# SENSITIVITY ANALYSIS OF THE BULLWHIP EFFECT IN A THREE-LEVEL SUPPLY CHAIN WITH STOCHASTIC DEMANDS AND LEAD TIMES

## INTRODUCTION

A real-world supply chain (SC) may consist of more than two levels, such as retailers, distributors, manufacturers, and suppliers. Each level may have only one or multiple parties. When each party manages its organization without any coordination, the so-called "Bullwhip Effect" (BWE) happens (Lee *et al*., 1997a, 1997b). Variances of ordering patterns move up the SC from retailers, to distributors, to manufacturer, to supplier. This lack of coordination reduces profitability of the whole SC because the BWE almost always increases costs (e.g., inventory cost, transportation cost, labor cost, and manufacturing cost) and replenishment lead time (Chopra and Meindl, 2004; Krajewski and Ritzman, 2005). Efforts have been made to find causes and effects of the BWE. Methods include building a simulation model and applying some strategies such as vendor manage inventory (VMI), for examples, Waller *et al*. (1994) and Xu and Dong (2004). Examples of research works that trying to observe an extent of the BWE include Chatfield *et al*. (2004) and Disney and Towill (2003a).

Our system is modeled as a stochastic discrete-event system (DES). "Stochastic" means that there are some random input components such as stochastic demands and lead times. Since a real-world SC is often complex with stochastic elements, simulation may be the only appropriate tool available. Barton (2001) states that "discrete-event simulation modeling is a popular method for predicting the performance of complex systems, particularly systems that include random phenomena." Van der Vorst *et al*. (2000) use a DES to model the dynamic behavior of food SC's and evaluate alternative designs of SC's. Simulation has many benefits: Alternative system designs can be compared to see which configurations best meet the requirements. Simulation also allows you to study the system in different time frames. However, its disadvantages are expense and a long time to develop a model. Each simulation run produces only estimates of a model's true characteristics for a particular set of input parameters (Law and Kelton, 2000).

We construct a DES model that represents a three-level SC of a single product to explore characteristics and magnitudes of the BWE from downstream to upstream. The SC is modeled as a "pull system," where upstream members can supply goods or products to downstream members only when they receive orders from their downstream members. The first level of the SC consists of two retailers, while the second and the third levels have a distributor and a supplier, respectively. Customers are considered as external demands, and they can buy goods only from retailers. The supplier has an infinite supply to serve the distributor. All parties use a periodic review for an inventory control system. A periodic review system is convenient, and is often used in many real world SC's because of its conveniences: its inventory position is reviewed and replenishments are made at fixed time intervals. Orders for multiple items from the same supplier may be combined in to a single purchase order.

The inventory position needs to be known only when a review time is reached (Krajewski and Ritzman, 2005).

After the model is built, factors that influence the magnitudes of the BWE are examined. We use the $2^k$ factorial design, where each parameter is considered at high (+) and low (-) levels, for designing experimental runs. Data collected from running the model are analyzed to determine factors and their interactions that contribute to the BWE. Other key performance indicators (KPIs) are also considered, such as time-average inventory, average time in system of goods, stock-out fraction of time, and fraction of lost sales.

## Objectives

The objectives of this study are as follows:

1. To build a three-level SC simulation model where the first level consists of two retailers and the second and the third levels have a distributor and a supplier, respectively.
2. To quantify the extent of the BWE.
3. To examine how the SC parameters affect the magnitude of the BWE.
4. To determine what SC parameters significantly contribute to the BWE.

## Scopes

1. The system under study is a three-level SC which consists of a single supplier, a single distributor, and two retailers.
2. The SC is modeled as a pull system.
3. The SC simulation model is built on Arena (Rockwell Software) version 7.01.
4. Each customer, with random demands, purchases goods only from retailers. All customer demands are normally distributed.
5. Every party uses a periodic review of an inventory control system.
6. A supplier has an infinite supply, while a distributor and retailers can serve customers only the amount of their in-stock goods, i.e., no backorder is allowed. Unfilled demands are lost.
7. Delivery lead times to a distributor and retailers are stochastic and normally distributed.

## Benefits

This research provided insights on the BWE. Its contribution is in determining factors and their interactions that affect this phenomenon. Furthermore, it can be used as a decision tool that helps a company reduce the magnitude of the BWE in its SC.

## LITERATURE REVIEW

The literature review consists of four parts: the bullwhip effect, stochastic simulation, inventory control systems, and design of experiment techniques.

### The Bullwhip Effect

The BWE can be defined in many ways: Cachon *et al*. (2005) define the BWE as the phenomenon of increasing demand variability in the SC as one moves from the lowest echelon, or level, to the highest echelon. Lee *et al*. (1997ab) say that the BWE refers to increasing variability of demand further upstream in the SC. Chopra and Meindl (2004) define it as the increasing fluctuations in orders as they move up the SC from retailers to wholesalers, to manufacturers, and to suppliers (see Figure 1 for an example).

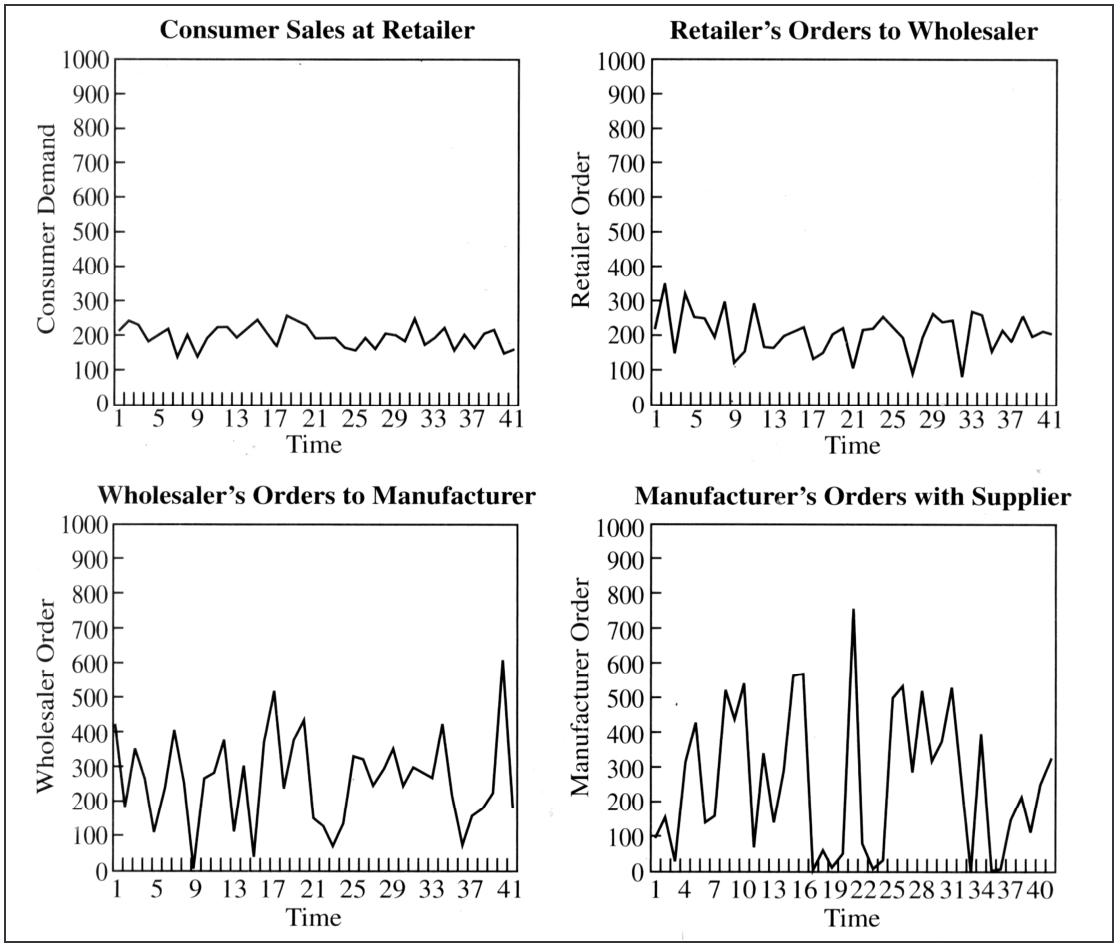


Figure 1 The bullwhip effect.
Source: Chopra and Meindl (2004)

Disney and Towill (2003a) investigate the existence of the BWE in the vendor managed inventory (VMI) supply chain and a traditionally serially-linked supply

chain. They use a spreadsheet simulation model (see Seila 2003 for details) consisting of two parties which are one supplier and one customer. This study is based on four causes of the BWE that Lee *et al*. (1997a, 1997b) have proposed: non-zero lead time and demand signaling processing (demand amplification), price variation, rationing and gaming, and order batching. Rationing and gaming (a.k.a. the Houlihan Effect) occurs when customers increase their safety stocks due to previous shortages or missed deliveries. Order batching or the Burbidge Effect means placing orders to downstream players in batches in order to gain economies of scale in set-up activities (Disney and Towill, 2003b). Disney and Towill (2003a) also suggest that VMI can help reduce the BWE in supply chains, and two sources of the bullwhip effect—rationing/gaming and order batching—may be completely eliminated. Moreover, they propose the following ratios to quantify the magnitude of the BWE as:

$$\text{Bullwhip Index (BWI)} = \frac{\dfrac{\sigma_O^2}{\mu_O}}{\dfrac{\sigma_S^2}{\mu_S}}, \qquad (1)$$

where $\sigma^2$ denotes variance and $\mu$ denotes a mean. The subscript $O$ and $S$ refer to the orders placed to a supplier, and sales or consumptions by customers, respectively.

Our study use the method proposed by Equation (1) to quantify the extent of the BWE in the simulation model. Sales and orders data of each party are collected by using a *DSTAT* element module in Arena, and then they are sent to Equation (1) by using an *OUTPUTS* element module.

Chopra and Meindl (2004) quantify the BWE differently, as a ratio of the variability in the customer orders to the variability in order placed to the supplier, i.e., $\sigma_O^2 / \sigma_S^2$. Similarly, Chen *et al*. (2000) also consider this ratio for a simple, two-level SC consisting of a single retailer and a single manufacturer. On the other hand, Fransoo and Wouters (2000) use slightly different measures from Equation (1), they consider standard deviations, rather than variance.

## Stochastic Simulation

Simulation is used to analyze many real-world complex problems which cannot be solved analytically. It uses a computer to evaluate a model numerically, and data are gathered in order to estimate the desired true characteristics of the model. A simulation consists of ten steps as shown in Figure 2 and can be classified into three dimensions (Law and Kelton, 2000):

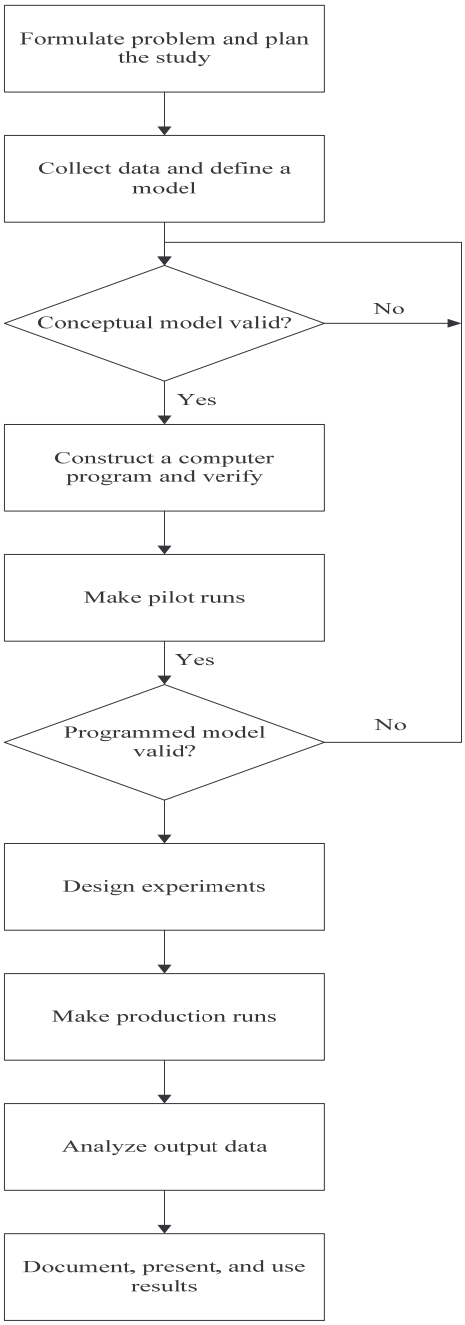


Figure 2 Steps in a simulation study.

