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An Industry 4.0 case study in fashion manufacturing

Antonio Grieco[a,]*, Pierpaolo Caricato[a], Doriana Gianfreda[a],

Matteo Pesce[b], Valeria Rigon[b], Luca Tregnaghi[b], Adriano Voglino[b],

[a]*Dipartimento di Ingegneria del'Innovazione,Università del Salento (LE), Italy*
[b] *Bottega Veneta srl, Montebello Vicentino (VI), Italy*

Abstract

We present an application of the Industry 4.0 enabling technologies to Bottega Veneta, an Italian luxury goods house renowned in the world for its leather goods. In particular, we address the production process throughout the supply chain. The proposed framework introduces a uniform data model, used by all the actors involved in the production process to collect and represent the large amount of data involved in the production process. A DSS (Decision Support System) allows the production planner to focus on different scenarios to take better decisions.

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1. Introduction

The "Piano Nazionale Industria 4.0", the Italian plan for the adoption of the Industry 4.0 paradigm by the Italian manufacturing system, indicates a set of enabling technologies that must be used to be able to achieve the rewards that such paradigm promises. Advanced manufacturing solutions, simulation, horizontal/vertical integration and Big Data and analytics are among them.

* Corresponding author. Tel.: +39-0832-297803
E-mail address: antonio.grieco@unisalento.it

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We present an application of these enabling technologies to the world-wide known luxury leather goods producer Bottega Veneta. In particular, we address the production process, which is distributed across several elements of the supply chain and the relative the management issues.

We show how the integration among the different entities in the supply chain and the interoperability of systems within each entity leads to the availability of a large set of data and information, that can be effectively used to feed data analytics systems such as decision support systems. These data are hence processed with advanced tools (analytics and algorithms) to generate meaningful information.

The Bottega Veneta supply chain includes: the main firm, controlled factories and several independent producers, which provide the ability to perform specific parts of the production process. The “as is” production management is conducted using different systems: an ERP system for the main firm, a vertical ERP solution tailored for fashion companies in the factories, an APS (Advanced Planning and Scheduling) tool to provide plans for the factories. The integration among the systems is achieved through traditional data exchange tools. The traditional ERP processes customers’ orders data to feed the APS, which provides its processed results in terms of due dates and production orders to the factories’ vertical ERPs. Independent producers are individually managed outside these systems.

We propose an Industry 4.0 inspired framework as an evolution of the current situation, introducing a uniform data model, used by all the actors involved in the production process. This model is used to collect and represent the large amount of data that are involved in the production process, including logistic information such as due dates and customers’ data, production details such as production cycles, technological constraints and feedback data from the floor shop.

The continuously collected data are both used to effectively coordinate the different actors in the supply-chain as well as within each factory and to feed a complex analytics system that includes, among the other, visual representations of the data that are meaningful to the proper user and a DSS (Decision Support System) that allows production planner at different levels to focus on different automatically generated and locally optimized scenarios to support them in taking better decisions. A specific insight in the algorithms and mathematical models used by the DSS is also presented.

2. Towards Industry 4.0

Industry 4.0 is the next step in a long process of development. The term Industry 4.0 was first introduced during the Hannover Fair event in 2011 (see [1]). It comes from an initiative launched by the German Federal Government as part of its comprehensive High-Tech Strategy. It describes both the fourth stage in the process of industrialization. An introduction to Industry 4.0 concepts can be found in [2]. In the recent work [3], a possible architecture for Industry 4.0-based manufacturing systems is presented.

One of the key objectives of Industry 4.0 is to combine two principles that are actually opposites, strictly speaking – production line manufacturing and custom manufacturing – in a smart environment referred to as smart factory; contributions to this subject were recently provided by the authors in [4, 5]. The concept of a smart factory makes the rather abstract idea of Industry 4.0 easier. This is where the Internet of Things comes into play, i.e. non-human parties communicating with each other. That could be a plant sending out a signal that it needs new material and the smart factory automatically and independently forwarding this information. The communication between these “things” takes place through the Internet in a smart way. This is the core point about Industry 4.0 – the Process Knowledge Automation. The Process Knowledge Automation resolves and enables the problem that work-pieces don’t have the technical capabilities to communicate on their own transforming physical systems into “cyber-physical systems” (CPS), whereby the work-piece is the physical element and the Knowledge Automation is the digital element. The role of humans in CPPS (Cyber-Physical Production Systems), however, should not be disregarded, as highlighted in [6].

