European Journal of Operational Research 215 (2011) 309–318

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Invited Review

Recent developments in Dual Resource Constrained (DRC) system research

J. Xu, X. Xu *, S.Q. Xie

Department of Mechanical Engineering, University of Auckland, Private Bag 92019, Auckland, New Zealand

ARTICLE INFO

Article history:
Received 11 March 2010
Accepted 2 March 2011
Available online 16 March 2011

Keywords:
(D) Human resources
Cross training
Workforce scheduling
Dispatching
Dual Resource Constrained (DRC) systems

ABSTRACT

Real world manufacturing systems are usually constrained by both machine and human resources. Human operators are often the constraining resource and transfer between workstations to process jobs when required. This kind of system is known as a Dual Resource Constrained (DRC) system and presents additional technical challenges which must be considered during planning and scheduling. These technical challenges can be categorised into the five main dimensions of job release mechanisms, job dispatching, worker flexibility, worker assignment and transfer costs. This paper aims to provide an overview of recent developments in DRC research concerned with each of these areas and also discusses some possible approaches to solving the resource scheduling problem in a DRC system. The focus is on materials published after 1995 and up to 2009. Previous reviews on DRC systems are commented on and followed by a review of recent works associated with each of the five dimensions of DRC system research. Advancements made and new methodologies proposed are discussed and future research directions are identified.

1. Introduction

Trends in recent years have shown a move towards more flexible and customised manufacturing that is often characterised by the rapid introduction of new products with shorter life cycles, small lot sizes and changing product mixes. In such an environment, manufacturing processes are becoming more worker-reliant and resource planning must take into account the unique characteristics inherent in different types of machine and human resources in order to provide optimal schedules. Systems are known as Dual Resource Constrained (DRC) when capacity constraints stem from both machines and human operators. More specifically, it can be defined as when operators are the constraining resource who can transfer across various workstations as required (Treleven, 1989; Hottenstein and Bowman, 1998).

DRC systems are more complicated than their single resource counterparts and present a number of additional technical challenges which must be considered during resource scheduling. One example is the additional interaction between job dispatching and worker assignment. It is now necessary to look at the aspects involved in worker assignment such as *where* to assign a worker and *when* to do so and how these elements affect and are affected by job dispatching. Due to these additional factors and details, analytical solution methods may no longer be feasible or adequate for solving the scheduling problem and other approaches such as meta-heuristic methods like genetic algorithms and simulated annealing (ElMaraghy et al., 1999, 2000; Chaudhry and Drake, 2009; Tao et al., 2007) have been considered to deal with DRC type scheduling problems.

Human operators, unlike machines, are capable of learning and acquiring new skills. It is often useful to take advantage of a flexible workforce where workers are trained in several skills or departments such that they can be assigned to a variety of jobs as the need arises. This raises issues concerning the optimal number of different skills a worker should have and consideration of different efficiency levels between individual workers. Just as a human learns, a human worker is also capable of forgetting and may require retraining or relearning after interruptions to their work. This unique human characteristic must be studied as it influences the type of training policy used as well as worker scheduling by introducing a transfer cost to cover aspects such as transfer delay and loss of productivity due to forgetting which effectively limits the benefits of worker flexibility.

Numerous research addressing issues presented by DRC systems has been conducted and published for over 40 years following the pioneering work by Nelson (1967). Since then, two review papers on DRC research have been published. The first by Treleven (1989) covered over 25 articles about DRC systems. The research and results were categorised into design and operating decisions and a brief summary of the different works in each area was provided. Design decisions examine the impact on the overall

Abbreviations: 2Q, two-queue; CEN, centralised; CLI, current labour information; CR, critical ratio; CWI, current workload information; DEC, decentralised; DRC, Dual Resource Constrained; EDD, earliest due date; FAP, flexibility acquisition policy; FCFS, first-come-first-served; FWI, future workload information; GA, genetic algorithm; HPP, hybrid push–pull; LFL, learn–forget–learn; LNQ, longest queue; MODD, modified operation due date; ORR, order review/release; SA, simulated annealing; SPT, shortest processing time; WIP, work in progress.

* Corresponding author. Tel.: +64 93737599.
E-mail address: x.xu@auckland.ac.nz (X. Xu).