1. Static vs. dynamic simulation models. A static simulation model represents a system at a particular point in time, or a system in which time is not considered. In contrast, a dynamic simulation model represents a system that evolves over time.

2. Deterministic vs. stochastic simulation models. A deterministic simulation model is a simulation model that does not consist of any probabilistic components, unlike a stochastic simulation model that has at least some random input components.

3. Discrete vs. continuous simulation models. A discrete system is the system that its state variables change instantaneously at separated point in time. On

the other hand, state variables change continuously with respect to time for a continuous simulation model.

Kleijnen and Smits (2003) classify simulation into four types: spreadsheet simulation, system dynamic, discrete-event dynamic system simulation, and business games. From methodological point of view, they describe four issues in simulation: validation and verification, sensitivity or "what-if" analysis, optimization and robustness, and risk/uncertainty analysis. Simulation is often used as a tool in selecting the best alternative because no closed-form mathematical functions of outputs in term of inputs are required. In addition, simulation may give insight into causes and effects of the SC performance such as which inputs significantly affect what outputs. They also state that a simulation model consists of three main characteristics:

1. It is a quantitative, mathematical and computer simulation.
2. It is a dynamic model.
3. It cannot be solved by mathematical analysis.

Spreadsheets have been used to implement manufacturing resource planning (MRP II) and VMI SC. System dynamics can demonstrate the BWE. Discrete-event dynamic system can estimate the performance measures which are random variables, such as fill rates.

After a simulation model is built, it is necessary to perform validation and verification, sensitivity analysis, optimization and robustness analysis of the model. Validation and verification may be done by using statistical techniques, such as the design of experiment (DOE). Sensitivity analysis provides insights into the behavior of the SC (including interactions between factors) and also gives insights on critical factors.

Chatfield *et al*. (2004) study the effects of stochastic lead times and of information sharing in a periodic order-up-to level inventory system. They use a simulation model called "SISCO" (Simulation for Integrated Supply Chain Operations), which is an object-oriented, multi-threaded simulation modeling environment. The simulation model uses agent-based representation, where each node operates autonomously. They investigate factors such as lead time variation, information quality, and information sharing. The simulation model is constructed serially from customers, retailers, wholesalers, distributors, and factory levels. The model is verified by comparing observed variance amplification levels to previous research, and it is validated by what currently exists in the literature. According to their study, the BWE is due to an attempt to adjust the inventory policy according to the latest data. They find that information sharing reduces total variance amplification, decelerates the BWE, and protects a SC against cascading failures. Information quality drives the BWE by affecting stability and accuracy of the lead time demand forecasting process.

Petrovic *et al*. (1998) construct a SC simulation model in an uncertain environment. Their SC is viewed as a series of facilities, where decisions made at one facility affect the performance of other facilities. Customer demand and external supply of raw material are two sources of uncertainty inherent in the external environment. They consider a single product, and inventory system is controlled by using periodic review policy for all facilities.

Our SC simulation model is built on Arena (Rockwell Software), which is one of high-level commercial simulation languages. Arena provides alternative and interchangeable templates of graphical modeling and analysis modules that can be combined to build a wide variety of simulation models. There are nine parts of a simulation model to be perceived before modeling (Kelton *et al*. 2003).

1. *Entities* are the dynamic objects, which are created, move around for a while, and then are disposed from the system. They affect and are affected by other entities and the state of the system, and also affect the output performance measures, or KPIs. Some entities are not disposed, but circulate in the model. Updating inventory and goods are two examples of entities in our study.
2. *Attributes*, sometimes called local variables, are common characteristics of all entities, but with a specific value. The same attribute (such as color) can have different values, such as red, green, and yellow, for different entities.
3. *(Global) variables* represent some quantities that change during simulation, such as number of goods in the system. Unlike attributes, they are not tied to any specific entity, but concern the system as a whole. There are two types of variables: Arena built-in variables, such as number in queue, and user-defined variables, such as average inventory levels and average time in system of goods.
4. *Resources* may be machines or persons. They are given to the entity. An entity seizes a resource when it is available, then releases it when the task finishes.
5. *Queues* occur when an entity cannot move on, so it has to wait at a particular place, such as a resource that is now serving other entities.
6. *Statistical accumulators* are variables that have to be updated or kept track in order to get the output performance measures. They should be initialized to zero.
7. *Events* are something that happens at a particular point in time, which might change attributes, variables, or statistical simulators. There are three main events: arrival (entering system of new entity), departure (leaving the system), and the end (stopping simulation).
8. *Simulation clock* is a variable that contain the current value of time. It lunges from the time of one event to the next event scheduled to happen.
9. *Starting and stopping* are the appropriate conditions for starting and stopping the simulation.

## Inventory Control Systems

Krajewski and Ritzman (2005) describe two main inventory control system which are different at their review periods: continuous review systems and periodic review systems. A continuous review system, or a reorder point (ROP) system, tracks inventory position of an item each time a withdrawal is made to determine whether an

order should be placed. A periodic review system, sometimes called a fixed interval reorder system or a periodic reorder system, was used in this study. Inventory position ($I_P$), the measurement of an item's ability to satisfy future demands, is reviewed every time period $P$. An order may be placed at the end of each review but does not arrive until after lead time, $L$, has elapsed. An order quantity ($Q$) for each review is equal to a target inventory ($T$) minus the inventory position at the time as follows:

$$I_P = O_I - S_R \tag{2}$$

$$Q = T - I_P \tag{3}$$

In Equation (2), $O_I$ and $S_R$ represent an on-hand inventory and scheduled receipts, respectively. Backorders are not relevant because unfilled demands are lost.

Hosoda and Disney (2006) analyze a three-echelon SC where all participants employ a periodic-review order-up-to policy, which is also a periodic review system, with a forecasting scheme that minimizes the mean square error. They demonstrate that the behavior of the stochastic ordering process observed at each level of the SC is mathematically traceable and show that the upstream participants have complete information of the market demand process. Equation (1) is used in their analysis. They find that the number of SC levels has no impact upon the magnitude of the BWE; rather it is determined by the accumulated lead time from a customer and the local replenishment lead time. The variance of the forecast errors conditioning on the lead time are identical to the variance of the net inventory levels (on-hand inventory, or actual stock, minus backorder), and that the net inventory variance is dominated by the local replenishment lead time.

Dejonckheere *et al*. (2003) develop a mathematical model which is a part of control system engineering and state that the replenishment rule used by SC members contributes significantly to the BWE. They analyze the BWE induced by the used of different forecasting methods in order-up-to replenishment policies. They prove that the BWE is guaranteed to happen in order-up-to models, irrespective of forecasting methods used. When production is inflexible, and significant costs are incurred by frequently switching production quantities up and down, order-up-to policies may no longer be desirable.

## Design of Experiment Techniques

The design of experiment (DOE) techniques is the way that experimenters perform experiments to discover something interesting for a particular process or system. Sanchez (2005) states that there are three fundamental concepts in DOE: control, replication, and randomization. Control means that the experiment is conducted in a systematic way, rather than by using a trial-and-error approach. Replication is a way to gain enough data to achieve narrow confidence intervals and powerful hypothesis tests, or for graphical methods to reveal the important

characteristics of a simulation model. Randomization provides a probabilistic guard against the possibility of unknown, hidden sources of bias surfacing to create problems with data.

Telford (2001) states that "experimental design is an effective tool for minimizing the amount of information gained from a study while minimizing the amount of data to be collected." In experimental design, factors are the input parameters and structural assumptions composing a model, and responses are the output performance measures (Law and Kelton, 2000). Estimating how changes in input factors affect responses is one of the main goals of experimental design.

Barton (2001) says that "factorial designs are based on a grid, with each factor tested in combination with every level of every other factor." When there are $k$ input factors and two values (or levels) are identified for each factor, there are $2^k$ different combinations of the input factors. This is the $2^k$ factorial design. Anderson (2004) states that changing only one factor at a time cannot detect interaction of factors, i.e., interaction effects. Factorial design enables the experimenter to investigate the individual effects of each factor (or main effect) and to determine whether the factors interact (or interaction effects). In addition, factors are varied simultaneously, instead of one at a time. The main effect measures the average difference in response when an individual factor changes or moves from its low level (-) to its high level (+). Interaction effect is significant when the effect of one factor depends on the level of one or more factors (Montgomery, 2005). Table 1 is an example of a $2^3$ factorial design with one replication for each experiment.

Table 1 $2^3$ factorial design.

| Run | A | B | C | Labels |
|---|---|---|---|---|
| 1 | - | - | - | (1) |
| 2 | + | - | - | a |
| 3 | - | + | - | b |
| 4 | + | + | - | ab |
| 5 | - | - | + | c |
| 6 | + | - | + | ac |
| 7 | - | + | + | bc |
| 8 | + | + | + | abc |

Chatfield *et al*. (2004) use full-factorial experiments on three factors: lead time variability, information quality and information sharing, resulting in 32 combinations (4 levels of lead time variability x 4 levels of information quality x 2 levels of information sharing). Their findings are explained in stochastic simulation section.

Paik (2005) uses computer simulation models to investigate the factors that are believed to affect demand amplification and to examine their effects on variability of orders in supply chains. Nine causes of the bullwhip effect are considered as variables in the simulation models with three levels for each. He uses a fractional

factorial design with a fraction of 1/81 of the full factorial in order to investigate the main effect of each of the selected causes of the bullwhip effect. Analysis of variance is also used to examine whether or not interaction exists. In this study, there are three different supply chain structure; four echelons, three echelons and two echelons. Data collected from running experiments are categorized and analyzed based on number of echelons. His study shows that (1) information sharing and coordination within and across organizations are essential to reduce demand amplification when there are multiple levels of echelons in a SC, and (2) market responsiveness or agility is a useful principle to dampen the bullwhip effect when there are few intermediaries involved in a SC.

# MATERIALS AND METHODS

## Material

### 1. Hardware

1.1 Microsoft Windows 95 (OSC-2), Windows 98, Window ME, NT 4.0 (Service Pack 5 or Later), Windows 2000, Windows XP

1.2 75 – 250 MB free hard disk space

1.3 64 MB RAM (Arena recommends 128 MB RAM or higher)

1.4 Minimum Pentium Processor, 3000 MHz or higher

### 2. Software

2.1 Arena version 7.01: a software used for building the SC simulation model

2.2 Minitab version 14: a software used for analyzing the importance of factors and their interactions

## Methods

We describe the SC simulation modeling in Section 1 and experimental design in Section 2.

### 1. The SC simulation modeling

The SC simulation model is built on Arena (Rockwell Software) version 7.01. In Section 1.1, we describe how we design the simulation model. Section 1.2 tells about components of the SC model. For Section 1.3, we state about KPIs and how to measure them.

1.1 The system design

Our SC simulation model represents a three-level SC of a single product. The first level consists of two retailers, while the second and the third levels have a distributor and a supplier, respectively (see Figure 3). Customers are considered as external demands, and they can buy goods only from retailers. The supplier has an infinite supply to serve the distributor. All parties use a periodic-review inventory control system. The modeling logic of each party, except a supplier, consists of two parts: one for meeting demands or orders, and the other is for inventory replenishment whereby orders to upstream members are generated. The supplier does not need to consider inventory replenishment because we assume that it has infinite supply of goods.

