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Control system analysis of labour supply flows in production systems

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ABSTRACT

This paper examines the effects of the labour supply chain on the control of a two tier VMI inventory model based on the work of Towill and Disney for the case of an individual company.

An extended labour plus the VMI model is used to produce an analytic expression for the combined system.

A discrete *z* transform model of inventory is obtained using conventional algebra. This is then analysed to produce an algebraic expression and then the general stability solution is derived from the unit circle condition.

The labour model alone is shown to be stable with the average employment duration and time to recognise a staff deficiency found to be the key parameters to achieve quick response to a labour shortage. Using MATLAB, the extended model incorporating the labour supply has been found to have a wider range of gains for stability, than without the labour component.

The system is described by a linear control model of the production process and does not include production limits or other resource limitations. It also does not include any past history of sales demand and responses.

Using the control measure integral of the time multiplied by the absolute error (ITAE), the combined labour and VMI model has been found to have different gains for optimum inventory than VMI alone, allowing a more flexible response to recruitment since labour costs are key cost parameters in the real world.

This work extends the original control system model of Towill and Disney to include the effects of the Labour supply chain. This has not been published before.

1. Introduction

The supply of the correct amount of labour at the right time is an essential feature of the financial success of any company. Investigating how this supply of staff governs the capability to produce the right volume of goods at the right time is an important part of the analysis of manufacturing systems.

Industrial commentators in China [1,2] claim that labour shortages have resulted in the reduction of the global supply of the production of PCBs by as much as 15–20% [3].

Labour hoarding [4], recruitment risks [5], and labour productivity are known to have effects on overall business success [6,7] are known to affect the product supply chain. Schnorback [8] notes the cost of labour is between 35 and 65% of most company costs, asserts that all aspects of managing labour should be a formal part of the whole business process, not relegated to a separate HR function. The ASCET report [9] outlines the importance of labour for scheduling leverage in the supply chain to create and sustain a high-performance business.

System dynamics (SD) computer models of supply chains systems including labour and capital flows were produced by Forrester [10] in the 1960s. System dynamics (SD) [11] modelling used model states, such as the number of vacancies, number of jobs, rates of change and allows the associated feedback loops to be identified and mathematically described. SD methods have been used [12] to examine the Japanese automotive supply chain, for example, with useful results.

Towill [13] simplified the system dynamics (SD) supply chain models by removing the contribution of labour and capital. Towill's unique contribution was in using control engineering analysis to simplify the Forrester model to one that just included only the interacting processes of inventory and sales demand. Whilst Towill's approach has enabled the effects of the retained dominant major factors to be investigated, the possible effects of those elements he simplified and removed from the models have not been explored.

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This paper is an attempt to show the effects that one of those component parts removed might have on the stability and performance of the overall system.

The simplified inventory model has been improved and extended over the years by not only the Cardiff group of researchers into supply chain control but also by a number of other investigators e.g. [14]. Disney and Towill [15] examined the issue of stability; they outlined general relationships between system parameters, which ensure stable operation.

This present paper describes a model of inventory production control systems incorporating the effect of labour supply based on Sterman's [11] ideas. The labour sub-model does not include factors such as loyalty, career paths, empowerment, information dissemination and those issues, which are becoming crucial to good employer–employee relationships [16].

The combined model thus obtained is applicable for workplaces where the processes are labour intensive, for example manual assembly tasks where the number of orders depends closely on manual effort and thus the net output depends on the labour productivity.

The analytic model is investigated with MATLAB© producing an optimum set of responses simulated with SIMULINK©. A Jury test is applied to find the optimum values guaranteeing stability. Rationale for the approach is that given by [17]. For a production manager the abstract mathematical concept of instability *translates* into the occurrence of real large cyclic swings in inventory and production level demands, often exceeding the capacity in place in the factory. The manager's perception of system instability is thus the pragmatic position of not being able to guarantee supply.

The principle aim of this paper is to determine the effects on the predicted stability of an inventory system model due to the addition of a labour supply chain sub-system, as a step back towards the more comprehensive SD model of Forrester. We take the published stability analysis of a VMI-APIOBPCS model of [15] as the basis for this analysis.

