Available online at www.sciencedirect.com
ScienceDirect
Procedia CIRP 44 (2016) 429 – 434
www.elsevier.com/locate/procedia

6th CIRP Conference on Assembly Technologies and Systems (CATS)

A model for complexity assessment in manual assembly operations through predetermined motion time systems

Bugra Alkan*, Daniel Vera, Mussawar Ahmad, Bilal Ahmad, Robert Harrison

Automation Systems Group, WMG, University of Warwick, CV4 7AL, Coventry, West Midlands, UK

* Corresponding author. Tel.: +44 (0)7786360026. *E-mail address:* B.Alkan@warwick.ac.uk

Abstract

Manual assembly processes are favoured for supporting low volume production systems, high product variety, assembly operations that are difficult to automate and manufacturing in low-wage countries. However, manual operations can dramatically impact assembly cycle times, quality and cost when the complexity of the manual operation increases. This paper proposes a method for assessing the process complexity of manual assembly operations, using a representation of manual operations based on predetermined motion time systems. The purpose of this framework is to provide a tool that can be used practically to assess, and therefore control, the complexity of manual operations during their design.

Keywords: Manual assembly; Task complexity; Complexity management; MODAPTS.

1. Introduction

A flexible assembly line requiring high precision typically favours manually assembly accomplished by skilled and experienced human operators [1]. During manual assembly operations, workers are confronted with multiple sources of information and need to make decisions concerning a process under a strict time pressure. However, the intrinsic mental and physical abilities or limitations of human worker have to be taken into account when designing work processes in order to achieve requirements in terms of process quality and cycle time. This can be achieved through analysing and controlling complexity of the process with appropriate information and rigorous work sequence planning [2].

In related literature, complexity of assembly tasks is largely examined by focusing only on physical characteristics of the parts/products to be assembled. Boothroyd et al. developed Design for Assembly (DFA) method based on a large number of empirical investigations to evaluate the difficulty of assembly tasks and to roughly estimate the assembly times [3]. Hinckley proposed an assembly complexity factor that associated the number of assembly operations and time to assembly related failures [4]. Shibata et al. extended Hinckley's methodology to predict the degree of assembly faults based on the complexity level of individual assembly steps [5]. Kim proposed a metric that measures the process complexity based on a combination of system elements [6]. ElMaraghy and Urbanic designed a complexity measure for manual manufacturing operations which takes some facets of cognitive factors [7]. Zaeh et al. proposed a multi-dimensional complexity model for manual assembly operations which extended the concept of systems of predetermined times by including actual human performance, attention allocation and learning effects [2]. Furthermore, Samy and ElMaraghy presented a product assembly complexity model that can be used as a decision support tool for designers to reduce potential assembly complexity and associated costs [8].

Complexity of assembly operations can be practically predicted through the physical features of objects that affect the difficulty of its assembly. However, such approaches address only isolated and individual assembly processes without directly accounting the interactions between cognitive processes, attention allocation, and workspace and design limitations. This article presents a complexity modelling approach based on Predetermined Motion Time Systems (PMTS) which is facilitated by virtual manufacturing (VM).

doi:10.1016/j.procir.2016.02.111

The proposed model extends PMTS by including dimensions of physical and cognitive task performance and is implemented as a module within the vueOne virtual manufacturing tool developed by the Automation Systems Group (ASG) at the University of Warwick. This research contributes to the body of knowledge and supports industry in three main ways. Firstly, the proposed model can support in identifying and comparing manual assembly process complexity to determine an optimal approach using an objective, quantitative method. Secondly, the model allows the designer to identify the complexity sources so that process design changes to search for an optimal are better informed. Finally, this approach supports concurrency between product design and manufacturing system design, highlighting potential problem areas prior to commissioning, reducing costs, product realisation time and increase the efficiency of the organisation. PMTS are commonly used to describe assembly sequences in labour oriented industries, thus the proposed method is a practical and economical way to assess task complexity in manual assembly stations. Furthermore, it can support process designers to select optimum task sequences which offer ease of operation and reduced physical and cognitive workload on workers. The nomenclature used in the paper is presented in Table 1.