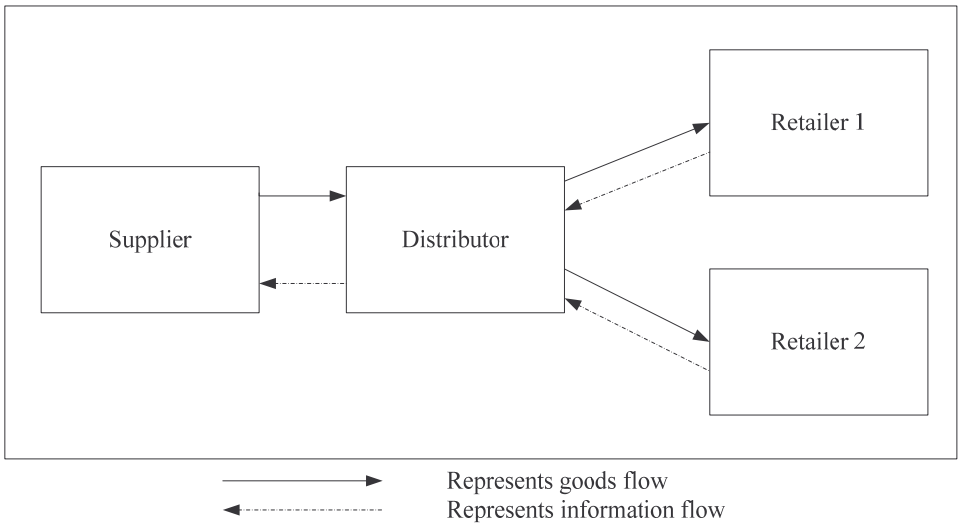


Figure 3 Our three-level SC.

1.2 The SC simulation model components

We explain our input variables in Section 1.2.1, demand signaling processes in Section 1.2.2 and inventory replenishment in Section 1.2.3.

1.2.1 Input variables

Table 2 shows all input variables and their values used in our Arena model; some of them are constant, and some of them are varied according to the factorial design. We set an initial inventory level equals to the target inventory for the sake of convenience. There is no target inventory for a supplier because this party has an infinite supply, so when its goods are drawn from a distributor, the supplier will be resupplied with those amount of goods immediately. For the factorial factors (e.g., rp_r1, and rp_r2), their values are the same for every party in each experiment. Customer demands are normally distributed because mean of demands and standard deviation of demands have to be used to quantify the magnitude of the BWE.

Table 2 Input variables for the model.

| Arena Variables | Description | Values |
|---|---|---|
| fill_r1 | Initial inventory at a retailer 1 | 30 |
| fill_r2 | Initial inventory at a retailer 2 | 30 |
| fill_d | Initial inventory at a distributor | 40 |
| fill_s | Initial inventory at a supplier | 60 |
| target_r1 | Target inventory for a retailer 1 | 30 |
| target_r2 | Target inventory for a retailer 2 | 30 |
| target_d | Target inventory for a distributor | 40 |
| rp_r1 | Time between inventory reviews at a retailer 1 | 3 or 7 |
| rp_r2 | Time between inventory reviews at a retailer 2 | 3 or 7 |
| rp_d | Time between inventory reviews at a distributor | 3 or 7 |

Table 2 (Cont'd)

| Arena Variables | Description | Values |
|---|---|---|
| lotsize_d_r1 | Lot sizes for a retailer 1 | 1 or 6 |
| lotsize_d_r2 | Lot sizes for a retailer 2 | 1 or 6 |
| lotsize_s_d | Lot sizes for a distributor | 1 or 6 |
| demand | Customer demands | Norm (1, 0.5)<br>Norm (1, 3)<br>Norm (4, 0.5)<br>Norm (4, 3) |
| lead time | Lead time for each party | Norm (1, 0.5)<br>Norm (1, 2)<br>Norm (4, 0.5)<br>Norm (4, 2) |

For demand and lead time variables, they behave following the normal distribution. The values in the parenthesis are a mean and a standard deviation, respectively.

1.2.2 Demand signaling processes

For each SC party in the model, a demand signaling process for each party may have some different procedures as follows:

a. Retailers

Demands for both retailers are from customers whom we do not model. They have stochastic demands. When customers come, our system will check whether there are enough goods or not. If not, our simulation model increments the number of times that retailers have stock-outs. In case that there are enough in-stock goods, customers send *signals* to the retailers to release goods from their stores equal to the amount demanded. If the amount of goods are not enough, but there are some goods in the stores, the signal will be equal to their in-stock inventory at that time, and unmet demands are counted as lost sales. And, if the stores are out of stock, all demands are counted as lost sales (see Figure 4 for Arena flow chart).

b. A distributor

Demands for a distributor are from orders placed by either retailers. Order quantities from retailers are computed from Equation (2). Logic for stock-outs and lost sales are similar to that of the retailers.

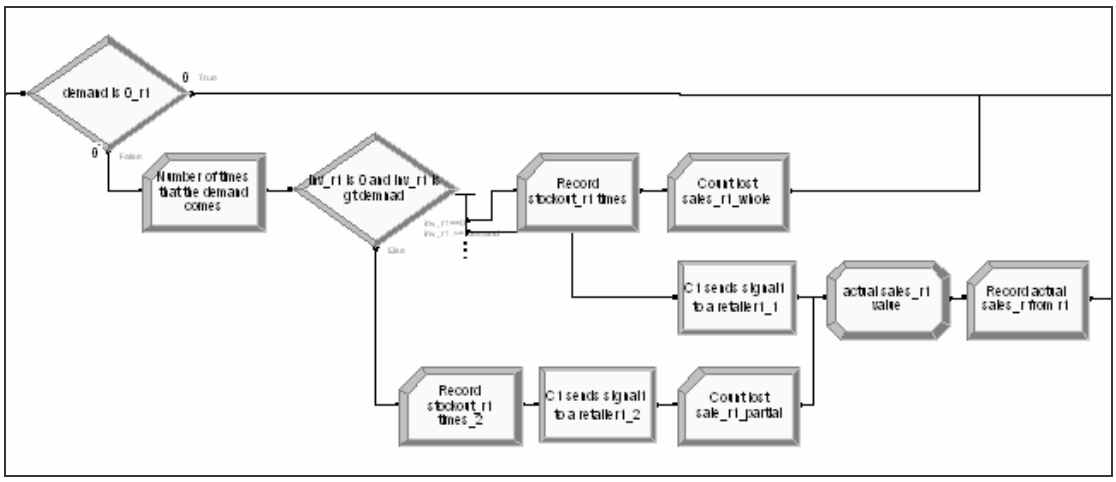


Figure 4 Demand signaling process at retailers.

c. A supplier

Demands to a supplier are from orders placed by the distributor. Because the supplier has an infinite supply to serve the distributor, stock-out times and amount of lost sales are not measured at this party (Figure 5).

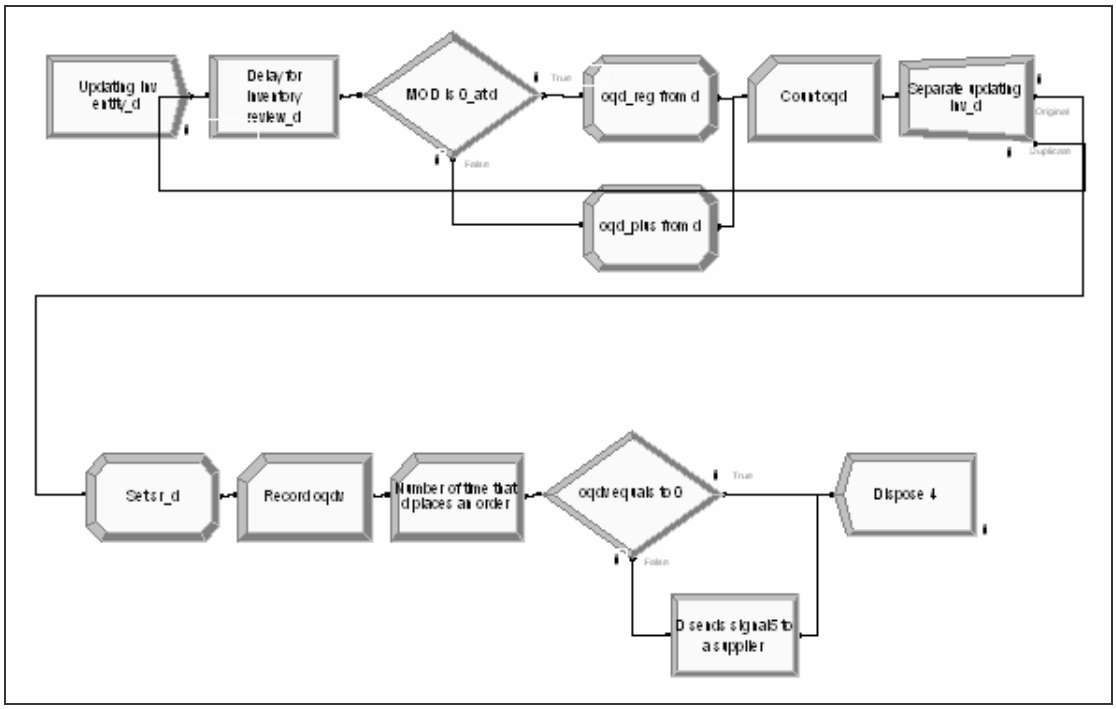


Figure 5 Demand signaling process at a supplier.

1.2.3 Inventory replenishment

We describe how each party generates orders and how goods are delivered to them. Every party uses a periodic order-up-to level inventory control system. Lead times for shipping goods are normally distributed.

a. Generating orders

Inventory levels of each party are updated everyday and reviewed every fixed time interval. When the review period is reached, a party determines an order quantity to be placed to its upstream member. The order quantity is obtained from Equation (2). However, the ordered quantities must be multiple of lot sizes. (Figure 6).

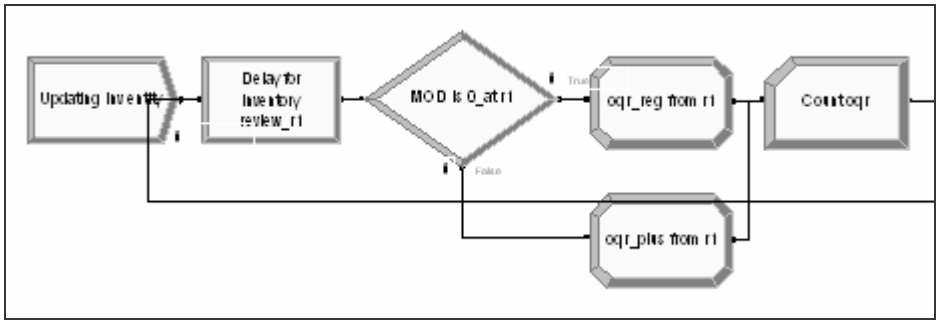


Figure 6 Inventory updating and order generating.

b. Delivery process

After the party places an order, goods do not arrive immediately, but they are held for a delivery lead time. For the distributor, orders received from retailers must be sourced in so that goods are shipped to the right retailer (Figure 7).

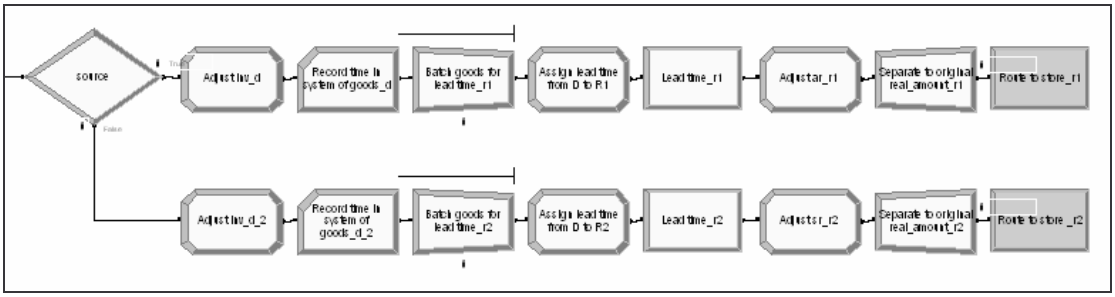


Figure 7 Delivery process.

1.3 Key performance indicators (KPIs)

Five KPIs are considered in this study. All of them are obtained by using an *OUTPUT*S element module in Arena.

1.3.1 The Bullwhip Index (BWI)

The extent of the BWE occurred at the second level of a SC (a distributor) relative to the extent of the BWE occurred at the first level (retailers) as shown in Equation (1). The variance of sales and variance of orders values are collected by *DSTAT* element module, and they are calculated by an *OUTPUT*S element module.

1.3.2 Time-average inventory

This KPI is a time-persistent statistics. Arena (*DSTAT* element module) collects values of an inventory level at a particular time and averages them by run length as shown in Equation (4):

$$\frac{\int_0^t I(t)dt}{t}, \tag{4}$$

where $I(t)$ is an inventory level at time $t$.

