International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 6 (2017) pp. 1020-1026

Simulation Model and Analysis for Uncertain Demand and Replenishment Policies in Supply Chain

Jihyun Kim and Jaehyun Han*

College of Business Administration, Kwangwoon University
447-1 Wolgye-dong, Nowon-gu, Seoul, South Korea
** Corresponding Author: Jaehyun Han*

Abstract
This paper describes a special purpose simulation model developed for analysing supply chain (SC) behaviour and performance in the presence of uncertainty. A SC is viewed as a series of facilities that performs procurement of raw materials, its transformation to intermediate and end-products, and distribution and sales of the end-products to customers. Uncertainties perceived in these SC data are described by imprecise natural language expressions and they are modelled by fuzzy sets. Also, this paper proposes the process of each object in SC and various replenish policies. The application of SC simulation in analysing and quantifying the effects of changing uncertainty in customer demand is discussed and illustrated by a numerical example.

Keywords : Supply Chain Simulation, Uncertainty, Replenish Policies, Multicriterion Selection

INTRODUCTION

In recent years, considerable emphasis has been placed on supply chain(SC) management and control. A SC is generally viewed as a network of facilities linked by a material flow from suppliers through production to end customer and an information flow through the network. The modern environment in which SCs operate, complex SC structures and relationships between their constituent parts, make SC analysis, management and control very complex and challenging tasks.

The modelling and analyzing SC dynamics has been an active area of research for many years. Vidal and Goetschalckx (1997) reviewed the strategic production-distribution model. They focused on global supply chain models with emphasis on mixed integer programming models. Petrovic et al. (1999) described fuzzy modelling and simulation of a supply chain in uncertain environment. Lee and Kim (2002) obtained more realistic optimal production-distribution plans for the integrated supply chain system reflecting stochastic natures by performing iterative hybrid analytic-simulation procedure. Georgiadis et al. (2011) used mixed-integer linear programming to design SC network under demand variation. A number of scenarios were utilized to represent demand uncertainty. Thomas and Griffin (1996) developed supply chain models to support both strategic supply chain planning and operational control of the supply chain. Cohen and Lee (1988) represented mathematical models that consider the whole supply chain networks.

However, existing mathematical models could not effectively represent the stochastic properties of the supply chain. And other approaches such as system dynamics modelling (Langroodi and Amiri, 2016) and metaheuristic (Cardona-Valdés et al., 2014) are being explored to cope with the uncertainty characteristic. A possible solution to this problem is using simulation. Simulation is an effective tool for analyzing supply chains with dynamically changing variables. Moreover, simulation can also work for global optimization of planning the entire supply chain optimal values of each component (Lee et al., 2002). Companies also promoted the development of simulators for SCM analysis. IBM developed SCA (Supply chain Analyzer) based on Simprocess, and provided inventory optimizer and supply planning (Bagchi et al, 1999).Compaq developed CSCAT (Compaq Supply Chain Analyzer Tool) based on Arena. Nokia developed LOGSIM based on ProModel. LOGSIM consists of five components - supplier, buffer, production and assembly process, customer, material requirement planning. In this paper, we developed an integrated simulator supporting multi-period, multi-product, multi-facility production and distribution model in supply chain environment.

The paper is organized as follows. Supply chain structure and operations are given in Section 2, including event and input data in SC, representation of uncertainty in SC data using fuzzy sets, each object in SC and replenish policies. Use of SC modelling and simulation for SC control under various replenishment policies is discussed and illustrated by a representative example in Section 3. Section 4 concludes this paper.

SUPPLY CHAIN MODEL AND SIMULATION

There are many uncertain variables with stochastic property in general supply chain environment. It is not an easy task to find the optimal solution with the existing analytical methods like linear programming (LP) and dynamic programming (DP). However, simulation is known as the most efficient method for dealing with stochastic natures existing within the SC management. The SC simulation is efficient in analyzing the total costs and order fill rate under many replenishment policies, and reflects all the uncertainties existing in the SC such as the demand of customers, lead time of products and raw materials by using fuzzy sets.

