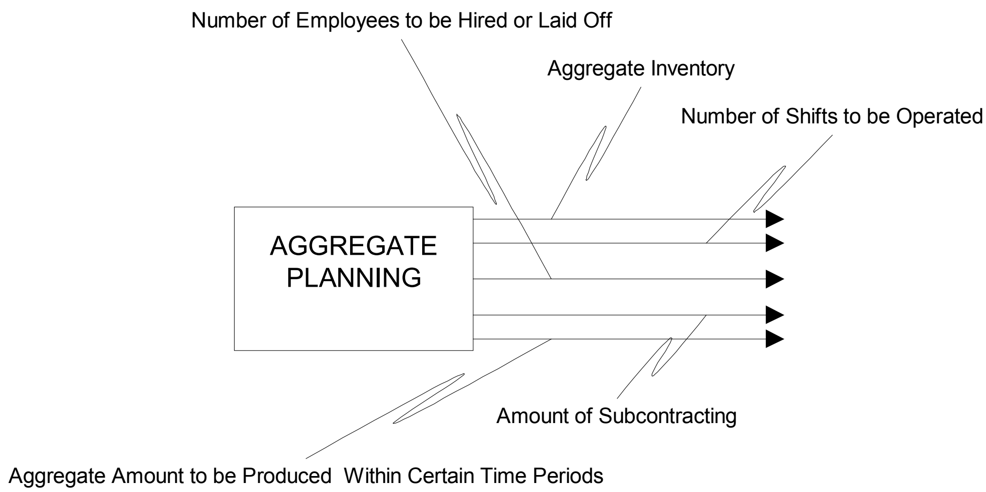


Figure 3.1: Outputs From APP

3.1.2. The Master Production Schedule (MPS)

The MPS is a short term production plan, usually with a time frame of 1 week to 1 month, and it represents a plan for manufacturing, from which the production schedules will be based on. It is not a sales forecast but a feasible manufacturing plan [32].

When a company uses a Material Requirements Planning (MRP[4]) system, the MPS provides the top-level input requirements. The MPS develops the quantities and dates to be exploded for generating per period requirements for subassemblies, piece parts, and raw materials. Inputs for the MPS are the customer order backlog, the product sales forecast, and the inventory on-hand.

It also serves as a customer order backlog system. It considers changes in capacity or loads and finished goods inventory as well as fluctuations in demand. A detailed MPS also determines the economics of production by grouping various demands for lot sizing purposes. The MPS should be consistent with the APP from which it is derived.

[4] MRP consists of a set of logically related procedures, decision rules, and records (alternatively, records may be viewed as inputs to the system) designed to translate a MPS into time phased net requirements, and the planned coverage of each requirement, for each component inventory item needed to implement this schedule [7].

The APP provides a basis for decision making regarding:

- Specific production dates;
- Available capacity;
- Total demand;
- Lead time;
- Inventory constraints.

From the information gathered both in literary reviews and in plant visits, the data used in the Production Planning activities may be divided into several time frames, with each document focusing on a certain time period and consequently having different objectives. Table 3.1 gives an overview of this matter, and provides additional information regarding the normal revision periods for the production plans.

Table 3.1: List of Commonly Available Production Plans

Time Frame	Document Name	Revision Period
2 or more years	Strategic Production Plan	Quarter or Semester
1 year to 1 month	Aggregate Production Plan	Monthly
1 month to 1 Week	Master Production Schedule	Daily

3.2. Overview of Production Scheduling Activities

According to Rodammer and White [38], production scheduling deals with the efficient allocation of resources over time for the manufacture of goods. Scheduling problems arise whenever a common set of resources (labor, material, and equipment) must be used to make a variety of different products during the same period of time. The objective of scheduling is to find a way to assign and sequence the use of these shared resources such that production constraints are satisfied and production costs are minimized. The development of a production schedule involves the selection of a sequence of operations (or process routing) that will result in the completion of a job, designating the resources needed to execute each operation in the routing, and assigning the times at which each operation in the routing will start and finish execution. Routings and resource assignments are the product of process planning, while scheduling generally refers to the activity of timetabling operations.

Diverse factors exist that influence the schedule development, as described by Rodammer and White [38]. Some of these factors include job priorities, due-date requirements, release dates, cost restrictions, production levels, lot-size restrictions, machine availabilities, machine capabilities, operation precedence, resource requirements, and resource availabilities.

To assist the human scheduler and improve the quality and consistency of production schedules, major manufacturers have developed or purchased database systems which track raw materials and work-in-process (WIP) inventories. Many of these database systems also incorporate software tools, which to a greater or lesser degree, automate some aspect of schedule generation. These commercial tools are generally classified by the scheduling technique or the underlying scheduling philosophy employed. Among the most current of the scheduling philosophies and associated software packages are Manufacturing Resource Planning (MRP II), Just-in-Time (JIT) production, and Optimized Production Timetables (OPT) [38]. Now with companies being diverse and global, Enterprise Resource Planning (ERP) is planning across the entire organization.

Several reasons exist for the importance of scheduling in the productive environment. Some of the issues that have caused this concern towards improving scheduling activities are:

- The increase of competition in the world market for manufactured goods; better production schedules provide a competitive advantage through gains in resource productivity and related efficiencies in operations management [38].

- The introduction of new manufacturing technologies systems (e.g. flexible manufacturing, and automation) has increased the necessity of companies to rethink the scheduling activities, in order to cope with different production equipment, requirements, and operational problems [38].

3.2.1. Scheduling Objectives

When scheduling operations, the schedule to be developed should be able to reach a defined goal, according to the objectives of the schedule and management directions. This goal (the scheduling objective) will decide not only the methodology used for creating the schedule but also which schedule is the more advantageous choice from those available. The scheduling goal can also be a composite of several basic objectives. From the existing scheduling objectives, the following are the most important of the basic choices [34]:

Throughput and Makespan Objectives – maximization of the output rate.

Due Date Related Objectives – minimization of the maximum lateness, minimization of the number of tardy jobs, minimization of the total or the average tardiness, minimization of the sum of the earlinesses[5].

Setup Costs – minimization of setup costs.

Work-in-Process Inventory Costs – minimization of the average throughput time, minimization of the sum of the completion times.

[5] In a JIT system, a job should not be completed until just before its committed shipping date to avoid additional inventory and handling costs [34].

Finished Goods Inventory Costs – minimization of the finished goods inventory costs.

Personnel Costs – minimization of required overtime.

3.2.2. Scheduling Considerations

As seen in the previous sections, several variables should be considered when scheduling production activities. Among these variables that influence the scheduling activities we have: end product, production costs, production constraints, operation sequence (or process routing), and resources needed per operation. This section will provide a more detailed view of these variables under the production environment of warp knitting, and dyeing and finishing operations.

3.2.2.1. End Product

Changes in the scheduling activities may greatly depend on the end product that is to be manufactured. From the warp knitting process a wide range of products may result, i.e., lingerie, light wear, shirting, sheeting, elastic fabrics, upholstery, curtains, drapes, and laces, just to name a few. Section 3.2.2.1 will provide information regarding the type of changes required in the scheduling of different product types.

For each different end product, a different set of constraints mainly connected to the production process will apply. As an example, all products are associated with setup times, these setup times will depend not only on the product to be produced, but also on the previous job that has been produced in a given equipment. Besides setup times, job flow consideration will apply, since not all jobs can be produced in the same equipment, but this is more related with routing considerations.

From the variety of different products, it is easily seen that each product will require special scheduling attention, due to the fact that special considerations have to be made in order for it to be in a good production sequence and free of faults. Although companies usually choose to specialize on a given set of products, and so these considerations are taken one in the everyday working conditions in a more flexible, and consequently more generalist production environment, these considerations have to be addressed in the everyday scheduling activities.

3.2.2.2. Production Costs

Costs to be considered in the production planning and scheduling are as follows [32]:

- Regular payroll and overtime cost;
- Cost of changing production rate;
- Inventory, backorder, and shortage costs;
- Subcontracting costs.

The following subsections will explain these costs in more detail.

3.2.2.2.1. Regular Payroll and Overtime Cost

Figure 3.2 (reproduced from Narasimhan et al [32]) shows the general shape of overtime costs for a given workforce size. The costs are kept to a minimum when the facilities are operated at optimum level. The cost increases when the plant is operated below the designed capacity. With continued increases in demand, more and more production is scheduled, and the cost curve rises at higher levels of production. The increase can be attributed to shift premium, supervision, and the decrease in production of workers as they toil through long hours [32].

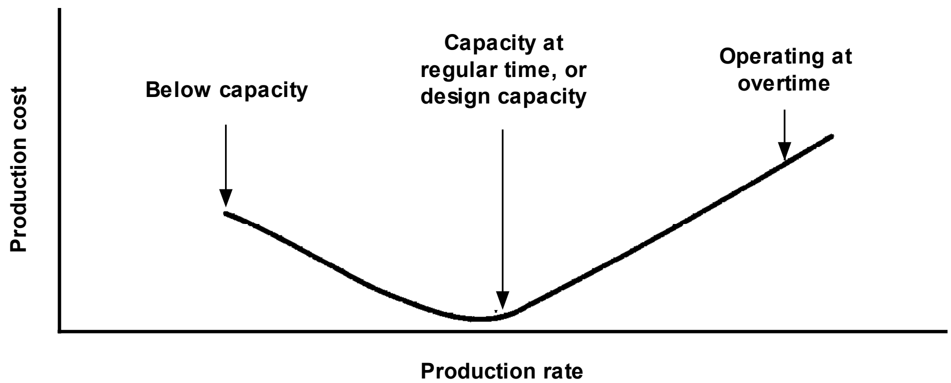


Figure 3.2: Regular Payroll and Overtime Cost

When the need of overtime production is imposed due to planning or scheduling imperatives, the company will need to study the costs involved in the actions according to their own production cost information, in order to study the feasibility of the proposed changes.

3.2.2.2.2. Cost of Changing Production Rate

The costs of changing the production rate can be attributed primarily to changes in the size of the workforce. The typical incremental cost of hiring and layoff is depicted in Figure 3.3, from Narasimhan et al [32]. When the size of the workforce is increased, the firm incurs costs of hiring, training and possible reorganization, resulting in lower productivity in the initial periods. Similarly, when employees are laid off, terminal pay, decreased moral in the remaining employees, and possible decreased productivity from fear of loosing their jobs increases the cost of production. Rarely is a laid-off worker rehired for the same job. In addition, social pressures, company image, and other factors prevent excessive hiring and firing. In many instances, union contracts and supplemental unemployment benefits (SUB) programs make it very costly for a firm to lay off workers. The incremental cost of increasing the production rate could be different from the incremental cost of decreasing the production rate, as illustrated by the shape of the curve along the vertical axis in Figure 3.3 [32].

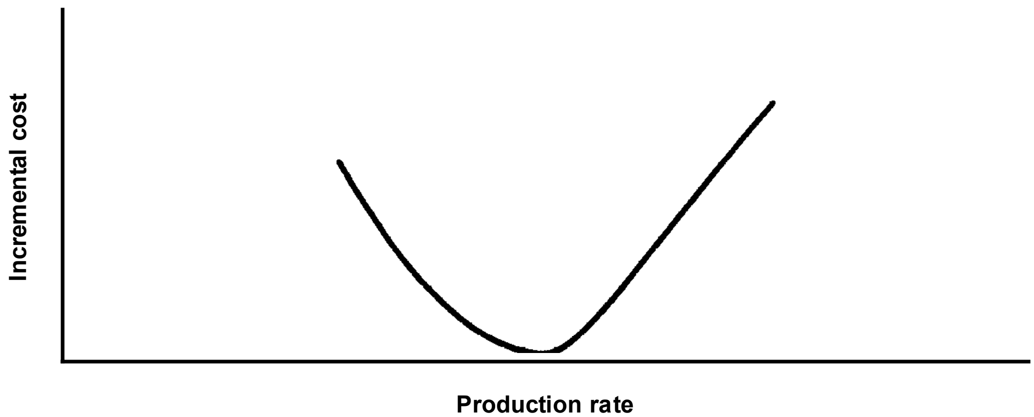


Figure 3.3: Cost of Changing Production Rate

In responding to changes in production levels, management should consider the costs of hiring and training and other associated layoff costs against the costs of overtime and undertime and the possible decrease in productivity caused by prolonged working hours [32].

3.2.2.2.3. Inventory, Backorder, and Shortage Costs

The cost per year of carrying inventory typically ranges from 5% to 50% of the value of items. The total inventory cost for all items is obtained by summing individual item inventory costs. The cost of backordering and lost sales could also be treated in the same manner. If lost sales occur too often, an easy path to competition might be opened, and hence the cost could be high. However, the cost of lost sales is very difficult to estimate [32].

3.2.2.2.4. Subcontracting Costs

As an alternative to changing production levels and carrying inventory, a firm may elect subcontracting to meet peak demands. Subcontracting may not be profitable, however, since the contractor may charge a much higher price than the firm usually pays employees. Subcontracting may also open the doors for competition. It is also hard, in many instances, to find a reliable supplier who delivers on time. Difficulties in forecasting the right quantities could result in excessive inventory or shortage costs [32].

3.2.3. Production Constraints

Pinedo and Chau [34] present a sample set of constraints that are applicable to the knitting and dyeing and finishing processes. Some of the applicable constraints are detailed below.

1. Precedence constraints ensure that a job can only start when a given set of jobs has been completed.

2. Routing constraints specify the route a job takes through the system. For example in a flow shop or a job shop, a given job may consist of a number of operations that must be processed on specified machines in a given sequence.

3. Material-handling constraints enforces strong dependencies between starting times of operations and the completion times of their predecessors. Moreover, the presence of a material-handling system often limits the amount of buffer space, which in turn limits the amount of WIP.

4. Sequence-dependent setup times and costs incur when machines often have to be reconfigured or cleaned between jobs. This process is known

as a changeover or setup. If the length of the setup depends on the job just completed and on the one about to be started, then the setup times are sequence-dependent. Besides taking valuable machine time, setups also involve costs in the form of labor, waste of raw material, and so on.

5. Often during the processing of a job, some event occurs that requires the job to be interrupted in favor of a different job, for instance, when a high-priority rush order arrives at the machine. The job taken off the machine is preempted.

6. Storage-space and waiting-time constraints occur in many production systems, especially those that produce bulky items, the amount of space available for WIP storage is limited. This constraint puts an upper bound on the number of jobs waiting for a machine. Storage space constraints in flow shops can cause blocking.

7. A manufacturing facility may opt to keep in stock items for which there is a steady demand and no risk of obsolescence. This decision to make-to-stock affects the scheduling process because items that have to be produced for inventory, do not have tight due dates. Make-to-order jobs, conversely, have specific due dates, and the amount of produced is determined by the customer. Many production facilities operate partly according to make-to-stock and partly according to make-to-order.

8. In a parallel-machine environment, a specific job may often not be processed on just any of the available machines, but rather must be processed on a machine belonging to a specific subset of machines. This situation arises when the available machines in parallel are not identical. Therefore machine eligibility constraints have to be taken into account,

9. Machines usually require one or more tools to process the jobs they handle and tooling constraints and resource constraints have to be considered. These tools may be of various types, some with only limited availability. In a parallel-machine environment jobs have to be scheduled such that the tooling requirements are met.

10. Personnel scheduling constraints occur when certain people have to operate certain machines. These constraints are also commonly of a form in which people must work a specified amount of consecutive days followed by a number of consecutive days off. However, there are many different types of shifts as well as many ways of rotating them.

3.2.4. Operation Sequence (or Process Routing)

The manufacturing process of knitted goods no matter what the end product might be, can be simplified to the operation sequences of knitting, dyeing, finishing, sewing, and after treatments (considering finished yarn as the raw material feeding the knitted process). The work developed will only cover the knitting, dyeing, and finishing operations, where details of the operations were explained in Chapter 2. Both manufacturing environments considered fall under the flow shop model[6]. This fact greatly simplifies the routing problem, due to the linear sequence of operations that the knitted goods undertake.

[6] In many manufacturing or assembly environments, jobs have to undergo multiple operations on a number of different machines. If the routes of all jobs are identical, that is, all jobs visit the same machines in the same order, the environment is referred to as flow shop. The machines are set up in a series, and whenever a job completes its processing on one machine, it joins the queue at the next. The sequence of the jobs may vary from machine to machine, since jobs may be resequenced between machines. However, if a material-handling system transports the jobs from one machine to the next, then the same job sequence is maintained throughout the system.
In some flow shops, if a job does not need processing at a particular machine, it may bypass that machine and go ahead of the jobs being processed or waiting for processing there. Other flow shops, however, do not allow bypass [34].

3.2.5. Resources Needed per Operation.

The resources required for productive processes fall under the categories of labor, material, and equipment. Labor includes the human workforce required to complete a job, materials are the inputs that will be transformed in the process, and equipment includes the tools and machines necessary for the transformation of the inputs into the final product (i.e., the job output).

The resources needed in the knitting and in the dyeing and finishing process vary substantially according to the different objectives of the process. While knitting provides the final product structure, dyeing and finishing operations will change the structure properties according to the end product final purpose.

3.3. Role of Information Technologies (IT)

Sections 3.1 and 3.2 explained the planning and scheduling processes that apply to knitting, dyeing and finishing. This section will explore the role of IT that is useful to the process.

3.3.1. The Importance of Information

The first reference made to the management of information as a separate area in the ever growing complex environment of the organization, is traced to Leavitt and Whisler [29] in the year 1958. The authors identified Information Technology as an individual area, serving as a management tool for business.

In the late 60's, with the publishing of "Management Information-Decision Systems: A new era ahead?" by Dickson [9], the asset of information inside the organization has came to the front of the business concerns. Dickson pointed out the need of a management information–decision system (MIS), to cope with the increasing complexity of organizations, MIS is pointed out as a management requisite, while information is viewed as a resource, parallel to land, labor, and capital, this resource must also be a subject of managerial planning and control.

The 70's brought the strengthening of the importance of MIS (Management Information Systems) in the organizations, and saw the birth of the first ERP (Enterprise Resource Planning) systems, introduced by SAP.

In a 1988 article [10], Peter Drucker develops an idea of the organization to come, the information based organization. He projects a knowledge based organization, composed largely of specialists who direct and discipline their own performance through organized feedback from colleagues, customers, and headquarters. Information is described as "data endowed with relevance and purpose".

This shift from the command and control organization to the knowledge-based organization, will imply several changes in the decision processes, management structure, work procedures, and organizational structure of the still typical command and control organizations of today.

As pointed out by Drucker [10], the requirements of the information-based organization are:

- Clear, simple, common objectives that translate into particular actions;
- Concentration on one objective or, at most, on a few – management should assure that the company keeps its focus on the objectives it has;
- Structured around goals that clearly state management's performance expectations for the enterprise and for each part and specialist and around organized feedback that compares results with these performance expectations so that every member can exercise self-control; and
- Everyone takes information responsibility.

Although the idea of an information based organization has been widely accepted in the management world, it is still an orientation that hasn't reached the majority of the organizations. In fact, even those that may have an IS working, may not be a KBO in the sense that knowledge being considered the main asset of the organization.

How can production planning and production scheduling work in a way that is in agreement with the concept of knowledge based organization? The planning and scheduling areas have been the initial focus of information technologies, with the MRP systems of the 70's, the evolution and the demand have increased the scope of the IT (with MRP and ERP systems), but have evolved from the core PP&S system, IT solutions have the core system of MRP. The data that can be extracted from this area is relevant as indicator of functioning conditions of the manufacturing. Data is available on:

- Amount of stocks that exists, enabling the company to understand the stock management procedures and correct it, sales personnel may have access to stocks and provide a quick response to customers regarding availability of articles; and
- Working conditions, not only regarding the overall efficiency of manufacturing, but also machine occupancy, waiting times for processing, interaction between departments (e.g. between knitting and dyeing and finishing).

In the 78th conference of The Textile Institute, Dr. Ercam [12] points out some reasons why information is important. These reasons are as follows:

- Proper use of information in planning, designing, and managing of production, distribution, and marketing facet of the business concerned will optimize the profit margins to be obtained;
- An efficient communication amongst the systems not only will speed up decision making at the planning, producing, and supplying levels, it will also bring about an innovative leap within the business;

- Well informed businesses are most generally more privileged in arriving at better ends. Proper information at the right time does miracles for both the enterprise and the individuals working there. To start with, the right system used correctly saves the nerves and health of all who are involved in the business;
- Decentralization of information avoids anomalous end result in the work produced, and wastage of resources and energy; and
- Those who share information amongst colleagues and co-workers improve in performance. Those who consider information as sacredly secret, on the other hand, keep on running perhaps to remain at the same point.

Information can be seen as a resource, generated inside the company, or arriving from the outside world, that in order to be transformed into competitive advantage, should be correctly dealt with, transformed, and transferred within the company, so that its usage, and there is no value added from unused information, may work for the development of the company as a whole.

3.3.2. Importance of IT in Textile Companies

From all the investigators that dedicated their work on the application of IT in the Textile Industry, one that proposes several papers and insights on this matter is Prof. Jayaraman from Georgia Tech.

Changes in the Textile Industry are occurring and will continue to occur during the years to come. Although some of the biggest changes have already taken place in consumers minds and attitudes, not all textile companies have managed to keep the pace of change and are now in situations where the direction is not clear and the road to success is not as bright as it might be, if any road can be seen.

Jayaraman [18] points out some of the changes that are taking place as well as these that are changing the way the Textile Industry interacts with the outside world, and vice versa. In fact, the simple fact of considering the outside world as a world apart from a company's daily reality is by itself a bad sign of vision, requiring the company to seriously consider having its vision checked.

From the key assets of the company: information[7] and people, the author sees Information Technology as the key enabler facilitating the transformations that must take place in the Textile Industry in the new millennium, and specifies the role of IT in the success of the textile company in the years that have came and will continue to come.

Change is caused by drivers that promote it. Jayaraman [18] pointed out the following drivers of change: smart shopper, emergence of alternate shopping channels, importance of globalization, and success of the free market paradigm. From these drivers, several transformations should take place in the company in order for it to cope with the challenges of new times, as a result the author points out the following new demands: smaller lot sizes (mass customization), increased product flexibility, higher product quality, and decreasing delivery times.

The textile industry has been in the forefront of a large number of changes in the productive, organizational, and managerial revolutions. Since the beginning of mankind, the production of textile goods has been a basic need for humans. It was one of the leading industries of the Industrial Revolution, together with one of the first mass production industries to being developed. It was in the forefront of the computerized productive machines, with the Jacquard. It keeps pace with the most advanced technological developments that happen on several industries, from automotive to airspace industries. It is one of the most automated manufacturing industries, with developments in completely automated spinning lines to continuous finishing lines.

[7] Jayaraman [18] defines the attributes of information as: Accurate, Quality, Useful, Applicable, Timely, Informative, Comprehensive, and Succinct (AQUATICS).

But in the middle of all this, it is noticeable that the biggest amount of organizations working in the textile industry still have a poor understanding of how fundamental and strategic information is in their organization. One of the leading world industries is now fading when it comes to cope with the information age developments.

