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A note on "lead time reduction strategies in a single-vendor-single-buyer integrated inventory model with lot size-dependent lead times and stochastic demand"

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ABSTRACT

Glock [2012. Lead time reduction strategies in a single-vendor-single-buyer integrated inventory model with lot size-dependent lead times and stochastic demand. International Journal of Production Economics 136, 37–44] recently presented an integrated inventory model where the lead time can be reduced by crashing the setup and transportation time, by increasing the production rate, or by decreasing the lot size. In this note, we introduce a more realistic lead time crashing cost and propose a modified integrated inventory model by adding the transportation time as a decision variable and assuming that there are two different safety stocks. Furthermore, we give some numerical examples to illustrate the advantages of the modified model.

Glock (2012) recently proposed an integrated inventory model with stochastic demand and controllable lead time under different lead time reduction strategies. In this model, the buyer orders a lot of size Q, and the vendor manufactures nQ units with a finite production rate $P(P>D)$ in a single production run and delivers n batches of size Q to the buyer. The inventory patterns for the vendor and buyer are depicted in Fig. 1.

As pointed out by Glock (2012), the lead time for the first shipment consists of production, setup and transportation time, i.e. $L(P,Q)=\frac{Q}{P}+t_S$, while the lead time for the shipments $2,\ldots,n$ is only transportation time t_T. Obviously, the nonproductive time t_S consists of the setup time t_0 in addition to the transportation time t_T, i.e. $t_S=t_0+t_T$. Moreover, Glock (2012) assumed that the transportation time t_T is a fraction of the nonproductive time t_S, i.e. $t_T=\varepsilon t_S$, which means $\Delta t_T=\varepsilon\Delta t_S$. Hence, the nonproductive time crashing cost $R(t_S)$ for the first shipment does not necessarily equal to the transportation time crashing cost $R(t_T)$ for the shipments $2,\ldots,n$.

Similar to the assumptions made by Glock (2012), we assume that the nonproductive time t_S consists of m mutually independent components t_{Sr} $(r=1,2,\ldots,m)$, i.e. $t_S=\sum_{r=1}^{m}t_{Sr}$. The rth component has a normal duration U_r, a minimum duration u_r and a crashing cost per unit time c_r. For convenience, we let $c_1\le c_2\le\ldots\le c_m$. Let t_S^i represent the length of nonproductive time with the components $1,2,\ldots,i$ crashed to their minimum duration, then t_S^i can be expressed as $t_S^i=\sum_{r=1}^{m}U_r-\sum_{r=1}^{i}(U_r-u_r)$, $i=1,\ 2,\ \ldots,m$. As shown in Glock (2012), the nonproductive time crashing cost $R(t_S)$ for the first shipment is given by

$$R(t_S)=c_i\left(t_S^{i-1}-t_S\right)+\sum_{r=1}^{i-1}c_r(U_r-u_r),t_S\in\left[t_S^{i},t_S^{i-1}\right] \tag{1}$$

To gain the transportation time crashing cost $R(t_T)$ for the shipments $2,\ldots,n$, we assume that the lth component of the nonproductive time t_S is the setup time. Thus, the transportation time t_T is composed of $m-1$ mutually independent components, i.e. $t_T=\sum_{\substack{r\neq l\\ r=1}}^{m}t_{Sr}$. For convenience, we rearrange $c_1,\ldots,c_{l-1},c_{l+1},\ldots c_m$ in such a way that $c'_1\le c'_2\le\ldots\le c'_{m-1}$. Let t_T^j be the length of the transportation time with the components $1,2,\ldots,j$ crashed to their minimum duration, then t_T^j can be expressed as $t_T^j=\sum_{r=1}^{m-1}U'_r-\sum_{r=1}^{j}(U'_r-u'_r)$, $j=1,2,\ldots,m-1$. Hence, by adopting the same technique used by Glock (2012), the transportation time crashing cost $R(t_T)$ for the shipments $2,\ldots,n$ is given by