The composition of the SC model and simulation is depicted in Figure 1. The SC models and the SC simulation are implemented in C++ and run on PC under the Windows operating system.

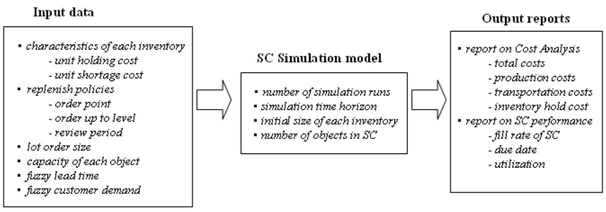

Figure 1. The general SC structure

Event :

An event is defined as something that happens at an instant of simulated time. The event has information such as time, object, production and transportation volume, demand volume, priority and due date. An event function is defined as something that processes the information of an event. The event function is activated by the event during simulated time. The event functions consists of order-arrival function, process function, production function, inventory function, and transport function according to each object. The simulator engine consists of event function, event calendar, event creation function, output function. Figure 2 shows the engine of the simulation.

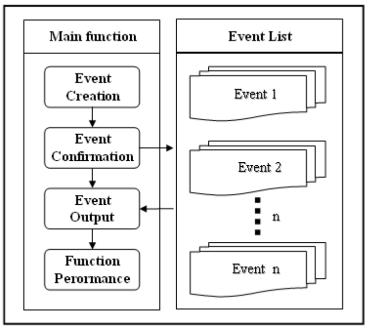

Figure 2. The overview of the simulator engine

SC structure and objects :

Figure 3 shows the classes representing the taxonomy of objects model in SC. The developed simulation model consists of the external objects like customer, DC, factory, supplier and internal object like the common object.

External objects consists of supplier, factory, distribution center(DC) and transport object. The roles of each object are as follows.

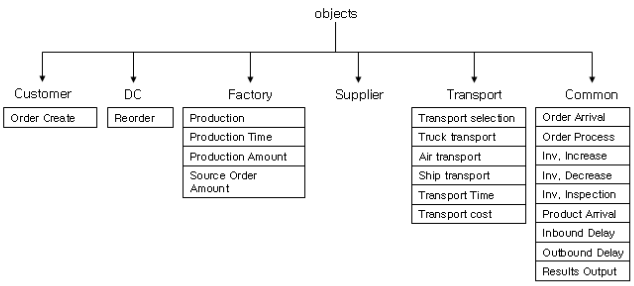

Figure 3. The taxonomy of objects model in supply chain

Supplier object

The input data of supplier object are consisted of production policy that determines production of raw materials, setup time, production time per lot size and delay time of outbound. The function of supplier object is consisted of order arrival function, order processing function, production function of raw materials and inventory function. Figure 4 shows the procedure of an order process in the supplier object.

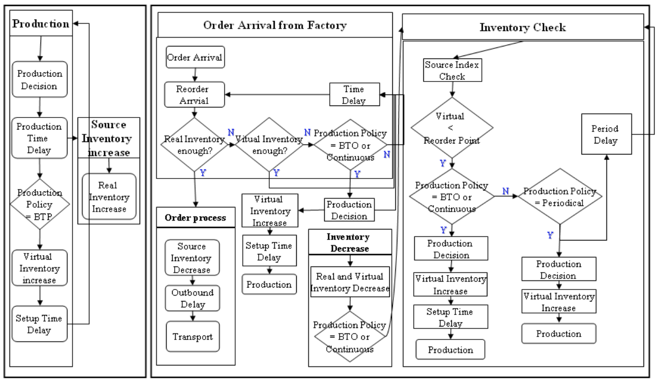

Figure 4. The procedure of the order process in supplier object

Factory object

The input data of factory object are composed of production policy that determines production of product, setup time, production time per lot size and delay time of inbound and outbound. The function of factory object consists of order arrival function, order processing function, production function of product and inventory function of raw material and product. Figure 5 and 6 show the order process procedure in the factory object.