The textile retail business has a different perspective on this. Fostered by the commercial aspects, information plays an important role when it comes to deciding trends and market needs. But why is the manufacturing side of the textile reality still working on a command and control basis? The knowledge age is here to stay, and companies should use their knowledge to increase competitiveness and continuous improvement.

Organizations should worry about knowledge creation, they should think backwards from knowledge, to information, and from information to data in order to define the data they need to generate and analyze in order to reach the objectives established.

3.3.3. Overview of Computer Integrated Manufacturing

Computer Integrated Manufacturing (CIM) was proposed in the late 1970s and early 1980s as a technique by which discrete manufacturing companies might take advantage of computer technology to reorganize the way in which information was collected, analyzed, and used to streamline their manufacturing plants operations. The resulting benefits should include: improved product quality; a company organization more responsive to new products, new customer requests and changing competition; higher productivity; and in addition would result in reduced costs and/or higher profits. Unfortunately, a high proportion of the attempts to achieve these benefits from the CIM technology that existed at that time, have been disappointing at best. These results were due to several factors [45]:

- Early practitioners did not realize the magnitude in sheer size and complexity of the overall task they were attempting. As a result, most were too small and specific to accomplish the benefits desired. This also resulted in many so-called "islands of automation", with plant areas unable to communicate with each other and thus defeating the desired information integration of the whole plant [45].
- A sufficiently detailed methodology for carrying out the CIM project was never developed and applied as a general procedure. As a result each project had to originate its own methodology thus greatly increasing the manpower, resources, time and costs required and eliminating the possibility of a learning curve developing in this field [45].
- Likewise early practitioners did not appreciate the extent to which the human factors involved affected the outcome of their projects. Lack of knowledge or of training combined with lack of acceptance of the new systems by plant workers spelled failure [45].

Chapter 4. Modeling Overview and Considerations

4.1. IDEF Modeling Methodology

During the 1970s, the U.S. Air Force Program for Integrated Computer Aided Manufacturing (ICAM) sought to increase manufacturing productivity through systematic application of computer technology. The ICAM program identified the need for better analysis and communication techniques for people involved in improving manufacturing productivity.

As a result, the ICAM program developed a series of techniques known as the IDEF (ICAM Definition) techniques that included the following:

IDEF0, used to produce a "function model". A function model is a structured representation of the functions, activities or processes within the modeled system or subject area.

IDEF1, used to produce an "information model". An information model represents the structure and semantics of information within the modeled system or subject area.

IDEF2, used to produce a "dynamics model". A dynamics model represents the time-varying behavioral characteristics of the modeled system or subject area.

In 1983, the U.S. Air Force Integrated Information Support System program enhanced the IDEF1 information modeling technique to form IDEF1X (IDEF1 Extended), a semantic data modeling technique. Currently, IDEF0 and IDEF1X techniques are widely used in the government, industrial and commercial sectors, supporting modeling efforts for a wide range of enterprises and application domains.

In 1991 the National Institute of Standards and Technology (NIST) received support from the U.S. Department of Defense, Office of Corporate Information Management (DoD/CIM), to develop one or more Federal Information

Processing Standards (FIPS) for modeling techniques. The techniques selected were IDEF0 for function modeling and IDEF1X for information modeling. The FIPS documents used [13, 14, 31] are based on the IDEF manuals published by the U.S. Air Force in the early 1980s.

4.1.1. IDEF0 Modeling Methodology

IDEF0 (Integration DEFinition language 0) is based on SADT (Structured Analysis and Design Technique), developed by Douglas T. Ross and SofTech, Inc. In its original form, IDEF0 includes both a definition of a graphical modeling language (syntax and semantics) and a description of a comprehensive methodology for developing models.

IDEF0 may be used to model a wide variety of automated and non-automated systems. For new systems, IDEF0 may be used first to define the requirements and specify the functions, and then to design an implementation that meets the requirements and performs the functions. For existing systems, IDEF0 can be used to analyze the functions the system performs and to record the mechanisms (means) by which these are done. The result of applying IDEF0 to a system is a model that consists of a hierarchical series of diagrams, text, and glossary cross-referenced to each other. The two primary modeling components are functions (represented on a diagram by boxes) and the data and objects that inter-relate those functions (represented by arrows).

As a function modeling language, IDEF0 has the following characteristics:

- It is comprehensive and expressive, capable of graphically representing a wide variety of business, manufacturing and other types of enterprise operations to any level of detail.
- It is a coherent and simple language, providing for rigorous and precise expression, and promoting consistency of usage and interpretation.

- It enhances communication between systems analysts, developers and users through ease of learning and its emphasis on hierarchical exposition of detail.
- It is well-tested and proven, through many years of use in Air Force and other government development projects, and by private industry.
- It can be generated by a variety of computer graphics tools; numerous commercial products specifically support development and analysis of IDEF0 diagrams and models.

The primary objectives of the IDEF0 standard [14] are:

a) To provide a means for completely and consistently modeling the functions (activities, actions, processes, operations) required by a system or enterprise, and the functional relationships and data (information or objects) that support the integration of those functions;

b) To provide a modeling technique which is independent of Computer-Aided Software Engineering (CASE) methods or tools, but which can be used in conjunction with those methods or tools;

c) To provide a modeling technique that has the following characteristics:

   - Generic (for analysis of systems of varying purpose, scope and complexity);
   - Rigorous and precise (for production of correct, usable models);
   - Concise (to facilitate understanding, communication, consensus and validation);
   - Conceptual (for representation of functional requirements rather than physical or organizational implementations);

- Flexible (to support several phases of the lifecycle of a project).

The use of the IDEF0 standard is strongly recommended for projects that:

a) Require a modeling technique for the analysis, development, re-engineering, integration, or acquisition of information systems;
b) Incorporate a systems or enterprise modeling technique into a business process analysis or software engineering methodology.

4.1.1.1. Definitions

In order to better familiarize the reader with the terminology used in the diagrams, Section 10.1.2 in Appendix I includes a set of definitions contained in the IDEF0 standard [14] that are used in the current work.

4.1.2. IDEF1 Modeling Methodology

IDEF1 can be viewed as a method for both analysis and communication in establishing CIM requirements. However, IDEF1 is primarily focused on support of the task of establishing the requirements for what information is or should be managed by an enterprise. In CIM applications, IDEF1 is generally used to:

1. Identify what information is currently managed in the organization;
2. Identify which of the problems identified during the needs analysis are caused by lack of management of appropriate information; and
3. Specify what information will be managed in the "TO-BE" CIM implementation.

The IDEF1, Information Modeling Method, derives its foundations from three primary sources: The Entity-Link-Key-Attribute (ELKA) method developed by Hughes Aircraft Co., the Entity-Relationship (ER) method proposed by Peter Chen, and Codd's Relational Model.

The original intent of IDEF1 was to capture what information exists or should be managed about objects falling within the scope of an enterprise. Thus, the IDEF1 perspective of an information system is one which includes not only the automated component, or the computer, but also includes humans, filing cabinets, telephones, etc. A design goal for IDEF1 was that it not be a database design method. At the time of the IDEF1 development, it was the opinion of the database community that what was needed was a way for organizations to analyze and clearly state their information resource management needs and requirements.

This was the motivation for the development of IDEF1. Rather than a design method, IDEF1 is an analysis method used to identify:

1. What information is collected, stored, and managed by the enterprise;
2. The rules governing the management of information;
3. Logical relationships within the enterprise reflected in the information;
4. Problems resulting from the lack of good information management.

The results of information analysis can be used by strategic and tactical planners within the enterprise to leverage their information assets to achieve competitive advantage. Part of their plans may include the design and implementation of automated systems which can more efficiently take advantage of the information available to the enterprise. IDEF1 models provide the basis for those design decisions. IDEF1, then, is not used to design a database; rather, it is used to provide managers with the insight and knowledge required to establish good information management policy.

The popularity of the IDEF1 method is principally due to its focus on enhancing human-to-human communication. Over the years, a variety of automated tools have emerged that support the application of this method. As these tools become integrated with traditional Computer Aided Software Engineering (CASE) environments, a new world of opportunities is emerging. In this new order, Frameworks of Systems architecture methods including IDEF1 as a component will feed enterprise repositories. These repositories (or knowledge bases) will enable the realization of integrated systems of a scale presently unattainable.

To date, one of the small but important missing pieces in this picture has been the availability of the original descriptions of the IDEF methods. The original IDEF1 document, painstakingly constructed by Dr. Robert R. Brown, Tim Ramey, and Reuben Jones under the direction of Dr. Steven LeClair and Dr. Richard J. Mayer, was published as a volume in an Air Force Technical Report [31].

4.1.3. IDEF1X Modeling Methodology

IDEF1X is used to produce information models, which represent the structure and semantics of information within an enterprise. IDEF1X is used to produce a graphical information model that represents the structure and semantics of information within an environment or system. Use of this standard permits the construction of semantic data models that may serve to support the management of data as a resource, the integration of information systems, and the building of computer databases [13].

This information modeling technique is used to model data in a standard, consistent, predictable manner in order to manage it as a resource. The primary objectives of this standard are:

a) To provide a means for completely understanding and analyzing an organization’s data resources;

b) To provide a common means of representing and communicating the complexity of data;

c) To provide a method for presenting an overall view of the data required to run an enterprise;

d) To provide a means for defining an application-independent view of data which can be validated by users and transformed into a physical database design;

e) To provide a method for deriving an integrated data definition from existing data resources.

4.1.3.1. Definitions

In order to better familiarize the reader with the terminology used in the diagrams, Section 10.1.3 in Appendix I includes a set of definitions contained in the IDEF1X standard [13] that are used in the current work.

4.2. Previous Textile Information Models

Section 4.1 described the modeling methodologies used in this work. In this section, an overview of some of the main models that have been developed for the textile industry will be presented, with special emphasis on the knitting process.

4.2.1. Modeling the Textile Processes

The Demand Activated Manufacturing Architecture (DAMA) is part of the AMTEX Partnership. AMTEX started in 1992 as a partnership of the US Department of Energy and its laboratories, universities, and textile companies, to enhance the competitiveness of the US textile industry. The DAMA project began in 1993 as one of several AMTEX initiatives with a vision statement as follows:

“By the end of the decade, the Demand Activated Manufacturing Architecture project will link the US Integrated Textile Complex, enabling effective and responsive decisions resulting in a net gain in the global marketplace” (DAMA, 1995, p.ii). The enterprise architecture task focuses on how a product moves through the textile pipeline as it is transformed from fiber to apparel over approximately a 55-week period to enhance the understanding of business practices. The project has completely modeled the production of men’s cotton slacks through the textile complex [17].

Campos [5] developed a data-flow model of a weft-knitting facility that included data-flow diagrams for the entire facility from the point of view of the plant manager. Ten major tasks were identified, and these were then expanded into 53 sub-tasks and 18 data-storage areas. A data dictionary with 84 items was developed. The weft knitting model was based on the Purdue Reference Model where the model was adapted for textile terminology and reorganized to reflect textile enterprises. The Purdue model proved to be a good basis for developing this generic textile model. The Data Flow Diagrams were also easily explainable to users within manufacturing. The weft knit facility model could be used for developing plant specific models and could serve as a functional network model for the definition of information systems. Based on the CIMOSA modeling framework, the model would be a partial model with an information view for requirement specification [17].

Shail [40] developed an IDEF0 model for a batch dye house facility for cloth. The model addressed both information and manufacturing areas of the facility. The point of view of the model was from that of the plant manager for day-to-day operation. The objective was to define the functions and interfaces within a dye house operation for the development of a computer integrated manufacturing system. The model consisted of six main activities, which were further expanded into 23 sub activities. A total of 35 inputs, outputs, controls, and mechanisms were defined. The model was developed using the software tool WizdomWorks! (Wizdom) such that a possible repository of models could be developed [17].

Under the title “Information Technology and Data Modeling in Large Diameter Circular Weft Knitting with Data Standardization and Profiling”, Cete [6] reviewed and expanded the DAME Textile Enterprise Model of yarn and fabric production activity for knitting yarn. The new activity model has been developed and implemented using Wizdom IDEF modeling software to provide reusable repository of models. A data model for knitting has been developed based on the IDEF1X methodology that is linked to the IDEF0 activity model. A data profile for knitting operations has been developed for the standardization of large diameter circular weft knitting data elements and data processing equipment.

Depending on the desired application, models and modeling tools for describing the Production Scheduling of general facilities are currently available. This section presents one of the models developed for warp knitting. One of the objectives of this work is to develop a specific model of the scheduling activity for the knitting industry.

The following images are Data Flow Diagrams (DFD) that represent the information that is transmitted between several different areas and activities in the company. Both diagrams (Figure 4.1 and Figure 4.2) have been presented by Campos [5] and were based on the Purdue Enterprise Reference Architecture.

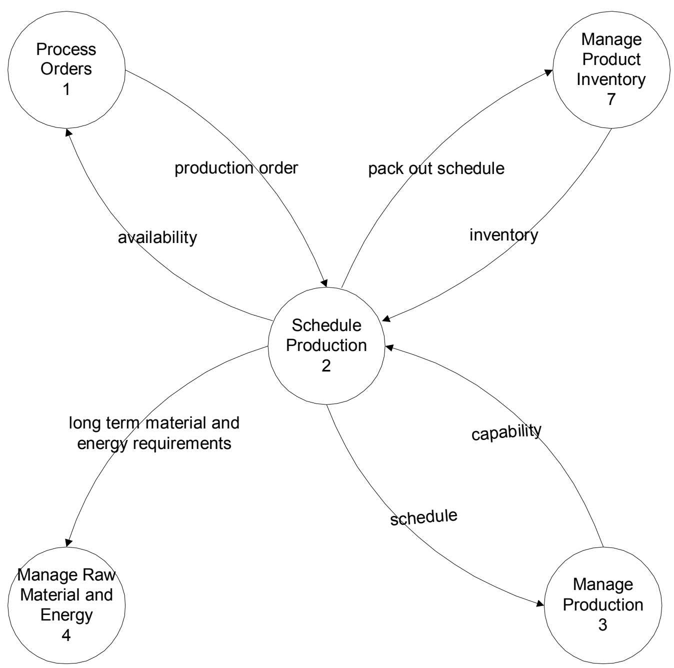


Figure 4.1: Parent DFD

In a DFD, arrows represent data transmission, and a description the data can be seen on the arrow. Arrow heads represent the data destination and activities are numbered and inserted inside a circle. These diagrams also allow the representation of data storage, that can be seen by the two parallel lines represented in Figure 4.2. Further detailed diagrams can be seen and the numbering reflects the parent activity for the child diagram. Child diagram activities are numbered as A.B, where A represents the parent diagram activity number, and B represents the child diagram activity number. The level of decomposition of DFD diagrams depends solely on the needs and objectives of the model created.

Both diagrams give a description on how the information is transmitted between production areas. In Figure 4.1 one can see how the schedule production activity interacts with the process orders, manage product inventory, manage raw material and energy, and manage production. Figure 4.2 presents a more detailed view of the schedule production activity, separating this activity in two other activities that are part of it, these child activities are: balance in process and product inventory and create production schedule.

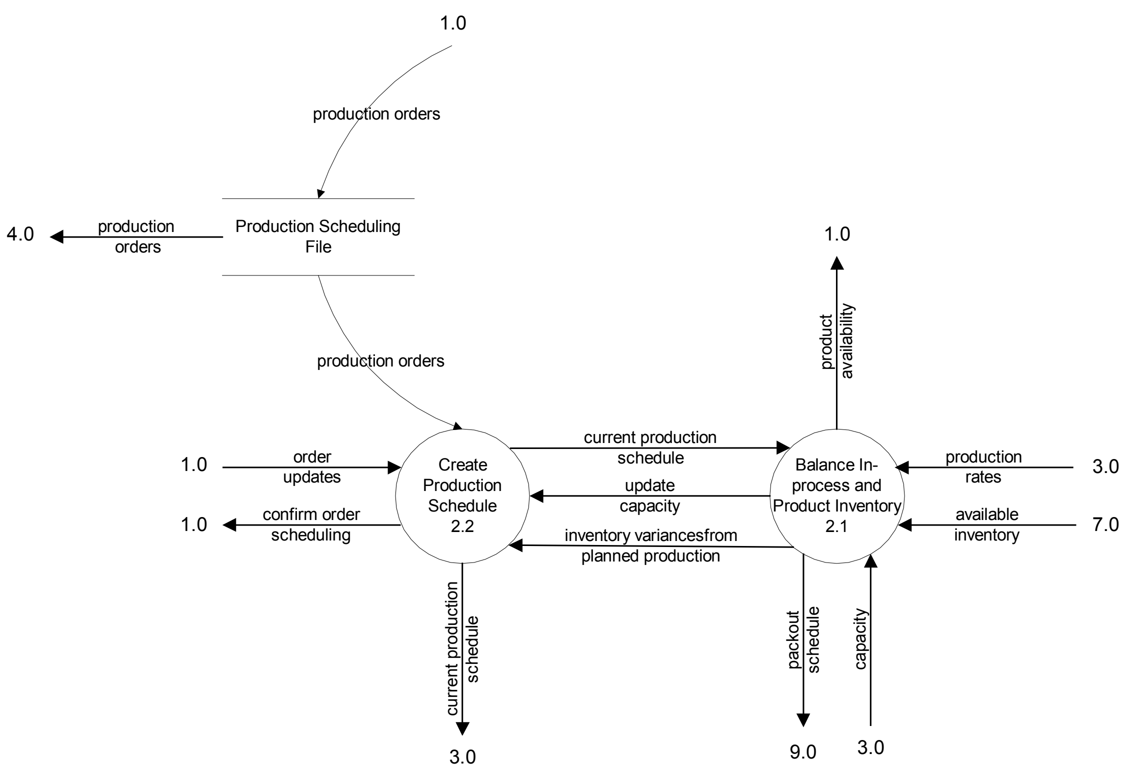


Figure 4.2: Child DFD

Both DFD and IDEF0 diagrams can provide the user with an increasing level of detail by decomposing parent activities into child activities and so on. The main difference refers to the type of information that is being modeled. While DFD focus on data transmission between different activities, IDEF0 focus on activity sequence and interaction.

4.3. Considerations on the Model

In the previous section several models developed for the textile industry have been described. However, when modeling there several considerations that should be taken into account. This section refers some of the issues that should be kept in mind when building a model.

4.3.1. Dangers of Modeling

Several dangers exist in the development, application, and interpretation of models. Solberg [41] points out some of these dangers as listed below:

- Danger of believing in the results of a model when it is wrong – in order to avoid these errors, validation is stressed.
- Danger of not believing that what a model indicates is correct, when in fact it is – in attempting to avoid the first error, the likelihood of falling into this type of error is increased.
- Decreased generality – consequence of excessively complex models. As details are added or the structure becomes more complicated, more and more assumptions are required. Although these assumptions may be entirely valid for the situation at hand, the increased specificity limits the range of applicability. If

conditions change, or slight variations need to be considered, the model may no longer apply.

- Another deficiency of complex models is the cost of developing and operating them. If the time required to collect the data necessary to run a model is excessive, or the expertise required to interpret the results is unavailable, or the time required to obtain results exceeds the time available for considering the decision, then the model is not very useful.

In the development of our models, described in Chapter 5 and Chapter 6, these dangers were dealt with by trying to provide an adequate validation of the models (please refer to Section 5.1 Model Validation) and by trying to avoid the development of a specific model, but rather a model that could be adaptable to different types of organizational structures.

4.3.2. Model Integration in Enterprise Architectures

This section will present the model proposed by the IFAC/IFIP Task Force on Architectures for Enterprise Integration and correlate it with the objectives established for the work proposed.

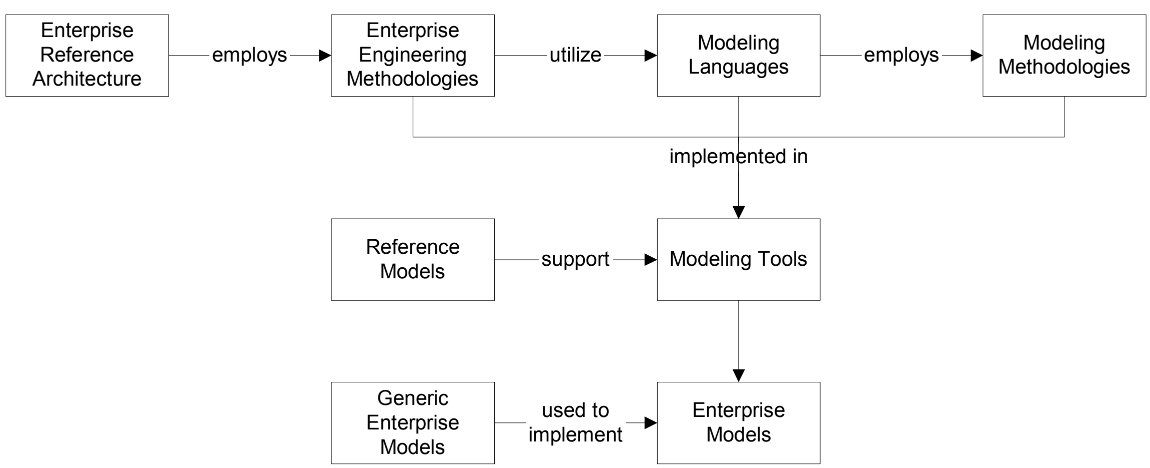


Figure 4.3: IFAC/IFIP Architectures for Enterprise Integration Model

The relationships between the architecture framework depicted in Figure 4.3 and the present modeling work are explained in Table 4.1.

Table 4.1: Relationship between the Architecture and the Models

GERAM Model	Description	Application
Enterprise Engineering Methodologies	Roadmaps and instructions of how to go about an enterprise integration project or program.	-
Modeling Languages	Needed to support enterprise integration, and should be placed in relation to each other by means of the reference architecture.	IDEF0 for activities model, and IDEF1x for the data model.
Modeling Methodology	Comprises a set of guidelines that define the steps to be followed during a modeling activity.	Please refer to Chapter 5 for IDEF0 and Chapter 6 for IDEF1X.
Modeling Tools	Computer programs that help the construction, analysis, and, if applicable, the execution of enterprise models as expressed in enterprise modeling languages.	WizdomWorks98!, ProcessWorks!98 for IDEF0 diagrams, and DataWorks!98 for IDEF1x diagrams.
Reference Models	Contain a formal description of a type (or part of an) enterprise.	Model of the Planning and Scheduling of the Warp knitting production.
Generic Enterprise Modules	Products that implement (parts of) a reference model; for example, an integration infrastructure, or components thereof.	-

This work will provide a Reference Model of the activities and data involved in the Production and Scheduling activities of the warp knitting process. By integrating the proposed models in the GERAM architecture, the new models general character is maintained which enables its application in different Enterprise Reference Architectures (CIMOSA, GRAI/GIM, and PERA).

4.3.3. Model Integration in Information Systems (IS) Architecture

In order to allow us to visualize how the models developed fit in an IS architecture for an enterprise, the choice was to use the Zachman framework as the descriptive structure of an IS. These models may be used in a model repository for the textile industry in particular, or included in a wider scope of industry models library. The framework would be a formal way of separating the several different model types allowing always the perspective of how these models fit in the organization. The framework for Information Systems Architecture (ISA) was introduced by John Zachman in 1987, when he published his study “A Framework for Information Systems Architecture” in the IBM Systems Journal. The framework has seen its scope extended as described in a paper from Sowa and Zachman in 1992 [42].

