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Lot Size Dependence for Energy Consumption per Unit of Production Throughput Considering Rush Orders in Manufacturing Lines

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Abstract: In an effort to further reduce energy consumption per unit, many studies have, in recent years, been conducted to formulate the relation between energy consumption per unit and lot size along the manufacturing line. Yet, little effort has been directed toward production management and management methods that optimize energy consumption per unit while considering frequent rush orders in the manufacturing system. In this study, we theoretically formulate a relation between lot size and energy consumption per unit that considers rush orders in the manufacturing line.

Keywords: Rush orders, Production Management, Energy consumption, Productivity, Lot size, Formulation, Energy consumption per unit, Manufacturing system simulation

1. INTRODUCTION

Efficient use of energy is becoming an essential issue in many fields. The April 2014 revision to the law streamlining energy use (the Energy Conservation Act) targeted businesses that use more than 1,500 kl of energy per year, and mandated that energy consumption per unit be reduced by 1% or more on average each year (Agency for Natural Resources and Energy, 2014), which demands that factory management and production planning carefully consider power consumption (Agency for Natural Resources and Energy, (2014)). Furthermore, according to the Paris Agreement of December 2015 (COP21), all participating countries were required to submit a reduction target for greenhouse gases and to put measures in place to achieve the target (United Nations Framework Convention on Climate Change, (2016)). For the industry to meet the required energy reductions in Japan, energy use throughout the manufacturing process needs to be analyzed so that innovation in energy management technology toward efficient use of energy can be achieved Ministry of Economy, Trade and Industry, Energy innovation strategy, 2016). In the near future, it is thus expected that industry will incorporate pre-evaluation methods in which energy consumption is considered alongside productivity, leading to the establishment of new production management (Herrmann and Thiede (2009); Hibino (2014); Wilson et al. (2016)).

A pre-evaluation method has been proposed that considers both productivity and energy consumption and simultaneously calculates productivity and energy consumption during the planning of the manufacturing system (Sakuma et al. (2013); Hibino et al (2014)). In addition, for production management and management methods that take productivity and energy consumption into consideration, it has been reported that if lot size, which is a measure of production planning efficiency, is too small, the number of setup steps increases and the energy

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consumption per unit for the time required to set up will increase (Sakuma et al. (2012)).

Furthermore, the lot size dependency of energy consumption per unit was formulated based on the relation between energy consumption per unit and lot size in the manufacturing line, and the validity of the theory was confirmed (Yamaguchi et al. (2016); Kobayashi et al. (2016)).

On the other hand, in an actual manufacturing line, rush orders often occur, which require production in less time than the normal lead time. As a result, production may be interrupted owing to rush orders, requiring setup changes to accommodate the rush order and also to accommodate the return back to normal production after the rush order is complete. As such, it is qualitatively understood that increased setup times lead to production stagnation by decreasing production and increasing energy consumption per unit. However, the previous studies did not study the influence of productivity, energy consumption, and rush orders on the production management and management method.

Thus, in this study, we employ a new production management and management method that considers productivity and energy consumption and theoretically formulate the relation between lot size and energy consumption per unit while considering rush orders in the manufacturing line.

2. OUR PROPOSED FORMULATION

2.1 Energy consumption per unit

The manufacturing industry employs "energy consumption per unit" as a representative index to evaluate productivity relative to energy consumption (Agency for Natural Resources and Energy, (2014); Ministry of Economy, Trade and Industry, Energy innovation strategy, (2016)). The energy consumption per unit (U) is calculated according to Eq. 1.

$$U = \frac{E}{P} \tag{1}$$

where:

U is energy consumption per unit of production during total operation time,

E is energy consumption during total operation time, and

P is production quantity during total operation time in a production line.

If energy consumption is assumed to be in units of power, then U is given in [Joule/unit]. Energy consumption and production quantity per unit time are henceforth referred to as power consumption (e) and throughput (p), respectively, where e is given in [Joule/second, W] and p is given in [unit/second]. Fig.1. shows the summary of the relationship between E, P, T, U, e and p. The power consumption (e) and throughput (p) is calculated according to Eqs. (2)-(3).

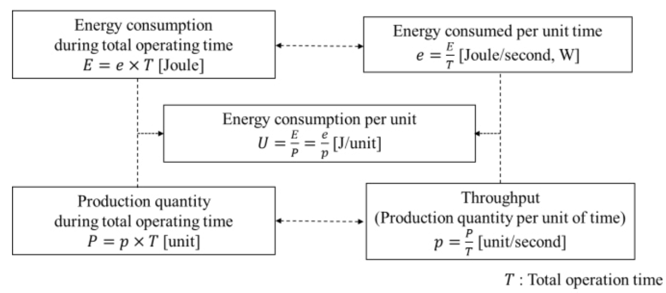

Fig. 1. Relationship between E, P, T, U, e and p.

$$p = \frac{P}{T} \tag{2}$$

$$e = \frac{E}{T} \tag{3}$$

where:

p is production quantity per unit of time in a production line,

e is energy consumed per unit time, and

T is total operation time.

2.2 Definition of rush orders

At production sites, rush orders require manufacturing to occur in times that are shorter than normal lead times. As a result, owing to longer setup times, etc., production stalls and the energy consumption per unit increases. In this study, we assume that rush orders occur at a frequency defined by the mean time between rush orders $(MTBR)$, as described in Fig.2. In the current study, the following two criteria must apply for the condition of a rush order to be met.

- According to the $MTBR$, production of the regular orders is interrupted.