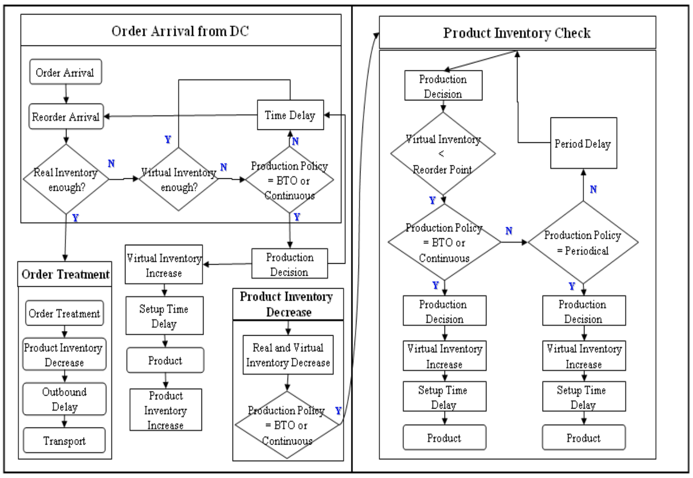

Figure 5. The procedure of the order process in factory object

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 6 (2017) pp. 1020-1026

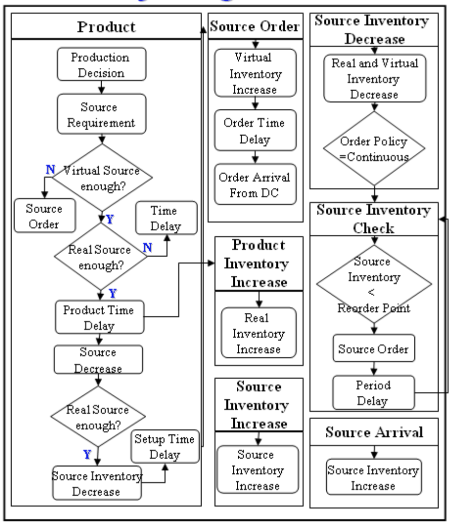

Figure 6. The procedure of the production process in factory object

DC object :

The input data of DC object consists of the order policy that determines the order planning and delay time of inbound and outbound. The function of DC object is consisted of order arrival function, order processing function and inventory function. Figure 7 shows the order process occurred in DC object.

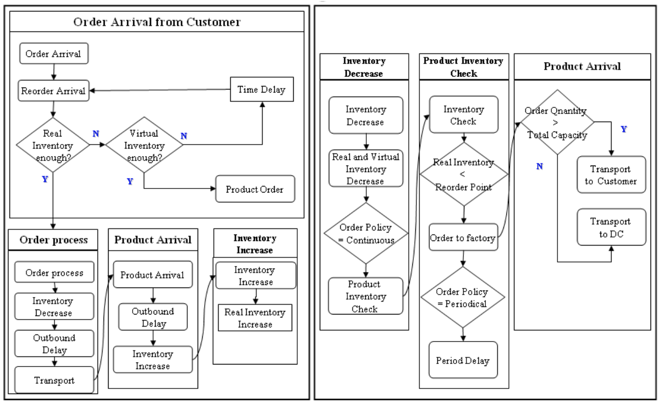

Figure 7. The procedure of the order process in DC object

Transport object

The input data of transport object are consisted of location information for all external objects and transportation time between all external objects. The function of transport object is consisted of the initial order function that first generates orders and order arrival function. Figure 8 shows the transportation process in the transportation object. Also, Figure 9 shows the architecture of integrated supply chain simulator which includes the simulation engine, internal and external objects.

