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Effect of information update frequency on the stability of production–inventory control systems

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Abstract

Production ordering and inventory dynamics in a manufacturing system are analyzed using function transformation techniques (z-transform) and their conditions for stability are examined. A generic model which captures the mixing and variability in the production process is developed. Variation in the stability of the system operating under sufficient inventory coverage and under limited inventory coverage is highlighted. The effects of the frequency of information update on stability are then examined by relating the update frequency to the sampling interval of the underlying difference equations. System dynamics simulations are used to demonstrate the stable or unstable behaviour of the production–inventory system.

Keywords: Production–inventory systems; Stability analysis; Z-transform; Sampling interval

1. Introduction

In current volatile markets, companies need to respond quickly to changes in customer demand and adapt quickly to changes in technology. This necessitates the modelling and analysis of the dynamic behaviour of companies, especially their production–inventory systems (Ortega and Lin, 2004). Analysis of production and inventory dynamics helps reveal periods of inventory build-ups, stock-outs, overtime production and production shutdown, which costs the companies in terms of profits, market position and customer satisfaction. Hence, it becomes critical to model and analyze the dynamics of production inventory systems. The dynamic behaviour or dynamic complexity is said to arise from the interaction between the various system components over time (Sterman, 2000). Dynamic systems, characterized by delays, feedbacks and non-linearities, cannot be adequately captured using mathematical programming techniques such as linear/non-linear/stochastic programming. A natural choice to examine the production and inventory dynamics is the application of control theoretic techniques. This often involves capturing of the production–inventory system using feedback-based structures (Forrester, 1961; Towill, 1982; Axsäter, 1985; Edghill and Towill, 1990;

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Nomenclature

t	index of time period $\{1,\ldots,T\}$, time (weeks)
δ	sampling interval, time (weeks)
α	fractional adjustment rate of WIP
β	fractional adjustment rate of inventory
ρ	exponential smoothing constant
SALES	actual sales rate, units/week
FD	forecasted demand, units/week
OBKLG	order backlog of sales, units
DSHIP	desired shipment rate, units/week
SHIP	shipment rate, units/week
INV	inventory, units
DINV	desired inventory, units
WIP	total work-in-process, units
DWIP	desired WIP, units
PREL	production release rate, units/week
DPRATE	desired production rate, units/week
PRATE	production rate, units/week
L	lead time for production, weeks
Q	total number of stages of production
XWIP_q	work-in-progress at production stage q, units
XPRATE_q	production rate at production stage q, units/week

Sterman, 2000) and analysis of the system through the application of control theoretic tools such as block diagrams, Bode plots, and functional transformations (Wikner et al., 1992; John et al., 1994; Grubbström and Wikner, 1996; Disney and Towill, 2002; Disney et al., 2004).

In this research work, modified causal loop diagrams are used to capture (model) the production–inventory system, which is then analyzed by applying z-transformation technique (a type of function transformation technique). Function transformation technique maps the system from the time domain to the frequency domain; the advantages of which are summarized below (Disney and Towill, 2002):

- Frequency response analysis has been found to be an efficient tool to examine the critical design parameters and identify ranges of parameter values that give good transient response performance (Ortega and Lin, 2004).
- Standard techniques exists to analyze the system performance such as rise time, peak overshoots, and settling time, without recourse to simulation (Bissell, 1996), Frequency domain calculations can be computationally very simple (Bissell, 1996). Closed loop transfer functions of the system can be obtained that enables to gain insight into the stability of the system, Appropriate integration of transfer functions with simulation enables additional system analysis (Disney and Towill, 2002).
- A number of techniques exists for transferring problems from one domain (Laplace, z, Fourier, w, frequency, etc) to another domain, to help gain insight from situations that have already been encountered and solved in other domains (Disney and Towill, 2002).
- Transforms can be used to capture the stochastic properties by serving as moment generating functions (Grubbström, 1998).

A comprehensive literature review on the use of control theoretic concepts for the dynamic analysis of production–inventory systems can be found in Ortega and Lin (2004) and Disney and Towill (2002). John et al. (1994) demonstrated the stabilizing effect of including a supply line (work-in-progress, WIP) component into an inventory and order based production control system (Towill, 1982), using block diagrams and Laplace transform. Towill et al. (1997) examined the critical design parameters within an adaptive model consisting of three feedback loops—inventory error loop, desired order in pipeline loop and the lead time loop, and highlighted how the total orders in the pipeline can be used for assessing the load of the internal manufacturing pipeline. Grubbström (1998) used Laplace transform, z-transform and Net Present Value on MRP systems and showed a three-fold use of transfer functions: (1) describes production, demand and inventory dynamics in a compact way, (2) captures stochastic properties by serving as moment generating functions, and (3) assesses the cash flows up capturing the net present value in the transfer functions. White (1999) has showed that simple inventory management systems are analogous to the proportional control in conventional control theory, and has demonstrated that the use proportional, integrative and derivative (PID) control algorithms can result in saving of up to 80%.