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Decentralized Control of dynamic supply chain systems with parametric uncertainties

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Abstract: Dynamic supply chain control is tackled in this paper using the concept of differential flatness where we focus on operational activities and algebraic estimation techniques for the uncertain parameters. The main objective is to maintain the inventory level at a desired one according to the customer demand while synchronizing the flows within a set of physical boundaries and constraints. In addition, we consider uncertainties on delay and adaptation times and we use the new setting of the algebraic estimation techniques to adapt and update the controller when any change occurs. These two methods lead to a simple design of the control algorithm without integration of any differential equation and without a need to any model to estimate, which yield to an efficient control action. Convincing numerical simulations using a case study of a crude oil blending and distribution system demonstrate the effectiveness of the proposed approach. *Copyright 2017 IFAC.*

Keywords: Manufacturing plant control; Manufacturing automation over networks; Intelligent manufacturing systems.

1. INTRODUCTION

Supply chains represent a complex network of facilities which include manufacturers, suppliers, transporters, warehouses, retailers and customers them selves that performs the function of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of finished products to customers (Chopra, Meindl [2003]), (Hugos [2011]). In this frame a supply chain management can be defined as the coordination of production, inventory, location, and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served. A supply chain is typically characterized by forward flow of materials and backward information flow. In this work we will present a systems approach of supply chain management to understanding and managing the different activities needed to coordinate the flow of products and services to best serve the ultimate customers. The systems approach provides a framework in which to best respond to business requirements that otherwise would be conflicting (Ganeshan, Harrison [1995]). From early 1950s it becomes evident that a rigorous framework for analyzing the dynamics of supply chains and taking proper decisions could improve substantially the performance of the system. Due to the resemblance of supply chains to engineering dynamical systems, and to the increasing complexity of such systems, (which is a result mainly of changes in customer preferences, globalisation of the economy and stringy competition among companies) control theory has provided a solid background for building such a framework and provides a solid background that helps managers make optimal decision making (Sarimveis & al [2008]).

From the modeling point of view, several approaches of supply chain models have been developed. According to Beamon (Beamon [1998]), they can be classified into four categories: *deterministic*, where all parameters are known, *stochastic* ones where at least one parameter is unknown but follows a *probabilistic distribution*, *economic game theoretic* models and those based on simulation, which evaluate the performance of various supply chain strategies (Sarimveis & al [2008]). These models can be represented by continuous-time differential equation models, discrete-time difference or discrete event models and classical operational research methods (Riddalls & al [2000]). In this work, the used mathematical model is based on balances of inventory and orders that allows us regulating inventory levels and simultaneously supply chain flow synchronization. Inventory control in a supply chain is mainly divided into two categories: centralized and decentralized control (Swaminathan & al [1998]). Due to their high performances, the paper proposes the use of the decentralized control, where each sub-system makes its own decisions based on its knowledge almost regardless to the rest of the chain, contrary to centralized control which operates on centrally made decisions commonly used in internal supply chain of corporations with separate