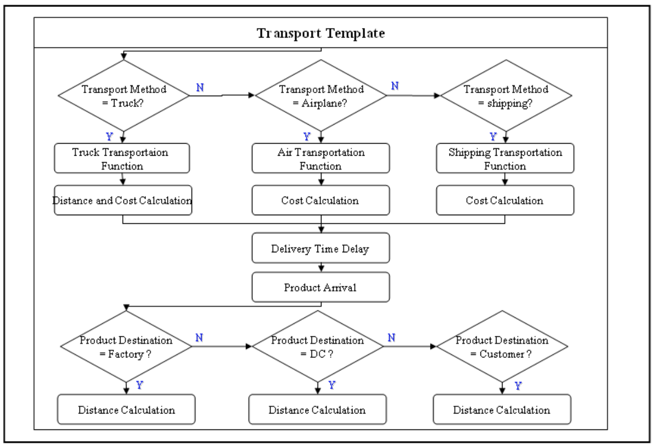

Figure 8. The procedure of the transportation process in transport object

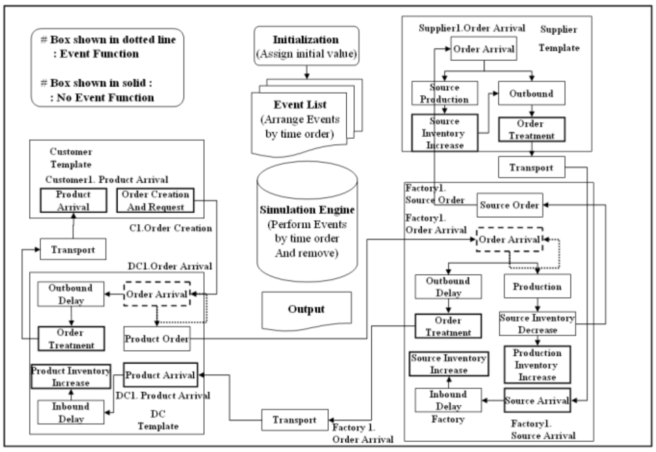

Figure 9. The architecture of integrated SCM simulation model

Treating uncertainty in SC by fuzzy sets :

Uncertainties in parameters in SC management have been treated as stochastic processes and described by probability distributions. A probability distribution is usually derived from evidence recorded in the past. This requires a valid hypothesis that collected evidence are complete and unbiased, and that the stochastic mechanism generating the recorded date continues unchanged. There are, however, situations where all these requirements are not satisfied and, therefore, the conventional probabilistic reasoning methods are not appropriate. For example, there may be a lack of evidence available or lack of confidence in evidence or simple evidence may not exist, as in the case of launching a new product. In these situations, uncertainties in parameters can be specified based on the managerial experience and subjective judgement. It may be convenient to express these uncertainties using various imprecise linguistic expressions; for example, customer demand D is about dm, but definitely not less than d1 and not greater than du, lead time L is most likely to be in the interval $[l_1^l, l_u^l]$, and so forth. Fuzzy sets are found to be useful in representing these approximate qualifiers, due to their conceptual and computational simplicity. The typical membership functions that can represent fuzzy customer demand, fuzzy lead time mentioned above are shown in Figure 10. They can be derived from subjective manager's experience and/or belief.

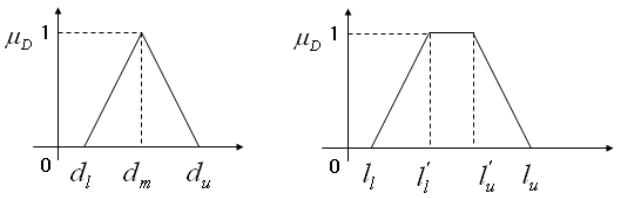

Figure 10. Typical fuzzy sets which represent: (a) fuzzy customer demand, (b) Fuzzy lead time

Inventory replenishment policy :
In this paper, we consider the following replenish policies that have been most extensively studied in inventory theory and most widely applied in practice.