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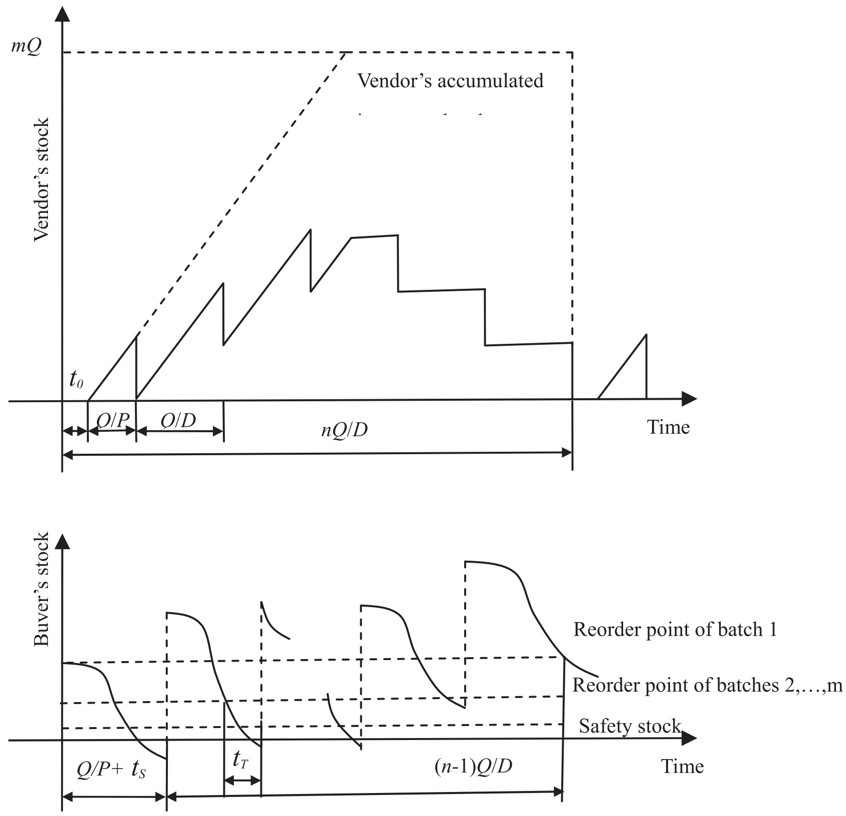

Fig. 1. Inventory patterns for a single vendor and a single buyer.

$$R(t_T) = c'_j\left(t_T^{j-1} - t_T\right) + \sum_{r=1}^{j-1} c'_r\left(U'_r - u'_r\right), \quad t_T \in \left[t_T^j, t_T^{j-1}\right] \tag{2}$$

Then, the lead time crashing cost per unit time should be modified as

$$\frac{D}{nQ}\left[R(t_S) + (n-1)R(t_T)\right] \tag{3}$$

On the other hand, Glock (2012) assumed that the transportation time t_T is a fraction of the setup and transportation time t_S, i.e. $t_T = \varepsilon t_S$, where t_S is a decision variable. According to $t_T = \varepsilon t_S$, we can deduce the equation $\Delta t_T = \varepsilon \Delta t_S$, which may lead to an irrational model behavior. (1) Firstly, the transportation time t_T for the shipments $2, \ldots, n$ may be reduced to a shorter time than its minimum. However, it is impossible in real situations. (2) Secondly, the assumption $t_T = \varepsilon t_S$ means that t_T will be reduced proportionally once t_S is reduced. In fact, it is possible that we only reduce the nonproductive time t_S for the first shipment but do not reduce the transportation time t_T for the shipments $2, \ldots, n$. To be more rational, we relax the assumption that $t_T = \varepsilon t_S$ by treating t_S and t_T as two independent variables.

Additionally, the reduction of lead time leads to a lower demand uncertainty, which may decrease the safety stock and the stock-out loss. Because $Q/P + t_S \gg t_T$, for the shipments $2, \ldots, n$, it might be beneficial to avoid holding additional safety stock by decreasing the reorder points. Therefore, this note considers that there are two different safety stocks and reorder points for the first shipment and the shipments $2, \ldots, n$. Then, the buyer's expected holding cost per unit time is given as

$$h_b\left(\frac{Q}{2} + \frac{1}{n}k_1\delta\sqrt{\frac{Q}{P} + t_S} + \frac{n-1}{n}k_2\delta\sqrt{t_T}\right). \tag{4}$$

Accordingly, the modified expected total cost is given as

$$METC = \frac{D}{nQ}(C_o + C_S + nC_T) + h_b\left(\frac{Q}{2} + \frac{1}{n}k_1\delta\sqrt{\frac{Q}{P} + t_S} + \frac{n-1}{n}k_2\delta\sqrt{t_T}\right) + h_v\frac{Q}{2}\left[m\left(1 - \frac{D}{P}\right) - 1 + 2\frac{D}{P}\right]$$
$$+\frac{D}{nQ}\pi\left[\delta\sqrt{\frac{Q}{P} + t_S}\,\psi(k_1) + (n-1)\delta\sqrt{t_T}\,\psi(k_2)\right] + \frac{D}{nQ}\left[R(t_S) + (n-1)R(t_T)\right] + D\left(\frac{a_1}{P} + a_2P\right) \tag{5}$$

where $\psi(k_r) = \varphi(k_r) - k[1 - \Phi(k_r)]$, $r = 1, 2$, and $\varphi(k_r)$, $\Phi(k_r)$are the standard normal probability density function and cumulative distribution function, respectively.

To simplify notation, we let

$$G(n, t_S, t_T) = \frac{C_o + C_S + nC_T + R(t_S) + (n-1)R(t_T)}{n}$$

$$H(n, P) = h_b + h_v\left[n\left(1 - \frac{D}{P}\right) - 1 + 2\frac{D}{P}\right]$$

Consequently, Eq. (5) can be rewritten as