In this paper, a method to support the decision process along the supply-chain is de- scribed, focusing on the coordination of the supply-chain of an actual manufacturing case. The knowledge support system has been the result at the end of a development process. The first step was the knowledge capture. In this first phase, a deep insight on the production flow and production rules was conducted in strict synergy with the production engineers who own of the decision process. The second step was the formalization of such knowledge structures according to the ISA95 standard. Finally, in the third step, a mathematical model was developed in order to solve the problem among all the actors within the supply-chain. The innovation hereby proposed is not only limited to the mathematical formulation of an original model but it also includes the formalization of an approach to capture and code unstructured knowledge.

3. The production planning problem

The production planning problem can be modeled using discrete optimization techniques, in particular MIP (Mixed Integer Programming) and CP (Constraint Programming). We developed a first prototype of the tool using MIP, but we plan to also take advantage of CP techniques in future releases.

Two main decisions need to be taken for each task of each production order: who will perform it and when. In order to take this decisions, however, multiple and complex constraints must be considered, some representing technological constraints and some related to supply chain aspects. Finally, multiple objectives must be pursued, mainly: minimizing delayed deliveries and optimize the usage of the available resources.

3.1. Technological constraints

A range of constraints must be defined to take into account aspects strictly related with production-related issues, namely: the possibility or not for a given resource to process a task, the need to respect a production cycle and maximum saturation of the capacity of each resource.

3.1.1. Skills matrix

In order to let the tool to provide actually usable production plans and yet allow the user to make minimal data-entry activities, we used two data sources: the historical production data and a user editable set of exception rules. Hence, to check whether a resource can process or not a task, the following checks are done:

- according to specific features of the task and of the order it is part of (such as model, part, material, required operation, etc.), the tool verifies if previous orders with the same required features set has ever been processed before by the selected resource;
- if the first check is passed, the tool verifies if the user has inserted a rule that specifically forbids the assignment to the resource, even if it was previously done in the past (to manage, for instance, quality issues of the resource with the features set required by the task);
- otherwise, it checks if the user has specified a rule to allow the resource to process tasks with the given features set even if it has never processed them in the past (for instance, to allow the user to specify how to treat new models).

The result of the above processing is a skills matrix that is used to define constraints indicating which tasks can/cannot be assigned to each resource.

3.1.2. Precedence constraints

Each order is characterized by a production cycle, as detailed in section 4.1. Each task of an order, hence, can include a set of one or more tasks that depend on it. The decision model allows a task to be planned to start only after all the tasks that precede it have been completed.

3.1.3. Saturation

The internal job shops and the subcontractors are generically treated as finite capacity resources. Each resource is characterized by its FTE (Full Time Equivalent), i.e. the equivalent of the number of employees working full-time. The user can both define a different default FTE for each resource, used to define its standard daily capacity in terms of available hours, and possible exceptions for a resource in specific dates, to be able to model possible deviations from the default values.

The planning considers the saturation of each resource both as a hard constraint and as an objective (see section 3.3.2). As a hard constraint, a resource cannot be planned to exceed its capacity plus a tolerance specified by the user: e.g. the user can set the tool to allow a maximum of 120% saturation of some resources, when he/she knows that such resource can count on external support when needed.

3.2. Supply chain constraints

The following constraints are used to allow for modeling aspects that derive from the supply chain structure, namely: transit times between two tasks of a same order, dependencies among assignment decisions taken within two or more tasks of the same order and intermediate due dates specified for certain tasks.

3.2.1. Transit times

Transit times are required when the items of an order must be physically transferred from a component of the supply chain to another one, e.g. when a task of an order must be processed by a subcontractor immediately after an internal production phase or vice versa.

The tool allows the user to define transit times between each possible couples of supply chain components and then uses them as delay constraints between the end of a task and the start of the following one.

3.2.2. Dependencies

Assignment of tasks to resources do not depend only on the task/resource constraints defined in section 3.1.1, but they must also consider supply chain-related constraints expressed in the form "if task 1 of an order is assigned to resource A, then also tasks 2, 3 and 4 of the same order must be assigned to the same resource" or "if task 1 of an order is assigned to resource A, then tasks 2, 3 and 4 of the same order must be assigned to resource B".

3.2.3. Intermediate release/due dates

Some tasks within an order can be characterized by specific due dates or release dates that depend on the arrival of raw materials or on the need to provide semi-finished items within specific dates. These cases are treated through absolute time constraints within the decision model.