2. Review of labour SD models

Table 1 lists publications which use SD methods and models used to evaluate labour supply problems, these references cite examples ranging from typical manufacturing supply chains to tourism and other service industries. Gunderson reports that offers of staff training [18] have a significant effect on recruitment. Abdel-Hamid and Madnick's [19] pivotal paper on Information Technology (IT) manpower describes staffing level effects in the field of IT project management. Brett et al. [20] examined the problem of oil drilling manpower planning using an SD model with three states describing the well status. Models of economic transition in Slovakia [21] predicted an economic downturn. Coyle [22] describes the operation of the supply of consultants in a consultancy firm; Torres and Lechón [23] described the behaviour of the Spanish labour market and Pidd [24] gives an example of the manpower recruitment process in a company called Dynastat Ltd. showing good agreement between the model's predictions and actual hiring rates. Winch [25] targeted the effect of skills on the management team of a chemical plant with a two state model. Hafeez and Abdelmeguid [26] dealt with the problem of knowledge management using a two state SD model of trainees and level of skill, obtaining oscillatory solutions. Rodrigues and Martis [27] investigated human resource and knowledge management in engineering education with a three state SD model modelled via a control theoretic formulation while Ziomek [28] modelled the impact on the Polish labour market in Glaxo SmithKline pharmaceuticals. Burns and Janamanchi [29] used a variant of Forrester' supply chain model with the labour input modelled as a single state equation, including layoff switches. Mehmood [30] estimated the effects of trained naval reservists using a three state model verified by real data. Lewis [31] examined the effects of tourism on labour demand in Jamaica agreeing with real data. Haghighi's PhD [32] was concerned with the behaviour of the supply of labour in Iran's agricultural system. Johnson et al. [33] used a multilevel model of agriculture and rural development including birth and death rates as well as educational changes. Choi et al. [34] examined the labour component of IT resources including hiring and firing, looking specifically at skills acquisition and training; as well as labour availability. An et al. [35], Lee et al. [36], and Lee et al. [37] at IBM show a transfer function model based on service supply, illustrating how oscillations in trained labour supply could develop. Skribans [38] investigated Latvia's labour market illustrating the effect of education on supply. Größler and Zock [39] looked at the service industry using a four state model. Their key finding is that "the ageing chain of service operators is affected by a variety of delays" including training, promotion and supply. Rabello et al. [40] examined the stability of the supply chain including a two state labour model similar to than employed here employing swarm optimisation. Lee [41] used SD to investigate labour shortages in Norway his findings suggesting that tertiary education improvements will result in an increased supply of skilled labour in future years. SD has been used [42] to examine the ageing problem in the population of the Netherlands. A major personnel planning exercise using SD was undertaken for the Italian military [43].

The labour model used by White and Censlive [44] is not significantly different from the SD models described above. Several authors have shown that these models will yield oscillatory responses to demand changes, similar to those occurring in material supply chain models.

3. Control theory based models of inventory systems

The use of control theoretic models in inventory systems has a long pedigree and the main developments are described in the reviews of Yuan and Ashayeri [45], Ortega and Lin [46], Sarimveis et al. [47] and Duffie et al. [48], Duffie et al. also discussed work on regulation topology and lead time. These applications are extended in Table 2 from the review in White and Censlive [49] for work comparable to this application. This section will briefly mention the important work related to the research described later.

Tustin [50] and Vassian [51] applied transform techniques to examples of economic and inventory systems in the 1960s. Later in the 1960s Brown [52], applied the z transform method to production and inventory control. Adelson [53] used z transforms in an inventory and order-based system, producing an analytical expression for bullwhip for the first time, while Dezeil and Eilon [54] used z transforms and quadratic cost functions to obtain solutions to similar systems.

Wikner et al. [55] showed how inventory models could be reduced to a simpler form while Ferris and Towill [56] gave a general set of Laplace transfer functions for a range of configurations of in inventory systems control theoretic models. The advantage of these linear transform models is that they allow general rules to be derived, which are applicable to other systems and as explained later they can be used to obtain stability boundaries.

Early work by Towill's group and others used models with continuous Laplace transforms, but later Disney and Towill [15] developed a z transform, discrete model using a finite delay representation, and published a comprehension analysis of the stability of series of models with similar configurations, one of these models, designated an Automatic Pipeline and Order based production control system (APIOBPCS), is used in this present work to incorporate the labour supply sub system to allow comparison of the differences in performance of the original and modified models.