As described by Sowa and Zachman [42], the framework has the objective of linking the concrete things in the world (entities, processes, locations, people, time, and purposes) with the abstract bits in the computer (bits, bytes, numbers, and the programs that manipulate them). If the computer is to do anything useful, the concrete things in the world must be related to the abstract things in the computer. The framework provides a systematic taxonomy of concepts for relating things in the world to the representations in the computer. It is not a replacement for other programming tools, techniques, or methodologies. Instead, it provides a way of viewing a system from many different perspectives and showing how they are all related. The purpose of the ISA framework is to show how the IS relates to the enterprise and its surrounding environment. The purpose of the ISA framework is to show how everything fits together [42].

The framework gives us a logic structure that enables us to see in a schematic way, how all the complex aspects of the enterprise fit in the enterprise model, are related to each other, and are integrated with the whole.

The framework is composed of 30 boxes or cells organized into six columns and five rows. Each cell describes a defined type of information, which can be described using any adequate representation tool, the ISA framework shows how all the cells are related to each other, in other words, it shows how the information is related to each other and fits the architecture of the IS for the organization.

This work is focused on two perspectives, the planner and the owner, each representing the scope of the model and the enterprise model, as referred in the framework. Each perspective is different in that it is dealing with a different set of constraints relevant to that perspective [42]. According to this perspective, the models will describe the DATA and the FUNCTION involved in the modeled system.

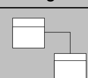
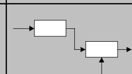
	What DATA	**How FUNCTION**	**Where NETWORK**	**Who PEOPLE**	**When TIME**	**Why MOTIVATION**
SCOPE Planner	 Things List	 Process List	List of locations in which the bus. operates	List of organizations important to the business	List of events/ cycles significant to the business	Lists of business goals/ strategies
BUSINESS MODEL Owner	 IDEF1x	 IDEF0	e.g. Business logistics system	e.g. Work flow model	e.g. Master schedule	e.g. Business plan
SYSTEM MODEL Designer	e.g. Logical data model	e.g. Application architecture	e.g. Distributed systems architecture	e.g. Human interface architecture	e.g. Processing structure	e.g. Business rule model
TECHNOLOGY MODEL Builder	e.g. Physical data model	e.g. System design	e.g. Technology architecture	e.g. Presentation architecture	e.g. Control structure	e.g. Rule design
DETAILED REPRESENTATIONS Subcontractor	e.g. Data definition	e.g. Programs	e.g. Network architecture	e.g. Security architecture	e.g. Timing definition	e.g. Rule specification

Figure 4.4: Scope of the Models in the Zachman Framework [42]

The scope of this work is represented in Figure 4.4 by the gray cells inside the diagram, these cells are further described in Table 4.2. The diagram also gives an example of the applicable types of models, structures, architectures, and applications for each cell that may be used for representing the various views that constitute the Zachman framework.

Table 4.2: Cell Definition for the Model Scope

Perspective	Column	Cell Name	Cell Definition
Scope	Data	Things List	List of things (or objects, or assets) that the enterprise is interested in. It defines the scope, or boundaries, of the things that are significant to the enterprise [46].
	Function	Process List	List of processes (or functions) that the enterprise performs. It defines the scope, or boundaries, of the models of processes that the enterprise performs [46].
Business Model	Data	IDEF1x	Model of the actual enterprise things (objects, assets) that are significant to the enterprise [46].
	Function	IDEF0	This is a model of the actual business processes that the enterprise performs [46].

4.3.4. Information Flow Considerations

Pinedo and Chao [34] have presented a simple diagram representing the information flow in a manufacturing system as shown in Figure 4.5.

The diagram in Figure 4.5 is a simplified view of information flow in a manufacturing system. The initial input to the system arrives under the shape of an order or a forecasted demand, that goes to the production planning and master scheduling activity. Production scheduling and master scheduling provide information regarding quantities and due dates, that are analyzed regarding material requirements, planning and capacity planning, according to the needs, materials requirements are issued.

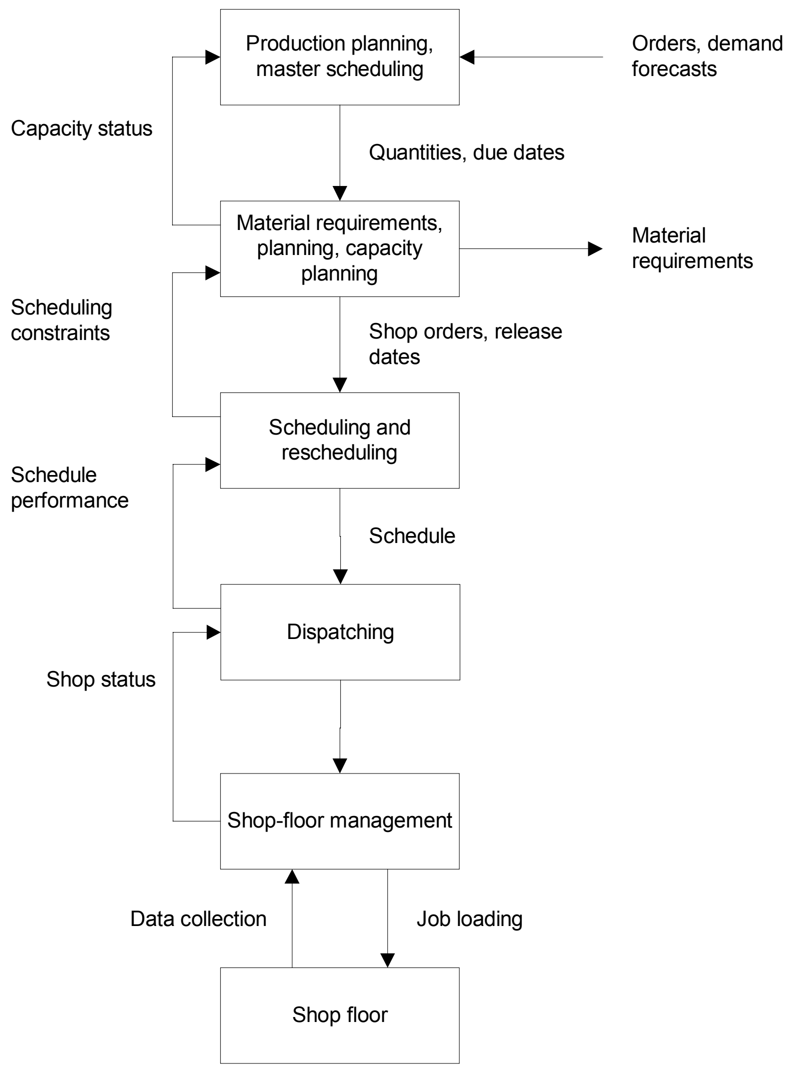


Figure 4.5: Information Flow in a Manufacturing System

Scheduling and resechuduling is the next activity, which output is the schedule that is into dispatching and then shop-floor management. The diagram includes the feedback between the several activities involved, such as:

- Capacity status – provides information regarding the feasibility of the planned quantities and due dates;
- Scheduling constraints;
- Schedule performance;
- Shop status – feedback from the data collected in the shop floor.

4.3.5. Further Considerations on the Model

4.3.5.1. Enterprise Operating Paradigm

Two enterprise operating paradigms may be distinguished: the push or vendor driven, and the pull or customer driven. As pointed out by Jayaraman [18], the consumer will transform the enterprise operating paradigm from a push to a pull system. This situation is supported by the usage of point-of-sale data in order to determine manufacturing order quantities, instead of developing sales forecasts based on historical data of the always-changing consumer behavior.

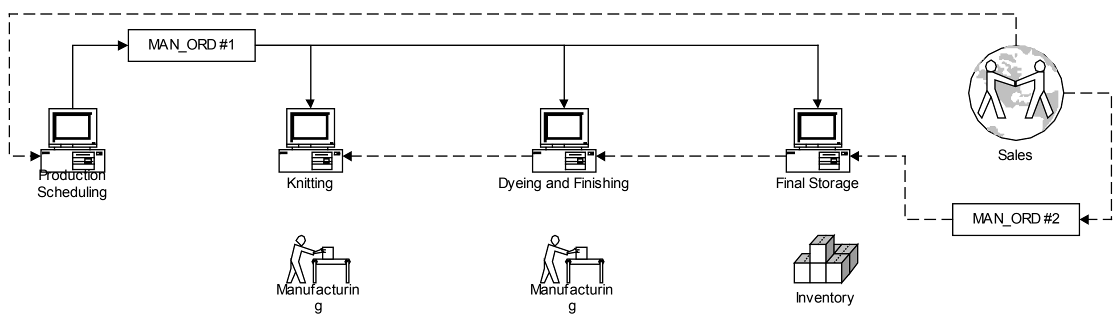


Figure 4.6: Push and Pull Paradigms

Figure 4.6 gives a general view of the two paradigms. Push is represented by the path of MAN_ORD #1[8] that is triggered upstream of the production flow, and Pull is represented by the path of MAN_ORD #2 that is triggered downstream of the production flow.

4.3.5.2. Interplant Requirements

When the physical location of the processes is in different plants such that the time required for transportation will influence the production lead time,

[8] Manufacturing Order #1.

considerations of transport time should be included in the planning and scheduling processes.

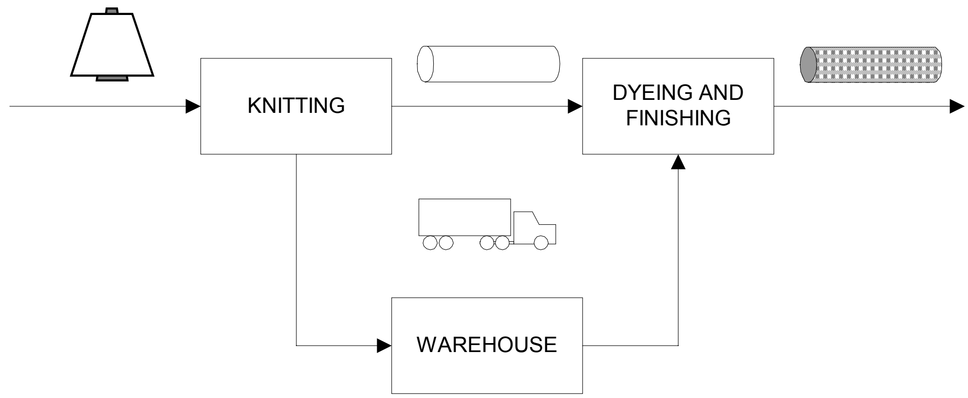


Figure 4.7: Intermediate Storage and Transportation

For the processes considered in this work, it is possible to have different locations of the knitting and the dyeing and finishing plants as seen in Figure 4.7. Routing considerations take a different importance in this case. The existence of warehouses in the process will imply the distinction of the warehouse to use and distance, or time to transport the product should be considered in the planning and scheduling activities.

4.3.5.3. Model Application

The graphic in Figure 4.8 shows the distribution (in percentile values) of the knitting (flat, large, and small diameter) industry in the US. The information was taken from the 2001 ATI Red Book, and as one can see, North Carolina is the location for more than 35% of the total knitting industry in the US, forming a total of more than 300 knitting companies.

Considering the scope of the model, company sizes and end products, an estimate of about 75% of the companies can be considered under the scope of the model proposed in this work, totaling near 225 companies in the state of North Carolina.

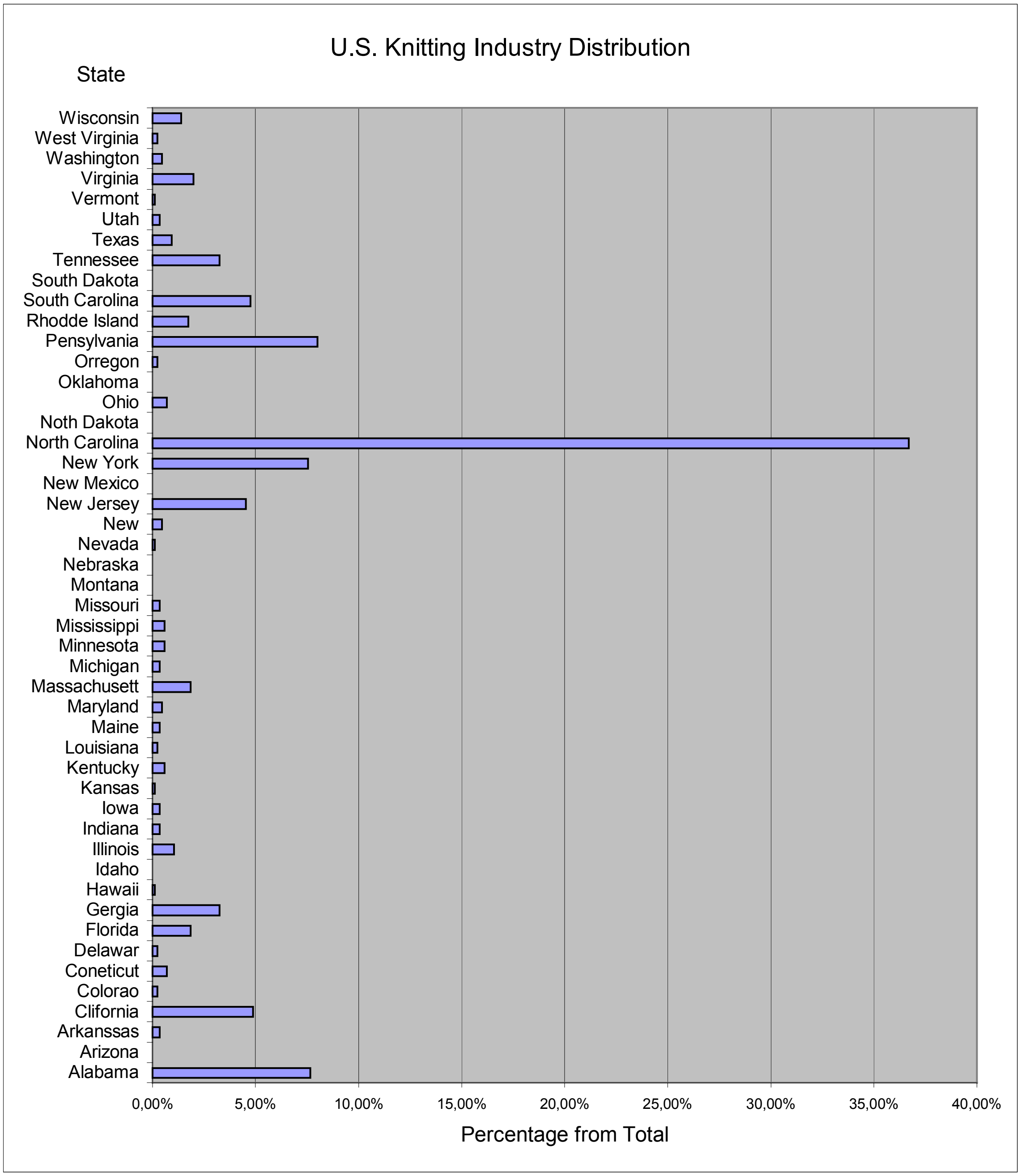


Figure 4.8: US Knitting Industry Distribution

4.3.5.4. Model Application in Extended Enterprise Environment

Technologies are available that assure the sharing of information between different companies in a simultaneous environment, as depicted in Figure 4.9. The databases, developed in the IDEF1X models, may be part of an integrated system assuring information transfer and sharing may be done by different users in different locations. Since data digitally stored is easily transported, transferred, accessed, changed and available, location is no longer a constraint for availability.

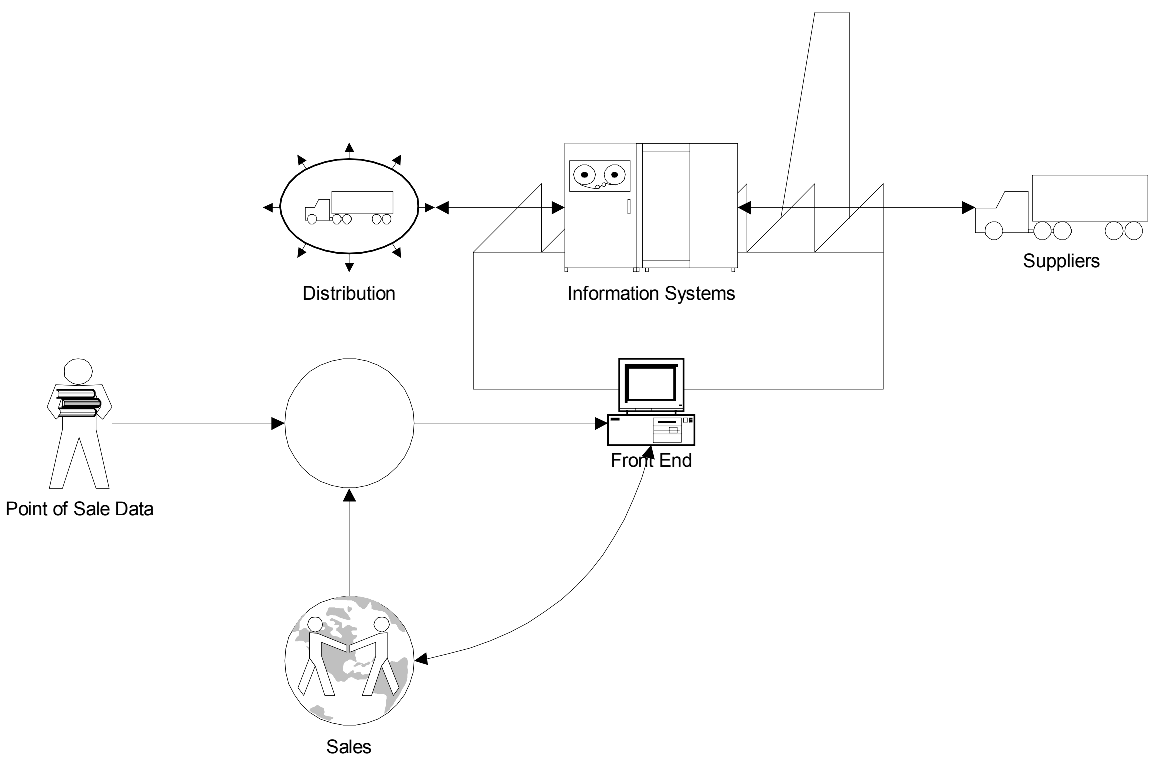


Figure 4.9: Interaction Between the System and Outside Entities

Chapter 5. The IDEF0 Model for Production Planning and Scheduling

5.1. Model Validation

In order to determine the accuracy of the models developed in this chapter, as well as in Chapter 6 and to ensure the applicability of it to real plants, plant visits were made in order to collect enough data that would allow the correction of the initial models and reach a final model that could find application in the everyday work of a company.

Table 5.1: General Data of the Companies Visited

Characteristic		Company			
		A	B	C	D
# Employees		150	225	350	5000
Product Range		Intimate apparel, active wear, and light industrial	Orthopedic, casting, industrial windings for motors and transformers, insulation tape, composite knitted goods	Golf shirts	Knit fabrics in general
Type		Production plant	Production plant	Production plant	Corporate office
Activities	Planning	• Trimester production plan	• Monthly production plans	• Forecast updates • Sowing plan preparation	• Capacity planning • Operations planning
	Scheduling	• Job allocation to knitting and dyeing machines	• Job allocation to knitting and dyeing machines	• Job allocation to knitting and dyeing machines	• Scheduling is done individually by the plants where the goods are produced
Tools		No software tools	No software tools	No software tools	Software for planning
Lead Time		3 to 4 weeks	2 weeks minimum	8 weeks	5 weeks (1)
Notes					(1) Plus 2 to 3 weeks for product engineering

The companies visited give a broad vision of the different views that Production Planning and Scheduling activities have in different manufacturing environments, due to end product, resources availability, types of processes involved, and company culture. Table 5.1 gives a general view of some characteristics that differentiate the type of companies visited while Appendix II gives more details on each company.

The companies selected provide a wide scope in what refers to company size and end products, in order to give a good scope of the way different companies deal with Planning and Scheduling issues. Each company visited was asked to describe the activities and data involved in Planning and Scheduling issues, this information was compared with the data gathered from the literature review, in order to reach a model that respects both the current industrial practice, and the academic work that has been previously done. From these visits, it is possible to conclude the following:

- The usage of software tools in the scheduling area is not a priority, due to different reasons in different cases.
- Production plans are usually a result of forecasts from the sales department.
- Smaller companies (companies A, B, and C) do not differentiate between Planning and Scheduling activities. These companies do not separate into different company areas the Planning and Scheduling activities, and these are usually made by one individual worker. Although there isn’t a clear separation inside the company, the basic activities may be separated into those belonging to each different area. Even if areas are considered as one, the models proposed describe activities that may be done by the same person in one functional area, but have a formal sequence, even if the sequence is not explicitly separated in two areas in the every day work of the company.

- Most companies do not have a written procedure of the activities involved in planning and scheduling[9].
- The usage of scheduling algorithms for the allocation of jobs to machines, with the objective of maximizing or minimizing a certain parameter has not been evidenced in any of the companies visited.

5.2. General Considerations

Based on the plant visits, the IDEF0 diagram (FEO diagram) in Figure 5.1 positions the model developed inside the organization and provides information regarding the existing interactions between the Production Planning and Scheduling area with the other existing organizational areas in the company.

[9] Exception should be made to company C that had the description due to strategic reasons.