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departments, where some institutions have the power to govern the whole internal supply chain. Nevertheless, such, control is very rare due to the lack of authority of a single decision maker. The decentralized method is the most common control in real world even if it is not the ideal control for supply chain. This approach using control engineering tools was applied with its varied techniques which goes from classical control theories (in the 1950s) to highly sophisticated control methodologies.
PID control have been presented in (Wikner & al [1992]) and recently applied in (Rodríguez & al [2008]) in order to maintain the inventory level at a desired value which is considered as the optimal one which satisfies the market demands in timely and most effective way and to synchronize the incoming and outgoing flows of each supply chain component. In the same perspective flatness based control has been applied in (Hamiche & al [2016a,b]). Dynamic programming and optimal control methods aims to optimize an objective function that describes the performance of the system were applied by (Scarf [1960]) and (Iglehart [1963]), this procedure is a standard one to obtain an optimal state feedback control (Sarimveis & al [2008]). Robust control theory takes into account uncertainties concerning customer demand, machine failure and lead times as shown in (Blanchini & al [2000a,b]) and (Blanchini & al [2004]). In this framework, uncertainties can be the unknown but bounded quantities and constraints dictated by specifications and physical limitations (Sarimveis & al [2008]). Notice that for most realistic and optimal results, it is important to forecast the changing demand and uncertainties in the market in supply chain planning to maintain an inventory level in order to satisfy the customer demand. As shown in (Dong & al [2011], Wang & al [2007]) and (Rasku [2004]), model predictive control (MPC) has been applied to solve a dynamic optimization problem of the inventory. In (Schwartz & al [2006]), MPC control is used to demonstrate that safety stock levels can be significantly reduced and financial benefits achieved while maintaining satisfactory operating performance in supply chain.
The work presented in this paper focuses on operational activities of the supply chain dynamics and proposes a controller that allows us to regulate the inventory level while synchronizing the flow at the whole supply chain system. The proposed approach rests on the use of flatness based concept, where the whole system is described by the so-called “flat output” and a number of its time-derivatives while estimating the unknown or changing parameters using on-line estimation to adapt the controller for each change.
The paper is organized as follows. Section (2), presents the used dynamic mathematical model of the supply chain. Section (3), presents a brief description of flatness based control and algebraic estimation and shows the design of the control action which allow us inventory level control and flow synchronization. Section (4), illustrates the application of the synthesized control law on a case study example of a crude oil blending and distribution system which demonstrate the effectiveness of the proposed approach. Finally, section (5) summarizes the main results and lists some perspectives for future research.

2. DYNAMIC SUPPLY CHAIN MODEL

Supply chain models, with analogy to traffic flow theory (Helbing [2003]), are based on macroscopic balance equations which is represented by mass variation between inflow and outflow rate. It takes into account also information flows, particularly orders among downstream and upstream entities. In some situations such information flows have to be taken into account, either to strive for performance improvement or because not all orders are fulfil immediately, then an unattended orders balance appears (Rodríguez & al [2008]). The models represent systems in which the material delivery flow rate corresponds exactly and without delay to the demanded one. The following figure (1) shows the general representation of a supply chain.

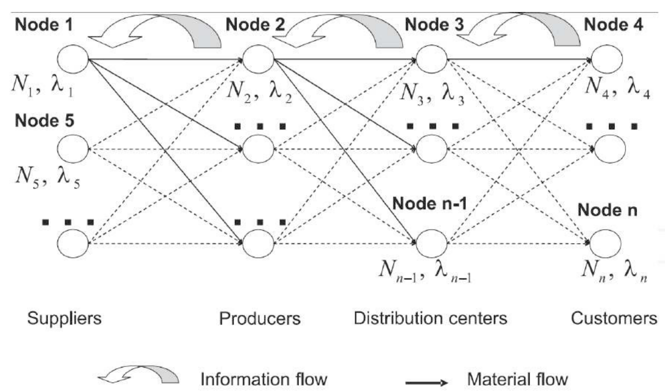

Fig. 1. General representation of supply chain system

The key variables of the model are:

- The nodes (represented by circles) represent different suppliers i and $N_i(i = 1, ..., n)$ defines the inventory level for each supplier.
- λ_i represents the production or incoming rate depending if the node is producer, warehouse, supplier or distribution center.
- $i = 0$ corresponds to a resource center that provides raw materials and $i = n + 1$, is the final customer.

Then using the principle of macroscopic mass balance, the mass variation is equal to the difference between the material inflow and the outflow rate. It is important to underline that before the obtention of the model we must distinguish the category of the supply chain nodes. Indeed and as defined in (Rodríguez & al [2008]), these nodes are divided into two categories: non producer nodes such as a warehouses and producer nodes such as manufacturers. The main difference between them is that the producer node can vary its production rate by varying its internal production policy while the non producer node can only vary its production rate by incoming flows.

2.1 Non producer node model

The change inventory level in a non-producer (suppliers, warehouses or distribution centers) is represented by the difference between the production of incoming rate λ_i and