BTO (Build to Order) policy
The build-to-order policy maintains a minimum inventory. The object generates a replenishment order only if a customer order arrives and not enough product is available to fill the order. The replenishment order requests only the amount of the product needed to satisfy the customer order.

Continuous review policy
The object generates a replenishment order every time the inventory level falls below its reorder point.

Periodic review policy
This policy is controlled by a periodic review policy instead of a continuous review policy. The term periodic means that the inventory position is inspected at the beginning of each period. The object generates a replenishment order only when the inventory level is below its reorder point.

SECTION OF BEST REPLENISHMENT POLICIES

Criteria :
With each the combination of replenishment policies ($CRPs$), a number of performance measure criteria are associated. It is assumed that all the criteria that enter into the evaluation of $CRPs$ are relevant for each RP . The values of all criteria for each particular CRP can be obtained by simulation.
Three criteria are as follows;

Total cost
The total cost can be expressed as follows:
TC=total production cost in factories + total inventory cost in factories and *DC*s + transportation cost from suppliers to factories + transportation cost from *DC*s to customers + total shortage cost.

Total number of tardy demands
The total number of tardy demands caused by the optimization results is independent of quantity of demand and duration of tardiness time of the demand.

Total lead time
This criterion can be represented as part of the customer service level. Total lead time required for demand k (D_k) = production lead time in factories + storage time spent in factories + transportation lead time from suppliers to factories and from factories to *DC*s, and from *DC*s to customers.
All the criteria usually do not have the same importance. The relative importance of each criterion is assigned by using weighting coefficients according to the decision maker's choices. A discrete fuzzy sets associated with each vague linguistic expression of the weighting coefficients are given in Figure 11. The discrete fuzzy sets are defined in the near standard integer scale of 1 to 9.

Matrix form of the problem statement :
Generally, the problem of selecting the best from a finite number of $CRPs$ based on I replenishment policies, RP_1 to RP_I and K criteria C_1 to C_k . In this paper, the criterion is of a cost type - the smaller the criteria value the better. Criteria values f_{ik} ($i \in I, k \in K$), where I and K are corresponding sets of indices, are arranged in an $I \times K$ matrix F . The values f_{ik} for each column $k \in K$ are cardinal. With each criterion k , relative importance w_k as a vague linguistic expression is associated and given in the last row of F . The linguistic values of w_k is defined by discrete fuzzy sets. The problem is to rank all $CRPs$ and choose the best CRP^* with respect to all the criteria, simultaneously taking into account the type of each criterion and its relative importance.

$$
\begin{array}{c} \\ \\ F = \end{array}
\begin{array}{c} \\ RP_1 \\ \vdots \\ RP_i \\ \vdots \\ RP_I \\ \\ \\ \end{array}
\begin{array}{ccccc} C_1 & \cdots & C_k & \cdots & C_K \\ \hline & & & & \\ & & \vdots & & \\ \cdots & \cdots & f_{ik} & \cdots & \\ & & & & \\ & & & & \\ \hline \min & \cdots & \min & \cdots & \min \\ w_1 & \cdots & w_k & \cdots & w_K \end{array}
$$

Figure 11. The matrix form of the problem

Algorithm for the selection of the best combination of CRPs :
A new algorithm for multi-criteria selection of the best CRP^* is proposed on the basis of adaptation of a Hurwitz approach for selecting a combined optimistic-pessimistic solution. The algorithm developed for selecting such a CRP^* has the following steps;

Step 1: Transform all the cardinal criteria values f_{ik} into r_{ik} defined on a common scale [0, 1] by applying linear transformations:

$$r_{ik} = 1 - \frac{f_{ik} - f_{ik}^{\min}}{f_k^{\max}}, \quad where\, f_k^{\min} = \min_i f_{ik} \text{ and } f_k^{\max} = \max_i f_{ik}$$

Step 2: Transform all the relative weights of criteria $k \in K$ into the degrees of belief B_k ($k \in K$) that a criterion k is more or equally important as all other criteria in the set K / k ; each B_k belongs to a common scale [0, 1], and is calculated using the fuzzy sets.
Step 3: Calculate the elements of weighted normalized $I \times K$

decision matrix D = [d_{ik}] with the following element; $d_{ik} = B_k \times r_{ik}$ for all columns $k \in K$ which correspond to the cardinal criteria.