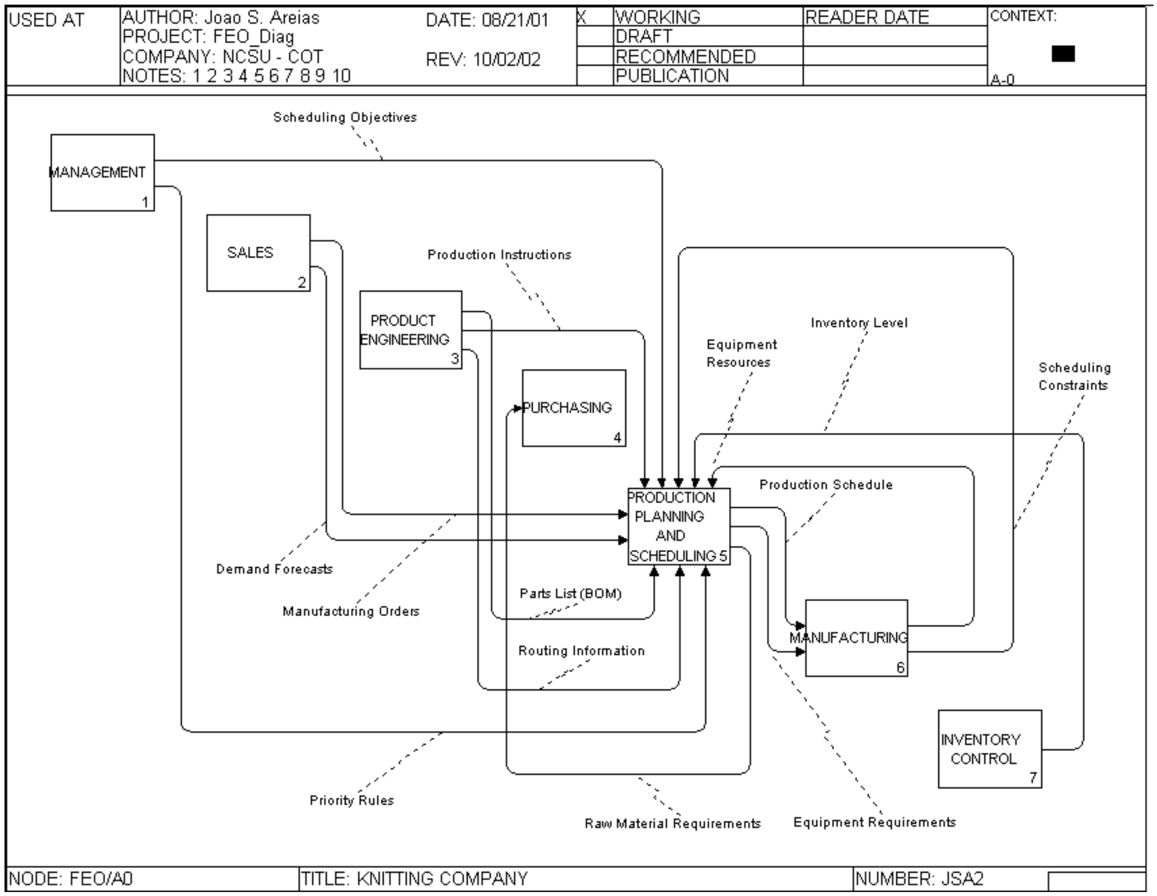


Figure 5.1: Main ICOM from Production Planning and Scheduling

The interactions shown by the ICOM arrows are used for connecting the several organizational areas (considered here as activities), inputs, controls, outputs and mechanisms guarantee the functioning of the production planning and scheduling area together with the rest of the organization (e.g., management, sales, etc.). This diagram does not consider the feedback of information that is necessary for the improvement and synchronization of the Planning and Scheduling with the other activities that compose the company.

5.3. Node Tree Diagram

The node tree diagram is a structural representation of the IDEF0 diagrams that constitute the modeled system. This view helps the reader understand the sequence of the diagrams and the interdependencies that exist between the activities that compose the model. For example, A0 is broken into sub activities A-1 and A-2.

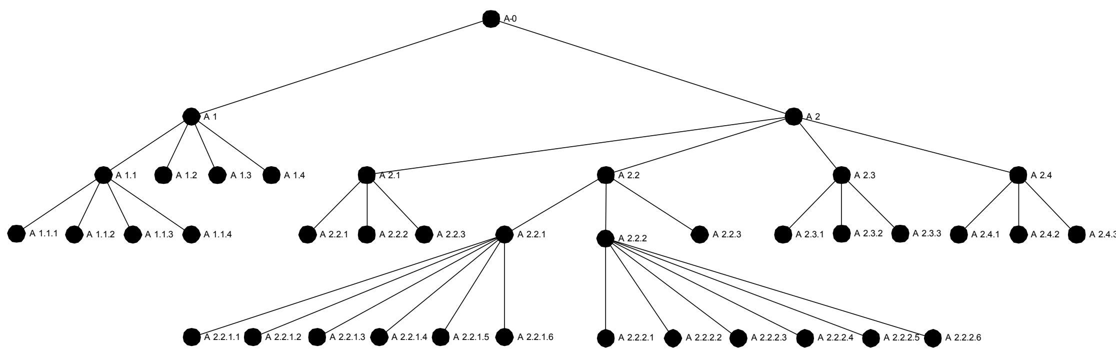


Figure 5.2: Node Tree Diagram

5.4. Node Index

The Node Index is a listing of all the processes represented in the IDEF0 diagrams. This list provides information regarding the node number and the activity name.

A - 0 PRODUCTION PLANNING AND SCHEDULING

A 1 PRODUCTION PLANNING

A 1.1 PRODUCTION ANALYSIS

A 1.1.1 STYLE ANALYSIS
A 1.1.2 STYLE GROUP ANALYSIS
A 1.1.3 ANALYSIS OF DELIVERY SCHEDULES
A 1.1.4 ANALYSIS OF YARN SCHEDULING

A 1.2 EVALUATE MACHINE NEEDS
A 1.3 EVALUATE HUMAN RESOURCES NEEDS
A 1.4 MASTER PRODUCTION SCHEDULING

A 2 PRODUCTION SCHEDULING

A 2.1 ACTIVITY SEPARATION
A 2.2 KNITTING SCHEDULE

A 2.2.1 EVALUATE KNITTING NEEDS

A 2.2.1.1 EVALUATE KNITTING MATERIAL NEEDS
A 2.2.1.2 EVALUATE KNITTING MACHINE NEEDS
A 2.2.1.3 EVALUATE WARPING NEEDS
A 2.2.1.4 EVALUATE KNITTING EQUIPMENT NEEDS
A 2.2.1.5 EVALUATE KNITTING OPERATOR NEEDS
A 2.2.1.6 COMPILE KNITTING NEEDS

A 2.2.2 EVALUATE KNITTING AVAILABILITY

A 2.2.2.1 EVALUATE KNITTING MATERIAL AVAILABILITY
A 2.2.2.2 EVALUATE KNITTING MACHINE AVAILABILITY
A 2.2.2.3 EVALUATE WARPING AVAILABILITY

A 2.2.2.4 EVALUATE KNITTING EQUIPMENT AVAILABILITY
A 2.2.2.5 EVALUATE KNITTING OPERATOR AVAILABILITY
A 2.2.2.6 COMPILE KNITTING AVAILABILITY

A 2.2.3 CREATE KNITTING SCHEDULE

A 2.3 DYEING AND FINISHING SCHEDULE

A 2.3.1 EVALUATE DYEING AND FINISHING NEEDS
A 2.3.2 EVALUATE DYEING AND FINISHING AVAILABILITY
A 2.3.3 CREATE DYEING AND FINISHING SCHEDULE

A 2.4 CREATE PRODUCTION SCHEDULE

A 2.4.1 SCHEDULE GENERATION
A 2.4.2 SCHEDULE SELECTION
A 2.4.3 RELEASE PRODUCTION SCHEDULE

A condensed version of both the node tree diagram (as seen in Figure 5.2) and the node index can be seen in Figure 5.3.

- **A - 0** PRODUCTION PLANNING AND SCHEDULING
  - **A 1** PRODUCTION PLANNING
    - **A 1.1** PRODUCTION ANALYSIS
      - **A 1.1.1** STYLE ANALYSIS
      - **A 1.1.2** STYLE GROUP ANALYSIS
      - **A 1.1.3** ANALYSIS OF DELIVERY SCHEDULES
      - **A 1.1.4** ANALYSIS OF YARN SCHEDULING
    - **A 1.2** EVALUATE MACHINE NEEDS
    - **A 1.3** EVALUATE HUMAN RESOURCES NEEDS
    - **A 1.4** MASTER PRODUCTION SCHEDULING
  - **A 2** PRODUCTION SCHEDULING
    - **A 2.1** ACTIVITY SEPARATION
    - **A 2.2** KNITTING SCHEDULE
      - **A 2.2.1** EVALUATE KNITTING NEEDS
        - **A 2.2.1.1** EVALUATE KNITTING MATERIAL NEEDS
        - **A 2.2.1.2** EVALUATE KNITTING MACHINE NEEDS
        - **A 2.2.1.3** EVALUATE WARPING NEEDS
        - **A 2.2.1.4** EVALUATE KNITTING EQUIPMENT NEEDS
        - **A 2.2.1.5** EVALUATE KNITTING OPERATOR NEEDS
        - **A 2.2.1.6** COMPILE KNITTING NEEDS
      - **A 2.2.2** EVALUATE KNITTING AVAILABILITY
        - **A 2.2.2.1** EVALUATE KNITTING MATERIAL AVAILABILITY
        - **A 2.2.2.2** EVALUATE KNITTING MACHINE AVAILABILITY
        - **A 2.2.2.3** EVALUATE WARPING AVAILABILITY
        - **A 2.2.2.4** EVALUATE KNITTING EQUIPMENT AVAILABILITY
        - **A 2.2.2.5** EVALUATE KNITTING OPERATOR AVAILABILITY
        - **A 2.2.2.6** COMPILE KNITTING AVAILABILITY
      - **A 2.2.3** CREATE KNITTING SCHEDULE
    - **A 2.3** DYEING AND FINISHING SCHEDULE
      - **A 2.3.1** EVALUATE DYEING AND FINISHING NEEDS
      - **A 2.3.2** EVALUATE DYEING AND FINISHING AVAILABILITY
      - **A 2.3.3** CREATE DYEING AND FINISHING SCHEDULE
    - **A 2.4** CREATE PRODUCTION SCHEDULE
      - **A 2.4.1** SCHEDULE GENERATION
      - **A 2.4.2** SCHEDULE SELECTION
      - **A 2.4.3** RELEASE PRODUCTION SCHEDULE

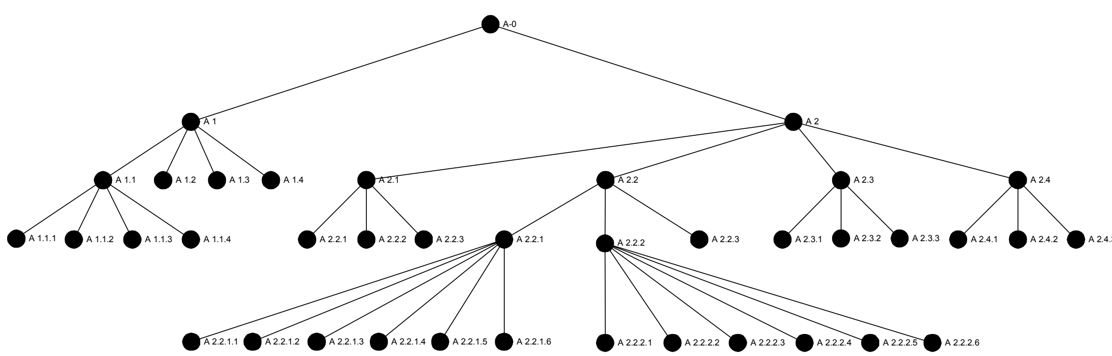


Figure 5.3: Node Tree Diagram and Node Index

5.5. Model Components Description – IDEF0 Diagram

5.5.1. Activities

ACTIVITY SEPARATION (A 2.1) – Once the master production schedule is received for scheduling, the activities necessary for the production of the required end products, need to be identified and separated, in order to allow the creation of the knitting and the dyeing and finishing schedule.

ANALYSIS OF DELIVERY SCHEDULES (A 1.1.3) – Evaluates the amounts to produce per style by comparison with inventory levels.

ANALYSIS OF YARN SCHEDULING (A 1.1.4) – This activity is responsible for defining the yarn needs and to schedule when each yarn type will be required.

COMPILE KNITTING AVAILABILITY (A 2.2.2.6) – Compilation of the data regarding the availability of all the knitting needs.

COMPILE KNITTING NEEDS (A 2.2.1.6) – Once all the material, machine, warping, knitting and operator needs are defined, this activity is responsible for compiling this information for knitting.

CREATE DYEING AND FINISHING SCHEDULE (A 2.3.3) – Based on the production plan and on the knitting schedule, the dyeing and finishing schedule is created in order to respond to the needs, and constrained by the available resources.

CREATE KNITTING SCHEDULE (A 2.2.3) – Based on the production plan, the knitting schedule is created in order to respond to the needs, and constrained by the available resources.

CREATE PRODUCTION SCHEDULE (A 2.4) – The activities involved are responsible for generating, selecting and releasing the final schedule for the production of the intended goods. The final schedule is composed of the schedules developed previously for knitting and for dyeing and finishing, being these an output of activities A 2.2 and A 2.3 respectively.

DYEING AND FINISHING SCHEDULE (A 2.3) – This activity is composed of the activities necessary for creating and developing the schedule for the dyeing and finishing of the knitted goods. The child diagrams of A 2.3 will not be further developed, since these would be, in general, very similar to the diagrams presented for the knitting schedule generation.

EVALUATE DYEING AND FINISHING AVAILABILITY (A 2.3.2) – Once all the dyeing and finishing needs are defined, it is necessary to evaluate their availability in order to allow the completion of the production plan.

EVALUATE DYEING AND FINISHING NEEDS (A 2.3.1) – Evaluation of how much of each resource will be necessary in dyeing and finishing, to accomplish the planned production.

EVALUATE HUMAN RESOURCES NEEDS (A 1.3) – For a given planned production level, there will be a certain amount of human resources that need to be allocated in order to allow the feasibility of the planned production.

EVALUATE KNITTING AVAILABILITY (A 2.2.2) – Once all the knitting needs are defined, it is necessary to evaluate their availability in order to allow the completion of the production plan.

EVALUATE KNITTING EQUIPMENT AVAILABILITY (A 2.2.2.4) – Evaluation of the availability of knitting equipment in order to allow the completion of the production plan.

EVALUATE KNITTING EQUIPMENT NEEDS (A 2.2.1.4) – This activity is responsible for determining which knitting equipment will be needed to produce the desirable end product in a previously defined set of knitting machines.

EVALUATE KNITTING MACHINE AVAILABILITY (A 2.2.2.2) – Evaluation of the availability of knitting machinery in order to allow the completion of the production plan.

EVALUATE KNITTING MACHINE NEEDS (A 2.2.1.2) – This activity is responsible for determining which knitting machines will be needed to produce the desirable end product.

EVALUATE KNITTING MATERIAL AVAILABILITY (A 2.2.2.1) – Evaluation of the availability of knitting material in order to allow the completion of the production plan.

EVALUATE KNITTING MATERIAL NEEDS (A 2.2.1.1) – Once a list of the knitting activities is available, it is necessary to determine the knitted goods necessary to be produced.

EVALUATE KNITTING NEEDS (A 2.2.1) – These needs may be divided in material, machine, equipment and human. It is necessary for the schedule to evaluate how much of each resource will be necessary to accomplish the planned production.

EVALUATE KNITTING OPERATOR AVAILABILITY (A 2.2.2.5) – Evaluation of the availability of knitting operator in order to allow the completion of the production plan.

EVALUATE KNITTING OPERATOR NEEDS (A 2.2.1.5) – This activity is responsible for determining the human needs that will be responsible for operating a previously defined set of knitting machines and equipment.

EVALUATE MACHINE NEEDS (A 1.2) – This activity is responsible for determining which equipment resources will be needed to produce the desirable end product.

EVALUATE WARPING AVAILABILITY (A 2.2.2.3) – Evaluation of the availability of the previously defined warping needs in order to allow the completion of the production plan.

EVALUATE WARPING NEEDS (A 2.2.1.3) – This activity is responsible for determining the warping needs (material, machine, equipment and human) necessary to feed the knitting machines for the production of the required end products. This may include needs related to the dyeing processes associated with the warp beams that will feed the knitting machines.

KNITTING SCHEDULE (A 2.2) – This activity is responsible for creating the knitting schedule.

MASTER PRODUCTION SCHEDULING (A 1.4) – Once all the information needed for the master production schedule is gathered, it is necessary to compile the information and develop the plan according to the data available.

PRODUCTION ANALYSIS (A 1.1) – The study of the processes and operations to be performed during the production phases of the manufacture of a product, resolving them into individual or separate operations, together with their accompanying material movements [35]. This activity is also responsible for creating the long and intermediate range plans.

PRODUCTION PLANNING (A 1) – Please refer to Section 3.1.

PRODUCTION SCHEDULING (A 2) – Please refer to Section 3.2.

RELEASE PRODUCTION SCHEDULE (A 2.4.3) – The selected schedule is released to the production floor so that it can be followed.

SCHEDULE GENERATION (A 2.4.1) – By using the available scheduling tools, several schedules can be generated with the same basic initial data from machines and jobs. Schedules are generated according to the scheduling objective.

SCHEDULE SELECTION (A 2.4.2) – Once the possible schedules are generated, it is necessary to select from these which schedule will better suit the objective.

STYLE ANALYSIS (A 1.1.1) – The arrangement of the groups or families of products according to their common production characteristics. This arrangement can be obtained by the usage of Group Technology methods.

STYLE GROUP ANALYSIS (A 1.1.2) – This activity creates a list of all styles by order number, quantity and delivery date for quick reference. It will also show the style distribution by machine groups as well as work load in each machine center.

5.5.2. Inputs, Controls, Outputs and Mechanisms

This section is the glossary for all the ICOM Codes associated with the arrows considered in the IDEF0 diagrams.

Manufacturing Orders – The orders to produce are outputted by the sales department based on actual orders made from the customers and/or sales forecasts[10]. Forecasting is the art of specifying meaningful information about the future [32]. Forecast of sales usually applies when the product demand is stable and the company has historical records with information on seasonability of the customer demand, short-term forecasts would probably be applicable in knitting and dyeing of knitted goods, where the maximum forecasted time period can reach one year.

Parts List (BOM) – The Bill Of Materials is a list that specifies the quantity of each item, ingredient, or material needed to assemble, mix, or produce an end product. A BOM also describes the relationships among parts [32].

Scheduling Objectives – Different objectives may apply according to the strategy chosen by the company. A list of different scheduling objectives is presented in Section 3.2.1.

Equipment Availability – Provides information on the equipment that is available, considering the ones that are not in use due to production reasons or are stopped for maintenance reasons.

Scheduling Constraints – Refer to Section 3.2.3.

Production Instructions – Provide information regarding how the jobs are conducted in a given operation using tools, machines, or other equipment.

Request Style Specifications – The Production Planning area issues this request to the Product Engineering area, when the style to be produced is

[10] In a Concurrent Engineering environment, the forecasting activity is developed by a joint effort of the Sales, Marketing, Production, and Planning departments.

not defined in a Style Specification (JSA11). This arrow is included in the diagram for feedback reasons.

Knitting Needs – Includes information regarding material, machine, warping, equipment and operator needs (JSA6).

Style List Schedule – Provides information on release date if item is available in the inventory, or the production required if the item is not available in the inventory (JSA11).

Knitting Activities List – Provides information regarding the jobs that need to be done, with data on the due dates and customer.

Master Production Plan – Includes production needs and inventory release dates depending on the existence in stock of the end product.

Yarn Requirements – Once the production needs are defined, the company has the information regarding the necessary amount of yarn (raw material) needed.

Product Groups – Arranged group or family of products with common production characteristics.

Style List – List of all the styles by order number, quantity and delivery date, style distribution by machine group, and work load in each machine center.

Style List Schedule – Provides information regarding the amounts to produce per style.

Scheduling Tools – These are usually computer programs that are used to generate schedules. These software solutions are an evolution of previous paper and pencil tools used for the development of production schedules.

Priority Rules – When scheduling jobs, different priorities may be given to certain orders, this situation occurs due to management options regarding the importance of a product or a higher importance of a customer, for example.

Inventory Level – Is usually provided by software tools, and will be used for determining the amount of product necessary for completing an order, or the amount of raw material needed for the production of the end product.

5.6. IDEF0 Model Diagrams

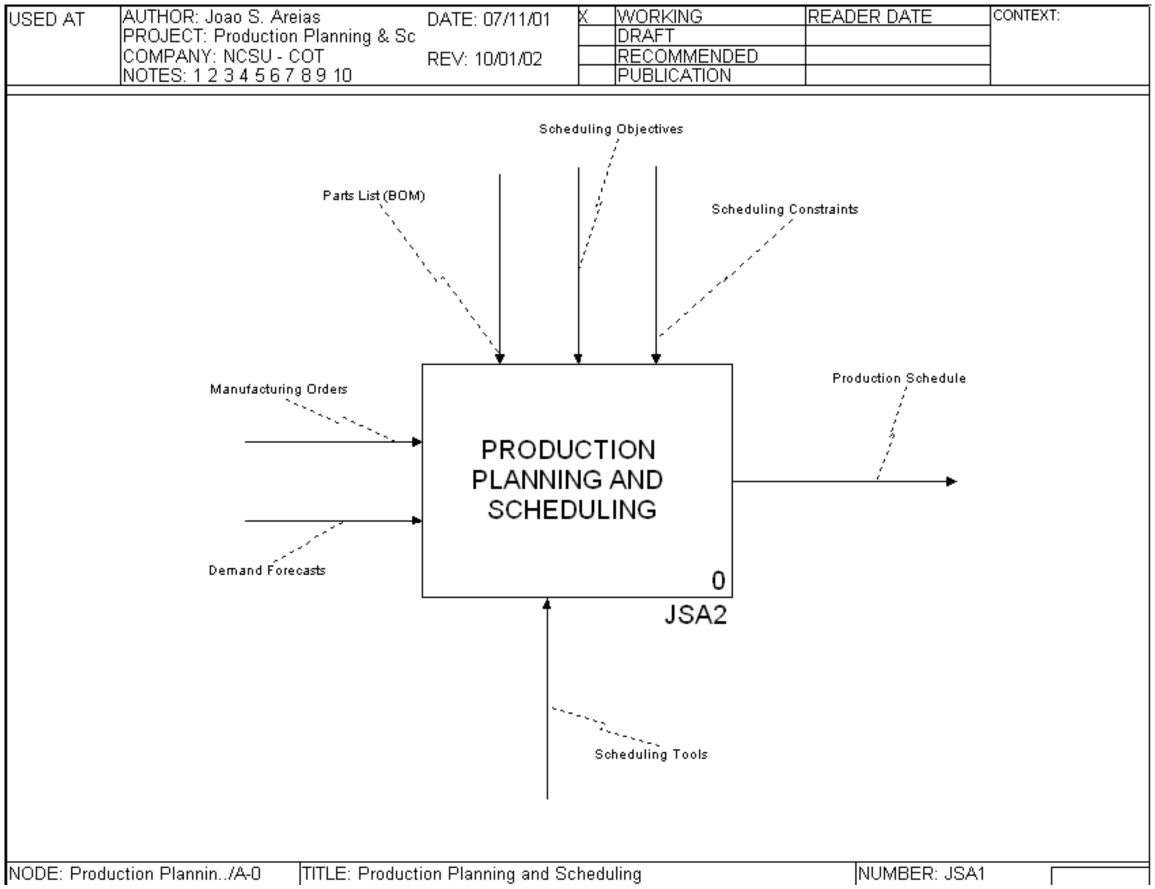


Figure 5.4: A-0 Diagram

The diagram in Figure 5.4 is the first level diagram of the IDEF0 models. It shows the basic inputs, outputs, mechanisms and controls that will be necessary for the production planning and scheduling activities. Although not all the ICOM arrows are shown, the selection of these was based on the basic parameters necessary for production planning and scheduling. The diagrams are based on the management viewpoint.