Table 1. Nomenclature

$C_{op,i}$	Overall operation complexity of i^{th} operation
$C^{*}_{op,i}$	$C_{op,i}$ with variation factor
$C^{k}_{op,i}$	Overall operation complexity of k^{th} variation of i^{th} operation
OCI_i	Operational complexity index of i^{th} operation
v_i	Product variation factor of i^{th} operation
$P_{k,i}$	Product mix ratio of k^{th} variant in i^{th} operation
$N_{k,i}$	Number of product variants entered to i^{th} operation
S_i	Size factor of i^{th} operation
N_i	Total number of tasks in i^{th} operation
$n_{m,j,i}$	Total number of movement activity in j^{th} task of i^{th} operation
$n_{t,j,i}$	Total number of terminal activity in j^{th} task of i^{th} operation
$n_{a,j,i}$	Total number of auxiliary activity in j^{th} task of i^{th} operation
D_i	Diversity factor of i^{th} operation
$d_{act,i}$	Diversity ratio of activities in i^{th} operation
$d_{task,i}$	Diversity ratio of task in i^{th} operation
$N_{dm,i}$	Number of distinct task with at least one movement activity
$N_{m,i}$	Number of task with at least one movement activity
$N_{dt,i}$	Number of distinct task with at least one terminal activity
$N_{t,i}$	Number of task with at least one terminal activity
$N_{da,i}$	Number of distinct task with at least one auxiliary activity
$N_{a,i}$	Number of task with at least one auxiliary activity
$n_{dm,j,i}$	Number of distinct movement activity in j^{th} task of i^{th} operation
$n_{dt,j,i}$	Number of distinct terminal activity in j^{th} task of i^{th} operation
$n_{da,j,i}$	Number of distinct auxiliary activity in j^{th} task of i^{th} operation
E_i	Effort penalty factor of i^{th} operation
$e_{m,z,j,i}$	Effort penalty of z^{th} movement activity in j^{th} task of i^{th} operation
$e_{t,z,j,i}$	Effort penalty of z^{th} terminal activity in j^{th} task of i^{th} operation
$e_{a,z,j,i}$	Effort penalty of z^{th} auxiliary activity in j^{th} task of i^{th} operation

2. Predetermined motion time systems

PMTS are work measurement systems which are used to calculate basic labour rates for an assembly line [9]. Typically, PMTS breaks down the entire operation to basic human movements and classifies each of them based on the nature of the movement (i.e. motional elements such as grasp, put and reach, and mental functions such as identify, locate and decide) and the condition in which the movement is being performed. Most common PMTS methods include; Modular Arrangements of Predetermined Time Standards (MODAPTS) [10], the methods time measurement [11] the Maynard Operation Sequence Technique (MOST) [12] and Master standard data [13]. In this research, MODAPTS was selected because it is used by the research project partners i.e. Ford Motor Company and Jaguar Land Rover. In MODAPTS, elements and functions are coded alpha-numerically, the letter describes the activity and the associated number is the completion time for the corresponding activity, expressed using MODs as a unit of time (one MOD equals to 0.129 seconds). MODAPTS classifies basic operator activities into three classes: movement, terminal and auxiliary. Movement class elements refer to movements through space with a finger-hand-arm-shoulder-trunk system. Terminal class activities are carried out at the end of a movement and in close proximity to the things being worked on. Auxiliary class refers to activities that do not include movement class, such as: juggling, deciding and reading. A work element can be formed using MODAPTS through combining activities being performed and identifying the corresponding MODS that indicates the time values required to complete the work element. For example, a work element can be coded as “M2G1”, with “M2” meaning moving the arm with two mods and “G1” means getting a workpiece with one MOD. The estimated time for this work element is therefore, 0.387 s (3×0.129 s). The MOD time increment value reflects the average abilities of a work force (i.e. age, gender, skills) in achieving a given activity.

3. Modelling of operational complexity

Human operators are subjected to various tasks of different complexities, ranging from simple pick and place operations to complex multi-dimensional joining operations. According to Falck et al. [14], assembly complexity, assembly time and action cost are strongly related. Thus, in order to increase the efficiency of an assembly operation, complex assembly solutions should be avoided. Based on the review of the related literature, sources of complexity in manual assembly operations are categorized into four groups: (*i*) product related factors which are composed of material, design and special specifications for each part or subassembly within the product [8,14], (*ii*) process related factors include effects induced by selected assembly methodology, sequences and volume requirements as well as the effects of product variation, operational uncertainties, process dependencies, insufficient work instructions [2,8,14–16], (*iii*) personal factors consist of several elements which affect the perceived complexity by the operator such as: mental and physical capacity of the operator, his/her training level, corresponding manufacturing knowledge, personality, culture and motivation to work [2,14,17,18] and (*iv*) environmental factors that affect the performance of the human operator and comfort of the assembly task e.g. workspace ergonomics, heat stress, confined space [14]. In the initial design stages of manual assembly operations much of this information is either unavailable of difficult to obtain requiring a time consuming and costly investigation phase To solve this problem this research presents a model to practically assess complexity that aggregates data available at the early