1.3.3 Average time in system of goods

This KPI is a tally statistics. First, the total amount of time all goods spend in the system are recorded and then an average is computed by dividing this sum by the number of goods. The average time in system can be obtained by using *TALLIES* element in order to gain time interval each goods spends in the system, and then this module automatically calculates the average time in system of goods.

1.3.4 Stock-out fraction of time

It is the fraction of time that inventory on-hand is not enough to meet demands.

1.3.5 Fraction of lost sales

It is the proportion of the total number of goods demanded that are lost by stock-out to the total number of goods demanded.

## 2. Experimental design

We explain our simulation setup in Section 2.1 and design of experiments in Section 2.2.

2.1 Simulation setup: before running simulation experiments, we have to decide on many issues, such as the simulation type, run time unit, warm-up periods, run lengths.

2.1.1 *Simulation type:* the model is non-terminating or steady-state because there is no obvious starting or stopping conditions. It is run for a long period of time to make sure that it is sufficiently close to steady state.

2.1.2 *Warm-up period:* it is the amount of time at the beginning of each replication that is eliminated or discarded in order to reduce the initial-condition bias.

In our study, the warm-up periods are obtained by plotting time in system of goods of every party by using Arena's Output Analyzer (see Figure 8). It can be observed that initial conditions affect time in system of goods only for the first 800 days, so we consider the warm-up periods for 850 days.

2.1.3 *Run time unit:* it is in days.

2.1.4 *Run length:* it has to be long enough to make sure that the system is close to steady state, and initial conditions do not significantly affect outputs. There is no exact way to determine run length, but the rule of thumb is to run for ten

times the length of the warm-up periods (Law and Kelton, 2000). Hence, the run length for our study is 8,500 days.

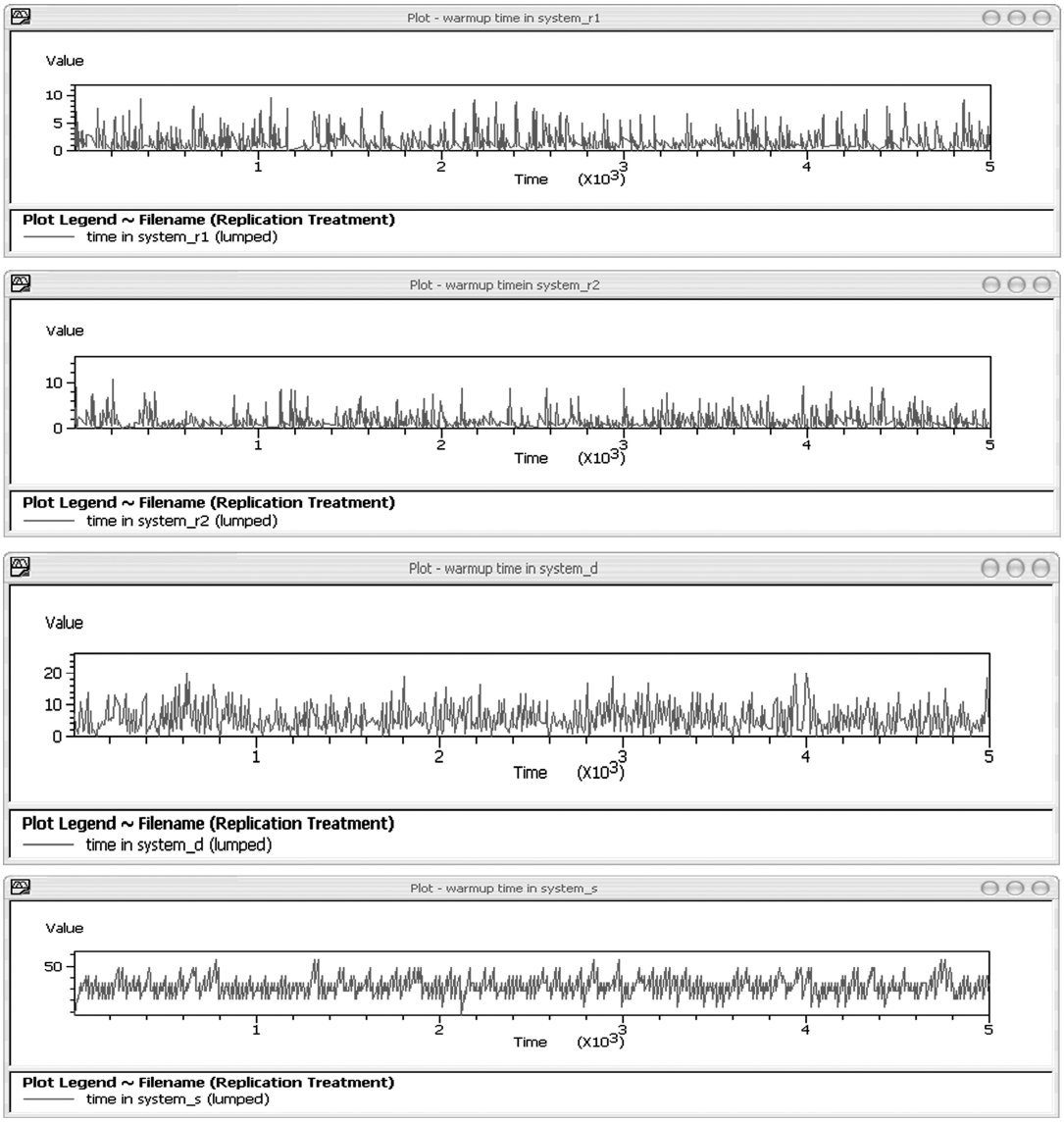


Figure 8 Plots of time in system of goods.

## 2.2 Design of experiments

We consider six factors: mean of demand (A), standard deviation of demand (B), mean of lead time (C), standard deviation of lead time (D), time between reviews (E), and multiple of lot sizes (F). Their low and high values are shown in the Table 3.

Table 3 Factor levels in the $2^6$ design.

| **Factors** | **Low (-)** | **High (+)** |
|---|---|---|
| Mean of demand, A (units of goods) | 1 | 4 |
| Standard deviation of demand, B (units of goods) | 0.5 | 3 |
| Mean of lead time, C, (days) | 1 | 4 |
| Standard deviation of lead time, D (days) | 0.5 | 2 |
| Time between inventory reviews, E (days) | 3 | 7 |
| Multiple of lot sizes, F | 1 | 6 |

We use the $2^6$ factorial design, resulting in 64 combinations, each of which we obtain ten replicates. Hence, there are 640 replications needed, and the results are shown in the Appendix A.

We analyze our factorial experiments as follows (Montgomery, 2005):

1. Estimate factor effects

We use a normal probability plot of effects to determine the important effects. Important effects are larger and further from the normal line than unimportant effects are. Unimportant effects tend to be small and centered around zero.

2. Formulate the model

Even though we plot the normality of effects, we also have to analyze factorial design with all interaction effects because each experiment applies ten replicates, not a single replicate. The results are used in the next step to find the highest levels of interaction effects that should be included in the model. The full-model with all main effects and interactions effects is shown below:

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_{23456} X_{23456} + \beta_{123456} X_{123456} + \varepsilon,$$

where $\varepsilon \sim \text{Norm}(0, \sigma^2)$.

3. Statistical test (ANOVA)

The ANOVA tests, one at a time, if each level of interaction should be in the model. Hypotheses for every level of interaction are shown below. If p-value for which interaction effects is less than our type-I error, $\alpha$ (set to 0.05 in this study), we reject the null hypothesis and conclude that interaction effects at that level are statistically significant and should be in the model. Minitab usually provides the results that consider up to the highest level of interaction effects including its p-value.

For main effects,

$$H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$$
$$H_1 : \text{at least one } \beta_i \neq 0, i = 1, 2, ..., 6.$$

For two-way interaction effects,

$$H_0 : \beta_{12} = \beta_{13} = \beta_{14} = ... = \beta_{56} = 0$$
$$H_1\text{: at least one } \beta_{ij} \neq 0, i \neq j \text{ and } i, j \in = \{1, 2, ..., 6\}.$$

For three-way interaction effects,

$$H_0 : \beta_{123} = \beta_{124} = \beta_{125} = ... = \beta_{456} = 0$$
$$H_1\text{: at least one } \beta_{ijk} \neq 0, i \neq j \neq k \text{ and } i, j, k \in = \{1, 2, ..., 6\}.$$

For four-way interaction effects,

$$H_0 : \beta_{1234} = \beta_{1245} = \beta_{1246} = ... = \beta_{3456} = 0$$
$$H_1\text{: at least one } \beta_{ijkl} \neq 0, i \neq j \neq k \neq l \text{ and } i, j, k, l \in = \{1, 2, ..., 6\}.$$

For five-way interaction effects,

$$H_0 : \beta_{12345} = \beta_{12456} = \beta_{12356} ... = \beta_{23456} = 0$$
$$H_1\text{: at least one } \beta_{ijklm} \neq 0, i \neq j \neq k \neq l \neq m \text{ and } i, j, k, l, m \in = \{1, 2, ..., 6\}.$$

For six-way interaction effects,

$$H_0 : \beta_{123456} = 0$$
$$H_1 : \beta_{123456} \neq 0, i \neq j \neq k \neq l \neq m \neq n \text{ and } i, j, k, l, m, n \in \{1, 2, 3, 4, 5, 6\}.$$

4. Refine the model

After performing ANOVA test, we fit a regression model that includes only significant effects and obtain a new regression model.

5. Analyze residuals

The residual, $e_i$, is the difference between the fitted values ($\hat{y}_i$) and the actual values ($y_i$) as shown below:

$$e_i = y_i - \hat{y}_i.$$

.

We perform residual analysis to examine if the assumptions of the error terms in the regression model—there are two important things: normality and constant variance—are satisfied. Our study uses the normality plot of residuals and the plot of residuals against fitted values.

6. Interpret the results

We interpret the suggested model from Minitab about the important main effects, two-way interaction effects and three-way interaction effects.

## RESULTS AND DISCUSSION

After we perform the factorial design experiments and analyze simulation outputs using Minitab, the results for each factor combination are shown in Appendix A, whereas the detailed results for each KPI are shown in Appendix B. In this section, we summarize our findings for each KPI.

### The Bullwhip Effect Index ( $KPI_1$ )

The estimates of factor effects can be obtained from a normal probability plot of effects. In Figure 9, we see that some higher-interaction effects, three-way interaction effects, four-way interaction effects and five-way interaction effects contribute significantly to the BWI (as defined in Equation (1)), not only main effects and two-way interaction effects. For example, ABE and CDE are three-way interaction effects that are statistically significant to the BWI.

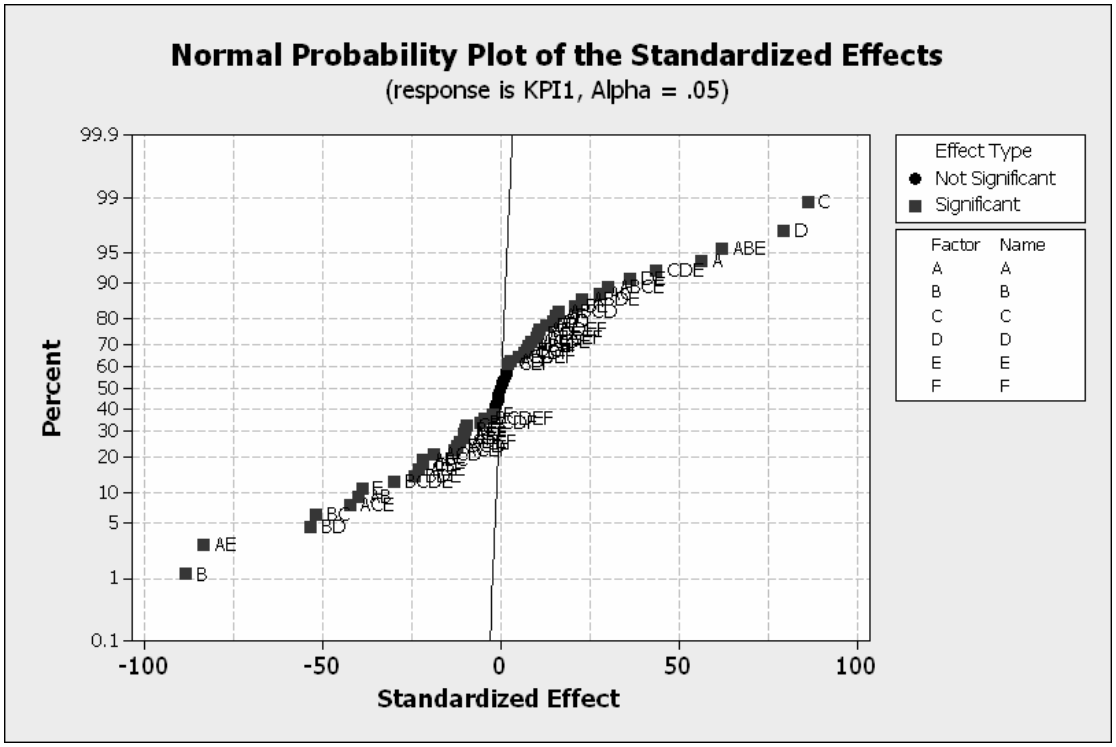


Figure 9 Normal probability plot of the standardized effects for $KPI_1$.