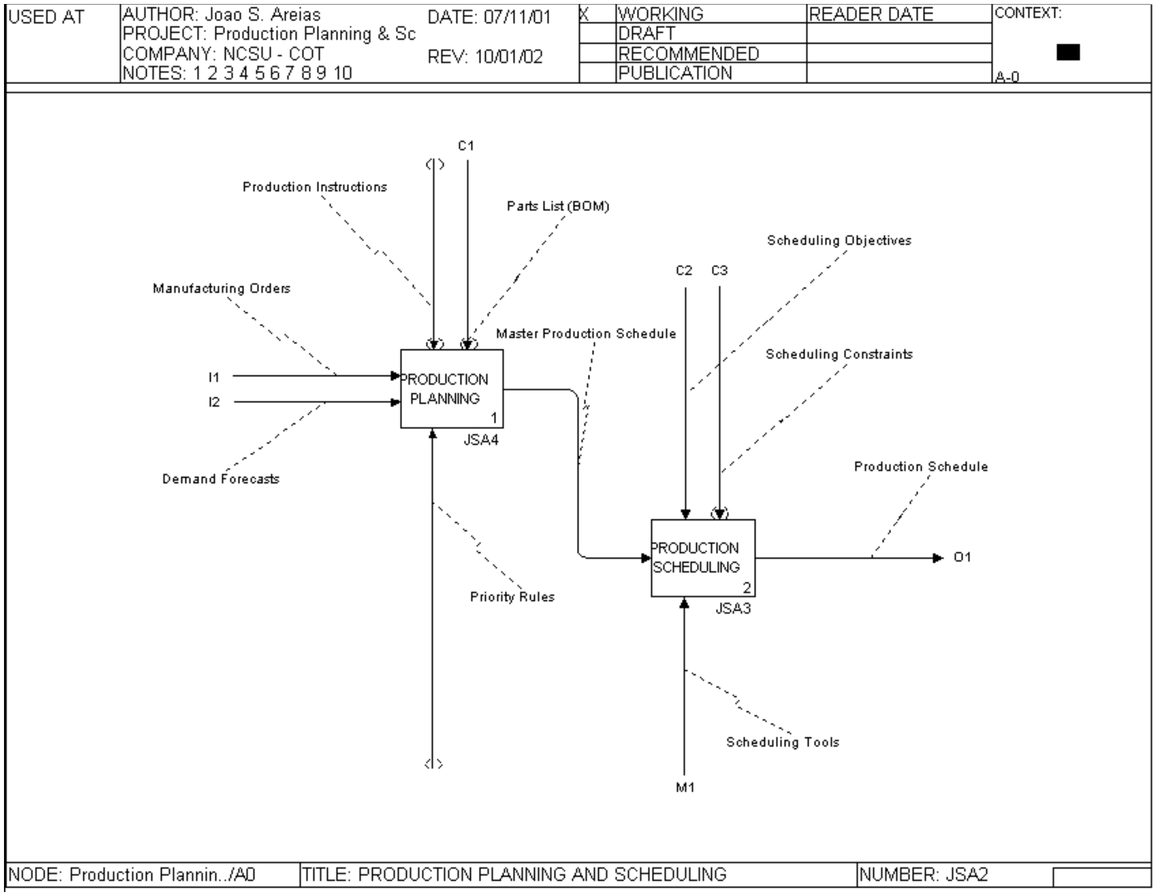


Figure 5.5: A0 Diagram

The A0 diagram in Figure 5.5 is the 2nd level diagram detailing the components of the A-0 diagram. The diagram represents the separation of the planning and the scheduling activities, detailing the ICOM that are part of each activity, and the connections between the two activities. Planning and scheduling are bonded by the Master Production Schedule (refer to Section 3.1.2 for more details), that will guarantee all the basic information for that will allow scheduling to comply with the planned deliveries.

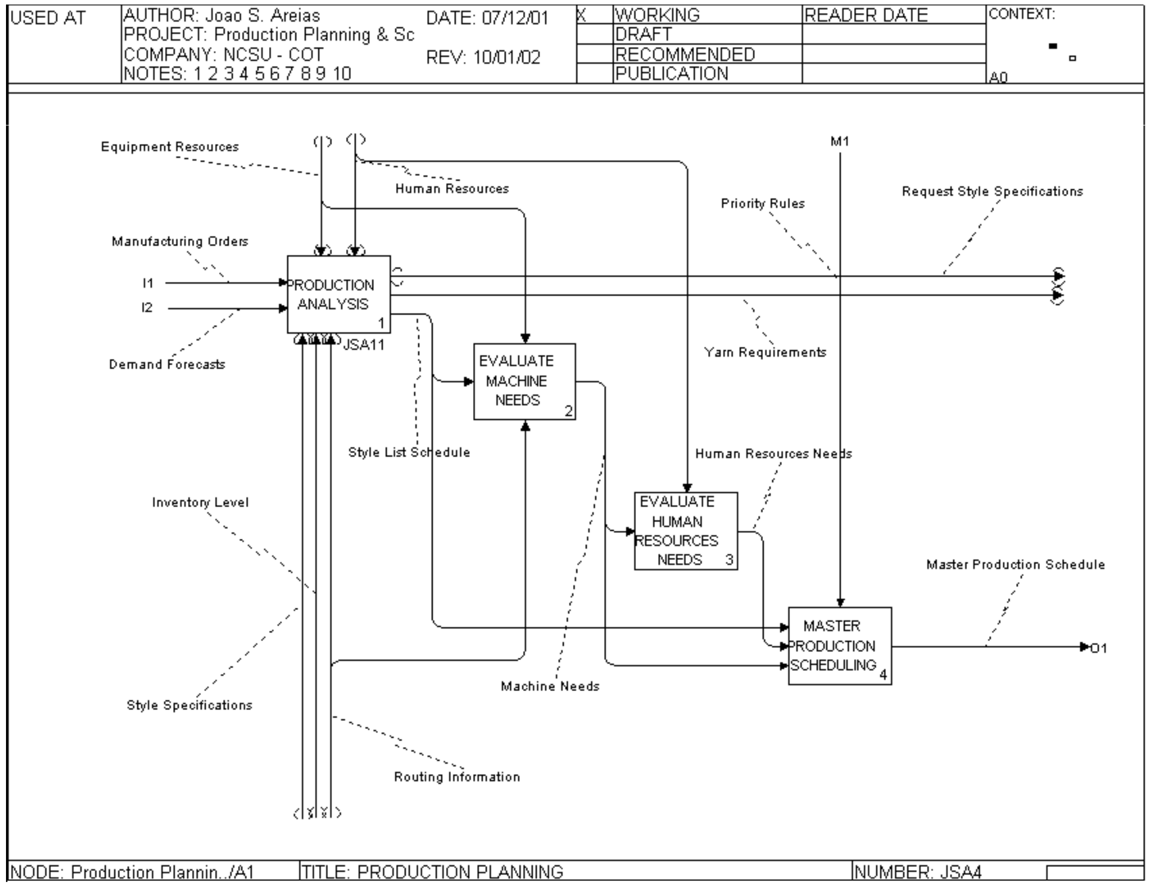


Figure 5.6: A1 Diagram

Figure 5.6 shows the activities involved in the production planning activity. The PRODUCTION ANALYSIS activity needs further detail, since the others are possible to be easily described by the description previously shown in Section 5.5 Model Components Description – IDEF0 Diagram.

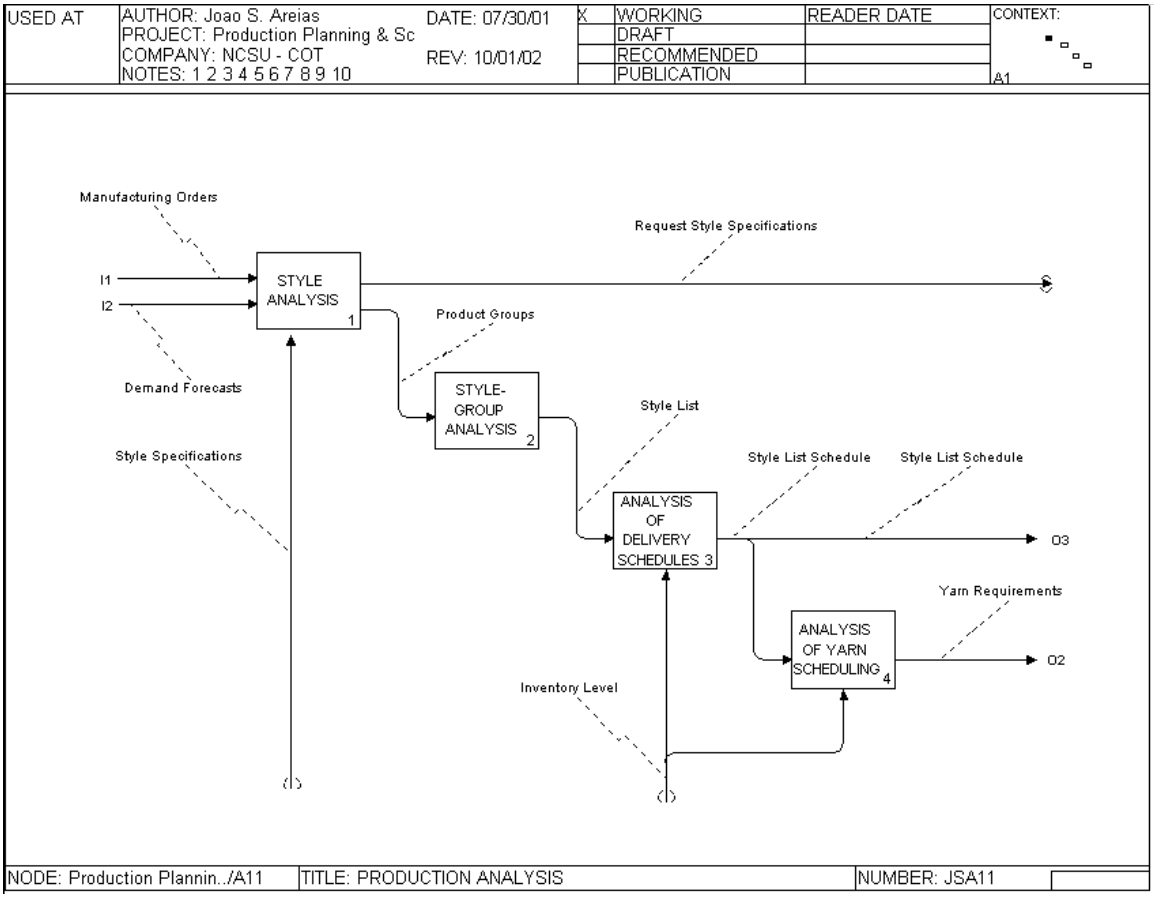


Figure 5.7: A1.1 Diagram

Following the previous diagram, Figure 5.7 is a detailed view of the activities involved in the PRODUCTION ANALYSIS. This diagram depicts the aggregation of styles in style groups to be included in the MPS. Once the delivery schedules for each style group are determined, the yarn needs are defined. Inventory level is set as a mechanism since it provides information for the availability of the yarn or the end product.

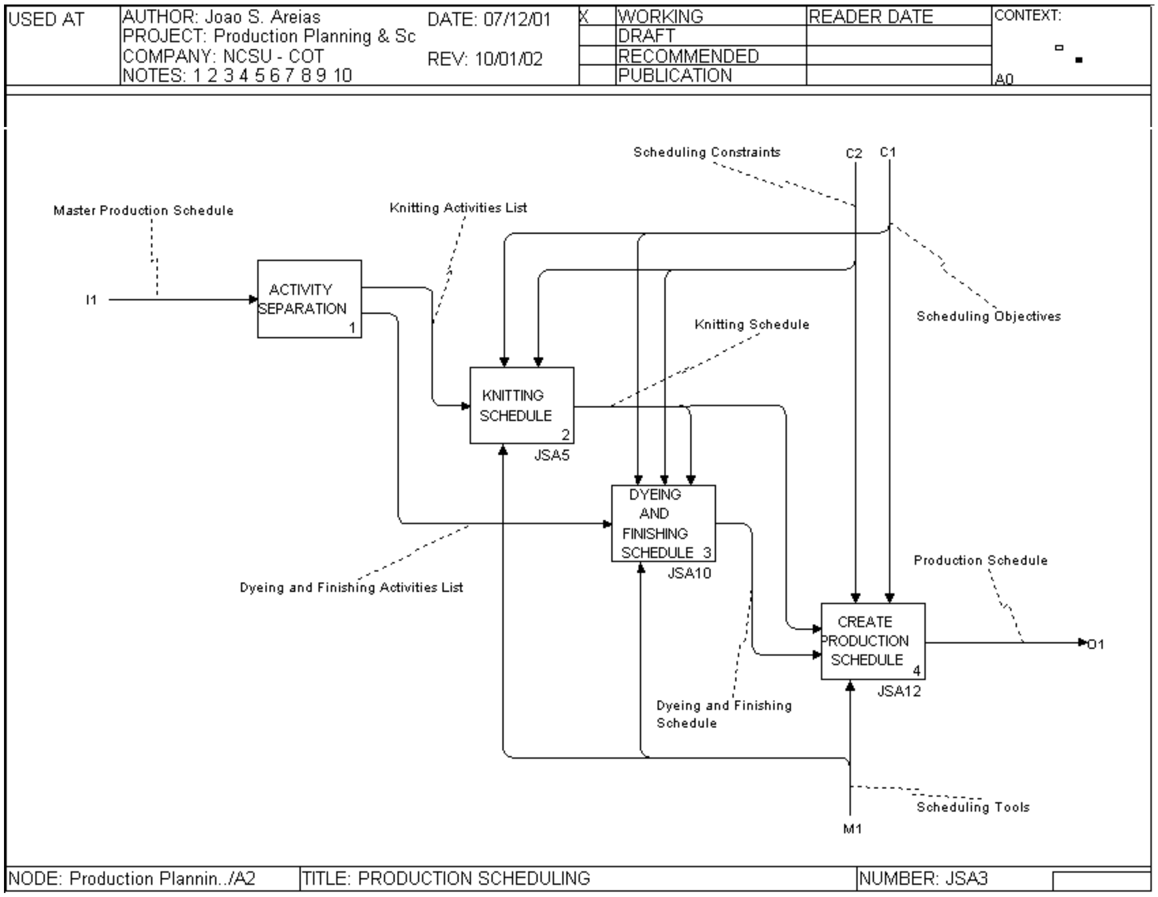


Figure 5.8: A2 Diagram

Once the Master Production Schedule is released for production scheduling, it is necessary to separate the activities in knitting and in dyeing and finishing, in order to allow the generation of a production schedule as seen in Figure 5.8. Based on the end product specifications, the processes that allow the production effort to reach these specifications need to be clearly defined and completed. For each process there should be an associated list of requirements, informing the company of all the necessary parts, processes and parameters, verifying the existence in stock, and alerting for the need of additional parts, or minimum amounts in stock.

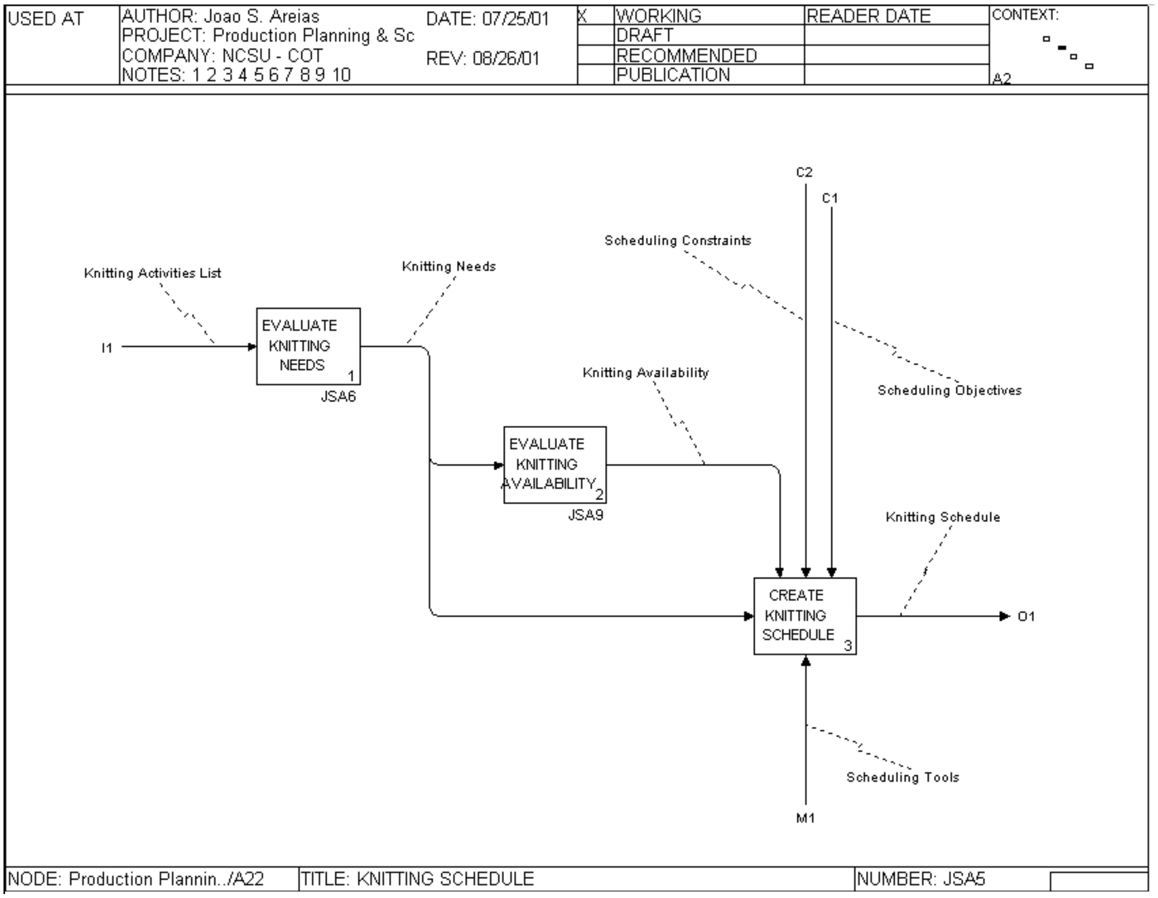


Figure 5.9: A2.2 Diagram

In order to create the knitting schedule, it is first of all necessary to evaluate what is required from the schedule, evaluate if it is possible to satisfy the schedules needs, and once the resources are secured, the schedule can be created as seen in Figure 5.9.

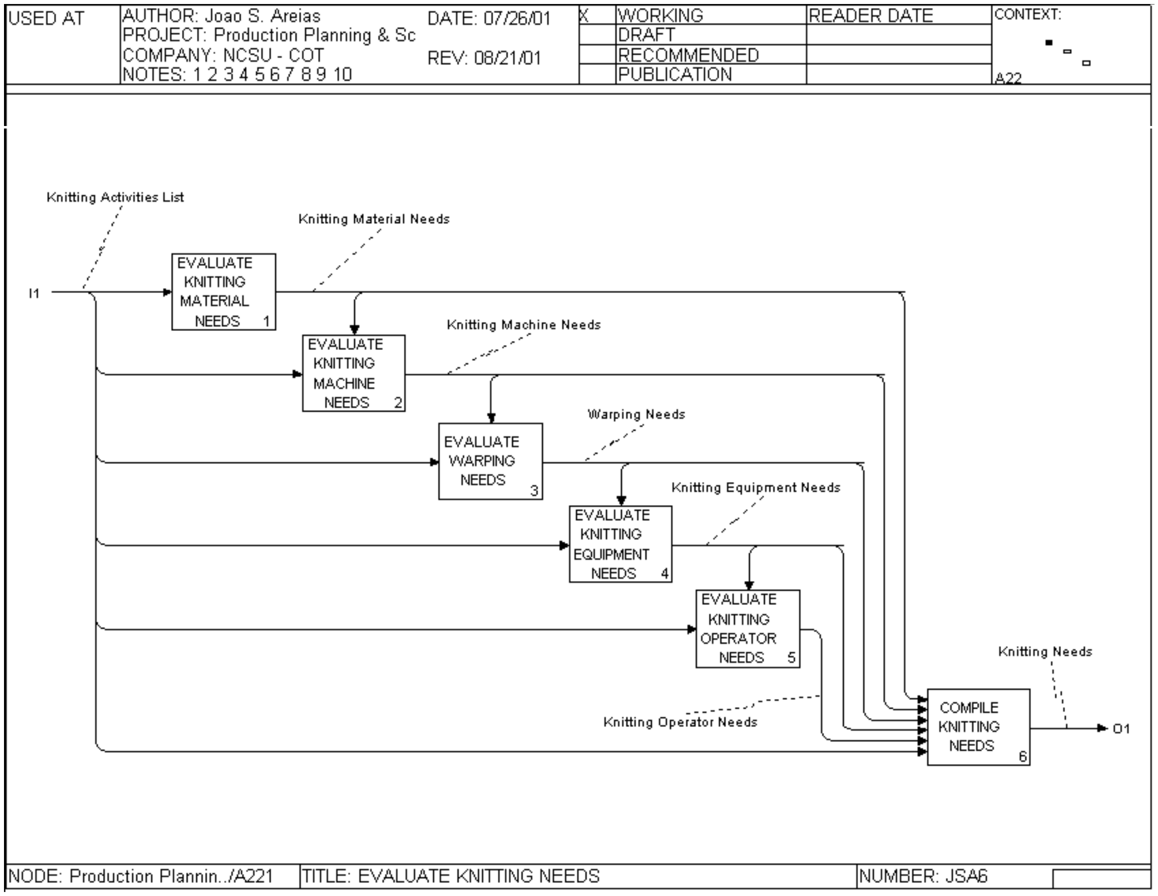


Figure 5.10: A2.2.1 Diagram

In order to know what is necessary to be done (i.e., EVALUATE KNITTING NEEDS, please refer to diagram in Figure 5.9), it is necessary to determine how much resources are needed for each process, or major process (in our case we consider knitting, dyeing and finishing as major processes). The diagram in Figure 5.10 describes the activities that are necessary to evaluate the knitting needs, according to the resources that will be used: material, machine, warping, equipment and operator. The last activity in this diagram is the compilation of all the resources needed for the knitting process which feeds into EVALUATE KNITTING AVAILABILITY.