Step 4: Find row i^*, the corresponding CRP^* in matrix D for which
$\max_i\{\alpha \cdot \min_k d_{ik} + (1-\alpha) \cdot \max_k d_{ik}\}$ is achieved.

The parameter α is referred to as the optimism-pessimism coefficient, it varies in the range of [0, 1], the smaller the α the more optimism is expressed and vice versa.
CRP^* is the best combination of replenishment policies in the sense that both its best and its worst criteria values are good enough. In the case of $\alpha = 0$, the max-max policy and, for $\alpha = 1$, the max-min policy is selected. These two cases express, respectively, the maximum optimism, i.e. a weight 0 to all others, and the maximum pessimism, where a weight of 1 is assigned to the worst criterion value and weight 0 to all others.

Illustrative example and results analysis :
Let us consider an illustrative example. The problem is to choose the best among the combination of the three different replenishment policies defined in Section 2.4 taking into accounting the three cost criteria. All alternative scenarios were simulated for the same number of iteration runs. A trial run for the current situation was used to fix the simulation period. An example of the simulation modelling of the test problem for this study is presented in Figure 5.
The common data, which characterize inventory environment for all *CRPs* treated are:

- Product unit cost: 1.5 / unit
- Factory inventory cost: 0.2 /unit per unit time
- DC capacity: 2000 units
- DC handling lead time: 1.0 unit time/ order
- DC inventory cost: 0.1 / unit per unit time
- Delivery cost from supplier to factory: 0.2 of product value
- cost form factory to DC: 0.8 of product value
- Delivery cost from DC to customer: 0.4 of product value
- Lead time and customer demand is uncertain and described by a linguistic expression “about 0.3-0.7 unit time” and “about 10 products per order” respectively.

Table 3 shows the optimization result of the test problem 1 when the combination of replenishment policies is the periodic policy at factory insource, the periodic policy at factory outsource, and the periodic policy at DC insource. Table 4 indicates CRP^* after applying the proposed algorithm for the selection of the best combination.

CONCLUDING REMARKS AND FURTHER RESEARCH
Mathematical modelling and analytical method of supply chain environment have been widely studied. However, existing analytical method could not cover all the variables with stochastic properties in the supply chain environment. We are interested in the development of supply chain simulator which considers the stochastic property. Utilizing vague linguistic expression, an efficient representation of stochastic environment of SC is made possible. The experiment was done to show the benefits of the developed simulator. The results show the potential of the proposed methodology for selecting the best combination of CRPs. For further research, it is necessary to develop the simulator for generating graphical output data such that decision makers can see how the supply chain acts over time during simulation.

Acknowledgement: The present Research has been conducted by the Research Grant of Kwangwoon University in 2017.

Table 1. Criteria Values

Index of CRP	Policies			Criteria Values		
	Factory		DC			
	Insource	Outsource	Outsource	Total Cost	# of tardy demands	total lead time
1	BTO	BTO	BTO	339,807	92	43
2	BTO	BTO	Continuous	361,774	87	234
3	BTO	BTO	Periodic	295,254	54	57
4	BTO	Continuous	BTO	357,113	41	173
5	BTO	Continuous	Continuous	377,447	43	290
6	BTO	Continuous	Periodic	293,754	41	120
7	BTO	Periodic	BTO	259,461	63	78
8	BTO	Periodic	Continuous	262,789	62	222
9	BTO	Periodic	Periodic	237,885	59	141
10	Continuous	BTO	BTO	360,664	38	53
11	Continuous	BTO	Continuous	371,231	79	207
12	Continuous	BTO	Periodic	292,121	59	79
13	Continuous	Continuous	BTO	378,557	29	167
14	Continuous	Continuous	Continuous	390,102	85	141