0377-2217/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.ejor.2011.03.004

Nomenclature

2Q	Two-Queue	FWI	Future Workload Information
CEN	Centralised	GA	Genetic Algorithm
CLI	Current Labour Information	HPP	Hybrid Push-Pull
CR	Critical Ratio	LFL	Learn-Forget-Learn
CWI	Current Workload Information	LNQ	Longest Queue
DEC	Decentralised	MODD	Modified Operation Due Date
DRC	Dual Resource Constrained	ORR	Order Review/Release
EDD	Earliest Due Date	SA	Simulated Annealing
FAP	Flexibility Acquisition Policy	SPT	Shortest Processing Time
FCFS	First-Come-First-Served	WIP	Work In Progress

performance by issues such as amount of worker flexibility, staffing levels and presence of transfer delays while operating decisions are more concerned with the dispatching of jobs and assignment of workers. Treleven also provided a section on directions for future research in which he outlined issues which still needs to be addressed and interesting possibilities worthy of further examination. The second review paper by Hottenstein and Bowman (1998) gave a more in-depth coverage of sixteen different DRC research outcomes with the most recent published in 1993. The authors have found that five main dimensions exist in past DRC studies, these are: worker flexibility, *when* to transfer a worker, *where* to transfer a worker, queue discipline (job dispatching) and the cost of transferring workers. The reviewed articles are discussed with respect to each of these five factors and a unique features section was also included. Propositions that summarise the main results from the reviewed studies have been provided and future research directions are explored with the objective of making DRC research a greater value to industry.

Many advances have been made by DRC researchers in recent years, especially where human operators are concerned. There is a recognised need to take into consideration those unique characteristics of human workers that set them aside from their machine counterparts to allow more accurate depictions of real life situations. Other advances in research include examining more detailed factors such as jobs of different types and priorities and dynamic responses to different disruptions and workshop situations. In order to familiarise potential DRC system researchers with the field and provide a foundation for continued research in this area, there is a need for a more up-to-date review of DRC literature. This review paper aims to provide readers with a good coverage of DRC research work ranging from 1995 up to early 2009. The review structure is adapted from the 1998 DRC review by Hottenstein and Bowman with the addition of a new job release mechanism section which covers research attempts to control the variance of jobs entering the DRC system. *When* and *where* worker transfer considerations have been combined under a single worker assignment section and a section covering specific approaches and methodologies for solving the DRC scheduling problem will be presented in place of the unique features section. Fig. 1 demonstrates the main dimensions of DRC systems research covered in this review and their places in a typical production cycle.

Thus, this paper is organised into six main sections: job release mechanism, job dispatching, worker flexibility, worker assignment, transfer costs and specific methodologies for DRC scheduling. A sectional summary is provided at the end of each section to outline the main findings. Further generalisations and directions for future research can be found in the discussions and concluding remarks at the end of the paper.

2. Job release mechanisms

Various researchers over the years have considered the effect of a planning system or job release mechanism which is responsible for the pattern of work release onto the shop floor. This mechanism is important due to its influence on the distribution of arriving jobs and can be used to reduce the amount of variance the shop floor experiences by smoothing the load received. Fredendall and Melnyk (1995) studied the effect of implementing a planning system and an order review/release (ORR) system for a DRC job shop. Level scheduling is initially carried out by the planning system to eliminate infeasible and fluctuating schedules while ORR rules further filter and smooth this load before sending it to the shop floor. The combination which produced the optimal value for the performance measure of total cost in this study was smoothing from the planning system with immediate release from the ORR and a simple first-come-first-served rule for job dispatching. These findings support conclusions drawn by previous research which demonstrates the operation of a planning system to have significant and positive effects on the performance of a simple random job shop (Melnyk et al., 1991; Philipoom and Fry, 1992). Although a complete job release mechanism was not considered by Kher and Fredendall (2004), the authors tested high and low variance levels in order arrival times and found that the proactive strategies of reducing variance in order arrivals as well as in processing times significantly reduced flow times.

DRC job shops are information intensive with current workload information (CWI), future workload information (FWI) and current

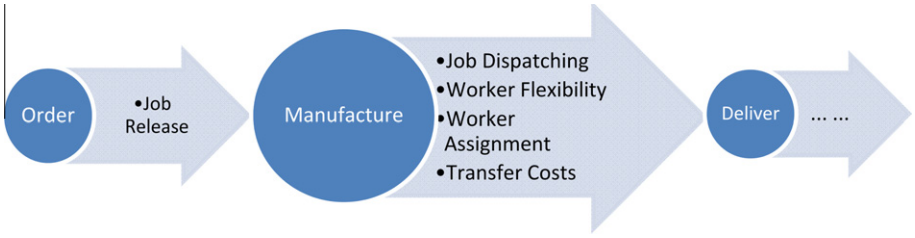

Fig. 1. Main dimensions of DRC system research.