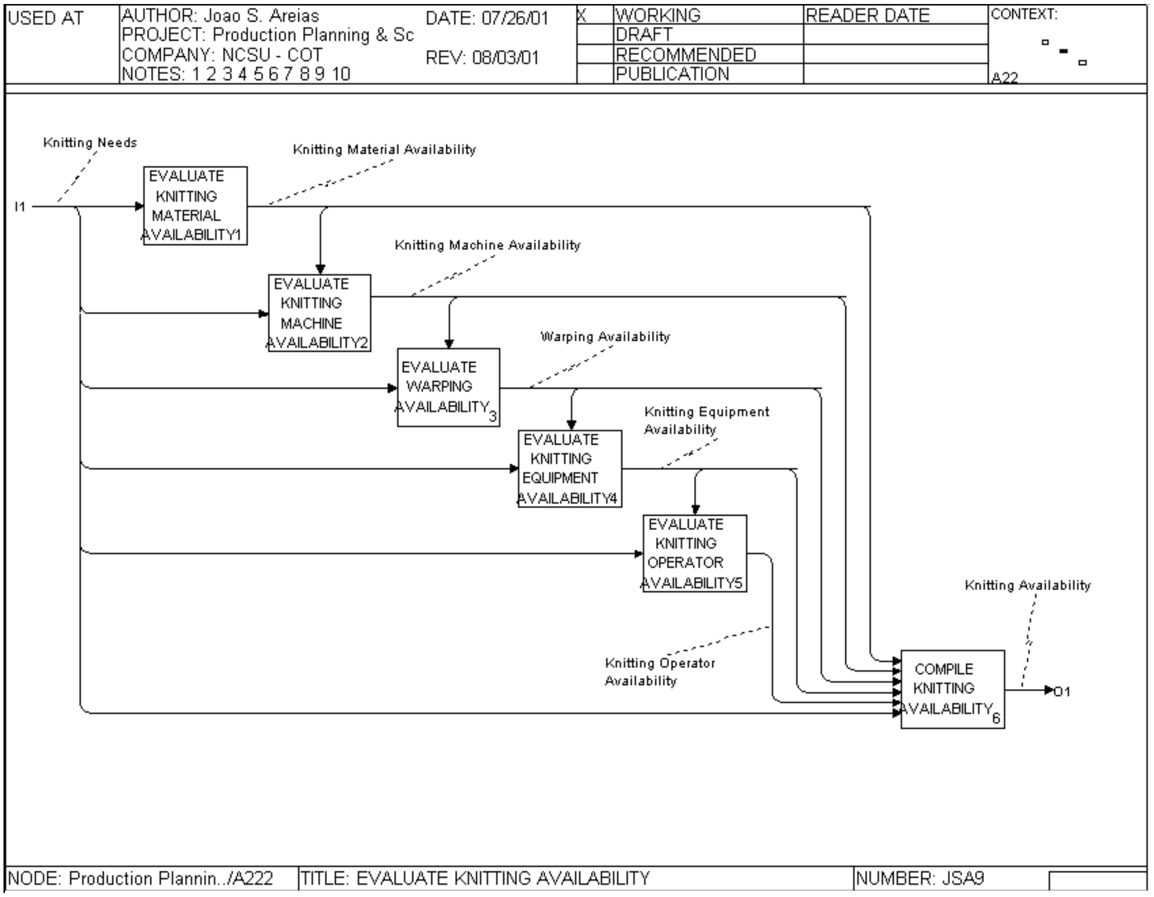


Figure 5.11: A2.2.2 Diagram

Once the necessary resources are identified, it is necessary to evaluate if these are available, in order to do so it is necessary to evaluate the availability of resources. Figure 5.11 outlines the activities that comprise the COMPILE KNITTING AVAILABILITY.

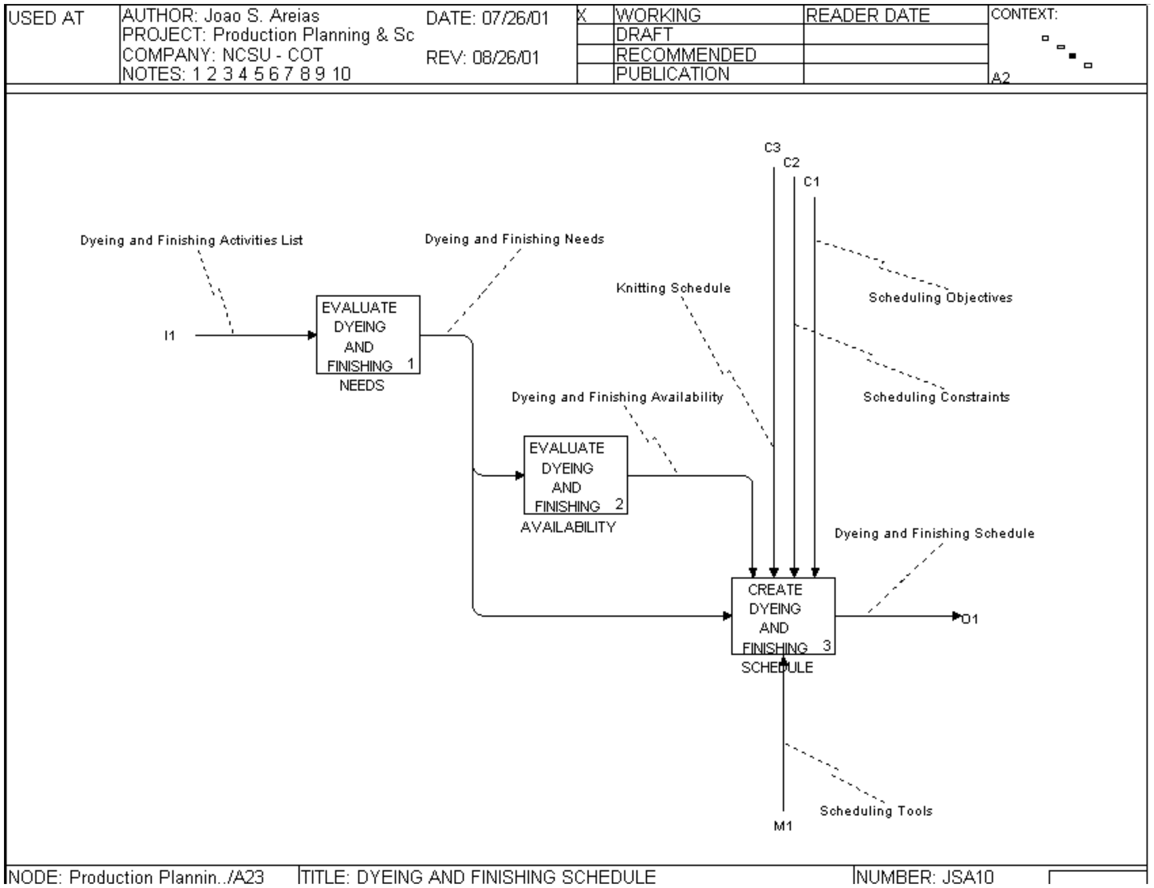


Figure 5.12: A2.3 Diagram

The diagram in Figure 5.12 is very similar to the one presented in Figure 5.9 where the differences are only between the schedules to be created. The previous diagram reflected the activities for the knitting schedule while the activities for the dyeing and finishing schedule are diagramed in Figure 5.12.

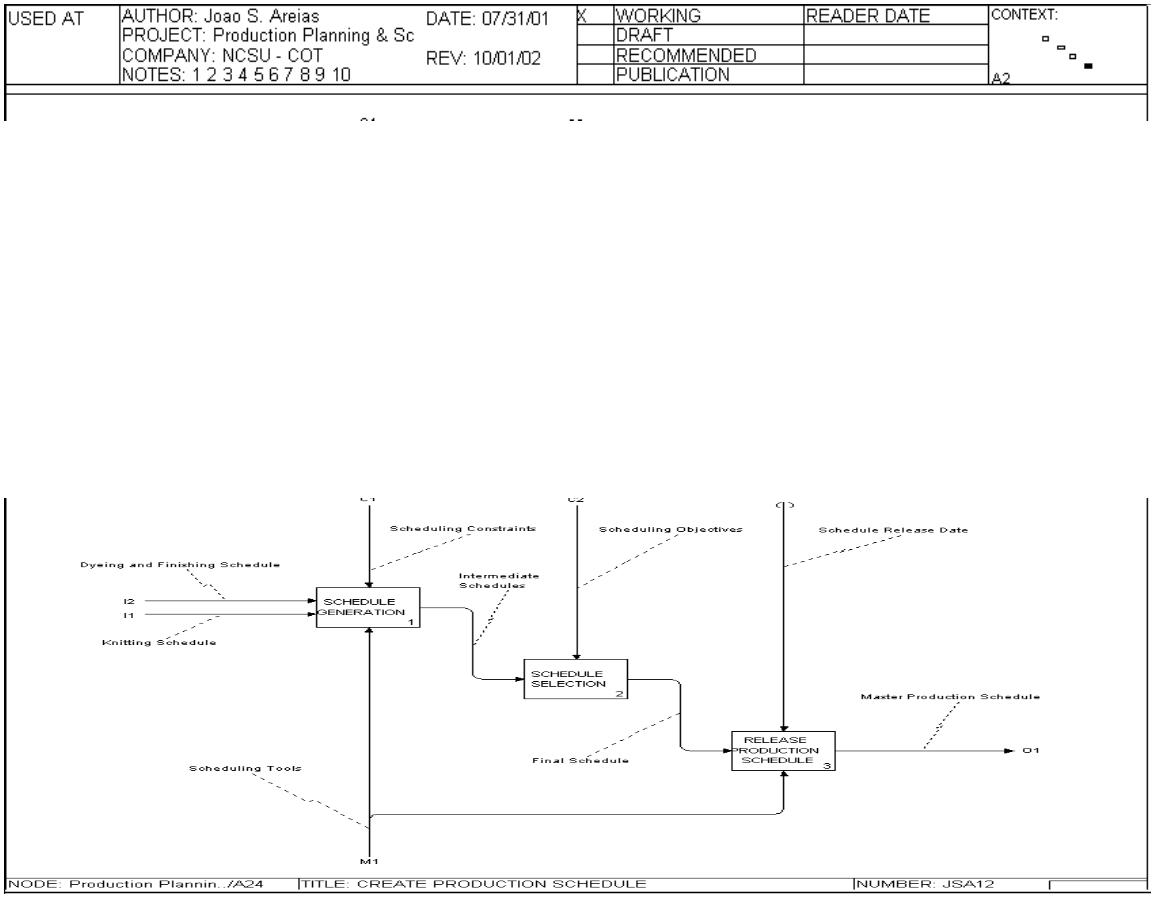


Figure 5.13: A2.4 Diagram

Once the schedules for knitting, dyeing and finishing are ready, it is necessary to aggregate these into a combined schedule. This is done in the SCHEDULE GENERATION activity where possible schedules are generated and then only one is selected from this set and released to production, as seen in Figure 5.13.

Chapter 6. Building The IDEF1X Model

Chapter 5 described the IDEF0 models developed for the planning and scheduling of the knitting, dyeing and finishing processes, while this chapter will describe the IDEF 1X data model. This model can be used to implement information technology for this process.

6.1. Phase Zero

The IDEF1X data model must be described and defined in terms of both its limitations and its ambitions. The modeler is one of the primary influences in the development of the scope of the model. Together, the modeler and the project manager unfold the plan for reaching the objectives of Phase Zero. These objectives include:

a) Project definition – a general statement of what has to be done, why, and how it will get done.

b) Source material – a plan for the acquisition of source material, including indexing and filing.

c) Author conventions – a fundamental declaration of the conventions (optional methods) by which the author chooses to make and manage the model.

The products of these objectives, coupled with other descriptive and explanatory information, become the products of the Phase Zero effort [13].

Table 6.1: Outputs from Phase Zero

Output	Description
Project Definition	Develop a model of the basic database structure for the production planning and scheduling activities in a warp knitting, dyeing and finishing facility.
Source Material	IDEF0 diagrams, information from literature review, and information from plant visits.
Author Conventions	The models will fit the ZIFA framework for IS architecture.
Scope	The models will include the IDEF0 activities according to the illustration in Figure 6.1.

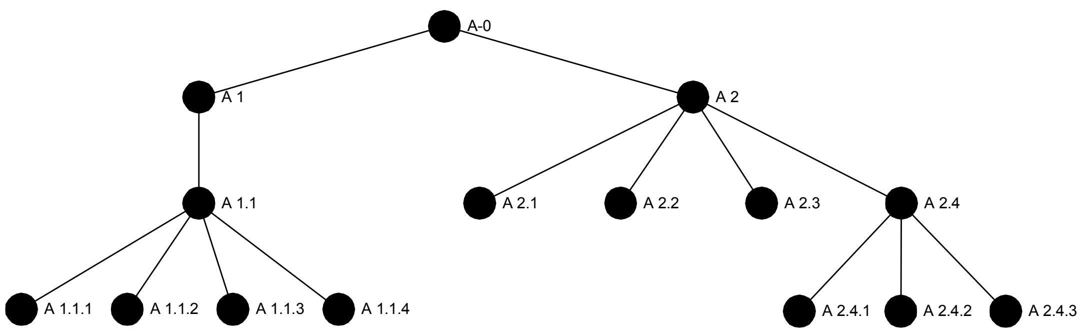


Figure 6.1: Scope of the IDEF1X Diagrams

6.2. Phase One

The objective of Phase One is to identify and define the entities that fall within the problem domain being modeled (the model scope is defined in 6.1). The first step in this process is the identification of entities [13]. An "entity" within the context of an IDEF1X Model represents a set of "things" which have data associated with them, where, a "thing" may be an individual, a physical substance, an event, a deed, an idea, a notion, a point, a place, etc. Members of the set represented by the entity have a common set of attributes or characteristics. For example, all members of the set of employees have an employee number, name, and other common attributes. An individual member of an entity set is referred to as an instance of the entity. For example, the employee named Jerry with employee number 789 is an instance of the entity EMPLOYEE. Entities are always named with a singular, generic noun phrase [13].

6.2.1. Entity Pool

The entity pool presented in Table 6.2 contains all of the names of entities defined within the context of the model for the knitting, dyeing and finishing planning and scheduling system. The entity pool also indicates the corresponding IDEF0 model.

Table 6.2: Entity Pool

Entity		Source
Code	Name	IDEF0 Node
E 01	Demand Forecasts	A0
E 02	Dyeing and Finishing Activities List	A2
E 03	Dyeing and Finishing Schedule	A2
E 04	Final Schedule	A2.4
E 05	Human Resources Needs	A1
E 06	Intermediate Schedules	A2.4
E 07	Inventory Level	A1.1
E 08	Knitting Activities List	A2
E 09	Knitting Schedule	A2
E 10	Machine Needs	A1
E 11	Manufacturing Orders	A0
E 12	Master Production Schedule	A0
E 13	Parts List (BOM)	A0
E 14	Product Groups	A1.1
E 15	Production Schedule	A0
E 16	Style List	A1.1
E 17	Style List Schedule	A1
E 18	Yarn Requirements	A1

6.2.2. Entity Glossary

The entities listed in the entity pool (please refer to Table 6.2) have been previously defined in Section 5.5.2 when describing the arrows used in the IDEF0 diagrams.

6.3. Phase Two

The objective of Phase Two is to identify and define the basic relationships between entities. At this stage of modeling, some relationships may be non-specific and will require additional refinement in subsequent phases. The primary outputs from Phase Two are the relationship matrix, the relationship definitions, and the entity-level diagrams [13].

A “relationship” can be defined as simply as an association or connection between two entities. More precisely, this is called a “binary relationship”. Owing to the fact the relationship is defined between two entities only, IDEF1X is restricted to binary relationships because they are easier to define and understand than “*n*-ary” relationships. They also have a straightforward graphical representation. The disadvantage is a certain awkwardness in representing *n*-ary relationships. But there is no loss of power since any *n*-ary relationships can be expressed using *n* binary relationships. A relationship instance is the meaningful association or connection between two entity instances [13].

6.3.1. Entity Relationship Matrix

The matrix in Table 6.3 represents the relationships of the entities defined in the entity pool. The arrow in the first cell indicates the direction for reading the table (e.g. E 02 is related to E03).

Table 6.3: Entity Relationship Matrix

	E 01	E 02	E 03	E 04	E 05	E 06	E 07	E 08	E 09	E 10	E 11	E 12	E 13	E 14	E 15	E 16	E 17	E 18
E 01												X		X				
E 02			X															
E 03						X												
E 04															X			
E 05												X						
E 06				X														
E 07																		
E 08									X									
E 09						X												
E 10												X						
E 11												X		X				
E 12		X						X					X		X		X	
E 13																		
E 14	X										X							
E 15																		
E 16							X							X			X	
E 17							X											X
E 18																		

6.3.2. Relationship Definitions

Now that the binary relations have been defined in the matrix, the definitions of each of those relationships has to be defined the relationship definitions include [13]:

a) Indication of dependencies;
b) Relationship name;
d) Narrative statements about the relationship.

In order to establish dependency, the relationship between two entities must be examined in both directions. This is done by determining cardinality at each end of the relationship.

Once the relationship dependencies have been established, it is necessary to define a name and a relationship definition. The relationship name is a short phrase, typically a verb phrase with a conjunction to the second entity mentioned. This phrase reflects the meaning of the relationship represented. Frequently, the relationship name is simply a single verb; however, a verb phrase may also appear frequently in relationship names. The relationship definition is a textual statement explaining the relationship meaning [13].

The relationships between the different entities may be of different types, as seen in the IDEF1X diagrams of Section 6.6. Table 6.4 summarizes the relationships and provides a definition of the relationship for better understanding of the diagrams.

Table 6.4: Relationship Description

Relationship	Description
Generates	One database generates another.
Gets information from	-
Provides information for	-
Is divided to	Information from one entity is divided in other entities.
Orders	Releases information associated with an order.
Is compiled	Is formed based on more than one entity.

6.3.3. Entity Level Diagrams

The entity level diagrams will not be presented in this section, since these are represented in the final IDEF1X diagrams in Section 6.6.

6.4. Phase Three

Once phase two is complete, the objectives of Phase Three are to [13]:

a) Refine the non-specific relationships from Phase Two,
b) Define key attributes for each entity,
c) Migrate primary keys to establish foreign keys, and
d) Validate relationships and keys.

This section will provide the basic information concerning the attributes associated with each entity, from these the primary and foreign key attributes are identified. Definitions of the entities and the attributes will also be a part of this section.

Results of Phase Three will, as listed in the first paragraph for items a) and d), will not be provided due to simplification reasons, but results from non-specific relationships refinement, and validation of relationships and keys can be seen in the final diagrams in Section 6.6.

6.4.1. Key Attributes Definition

Table 6.5 defines all of the attributes for each entity where the primary key (PK) and foreign key (FK) are indicated. A foreign key is an attribute which is imported from another entity.

Table 6.5: Key Attributes Definition

Code	Entity Name	Attributes
E 01	Demand Forecasts	• Dmnd_Frct # (PK) • Style_ID • Quantity • Need_Date
E 02	Dyeing and Finishing Activities List	• DF_Act_Lst # (PK) • Style_ID • Mas_Prod_Sch # (FK)
E 03	Dyeing and Finishing Schedule	• DF_Sch # (PK) • DF_Act_Lst # (FK)
E 04	Final Schedule	Considered as Production Schedule (E15)
E 05	Human Resources Needs	• Mach_Grp • Man_Hours
E 06	Intermediate Schedules	• Schedule # (PK) • Sch_Objective • Sch_Obj_Value • Knt_Sch # (FK) • DF_Sch # (FK)
E 07	Inventory Level	• Item_ID • Prod_Grp # (FK) • Style_ID • Item_Name • Quantity
E 08	Knitting Activities List	• Knt_Act_Lst # (PK) • Style_ID • Mas_Prod_Sch # (FK)
E 09	Knitting Schedule	• Knt_Sch # (PK) • Knt_Act_Lst # (FK)
E 10	Machine Needs	• Style_ID (PK) • Mach_Grp • Mach_Hours
E 11	Manufacturing Order	• Man_Ord # (PK) • Cust_ID • Style_ID • Quantity • Need_Date
E 12	Master Production Schedule	• Mas_Prod_Sch # (PK) • Due_Date • Need_Date • Man_Ord # (FK) • Dmnd_Frct # (FK) • Style_Lst_Sch # (FK) • Prod_Grp # (FK) • Style_ID (FK) • Mach_Grp (FK)
E 13	Parts List (BOM)	• Style_ID (PK) • Item_ID (PK) • Quantity

		• Mas_Prod_Sch # (FK) • Mas_Prod_Sch # (FK)
E 14	Product Group	• Prod_Grp # (PK) • Man_Ord # (FK) • Need_Date • Quantity • Style_ID • Dmnd_Frct # (FK)
E 15	Production Schedule	• Prod_Sch # (PK) • Date • Need_Date • Date_In • Date_Out • DF_Sch # (FK) • Knt_Sch # (FK) • Mas_Prod_Sch # (FK) • Schedule # (FK)
E 16	Style List	• Prod_Grp # (PK) (FK) • Mach_Grp • Need_Date • Work_Load
E 17	Style List Schedule	• Style_Lst_Sch # (PK) • Prod_Grp # (FK) • Amount • Date • Due_Date • Mach_Grp • Quantity • Style_ID
E 18	Yarn Requirements	• Yarn_Rqrm # • Yarn_Needs • Due_Date • Item_ID • Style_ID • Style_Lst_Sch # (FK) • Pro_Grp # (FK)

6.4.1.1. Entities Definition

The description of the entities in the IDEF1X diagrams is similar to the definitions presented for the IDEF0 ICOM arrows presented in Section 5.5.2. This section will include only the entities for which the previous definitions do not provide enough information for understanding the IDEF1X diagrams.

6.4.1.2. Attributes Definition

Table 6.6 provides a definition of the attributes associated with the entities.

Table 6.6: Attributes Definition

Attribute	Definition
Due_Date	Scheduled completion date associated with the order. Is a result of priority planning [32]
Need_Date	Time at which the order is actually needed. Depends on the customer requirements [32]
Customer_ID	Customer identification code
Item_ID	Item identification code
Machine #	Number that identifies a machine
Date_In	date that the job is scheduled to enter production
Date_Out	Date the job is scheduled to exit production
Prod_Inst_ID	Code that identifies the production instruction for a specific job
Sch_Obj	Specifies a specified scheduling objective
Sch_Obj_Val	Specifies a value for a defined scheduling objective (Sch_Obj)
Units_Available	Amount of available units from a defined item (Item_ID)
Wrk_Ld	Work load of a defined machine group for the production of a defined style
Style_ID	Code that identifies a specific product

6.5. Phase Four

Phase Four is the final stage of model developing. The objectives of this phase are to [13]:

a) Develop an attribute pool
b) Establish attribute ownership
c) Define non-key attributes
d) Validate and refine the data structure

The results of Phase Four are depicted in one or more Phase Four (attribute-level) diagrams. At the end of Phase Four, the data model is fully refined. The model is supported by a complete set of definitions and cross-references for all entities, attributes (key and nonkey), and relationships [13].

6.6. IDEF1X Model Diagrams

Table 6.7 provides a list of the several views that compose the IDEF1X diagrams, it also provides information regarding the IDEF0 diagram that was used as a basis for developing the database model.

Table 6.7: IDEF1X Diagrams Views

View Name		Reference in IDEF0
V1	Production planning and scheduling	A0
V2	Production planning	A1
V3	Production analysis	A1.1
V4	Production scheduling	A2
V5	Create production schedule	A2.4

The diagrams are presented in the following pages, where a brief explanation of the diagram is included.