15	Continuous	Continuous	Periodic	378,557	69	28
16	Continuous	Periodic	BTO	327,678	48	27
17	Continuous	Periodic	Continuous	335,861	66	11
18	Continuous	Periodic	Periodic	263,572	88	96
19	Periodic	BTO	BTO	249,042	56	51
20	Periodic	BTO	Continuous	259,467	67	73
21	Periodic	BTO	Periodic	220,244	72	280
22	Periodic	Continuous	BTO	262,925	89	108
23	Periodic	Continuous	Continuous	269,320	97	260
24	Periodic	Continuous	Periodic	231,384	86	291
25	Periodic	Periodic	BT O	233,883	19	45
26	Periodic	Periodic	Continuous	242,661	51	42
27	Periodic	Periodic	Periodic	211,382	63	96

Table 2. Normalized and transformed criteria values *(i =1; Total Cost, i=2; # of tardy demands, i=3; total lead time)*

Index of CRP	Policies			d_{ik}			CRP^*	
	Factory		DC					
	Insource	Outsource	Outsource	d_{1k}	d_{2k}	d_{3k}	max-max policy	max-min policy
1	BTO	BTO	BTO	0.67	0.12	0.89	0.524	0.146
2	BTO	BTO	Continuous	0.61	0.15	0.23	0.361	0.137
3	BTO	BTO	Periodic	0.78	0.32	0.84	0.495	0.376
4	BTO	Continuous	BTO	0.63	0.39	0.44	0.455	0.261
5	BTO	Continuous	Continuous	0.57	0.38	0.04	0.443	0.024
6	BTO	Continuous	Periodic	0.79	0.39	0.63	0.464	0.368
7	BTO	Periodic	BTO	0.88	0.27	0.77	0.516	0.321
8	BTO	Periodic	Continuous	0.87	0.28	0.27	0.511	0.162
9	BTO	Periodic	Periodic	0.93	0.29	0.55	0.548	0.325
10	Continuous	BTO	BTO	0.62	0.40	0.86	0.503	0.363
11	Continuous	BTO	Continuous	0.59	0.19	0.33	0.347	0.192
12	Continuous	BTO	Periodic	0.79	0.29	0.77	0.466	0.346
13	Continuous	Continuous	BTO	0.57	0.45	0.46	0.528	0.273
14	Continuous	Continuous	Continuous	0.54	0.16	0.55	0.325	0.188
15	Continuous	Continuous	Periodic	0.57	0.24	0.94	0.554	0.285
16	Continuous	Periodic	BTO	0.70	0.35	0.95	0.556	0.412
17	Continuous	Periodic	Continuous	0.68	0.26	1.00	**0.588***	0.303
18	Continuous	Periodic	Periodic	0.87	0.14	0.71	0.510	0.170
19	Periodic	BTO	BTO	0.90	0.31	0.86	0.531	0.364
20	Periodic	BTO	Continuous	0.88	0.25	0.79	0.516	0.297
21	Periodic	BTO	Periodic	0.98	0.23	0.08	0.575	0.044
22	Periodic	Continuous	BTO	0.87	0.14	0.67	0.511	0.164
23	Periodic	Continuous	Continuous	0.85	0.10	0.14	0.501	0.085
24	Periodic	Continuous	Periodic	0.95	0.15	0.04	0.558	0.022
25	Periodic	Periodic	BTO	0.94	0.50	0.88	**0.588***	**0.520***
26	Periodic	Periodic	Continuous	0.92	0.34	0.89	0.541	0.394
27	Periodic	Periodic	Periodic	1.00	0.27	0.71	**0.588***	0.321

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