Using the type-I error, $\alpha = 0.05$, the ANOVA table (Figure 10) shows that the main effects, two-way interaction effects, three-way interaction effects, four-way interaction effects, and five-way interaction effects are statistically significant (p-value less than $\alpha$), and they should be included in the model.

Analysis of Variance for KPI1 (coded units)

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 6 | 119259 | 127196 | 21199.3 | 8762.19 | 0.000 |
| 2-Way Interactions | 15 | 82471 | 70473 | 4698.2 | 1941.87 | 0.000 |
| 3-Way Interactions | 20 | 50968 | 49763 | 2488.2 | 1028.42 | 0.000 |
| 4-Way Interactions | 15 | 9110 | 9212 | 614.1 | 253.82 | 0.000 |
| 5-Way Interactions | 5 | 580 | 580 | 115.9 | 47.92 | 0.000 |
| Residual Error | 529 | 1280 | 1280 | 2.4 | | |
| Pure Error | 529 | 1280 | 1280 | 2.4 | | |
| Total | 590 | 263668 | | | | |

Figure 10 ANOVA table for $KPI_1$.

After identifying the significant effects in the ANOVA table, we consider the estimated effects and coefficient table (shown in Appendix B). All significant terms have their p-values less than $\alpha$. Therefore, BWI is affected by four five-way interaction effects, nine four-way interaction effects, fifteen three-way interaction effects, thirteen two-way interaction effects, and six main effects.

After ANOVA, we fit another regression model including only significant effects, and the model becomes:

$$\begin{aligned} KPI_1 = & - 10.0 - 14.5\,A + 14.8\,B + 1.71\,C + 9.54\,D + 0.458\,E - 2.55\,F - 0.043\,A*B \\ & + 14.0\,A*C + 10.2\,A*D + 2.59\,A*E + 1.79\,A*F - 1.60\,B*C - 9.76\,B*D \\ & - 1.77\,B*E - 7.85\,C*D - 0.511\,C*E - 0.849\,C*F - 0.543\,D*E + 0.502\,E*F \\ & - 3.27\,A*B*C - 0.171\,A*B*E - 0.369\,A*B*F - 2.30\,A*C*D - 2.13\,A*C*E \\ & - 1.70\,A*D*E - 0.335\,A*E*F + 3.39\,B*C*D + 0.259\,B*C*E + 0.249\,B*C*F \\ & + 1.18\,B*D*E - 0.0546\,B*E*F + 2.56\,C*D*E - 0.366\,C*D*F + 0.0416\,C*E*F \\ & + 0.0584\,A*B*C*D + 0.530\,A*B*C*E + 0.0792\,A*B*D*E + 0.0852\,A*B*E*F \\ & + 0.256\,A*C*D*E + 0.0189\,A*C*E*F + 0.0059\,A*D*E*F - 0.856\,B*C*D*E \\ & + 0.167\,B*C*D*F + 0.0877\,C*D*E*F - 0.00948\,A*B*C*E*F - 0.00167\,A*B*D*E*F \\ & - 0.0377\,B*C*D*E*F + \varepsilon, \end{aligned} \tag{5}$$

where $\varepsilon$ is independent and identically distributed (i.i.d.) normally distributed, and its variance estimate is the mean square error of 12. The coefficient of determination ($R^2$) shows that how the regression model (Equation (5)) can explain 97.5% of the variability in BWI. The $R^2_{adj}$, which it is the modification of $R^2$, but it increases only if a new term added to the old model improves the model, is 97.3%.

From Equation (5), factors A, B and D are three main effects that are very important to the magnitude of the BWE. Interactions between factors A-C, A-D, B-D, and C-D are important two-way interaction effects. For three-way interaction effects, combinations between factors A-B-C and B-C-D are the most important.

To verify the assumption of i.i.d. normal errors $\varepsilon$ in Equation (5), we perform residual analysis (Figure 11). Normal probability plot and the histogram of residuals show that residuals are normally distributed. The plot of residuals vs. fits and the

time-series plot of residuals confirm that residuals are random with constant variances.

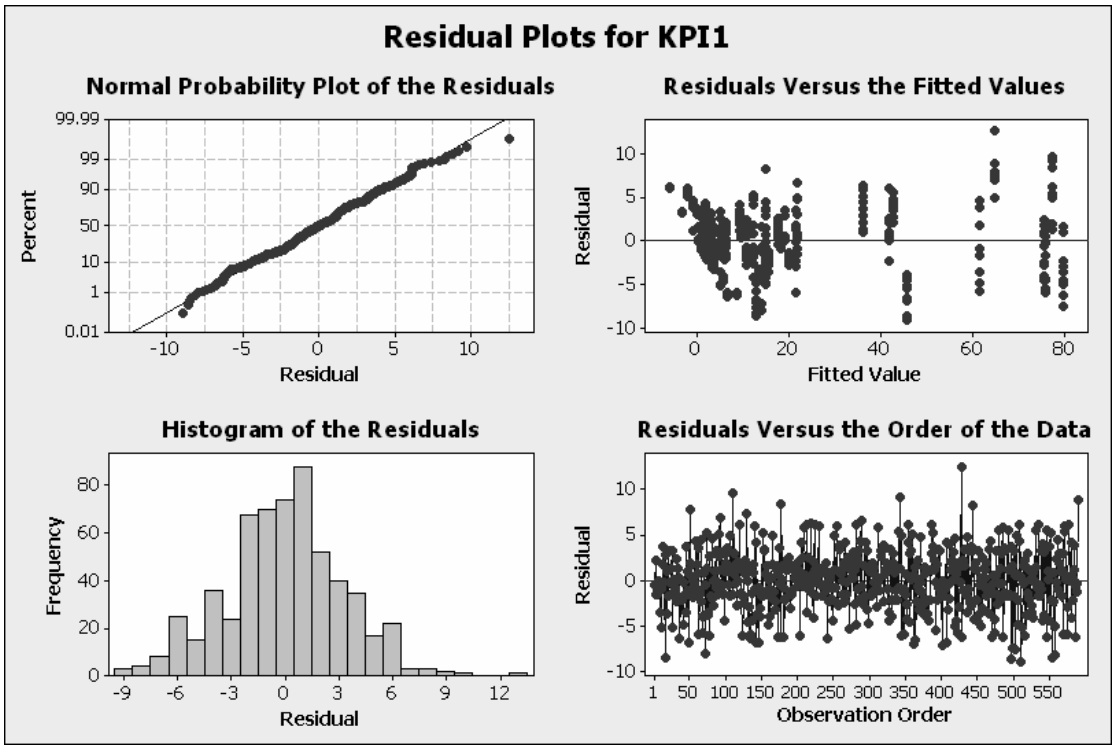


Figure 11 Residual plots for $KPI_1$.

## Time-average Inventory ($KPI_2$)

The estimates of effects can be obtained from a normal probability plot of effects. In Figure 12, we see that there are both main effects and interaction effects that contribute significantly to the time-average inventory. For example, factors A, E and F are the highest main effect, and combinations between factors A-E and E-F are the highest for two-way interaction effects.

Using the type-I error, $\alpha = 0.05$, the ANOVA table (Figure 13) shows that the main effects, two-way interaction effects, three-way interaction effects, four-way interaction effects, and five-way interaction effects are statistically significant (p-value less than $\alpha$), and they should be included in the model.

After identifying the significant effects in the ANOVA table, we consider the estimated effects and coefficient table (shown in Appendix B). All significant terms have their p-values less than $\alpha$. Therefore, time-average inventory is affected by four five-way interaction effects, nine four-way interaction effects, fifteen three-way interaction effects, thirteen two-way interaction effects, and six main effects.

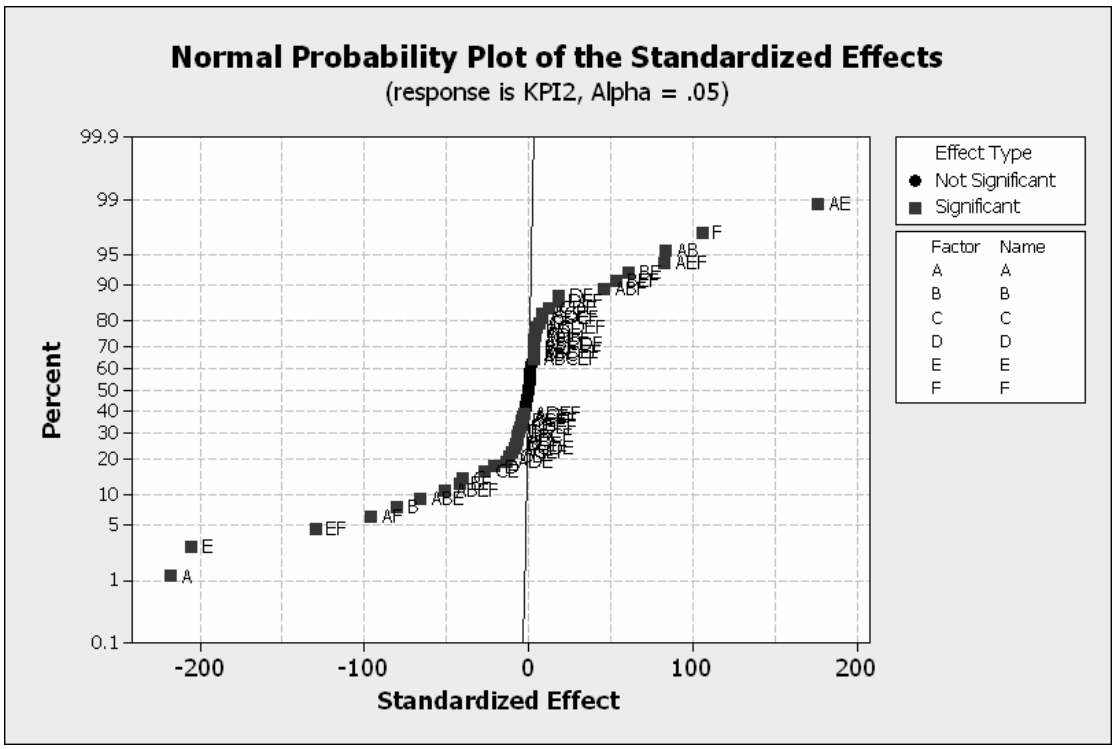


Figure 12 Normal probability plot of the standardized effects for $KPI_2$.

Analysis of Variance for KPI2 (coded units)

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 6 | 106157 | 77935.3 | 12989.2 | 29355.55 | 0.000 |
| 2-Way Interactions | 15 | 62534 | 55958.8 | 3730.6 | 8431.11 | 0.000 |
| 3-Way Interactions | 20 | 15446 | 14203.8 | 710.2 | 1605.03 | 0.000 |
| 4-Way Interactions | 15 | 2215 | 2203.5 | 146.9 | 332.00 | 0.000 |
| 5-Way Interactions | 5 | 40 | 39.8 | 8.0 | 18.00 | 0.000 |
| Residual Error | 532 | 235 | 235.4 | 0.4 | | |
| Pure Error | 532 | 235 | 235.4 | 0.4 | | |
| Total | 593 | 186626 | | | | |

Figure 13 ANOVA table for $KPI_2$.