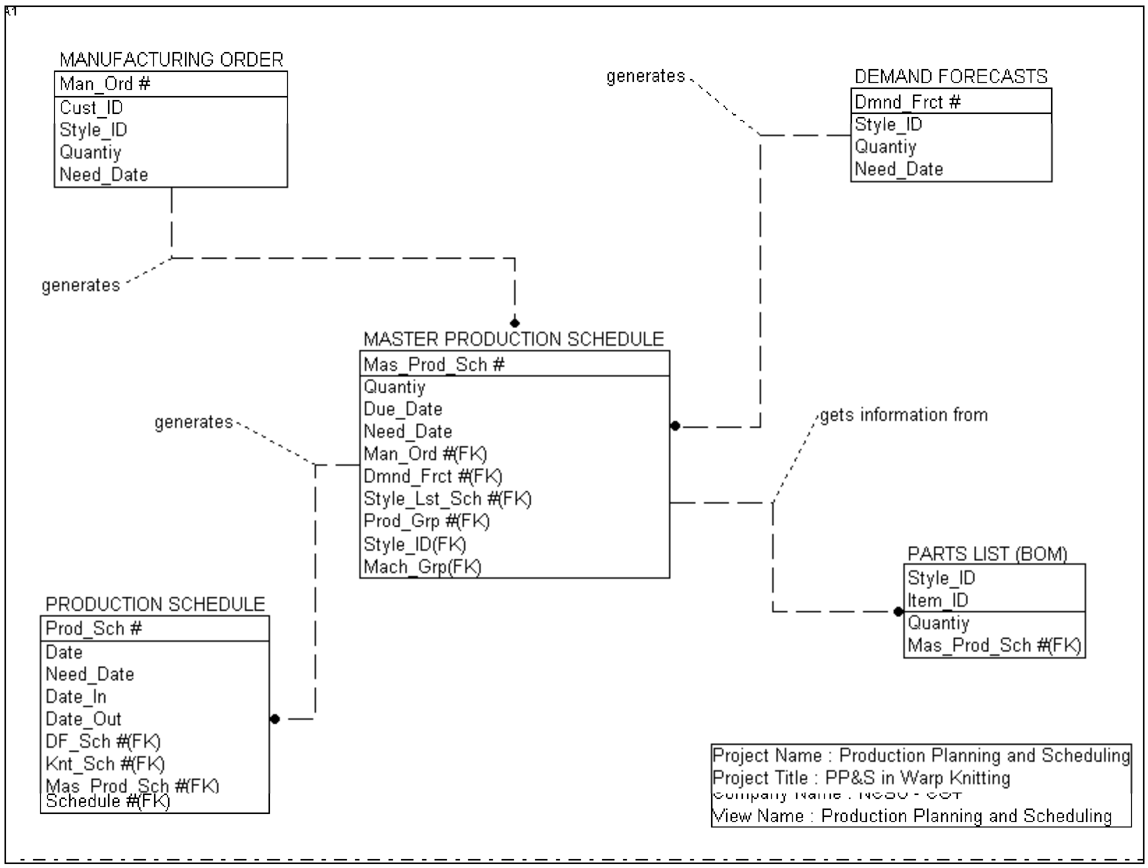


Figure 6.2: IDEF1X Diagram for Production Planning and Scheduling

The production schedule is generated from the MPS that uses the parts list to determine the components of a determined style and the amount to be produced of each component. The MPS is generated from the manufacturing orders and the demand forecasts.

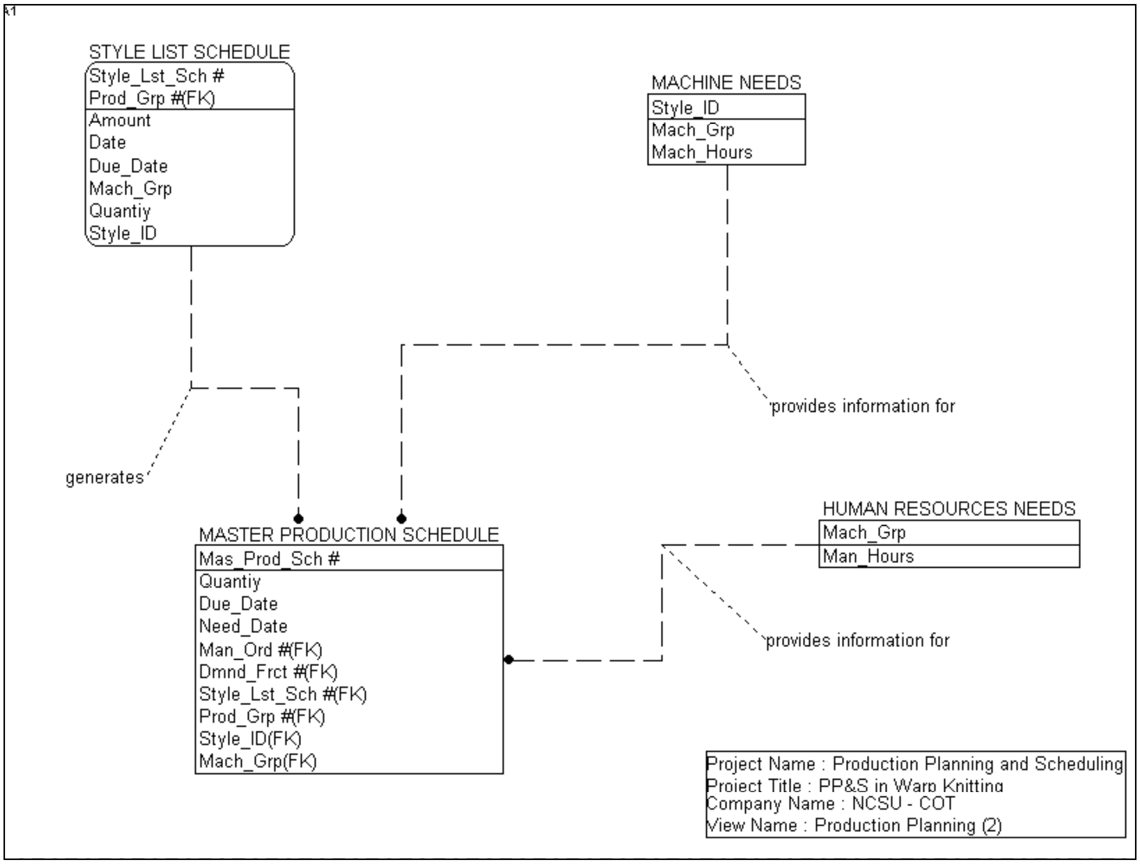


Figure 6.3: IDEF1X Diagram for Production Planning

Due to simplification concerns, the databases presented in this diagram do not represent all the information required for creating the MPS from the style list schedule, assuring that machine and personnel needs are guaranteed.

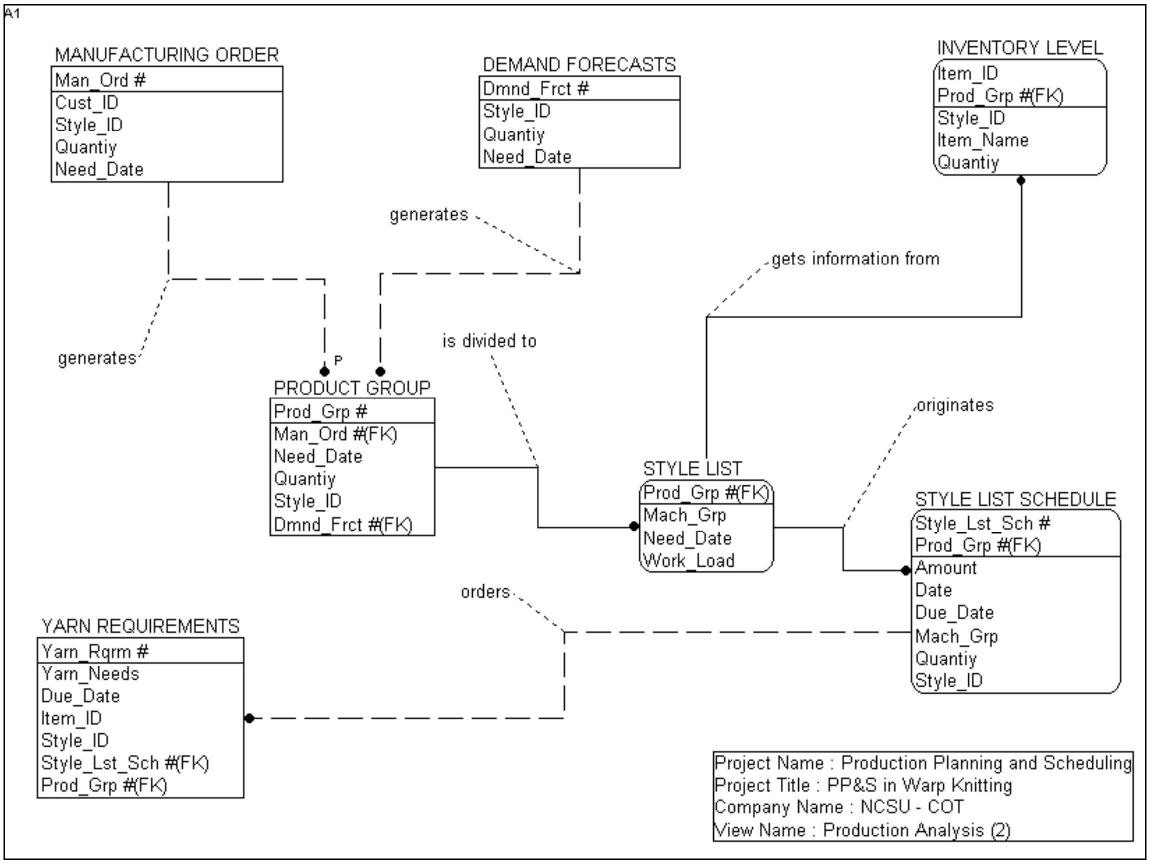


Figure 6.4: IDEF1X Diagram for Production Analysis

The information outputs are the yarn requirements for purchasing, and the styles needed for a determined production order.

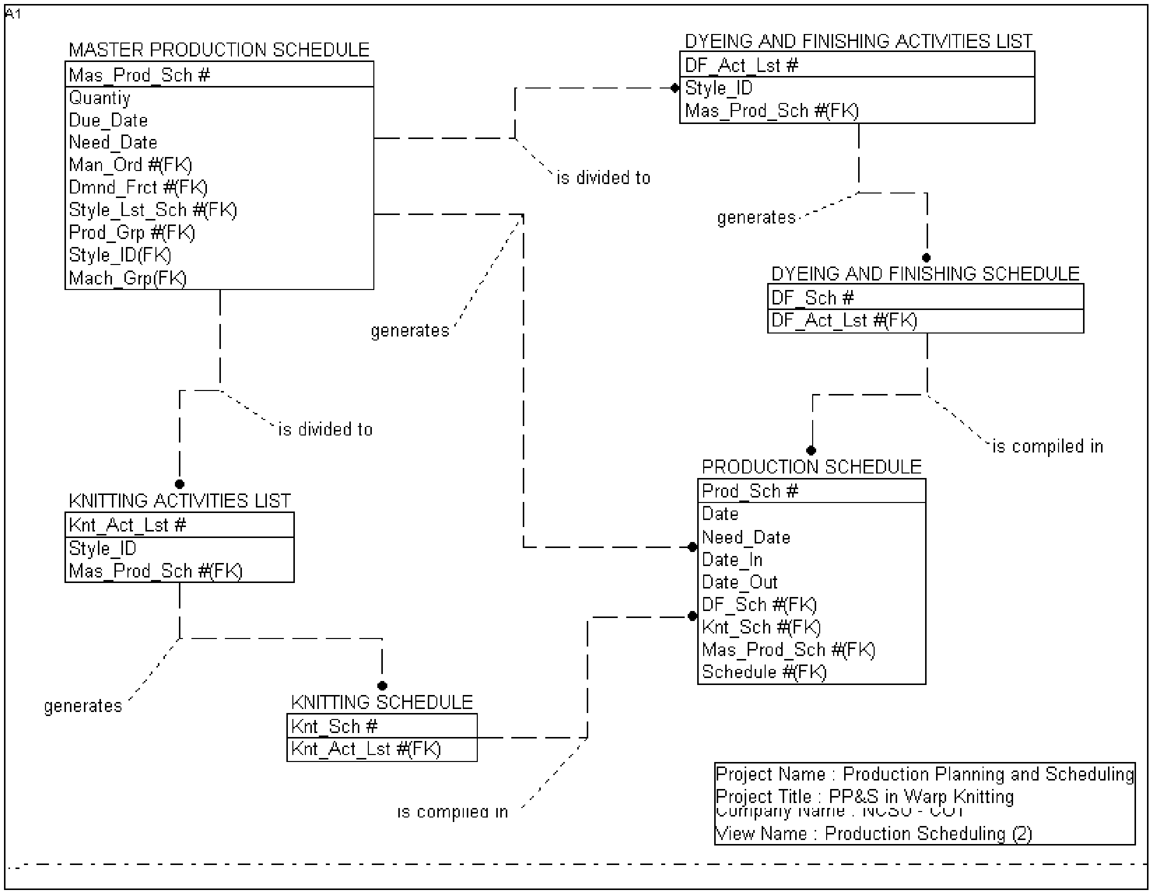


Figure 6.5: IDEF1X Diagram for Production Scheduling

The diagram in Figure 6.5 presents the basic databases involved in production scheduling, from the initial input (the MPS) to the final output (Production Schedule).

The MPS is separated into lists of activities for knitting and for dyeing and finishing. From the list of activities the schedules for these two processes are generated, and the combination of the two schedules will result in the production schedule.

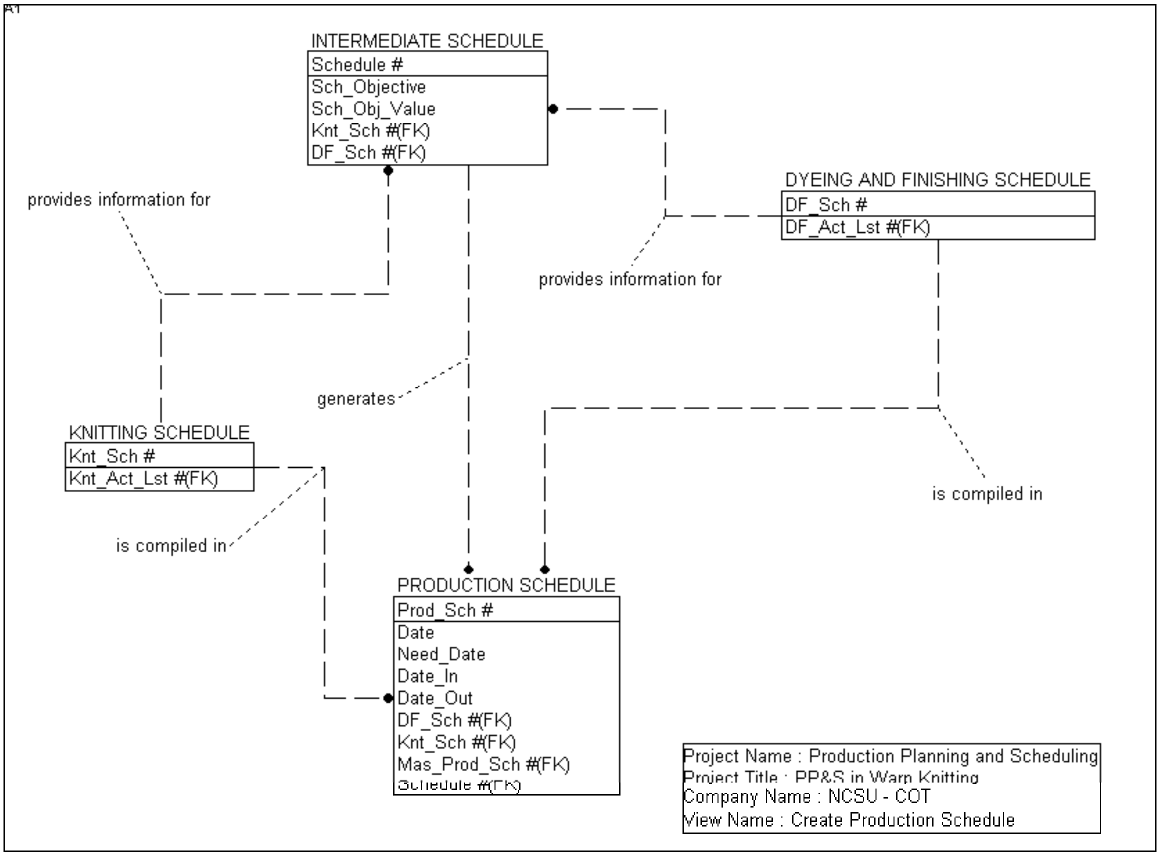


Figure 6.6: IDEF1X Diagram for Create Production Schedule

The diagram presents the basic databases involved in the creation of the production schedule that will be released to manufacturing.

Intermediate schedules are generated from the knitting and from the dyeing and finishing schedule. Each generated schedule will have a defined value for each selected scheduling objective, from these schedules, the final production schedule will be chosen and then released to manufacturing.

Chapter 7. Conclusions

From the work developed it is possible to draw the following conclusions.

The planning and scheduling areas are underdeveloped (considering the visits made) in the knitting industry as compared to other industries (e.g. automotive, and electronics) where it is possible to see state of the art solutions implemented. Companies are usually using in-house, developed solutions, which are tailored to the needs and the processes involved in the planning and scheduling activities, although tailored made solutions are a good way of responding to real world every day needs of a company, the fact that these are not based on scientific understanding of the system, will prevent from reaching an optimal or best possible result, as well as will impair the long term view of business and industry evolution.

The modeling method used can respond in an adequate way to the objective of modeling the warp knitting, finishing and dyeing processes. The IDEF0 modeling methodology has proven to be an adequate tool for modeling the activities and the ICOM involved in production planning and scheduling owing to its simple construction method and visualization, providing a good perspective of the activities represented for the production planning and scheduling of the knitting, and dyeing and finishing processes.

The IDEF1X methodology, although this work has chosen a simple approach, does face some disadvantages, mainly if compared with more recent object oriented methodologies, like UML[11]. Transitioning from IDEF0 to IDEF1X was a relatively simple process, mainly because these two modeling languages have been developed with integration in mind.

As a result of defining the activities that compose the Production Planning and Scheduling areas, improvements may be obtained by timing each activity

[11] UML: Unified Modeling Language.

and selecting the longest activities that could be improved in efficiency. Clearly defining the activities involved in production planning and scheduling, as in other areas of the company, provides a valuable starting point for several projects that the company may be interested in developing, from a simple activity interaction analysis, to a BPR[12] approach, or even with the objective of developing a QMS[13], mainly applicable with the ISO 9000:2000 process approach.

The work developed provides the basis for a company working with knitted goods to develop an information system network. A core part has been defined and can be easily modified to respond to a company's requirements. Having the models developed, their application as a starting point or for comparison with other existing or potential systems is linear. A company may use the models, since these are a simplified representation and provide generalized information, to help developing an information system, also with the help of the Zachman framework or other currently available methodologies for planning an information system.

[12] BPR: Business Process Reengineering.
[13] QMS: Quality Management System.

Chapter 8. Future Work

The following paragraphs provide guidelines for future work that may be developed.

Development of a complete model, including all the processes that play a part in warp knitted production. Developing a model with a broader scope would be a choice for future work. However, this would be a difficult and complex task.

Developing a scheduling algorithm according to the constraints applied to the production process that would maximize or minimize a certain set of scheduling objectives selected from the most current objectives in warp knitting. From this algorithm, a software tool could be built enabling the implementation of the solution.

Other future work would be to develop a model that takes into account a higher level of detail regarding machine settings for different operation types. Also, developing the FEO model presented in Section 5.2 with the objective of describing in higher detail the interactions occurring between the several areas of the company. Acknowledging the fundamental role that information plays in the organization, and being aware that this is often neglected due to many times to the fact that it is not recognized, awareness of how different areas of the company interact with each other is a very important step. The diagram in Section 5.2 is a basis for tackling with this problem.

Development of a product groups database to be used by the knitting industry. The product groups would be created by separating the products according to the operations that are required for their manufacture.

Study the changes that should take place in the shop-floor in order to decrease production lead time and increase flexibility. A broader scope of the model would be needed, which would not only include production planning and scheduling but also include production control features necessary for the shop-floor control, data acquisition, and continuous improvement.

Develop a model for a flexible environment that would allow a company to change the production paradigm according to the end product that is planned for production and from where is the information arriving, upstream or downstream. According to the end product, the production may work with a pull or a push system since these are easily interchangeable. Once storage is defined, with amounts and types of products, it is possible to analyze the product, define the production system (Push or Pull) and send the information to the terminal that is more able to satisfy this demand. We are proposing an automated choice of the production paradigm, in order to allow flexible choice of the paradigm.

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Chapter 10. Appendices

10.1. Appendix I – Glossary of Terms

10.1.1. General Terms

Production Organization – system that can manufacture products in accordance to prescribed production targets, provided that it is supplied with the resources needed to manufacture these products [3].

Product – end-item for manufacturing and a commodity for sale [3].

Resources – non-renewable items such as raw materials or renewable items such as tools, product designs, and machines [3].

Critical Path Lead Time – earliest time that the end product could be built from the time an order is received [32].

Bill Of Materials (BOM) – quantity of each item, ingredient, or material needed to assemble, mix or produce an end product [32].

Master Production Schedule (MPS) – Feasible manufacturing plan stated in terms of specific products that are to be produced in certain quantities by certain dates [32].

10.1.2. IDEF0 Definitions

The definitions presented in this section have been reprinted from the Federal Information Processing Standards Publications draft standard for IDEF0 [14].

A-0 Diagram: The special case of a one-box IDEF0 context diagram, containing the top-level function being modeled and its inputs, controls, outputs and mechanisms, along with statements of model purpose and viewpoint.

Arrow: A directed line, composed of one or more arrow segments, that models an open channel or conduit conveying data or objects from source (no arrowhead) to use (with arrowhead). There are 4 arrow classes: Input Arrow, Output Arrow, Control Arrow, and Mechanism Arrow (includes Call Arrow). See Arrow Segment, Boundary Arrow, Internal Arrow.

Arrow Label: A noun or noun phrase associated with an IDEF0 arrow or arrow segment, specifying its meaning.

Arrow Segment: A line segment that originates or terminates at a box side, a branch (fork or join), or a boundary (unconnected end).

Boundary Arrow: An arrow with one end (source or use) not connected to any box on a diagram. Contrast with Internal Arrow.

Box: A rectangle, containing a name and number, used to represent a function.

Box Name: The verb or verb phrase placed inside an IDEF0 box to describe the modeled function.

Box Number: The number (0 to 6) placed inside the lower right corner of an IDEF0 box to uniquely identify the box on a diagram.

Branch: A junction (fork or join) of two or more arrow segments.

Bundling/Unbundling: The combining of arrow meanings into a composite meaning (bundling), or the separation of arrow meanings (unbundling), expressed by arrow join and fork syntax.

C-Number: A chronological creation number that may be used to uniquely identify a diagram and to trace its history; may be used as a Detail Reference Expression to specify a particular version of a diagram.

Call Arrow: A type of mechanism arrow that enables the sharing of detail between models (linking them together) or within a model.

Child Box: A box on a child diagram.

Child Diagram: The diagram that details a parent box.

Context: The immediate environment in which a function (or set of functions on a diagram) operates.

Context Diagram: A diagram that presents the context of a model, whose node number is A-n (n greater than or equal to zero). The one-box A-0 diagram is a required context diagram; those with node numbers A-1, A-2, ... are optional context diagrams.