3.3. Objectives

The planning problem requires the achievement of two objectives: the minimization of orders delivered later than their due date and the minimization of the cases in which a resource is saturated more than its capacity (but always less then what specified in section 3.1.3).

An application of Industry 4.0 data analysis tools to support multi-criteria decision models was presented in [7].

An example of the typical trade-off problem between customer service-related and production-related decision drivers was presented in [8].

Pursuing multiple objectives can be accomplished in several ways. For the proposed tool, the choice was to allow the user to define a ranking between the objectives and, for the one indicated as the first one, to specify an allowed deterioration in order to pursue the other objective.

3.3.1. Lateness minimization

Each order has a due date for the last task of its production cycle and by a priority level of the customer that required it. The sum of the lateness accumulated by each order, weighted by the priority level of the order's customer, is minimized.

3.3.2. Over-saturation minimization

Each resource has both a maximum capacity and an allowed tolerance on it, as detailed in section 3.1.3. One of the objectives of the decision model is to minimize the sum of all the capacity surplus required by the proposed plan.

4. The proposed DSS

The proposed tool is a Decision Support System (DSS) designed to help the user take better decisions regarding the organization of the activities throughout the complex Bottega Veneta's supply chain, that involves: external raw materials suppliers, internal production job-shops and local subcontractors.

The tool provides several *points of view* over the analyzed data and about the proposed solutions in the selected scenarios. Specifically, the DSS provides: a graphical representation of each production order, focused on the complex links among the different tasks required by each order; reports centered on all the resources that were object of analysis and planning, with special attention on their usage; reports that provide an insight on the capacity of the plan to satisfy or not the required due dates.

4.1. The production orders point of view

The typical work cycle for the production of a finished item includes several activities, each possibly requiring a different element of the supply chain. An example is provided in Fig. 1: the details in each box have been intentionally anonymized for obvious industrial secrecy issues, but the representation itself is a valid demonstration of how the DSS can support the user with a synthetic yet complete description of an actual production order.

What is reported in Fig. 1, indeed, is an automatically generated output provided by the DSS for each analyzed and planned production order. A considerable amount of information is encoded through graphical elements, in order to provide the user with an immediately understandable detail about each order, which would otherwise require complex browsing through thousands of spreadsheet cells.

Each box represents a task within the production order:

- the boxes with grey text inside represent already finished tasks, while the ones with black text are tasks that have been planned using the DSS;
- each elliptical shape on the right side represents a date, and all tasks at the same height of a date are finished by that date;
- arrows represent precedence constraints among tasks;
- dotted lines boxes comprising other boxes represent technological constraints that force the included tasks to be processed at the same time;
- the colors of the frame of each box represents the type of supply chain component that is responsible of the execution of the task namely: green farmed boxes are processed by Bottega Veneta's internal job shops, orange ones are demanded to external suppliers, while blue ones are assigned to controlled sub-contractors.

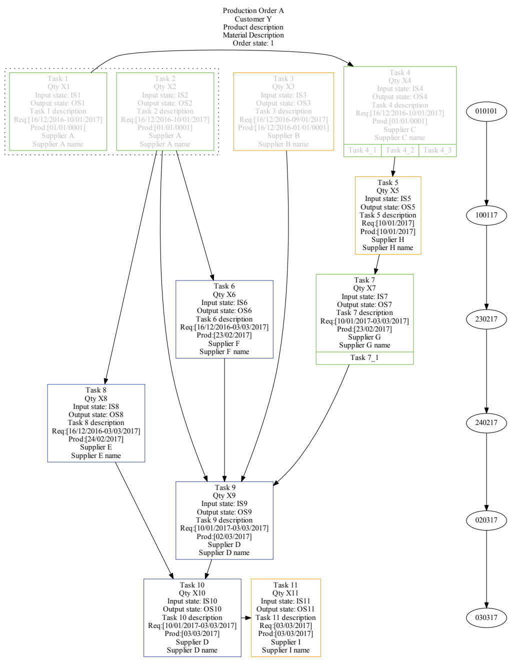

Fig. 1. The production order graphical representation

The overall layout gives the user an immediate feedback on the progress of the order, both in terms of timing of the activities and of the complex dependencies. To obtain a deeper insight, the user can zoom into the graph, to read the detailed information included within each box. In particular, such information includes: the order id, the task id, the supply chain component that is responsible of the task, the required due date, the release date, the planned production start and end dates.