After ANOVA, we fit another regression model including only significant effects, and the model becomes:

$$
\begin{aligned}
KPI_2 = {} & 97.9 - 7.58\,A - 1.08\,B + 1.99\,C + 2.68\,D - 0.457\,E + 26.0\,F + 0.301\,A*B \\
& + 0.669\,A*D + 1.07\,A*E - 6.13\,A*F + 0.506\,B*D - 0.193\,B*E - 5.92\,B*F \\
& - 1.49\,C*D - 0.646\,C*E - 0.262\,C*F - 0.925\,D*E - 0.842\,D*F - 3.93\,E*F \\
& - 0.0050\,A*B*C + 0.0072\,A*B*E + 1.50\,A*B*F + 0.0260\,A*C*E + 0.156\,A*C*F \\
& - 0.160\,A*D*E + 0.159\,A*D*F + 0.864\,A*E*F + 0.0808\,B*C*F + 0.0486\,B*D*F \\
& + 0.903\,B*E*F + 0.311\,C*D*E + 0.0530\,C*E*F + 0.268\,D*E*F - 0.0187\,A*B*C*F \\
& - 0.0308\,A*B*D*F - 0.222\,A*B*E*F - 0.0343\,A*C*D*E - 0.0278\,A*C*E*F \\
& - 0.0322\,A*D*E*F - 0.0120\,B*C*E*F - 0.0344\,B*D*E*F - 0.00906\,C*D*E*F \\
& - 0.00264\,A*B*C*D*F + 0.00349\,A*B*C*E*F + 0.00880\,A*B*D*E*F \\
& + 0.00529\,A*C*D*E*F + \varepsilon
\end{aligned}
\qquad (6)
$$

where $\varepsilon$ is i.i.d. normally distributed, and its variance estimate is the mean square error of 0.9. The $R^2$ shows that how the regression model (Equation (6)) can explain 99.7% of the variability in time-average inventory. The $R^2_{adj}$ is the same at 99.7%.

From the Equation (6), factors A and F are two main effects that are very important to the magnitude of the time-average inventory. Interactions between factors A-F, B-F and E-F are important two-way interaction effects. For three-way interaction effects, a combination between factors A-B-F is the most important.

To verify the assumption of i.i.d. normal errors $\varepsilon$ in Equation (6), we perform residual analysis (Figure 14). Normal probability plot and the histogram of residuals show that residuals are normally distributed. The plot of residuals vs. fits and the time-series plot of residuals confirm that residuals are random with constant variances.

## Average Time in System of Goods ($KPI_3$)

Before we analyze factorial design for this KPI, we have to transform it by taking natural logarithm to the $KPI_3$ ($\ln KPI_3$). The estimates of effects can be obtained from a normal probability plot of effects. In Figure 15, we see that there are both main effects and interaction effects that contribute significantly to the average time in system of goods. For example, factors E and A are the highest effect and combinations between factors A-E and A-B are the highest for two-way interaction effects.

Using the type-I error, $\alpha = 0.05$, the ANOVA table (Figure 16) shows that the main effects, two-way interaction effects, three-way interaction effects, four-way interaction effects, and five-way interaction effects are statistically significant (p-value less than $\alpha$), and they should be included in the model.

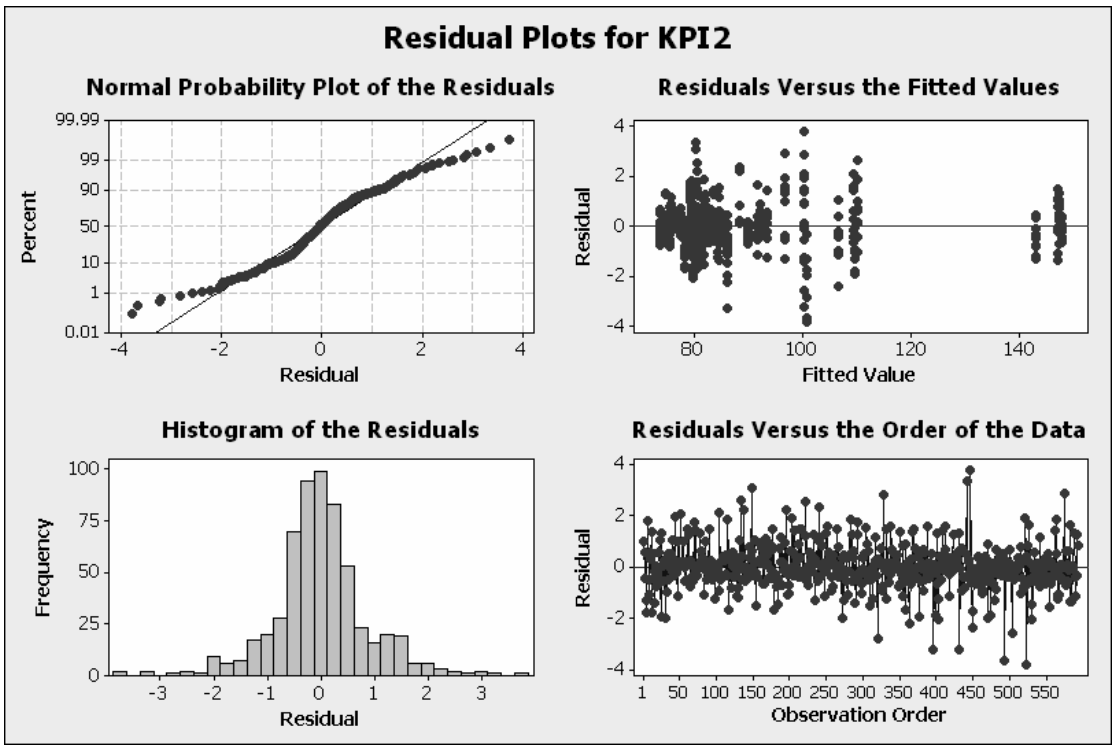


Figure 14 Residual plots for $KPI_2$.

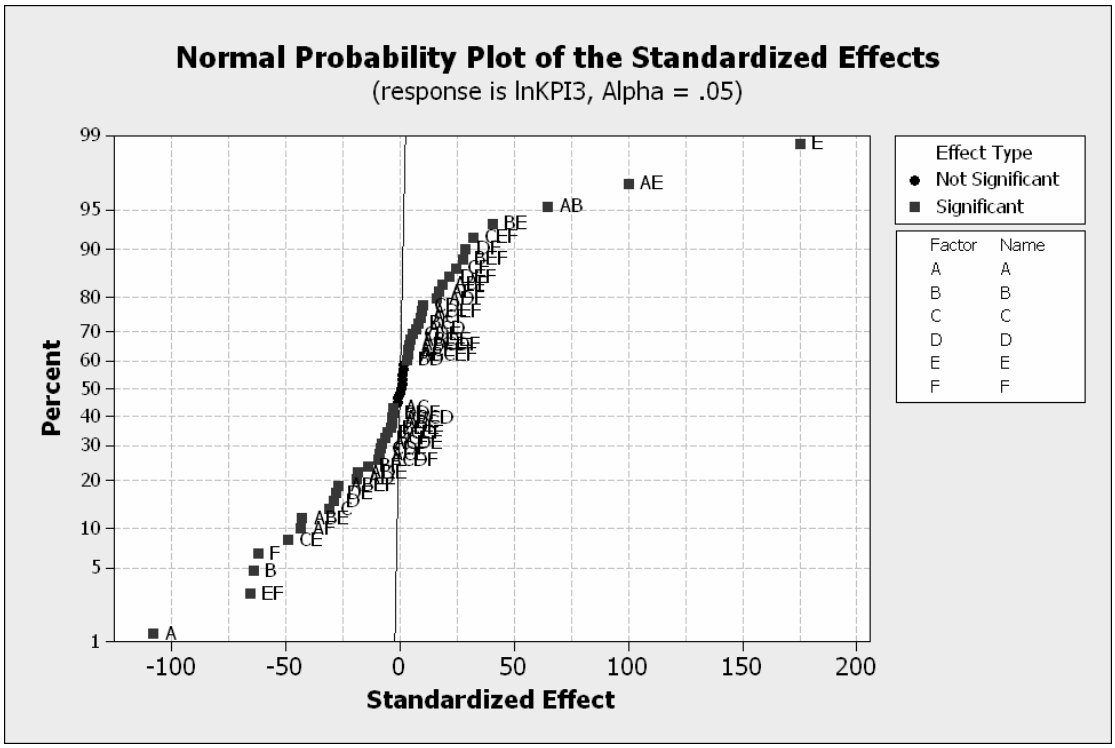


Figure 15 Normal probability plot of the standardized effects for $KPI_3$.

Analysis of Variance for lnKPI3 (coded units)

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 6 | 52.3541 | 25.0563 | 4.17604 | 12171.33 | 0.000 |
| 2-Way Interactions | 15 | 18.3843 | 10.3471 | 0.68981 | 2010.48 | 0.000 |
| 3-Way Interactions | 20 | 3.9147 | 3.2352 | 0.16176 | 471.45 | 0.000 |
| 4-Way Interactions | 13 | 0.5699 | 0.5797 | 0.04459 | 129.96 | 0.000 |
| 5-Way Interactions | 3 | 0.0179 | 0.0179 | 0.00595 | 17.34 | 0.000 |
| Residual Error | 499 | 0.1712 | 0.1712 | 0.00034 | | |
| Pure Error | 499 | 0.1712 | 0.1712 | 0.00034 | | |
| Total | 556 | 75.4121 | | | | |

Figure 16 ANOVA table for $KPI_3$.

After identifying the significant effects in the ANOVA table, we consider the estimated effects and coefficient table (shown in Appendix B). All significant terms have their p-values less than $\alpha$. Therefore, average time in system of goods is affected by two five-way interaction effects, eight four-way interaction effects, seventeen three-way interaction effects, fifteen two-way interaction effects, and six main effects.

After ANOVA, we fit another regression model including only significant effects, and the model becomes:

$$\begin{aligned}\ln KPI_3 = {} & 3.34 - 0.314\,A - 0.182\,B + 0.139\,C + 0.122\,D + 0.194\,E + 0.343\,F \\ & + 0.0327\,A*B - 0.0199\,A*C - 0.0118\,A*D + 0.0692\,A*E - 0.0721\,A*F \\ & + 0.0136\,B*C + 0.0273\,B*D + 0.00778\,B*E - 0.0742\,B*F - 0.0535\,C*D \\ & - 0.0353\,C*E - 0.0170\,C*F - 0.0243\,D*E - 0.0135\,D*F - 0.0649\,E*F \\ & - 0.000280\,A*B*C - 0.00137\,A*B*E + 0.0198\,A*B*F + 0.0270\,A*C*D \\ & - 0.000576\,A*C*E + 0.00276\,A*C*F - 0.0154\,A*D*E + 0.00181\,A*D*F \\ & + 0.00515\,A*E*F - 0.00101\,B*C*F - 0.00333\,B*D*E - 0.00243\,B*D*F \\ & + 0.0133\,B*E*F + 0.00865\,C*D*E + 0.00253\,C*D*F + 0.00392\,C*E*F \\ & + 0.00281\,D*E*F - 0.00138\,A*B*C*D + 0.000450\,A*B*D*E - 0.00326\,A*B*E*F \\ & - 0.00248\,A*C*D*E - 0.00261\,A*C*D*F + 0.000390\,A*C*E*F \\ & + 0.00245\,A*D*E*F - 0.000178\,B*C*E*F + 0.000189\,A*B*C*D*F \\ & + 0.000000\,A*B*C*E*F + \varepsilon \end{aligned} \tag{7}$$

where $\varepsilon$ is i.i.d. normally distributed, and its variance estimate is the mean square error of 0.0004. The $R^2$ shows that how the regression model (Equation (7)) can explain 99.7% of the variability in average time in system of goods. The $R^2_{adj}$ is the same at 99.7%.

From the Equation (7), factors A and F are two main effects that are very important to the magnitude of average time in system of goods. Interactions between factors A-E, A-F and E-F are important two-way interaction effects. For three-way interaction effects, a combination between factors A-C-D is the most important.

To verify the assumption of i.i.d. normal errors $\varepsilon$ in Equation (7), we perform residual analysis (Figure 17). Normal probability plot and the histogram of residuals show that residuals are normally distributed. The plot of residuals vs. fits and the time-series plot of residuals confirm that residuals are random with constant variances, even though it slightly has some patterns.