Control Arrow: The class of arrows that express IDEF0 Control, i.e., conditions required to produce correct output. Data or objects modeled as controls may be transformed by the function, creating output. Control arrows are associated with the top side of an IDEF0 box.

Decomposition: The partitioning of a modeled function into its component functions.

Detail Reference Expression (DRE): A reference (e.g., node number, C-number, page number) written beneath the lower right corner of an IDEF0 box to show that it is detailed and to indicate which diagram details it.

Diagram: A single unit of an IDEF0 model that presents the details of a box.

Diagram Node Number: That part of a diagram's node reference that corresponds to its parent box node number.

For Exposition Only (FEO) Diagram: A graphic description used to expose or highlight specific facts about an IDEF0 diagram. Unlike an IDEF0 graphic diagram, a FEO diagram need not comply with IDEF0 rules.

Fork: The junction at which an IDEF0 arrow segment (going from source to use) divides into two or more arrow segments. May denote unbundling of meaning.

Function: An activity, process, or transformation (modeled by an IDEF0 box) identified by a verb or verb phrase that describes what must be accomplished.

Function Name: Same as Box Name.

Glossary: A listing of definitions for key words, phrases and acronyms used in conjunction with an IDEF0 node or model as a whole.

ICOM Code: The acronym of Input, Control, Output, Mechanism. A code that associates the boundary arrows of a child diagram with the arrows of its parent box; also used for reference purposes.

IDEF0 Model: A graphic description of a system or subject that is developed for a specific purpose and from a selected viewpoint. A set of one or more IDEF0 diagrams that depict the functions of a system or subject area with graphics, text and glossary.

Input Arrow: The class of arrows that express IDEF0 Input, i.e., the data or objects that are transformed by the function into output. Input arrows are associated with the left side of an IDEF0 box.

Interface: A shared boundary across which data or objects are passed; the connection between two or more model components for the purpose of passing data or objects from one to the other.

Internal Arrow: An input, control or output arrow connected at both ends (source and use) to a box on a diagram. Contrast with Boundary Arrow.

Join: The junction at which an IDEF0 arrow segment (going from source to use) merges with one or more other arrow segments to form a single arrow segment. May denote bundling of arrow segment meanings.

Mechanism Arrow: The class of arrows that express IDEF0 Mechanism, i.e., the means used to perform a function; includes the special case of Call Arrow. Mechanism arrows are associated with the bottom side of an IDEF0 box.

Model Note: A textual comment that is part of an IDEF0 diagram, used to record a fact not otherwise depicted.

Node: A box from which child boxes originate; a parent box. See Node Index, Node Tree, Node Number, Node Reference, Diagram Node Number.

Node Index: A listing, often indented, showing nodes in an IDEF0 model in "outline" order. Same meaning and content as Node Tree.

Node Number: A code assigned to a box to specify its position in the model hierarchy; may be used as a Detail Reference Expression.

Node Reference: A code assigned to a diagram to identify it and specify its position in the model hierarchy; composed of the model name (abbreviated) and the diagram node number, with optional extensions.

Node Tree: The graphical representation of the parent-child relationships between the nodes of an IDEF0 model, in the form of a graphical tree. Same meaning and content as Node Index.

Output Arrow: The class of arrows that express IDEF0 Output, i.e., the data or objects produced by a function. Output arrows are associated with the right side of an IDEF0 box.

Parent Box: A box that is detailed by a child diagram.

Parent Diagram: A diagram that contains a parent box.

Purpose: A brief statement of the reason for a model's existence.

Semantics: The meaning of the syntactic components of a language.

Squiggle: A small jagged line that may be used to associate a label with a particular arrow segment or to associate a model note with a component of a diagram.

Syntax: Structural components or features of a language and the rules that define relationships among them.

Text: An overall textual (non-graphical) comment about an IDEF0 graphic diagram.

Title: A verb or verb phrase that describes the overall function presented on an IDEF0 diagram; the title of a child diagram corresponds to its parent box name.

Tunneled Arrow: An arrow (with special notation) that does not follow the normal requirement that each arrow on a diagram must correspond to arrows on related parent and child diagrams.

Viewpoint: A brief statement of the perspective of the model.

10.1.3. IDEF1X Definitions

The definitions presented in this section have been reprinted from the Federal Information Processing Standards Publications standard for IDEF1X [13].

Alias: A nonstandard name for an entity or domain (attribute).

Assertion: A statement that specifies a condition that must be true.

Attribute: A property or characteristic that is common to some or all of the instances of an entity. An attribute represents the use of a domain in the context of an entity.

Attribute, Inherited: An attribute that is a characteristic of a category entity by virtue of being an attribute in its generic entity or a generic ancestor entity.

Attribute, Migrated: A foreign key attribute of a child entity.

Attribute, Non-key: An attribute that is not the primary or a part of a composite primary key of an entity. A non-key attribute may be a foreign key or alternate key attribute.

Attribute, Optional: A non-key attribute of an entity that may be null in any instance of the entity.

Attribute, Owned: An attribute of an entity that has not migrated into the entity.

Attribute Value: A value given to an attribute in an entity instance.

Category Cluster: A set of one or more mutually exclusive categorization relationships for the same generic entity.

Category Discriminator: An attribute in the generic entity (or a generic ancestor entity) of a category cluster. The values of the discriminator indicate which category entity in the category cluster contains a specific instance of the generic entity. All instances of the generic entity with the same discriminator value are instances of the same category entity. The inverse is also true.

Conceptual Schema: See Schema

Constraint: A rule that specifies a valid condition of data.

Constraint, Cardinality: A limit on the number of entity instances that can be associated with each other in a relationship.

Constraint, Existence: A condition where an instance of one entity cannot exist unless an instance of another related entity also exists.

Database: A collection of interrelated data, often with controlled redundancy, organized according to a schema to serve one or more applications.

Data Model: A graphical and textual representation of analysis that identifies the data needed by an organization to achieve its mission, functions, goals, objectives, and strategies and to manage and rate the organization. A data model identifies the entities, domains(attributes), and relationships (or associations) with other data, and provides the conceptual view of the data and the relationships among data.

Data Type: A categorization of an abstract set of possible values, characteristics, and set of operations for an attribute. Integers, real numbers, character strings, and enumerations are examples of data types.

Domain: A named set of data values (fixed, or possibly infinite in number) all of the same data type, upon which the actual value for an attribute instance is drawn. Every attribute must be defined on exactly one underlying domain. Multiple attributes may be based on the same underlying domain.

Enterprise: An organization that exists to perform a specific mission and achieve associated goals and objectives.

Entity: The representation of a set of real or abstract things (people, objects, places, events, ideas, combination of things, etc.) that are recognized as the same type because they share the same characteristics and can participate in the same relationships.

Entity, Category: An entity whose instances represent a sub-type or sub-classification of another entity (generic entity). Also known as sub-type or sub-class.

Entity, Child: The entity in a specific connection relationship whose instances can be related to zero or one instance of the other entity (parent entity).

Entity, Generic: An entity whose instances are classified into one or more sub-types or sub-classifications (category entity). Also known as super-type or super-class.

Entity Instance: One of a set of real or abstract things represented by an entity. The instance of an entity can be specifically identified by the value of the attribute(s) participating in its primary key.

Entity, Parent: An entity in a specific connection relationship whose instances can be related to a number of instances of another entity (child entity).

Existence Dependency: A constraint between two related entities indicating that no instance of one (child entity) can exist without being related to an instance of the other (parent entity). The following relationship types represent existence dependencies: identifying relationships, categorization relationships and mandatory non-identifying relationships.

External Schema: See Schema

Functional Dependency: A special kind of integrity constraint that applies within the confines of a single entity "R", where each "X" value of "R" has associated with it at most one "Y" value of "R" (at any one time). Attributes "X" and "Y" may be composite.

Glossary: A set of definitions of entities and domains (attributes).

IDEF1X Diagram: See View Diagram.

IDEF1X Model: A set of one or more IDEF1X views, often represented as view diagrams which depict the underlying semantics of the views, along with definitions of the entities and attributes used in the views. See Data Model.

Identifier Dependency: A constraint between two related entities that requires the primary key in one (child entity) to contain the entire primary key of the other (parent entity). The following relationship types represent identifier dependencies: Identifying relationships, categorization relationships.

Key, Candidate: An attribute, or combination of attributes, of an entity whose values uniquely identify each entity instance.

Key, Alternate: Any candidate key of an entity other than the primary key.

Key, Composite: A key comprised of two or more attributes.

Key, Compound: Same as Key, Composite.

Key, Foreign: An attribute, or combination of attributes of a child or category entity instance whose values match those in the primary key of a related parent or generic entity instance. A foreign key results from the migration of the parent or generic entities primary key through a specific connection or categorization relationship.

Key, Migrated: Same as Foreign Key.

Key Migration: The modeling process of placing the primary key of a parent or generic entity in its child or category entity as a foreign key.

Key, Primary: The candidate key selected as the unique identifier of an entity.

Key, Split: A foreign key containing two or more attributes, where at least one of the attributes is a part of the entities primary key and at least one of the attributes is not a part of the primary key.

Normal Form: The condition of an entity relative to satisfaction of a set of normalization theory constraints on its attribution. A specific normal form is achieved by successive reduction of an entity from its existing condition to some more desirable form. The procedure is reversible.
a) First Normal Form (1NF) - An entity is in 1NF if and only if all underlying simple domains contain atomic values only.
b) Second Normal Form (2NF) - An entity is in 2NF if and only if it is in 1NF and every non-key attribute is fully dependent on the primary key.
c) Third Normal Form (3NF) - An entity is in 3NF if and only if it is in 2NF and every attribute that is not a part of the primary key is non-transitively dependent (mutually independent) on the primary key. Two or more attributes are mutually independent if none of them is functionally dependent on any combination of the others.

Normalization: the process of refining and regrouping attributes in entities according to the normal forms.

Null: A condition where a value of an attribute is not applicable or not known for an entity instance.

Relationship: An association between two entities or between instances of the same entity.

Relationship Cardinality: The number of entity instances that can be associated with each other in a relationship. See Constraint, Cardinality.

Relationship, Categorization (Category): A relationship in which instances of both entities represent the same real or abstract thing. One entity (generic entity) represents the complete set of things the other (category entity) represents a sub-type or sub-classification of those things. The category entity may have one or more characteristics, or a relationship with instances of another entity not shared by all generic entity instances. Each instance of the category entity is simultaneously an instance of the generic entity.

Relationship, Connection: Same as Relationship, Specific Connection.

Relationship, Identifying: A specific connection relationship in which every attribute in the primary key of the parent entity is contained in the primary key of the child entity.

Relationship, Mandatory Non-identifying: A non-identifying relationship in which an instance of the child entity must be related to an instance of the parent entity.

Relationship Name: A verb or verb phrase which reflects the meaning of the relationship expressed between the two entities shown on the diagram on which the name appears.

Relationship, Non-specific: An relationship in which an instance of either entity can be related to a number of instances of the other.

Relationship, Non-identifying: A specific connection relationship in which some or all of the attributes contained in the primary key of the parent entity do not participate in the primary key of the child entity.

Relationship, Optional Non-identifying: A non-identifying relationship in which an instance of the child entity can exist without being related to an instance of the parent entity.

Relationship, Parent-Child: Same as Relationship, Specific Connection.

Relationship, Specific Connection: A relationship where a number of instances of one entity (child entity) can be related to zero or one instance of the other entity (parent entity). In a specific connection relationship the primary key of the parent entity is contributed as a foreign key to the child entity.

Role Name: A name assigned to a foreign key attribute to represent the use of the foreign key in the entity.

Schema: A definition of data structure:

a) Conceptual Schema: A schema of the ANSI/SPARC Three Schema Architecture, in which the structure of data is represented in a form independent of any physical storage or external presentation format.
b) External Schema: A schema of the ANSI/SPARC Three Schema Architecture, in which views of information are represented in a form convenient for the users of information; a description of the structure of data as seen by the user of a system.
c) Internal Schema: A schema of the ANSI/SPARC Three Schema Architecture, in which views of information are represented in a form specific to the data base management system used to store the information: a description of the physical structure of data.

Semantics: The meaning of the syntatic components of a language.

Synonym: A word, expression, or symbol accepted as a figurative or symbolic substitute for another word or expression; that is, an alternative name for the same thing. (See Alias)

Syntax: Structural components or features of a language and rules that define relationships among them.

Verb Phrase: A phrase used to name a relationship, which consists of a verb and words which comprise the object of the phrase.

View: A collection of entities and assigned attributes (domains) assembled for some purpose.

View Diagram: A graphic representation of the underlying semantics of a view.

Acceptance Review Committee: A committee of informed experts in the area covered by the modeling effort which provides guidance, arbitration and passes final judgment over the validity of the representation depicted in the completed product (i.e. model acceptance).

Attribute Population: That effort by which “ownership” of an attribute is determined.

Author Conventions: The special practices and standards developed by the modeler to enhance the presentation or utilization of the IDEF model. Author conventions are not allowed to violate any method rules.

Data Collection Plan: The plan which identifies the functions, departments, personnel, etc. which are the sources of the material used for the development of the IDEF model.

Entity Diagram: A diagram which depicts a “subject” entity and all entities directly related to the “subject” entity.

Expert Reviewer: One of the members of the modeling team whose expertise is focused on some particular activity within the enterprise, and whose responsibility it is to provide critical comments on the evolving IDEF model.

FEO (For Explanation Only): A piece of documentation (e.g. diagrams, text, etc.) which provides supportive or explanatory information for the IDEF model. Violation of syntax rules are allowed in an FEO.

Function View: A view diagram constructed to display the data structure related to the functional aspects of the enterprise being modeled. Function views enhance comprehension of a large complex model by displaying only the information associated with a specific topic or perspective.

IDEF Kit Cycle: The regular interchange of portions of an IDEF model in development between the modeler and readers and expert reviewers. The purpose of the kit cycle is the isolation and detection of errors, omissions, and misrepresentations.

IDEF Model: Any model produced using an Integration Definition modeling method (e.g IDEF0, IDEF1X).

Modeler: One of the members of the modeling team whose responsibilities include the data collection, education and training, model recording, and model control during the development of the IDEF model. The modeler is the expert on the IDEF modeling method.

Phase Zero: The initial efforts of the modeling activity in which the context definition is established i.e., project definition, data collection plan, author conventions, standards, etc.

Phase One: The second step in an orderly progression of modeling efforts, during which data is collected and the entities are identified and defined.

Phase Two: The third step in an orderly progression of modeling efforts, during which the relationships between entities are identified and defined.

Phase Three: The fourth step in an orderly progression of modeling efforts, during which non-specific relationships are resolved and primary keys are identified and defined.

Phase Four: The fifth step in an orderly progression of modeling efforts, during which the non-key attributes are identified and defined and the model is completed.

Project Manager: One of the members of a modeling team whose responsibilities include the administrative control over the modeling effort. The duties include: staff the team, set the scope and objectives, chair the Acceptance Review Committee, etc. The member of the project team who has final responsibility for the finished project.

Source(s): One of the members of the modeling team whose responsibility it is to provide the documents, forms, procedures, knowledge, etc. on which the development of the IDEF model is based.

Validation: The process of checking data for correctness or compliance with applicable standards, rules, and policies.

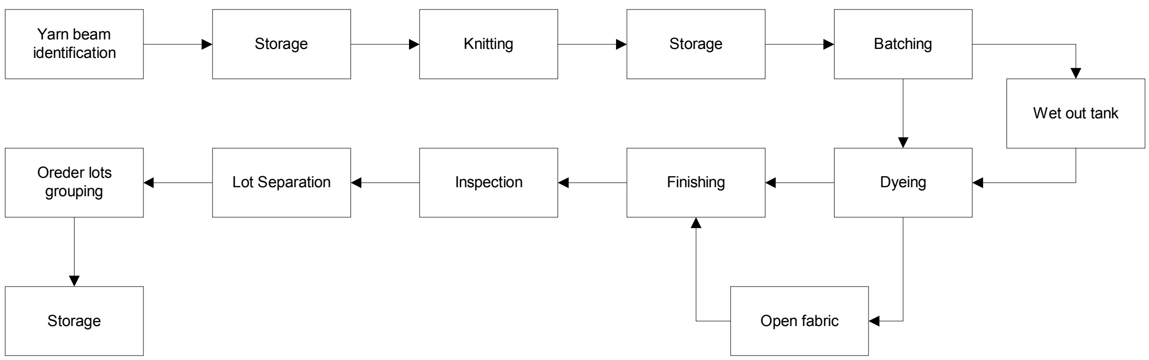
10.2. APPENDIX II – Visit Reports

10.2.1. Company A

Products: intimate apparel, active wear, and light industrial.
Date: 09/19/2001

The company has a total of approximately 150 workers in the plant, and is equipped with 50 two-bar tricot knitting machines, 6 beam dyeing machines, 5 dyeing jets, and 2 turner frames for finishing operations.

The company works with a push operating paradigm, with a make-to-order oriented manufacturing. The beamed yarn is received in an initial storage area, and from that point forward it enters the production sequence, as depicted in the diagram below.



The production plan is developed based on customer projections that can be made with a maximum of 3 months in advance. Yarn orders are made with 5 to 6 weeks in advance, and the end product lead-time is estimated in 3 to 4 weeks. The company works with a high level of different styles, and due to a high style change rate, forecasting is seen as a non-feasible method for generating the data used in the production plan.

The scheduling process is based in informal methodologies, and although setup times are considered the company doesn't have available data that would enable an accurate schedule of jobs considering the required setup times. The company is equipped with a bar code system that enables the tracking of the product throughout almost all the processes in the company.

10.2.2. Company B

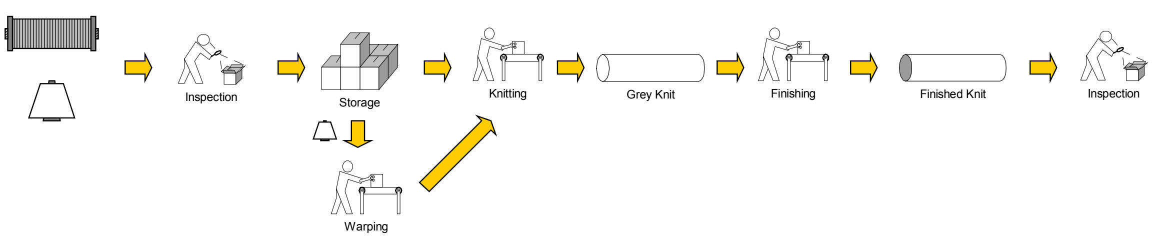
Products: orthopedic, casting, industrial windings for motors and transformers, insulation tape, composite knitted goods.
Date: 09/20/2001

The company has a total of approximately 225 workers in the plant, and is equipped with 9 circular knitting machines, 18 Raschel knitting machines, 2 crochet knitting machines, 1 dyeing machine, and 1 printing machine.

The Planning and Scheduling activities are not considered as independent areas in the company, and these are under the same department and executed by the same person. The company does not have long term production Planning, but a monthly production plan, based on forecasts and customer orders. The activities involved are as follow: Receive customer order; Create production plan; Review yarn inventory – check for yarn needs and availabilities in the desired date; Schedule production; Generate production order.

The allocation of jobs to the machines is done mainly by style, and no formal scheduling rules are used, since the company has an excess of equipment, and so scheduling is not constrained by the equipment characteristics. The constraints considered in the scheduling of jobs are as follows: raw materials inventory, available operators, equipment inventory (e.g. needles, guides), and the next job to be processed. When scheduling, the setup times are considered when style changes are necessary.

Yarn inventory is controlled by a system of minimum inventory level, where yarn orders are made once the inventory reaches this minimum level. The company works with 25 to 30 different kinds of yarn, ranging from polyester, glass fiber, cotton, carbon fibers, Kevlar, and metallic yarns. The beams used in the warp knitting machines are directly supplied by the vendor in an order-to-order basis, according to the specifications provided by the company.



The previous diagram is the general sequence of operations performed to the products produced in the plant. After the final inspection, finished goods are stored and then delivered to the customer. The company end markets are mainly in the US, but exports to Canada, Mexico, and Austria are also among the markets operated.

10.2.3. Company C

Products: golf shirts
Date: 09/21/2001

The company has a total of approximately 350 workers in the plant working in 3 shifts and 40 weekly hours, and is equipped with flat and circular knitting machines, 4 dryers, 8 extractors, 3 resin ranges, 6 calendars, and 4 compactors. The manufacturing is oriented 55% on a make-to-stock system, and 45% on a make-to-order system.

The company buys the dyed yarn, makes a random sampling inspection (amount, count, evenness, and strength), knits the yarn, dyes and finishes it in the same plant. Once the fabric is finished it is wrapped and sent overseas for cutting and sowing. Two overseas plants are responsible for the cutting and sowing operations, one of the plants is company owned, and the other, although independently managed, works mainly for Company C. The contacts to overseas are done by daily reports sent from the headquarters in the US, and weekly phone meetings.

The Planning and Scheduling activities are considered as independent areas in the company. The higher level planning document is an annual forecast (not as accurate as desirable) that is quarterly updated, this document is based on the information provided by the company's sales force. The company prepares a monthly sowing plan with information on the dozens per week required for a certain product type.

The lead time is approximately 8 weeks, being this separated as follows (considering an order of 1000 to 2000 garments): yarn arrival (1 day), knitting (3 days), dyeing (2 days), inspection and shipping (2 days), transport to Central America (1 week), cutting and sowing (4 ½ weeks), transport from Central America (1 week).

10.2.4. Company D

Products: knit fabrics
Date: 09/26/2001

Company D is a private company, with facilities distributed in the US located in Virginia, Tennessee, Georgia, South Carolina, and North Carolina. The visit was made to the company corporate office (headquarters). The number of employees in the corporate office is of approximately 150, included in a total of more than 5000 workers distributed in 7 yarn manufacturing plants, and 4 plants that are responsible for the knitting, finishing and cutting operations. Once the goods are cut, these are shipped to the customers (mainly overseas customers, and a few domestic).

Planning and Scheduling activities are considered as separate areas in the company. The planning activities are centralized in a planning office in the headquarters, and the scheduling activities are done independently in each plant. The production planning activities are done using the Supply Chain Planner software from I2. This software took 2 years to implement and is now in use for the last 2 years (working at 100% in the last year). The Planning Director reports directly to the CEO of the company, and is responsible for the Capacity Planning, and the Operations Planning of the company.

Data used in the planning documents, regarding the amounts to be produced, is obtained based on forecasts and direct customer orders. The higher-level document in production planning is the Annual Operations Plan (AOP), which is quarterly updated. The capacity planning is a master schedule that is fed into the plants. This document is generated once a month, and subjected to weekly updates. The Supply Chain Manager software generates the Master Schedule, as a result of the customers requirements previously fed into the system. The company has a Customer Service Group that provides updates to customers regarding the stage of the orders.

The allocation of the jobs to the different plants is based on the following attributes: quality required, equipment available, and previous plant experience with the product. The plants responsible for processing the jobs are provided with the product, knitting, and finishing specifications. These are electronically transmitted to the plant. Regarding what would make the Planning work more accurate, the opinions fall in the higher forecast accuracy, and a sooner demand anticipation.