4.2. The resource saturation point of view

Once a production plan is proposed by the tool, the user can focus his/her analysis on the components of the supply chain, in order to spot potential critical issues, such as internal job shops or subcontractors that are saturated too much over (or below) their capabilities. This point of view responds to the typical needs of production staff.

The tool provides the user with several reports that help him/her rapidly highlight problems and then investigate in deeper detail where needed. The report in Fig. 2 shows a list of all the internal job shops and external subcontractors, cumulatively referred to as "resources". The columns represent production weeks. For each resource, three rows are reported:

- row "0" represents the percent of the resource's capacity occupied, in each week, by tasks that are part of an order that is planned to be delivered on time;
- row "1" is relative to tasks that are part of orders that will be shipped late;
- row "Tot" is the sum of the above ones.

Resource	Late	201708	201709	201710	201711	201712	201713	201714	201715
Subcontractor 1	0	11,98%	0,00%	25,26%	63,15%	16,17%	0,00%	0,00%	0,00%
Subcontractor 1	1	35,59%	119,39%	77,41%	50,52%	25,83%	62,01%	17,73%	36,59%
Subcontractor 1	Tot	47,57%	119,39%	102,67%	113,67%	42,00%	62,01%	17,73%	36,59%
Job shop 1	0	0,00%	58,38%	51,17%	32,06%	14,74%	0,00%	0,00%	0,00%
Job shop 1	1	18,50%	38,28%	67,69%	86,49%	100,12%	115,09%	55,63%	0,00%
Job shop 1	Tot	18,50%	96,66%	118,87%	118,54%	114,86%	115,09%	55,63%	0,00%
Subcontractor 2	0	33,11%	49,51%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Subcontractor 2	1	10,03%	46,47%	94,93%	71,95%	101,69%	95,71%	89,52%	58,53%
Subcontractor 2	Tot	43,14%	95,97%	94,93%	71,95%	101,69%	95,71%	89,52%	58,53%

Fig. 2. The saturation point of view

A coloring scheme of the cells helps the user having an overall intuition of the proposed plan in terms of saturation of the available resources. A 100% cell in a "0" row, for instance, represents a desirable situation: so, cells in "0" rows are colored with a more and more saturated green as they approach higher values. On the contrary, a 100% value in a cell within a "1" row represents a highly undesirable situation, so a red scale is used for such rows. In general, any situation in which a resource is saturated beyond its capacity is a potential issue, so, in the "Tot" rows, cells are colored with a yellow based scheme whenever a value exceeds 100%.

Once the user wants to better study a potential issue, it is possible to select a specific cell and obtain the detailed report of all the tasks allocated to the specified resource in the selected week.

4.3. The orders timeliness point of view

An alternate point of view is the one that helps the user highlight potential issues related to delayed deliveries of the production orders. This is a typical concern of the customers' satisfaction staff.

The tool provides a list of all the considered orders. Each column represents a production week. For each production order, the following information is reported in the columns: production times, transit times, initial release date, original due date, planned production end. A coloring scheme is used to drive the user's attention towards potential issues.

The example in Fig. 3, for instance, shows an order that is planned for delivery past beyond its due date. For each order, the rows indicate:

- RD/DD: the release date and the due dates of the order, in terms of week;
- PT: production time, i.e. the weeks in which one or more tasks of the order are actually planned for processing;
- TT: transit time, i.e. weeks in which no task is processed because of transit among different components of the supply chain;
- IT: idle time, i.e. weeks in which both no processing and no transits are planned for the order;
- PS/PE: the planned production start and end for the order.

A continuous orange rectangle highlights the originally required lead time of the order, starting with its release date and ending with its due date. The actual lead time, from the planned production start to the planned production end, is highlighted by the last rectangle, which is purple in this case, to highlight a late order. Processing activities that are executed in a timely manner are highlighted in green, while processing and transit times that produce a delay are highlighted in yellow. Finally, idle times that produce a delay are highlighted in red. In the example, the user can easily see that the order starts in time, some delay is caused by the first idle time in week 12 of 2017 and most delay is accumulated in weeks from 16 to 18, leading to a late delivery in week 20, six weeks after the required due date.

Once an issue is detected, the user can obtain details about the selected orders, as well as about all the resources that are involved in the production of that order in the same weeks.

Order ID	Detail	201708	201709	201710	201711	201712	201713	201714	201715	201716	201717	201718	201719	201720	201721
Ord1	RD/DD			x				x							
	PT			x			x						x	x	
	TT				x				x						
	IT					x				x	x	x			
	PS/PE			x										x	

Fig. 3. The orders timeliness point of view

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