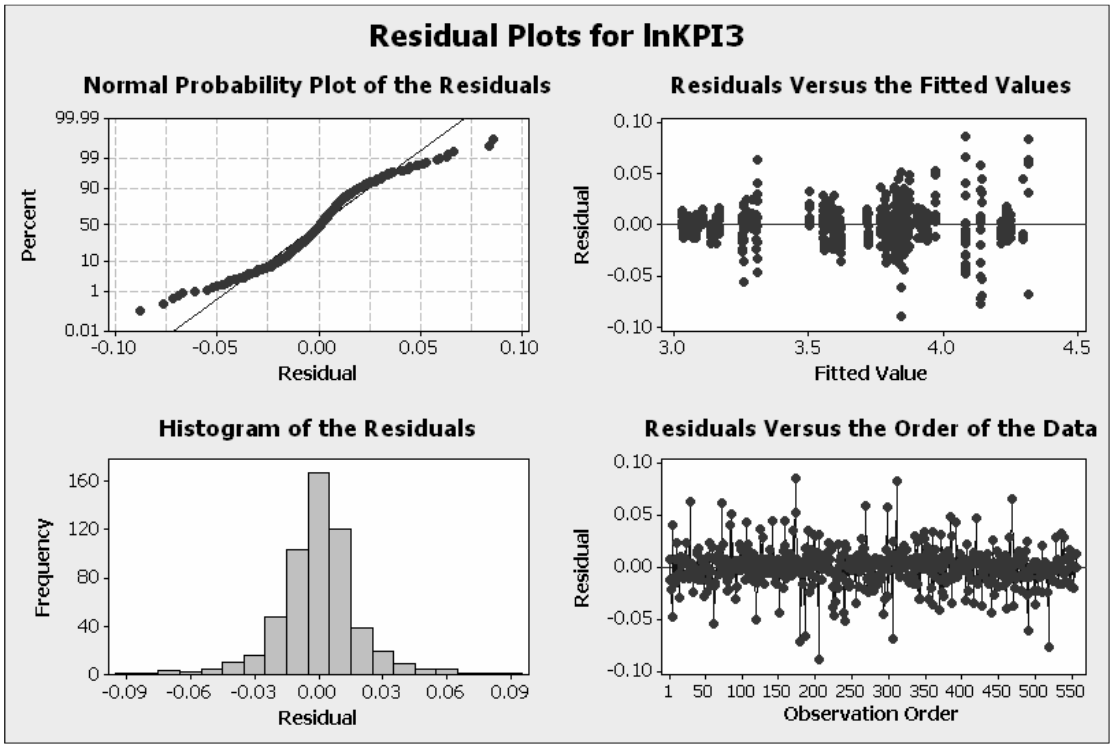


Figure 17 Residual plots for $KPI_3$.

## Stock-out Fraction of Time ($KPI_4$)

The estimates of effects can be obtained from a normal probability plot of effects. In Figure 18, we see that there are both main effects and interaction effects that contribute significantly to the stock-out fraction of time. For example, factors A, E and F are the highest main effects. The combination between factors A-E and A-B are the highest for two-way interaction effects.

Using the type-I error, $\alpha = 0.05$, the ANOVA table (Figure 19) shows that the main effects, two-way interaction effects, three-way interaction effects, four-way interaction effects, and five-way interaction effects are statistically significant (p-value less than $\alpha$), and they should be included in the model.

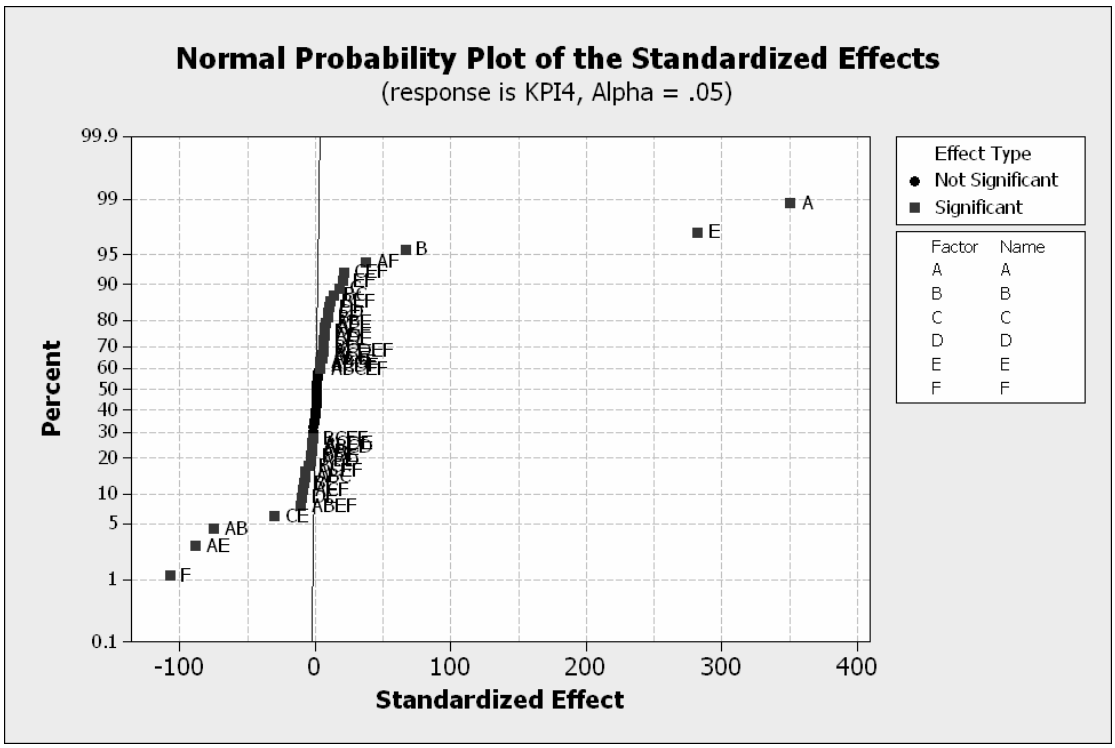


Figure 18 Normal probability plot of the standardized effects for $KPI_4$.

Analysis of Variance for KPI4 (coded units)

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 6 | 34.7782 | 34.6485 | 5.77474 | 74988.55 | 0.000 |
| 2-Way Interactions | 15 | 2.4884 | 2.4647 | 0.16431 | 2133.72 | 0.000 |
| 3-Way Interactions | 20 | 0.0888 | 0.0841 | 0.00421 | 54.64 | 0.000 |
| 4-Way Interactions | 15 | 0.0290 | 0.0297 | 0.00198 | 25.72 | 0.000 |
| 5-Way Interactions | 5 | 0.0055 | 0.0055 | 0.00110 | 14.33 | 0.000 |
| Residual Error | 549 | 0.0423 | 0.0423 | 0.00008 | | |
| Pure Error | 549 | 0.0423 | 0.0423 | 0.00008 | | |
| Total | 610 | 37.4322 | | | | |

Figure 19 ANOVA table for $KPI_4$.

After identifying the significant effects in the ANOVA table, we consider the estimated effects and coefficient table (shown in Appendix B). All significant terms have their p-values less than $\alpha$. Therefore, stock-out fraction of time is affected by three five-way interaction effects, seven four-way interaction effects, thirteen three-way interaction effects, fourteen two-way interaction effects, and six main effects.

After ANOVA, we fit another regression model including only significant effects, and the model becomes:

$$
\begin{aligned}
KPI_4 = &- 0.432 + 0.207\ A + 0.0800\ B + 0.0280\ C + 0.0153\ D + 0.147\ E - 0.0334\ F \\
&- 0.0242\ A*B + 0.00625\ A*C - 0.00045\ A*D - 0.0189\ A*E + 0.00801\ A*F \\
&+ 0.0102\ B*C + 0.0105\ B*D - 0.00827\ B*E - 0.00169\ B*F - 0.00142\ C*D \\
&- 0.0106\ C*E - 0.00786\ D*E - 0.00142\ D*F - 0.00288\ E*F - 0.00182\ A*B*C \\
&- 0.000646\ A*B*D + 0.00211\ A*B*E + 0.000189\ A*B*F + 0.000244\ A*C*E \\
&- 0.00201\ A*C*F + 0.000737\ A*D*E - 0.00199\ B*C*F - 0.00101\ B*D*E \\
&+ 0.00128\ B*E*F + 0.000936\ C*D*E + 0.000782\ C*E*F + 0.000583\ D*E*F \\
&- 0.000165\ A*B*C*D + 0.000568\ A*B*C*F - 0.000199\ A*B*E*F \\
&- 0.000013\ A*C*D*E + 0.000047\ A*C*D*F + 0.000136\ A*C*E*F \\
&+ 0.000167\ B*C*E*F - 0.000066\ A*B*C*E*F + 0.000014\ A*C*D*E*F + \varepsilon
\end{aligned}
\tag{8}
$$

where $\varepsilon$ is i.i.d. normally distributed, and its variance estimate is the mean square error of 0.00012. The $R^2$ shows that how the regression model (Equation (8)) can explain 99.8% of the variability in stock-out fraction of time. The $R^2_{adj}$ is the same at 99.8%.

From the Equation (8), a Factor A is the main effects that are very important to the magnitude of the stock-out fraction of time. Interactions between factors A-B and A-E are important two-way interaction effects. For three-way interaction effects, there are very small coefficient values, so we do not consider three-way interaction effects to five-way interaction effects.

To verify the assumption of i.i.d. normal errors $\varepsilon$ in Equation (8), we perform residual analysis (Figure 20). Normal probability plot and the histogram of residuals show that residuals are normally distributed. The plot of residuals vs. fits and the time-series plot of residuals confirm that residuals are random with constant variances.

## Fraction of Lost Sales ($KPI_5$)

Before we analyzed factorial design for this KPI, we had to transform it by taking natural logarithm to the $KPI_5$ ($\ln KPI_5$). The estimates of effects can be obtained from a normal probability plot of effects. In Figure 21, we see that there are both main effects and interaction effects that contribute to the fraction of lost sales. The factors A, E, F and B are the highest main effects. The combination between factors A-E, A-B and B-E are the highest for two-way interaction effects.

Using the type-I error, $\alpha = 0.05$, the ANOVA table (Figure 22) shows that the main effects, two- way interaction effects, three-way interaction effects, four-way interaction effects, and five-way interaction effects are statistically significant (p-value less than $\alpha$), and they should be included in the model.

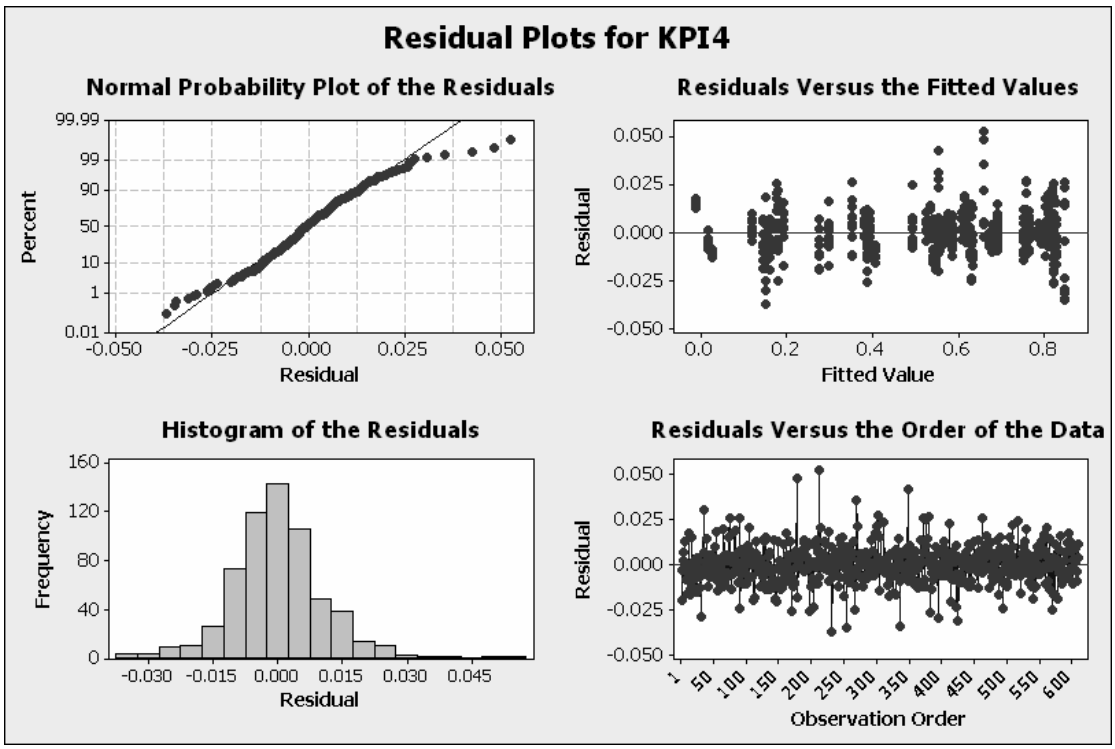


Figure 20 Residual plots for $KPI_4$.

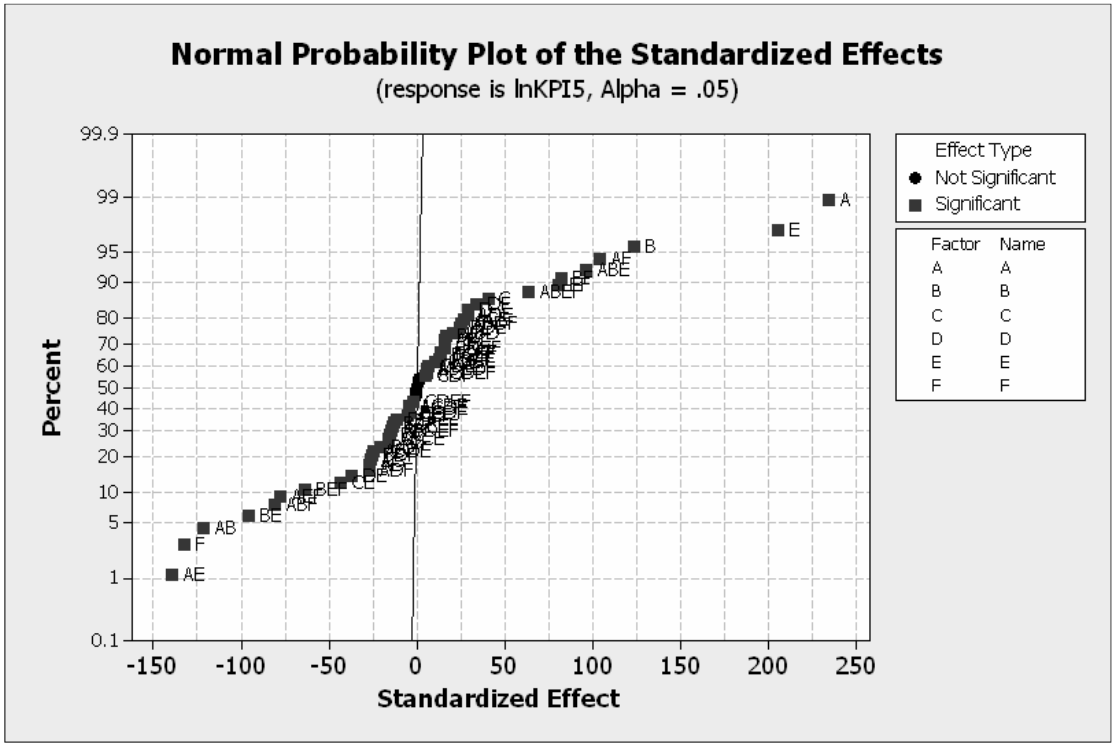


Figure 21 Normal probability plot of the standardized effects for $KPI_5$.

Analysis of Variance for lnKPI5 (coded units)

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 6 | 257.988 | 211.218 | 35.2030 | 21095.29 | 0.000 |
| 2-Way Interactions | 15 | 126.230 | 140.962 | 9.3975 | 5631.42 | 0.000 |
| 3-Way Interactions | 20 | 66.242 | 71.153 | 3.5576 | 2131.90 | 0.000 |
| 4-Way Interactions | 15 | 18.028 | 18.339 | 1.2226 | 732.64 | 0.000 |
| 5-Way Interactions | 6 | 1.507 | 1.507 | 0.2512 | 150.53 | 0.000 |
| Residual Error | 548 | 0.914 | 0.914 | 0.0017 | | |
| Pure Error | 548 | 0.914 | 0.914 | 0.0017 | | |
| Total | 610 | 470.909 | | | | |

Figure 22 ANOVA table for $KPI_5$.

After identifying the significant effects in the ANOVA table, we consider the estimated effects and coefficient table (shown in Appendix B). All significant terms have their p-values less than $\alpha$. Therefore, fraction of lost sales is affected by four five-way interaction effects, thirteen four-way interaction effects, eighteen three-way interaction effects, fourteen two-way interaction effects, and six main effects.

After ANOVA, we fit another regression model including only significant effects, and the model becomes:

$$\begin{aligned}
\ln KPI_5 = & - 2.53 + 0.364\,A - 0.0303\,B + 0.185\,C + 0.0788\,D + 0.373\,E - 2.69\,F \\
& + 0.0048\,A*B - 0.0173\,A*C - 0.0070\,A*D - 0.0598\,A*E + 0.665\,A*F \\
& + 0.0367\,B*C + 0.0485\,B*D - 0.0163\,B*E + 0.844\,B*F - 0.0339\,C*E \\
& + 0.187\,C*F - 0.0741\,D*E + 0.498\,D*F + 0.345\,E*F - 0.00927\,A*B*C \\
& - 0.0101\,A*B*D + 0.00438\,A*B*E - 0.210\,A*B*F + 0.00402\,A*C*E \\
& - 0.0474\,A*C*F + 0.0157\,A*D*E - 0.121\,A*D*F - 0.0863\,A*E*F \\
& - 0.00516\,B*C*E - 0.0638\,B*C*F + 0.0102\,B*D*E - 0.160\,B*D*F \\
& - 0.112\,B*E*F - 0.00024\,C*D*E - 0.00258\,C*D*F - 0.0270\,C*E*F \\
& - 0.0599\,D*E*F + 0.00143\,A*B*C*E + 0.0159\,A*B*C*F - 0.00299\,A*B*D*E \\
& + 0.0396\,A*B*D*F + 0.0278\,A*B*E*F - 0.000240\,A*C*D*E - 0.00038\,A*C*D*F \\
& + 0.00684\,A*C*E*F + 0.0145\,A*D*E*F - 0.00193\,B*C*D*F + 0.00956\,B*C*E*F \\
& + 0.0196\,B*D*E*F + 0.00193\,C*D*E*F + 0.000481\,A*B*C*D*F \\
& - 0.00240\,A*B*C*E*F - 0.00483\,A*B*D*E*F - 0.000233\,A*C*D*E*F + \varepsilon
\end{aligned} \tag{9}$$

where $\varepsilon$ is i.i.d. normally distributed, and its variance estimate is the mean square error of 0.0024. The $R^2$ shows that how the regression model (Equation (9)) can explain 99.7% of the variability in stock-out fraction of time. The $R^2_{adj}$ is the same at 99.7%.

From the Equation (9), a Factor A is the main effects that are very important to the magnitude of the fraction of lost sales. A factor F is the most important main effect. Interactions between factors A-F, B-F and D-F are important two-way interaction effects. For three-way interaction effects, interactions between A-B-F, A-D-F, B-D-F, and B-E-F are important.

To verify the assumption of i.i.d. normal errors $\varepsilon$ in Equation (9), we perform residual analysis (Figure 23). Normal probability plot and the histogram of residuals show that residuals are normally distributed. The plot of residuals vs. fits and the time-series plot of residuals confirm that residuals are random with constant variances.

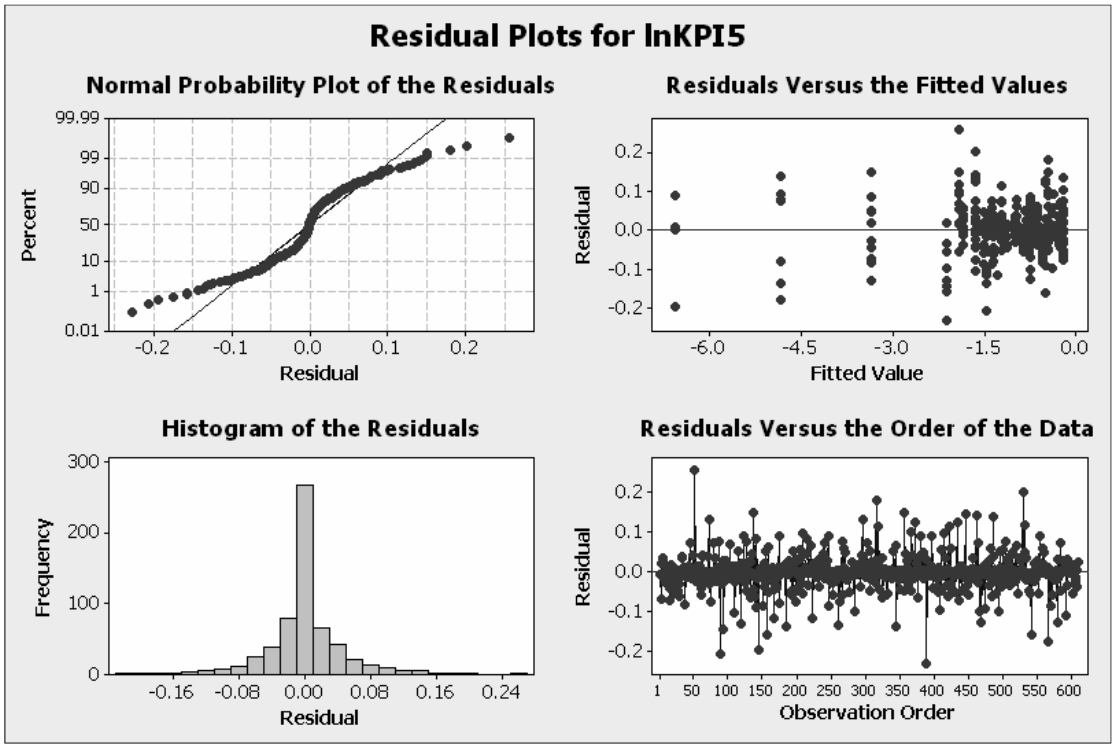


Figure 23 Residual plots for $KPI_5$.

# CONCLUSIONS

Our study focuses on six factors: mean of demands, standard deviation of demands, mean of lead times, standard deviation of lead times, time between inventory reviews, and multiple of lot sizes. The factorial experiments reveal that, in addition to the typical main effects and the two-way interaction effects, three-way interaction effects, four-way interaction effects, and five-way interaction effects are significant. This leads to reduction of importance of the main effect and two-way interaction effects, because when interaction effects are important, main effects may be not helpful. This may be because changing one important factor may affect another one or more factors to be changed at the same time.

We can summarize about how each factor affect to each KPI below.

1. The BWI increases when standard deviation of demands, mean of lead time, standard deviation of lead times, and time between inventory reviews are set at high levels, and mean of demands and multiple of lot sizes are set at low levels.
2. Time-average inventory increases when mean of lead times, standard deviation of lead times, and multiple of lot sizes are set at high levels, and mean of demands, standard deviation of demands, and time between inventory reviews are set at low levels.
3. Average time in system of goods increases when mean of lead times, standard deviation of lead times, time between inventory reviews, and multiple of lot sizes are set at high levels, and mean of demands and standard deviation of demands are set at low levels.
4. Stock-out fraction of time increases when all factors are set at high levels, except multiple of lot sizes.
5. Fraction of lost sales increases when mean of demands, mean of lead times, standard deviation of lead times, and time between inventory reviews are set at high levels, and standard deviation of demands and multiple of lot sizes are set at low levels.

Our study considers six factors and most common operations in a real-world SC. For future work, other important factors can be added to the system, and other operations and real-world SC performance measures can also be considered.

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# APPENDIX

**APPENDIX A**

# Simulation Outputs of 10 Replicated $2^6$ Factorial Design

Appendix A1 Results of simulation runs

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 231 | 1 | 1 | 3.0 | 4 | 0.5 | 3 | 6 | 5.4203 | 111.130 | 36.630 | 0.155950 | 0.222420 |
| 281 | 2 | 1 | 0.5 | 1 | 2.0 | 7 | 1 | 32.0340 | 84.006 | 68.570 | 0.533580 | 0.447090 |
| 371 | 3 | 1 | 3.0 | 1 | 0.5 | 7 | 6 | 3.6729 | 83.541 | 49.124 | 0.549480 | 0.477090 |
| 35 | 4 | 1 | 3.0 | 1 | 0.5 | 3 | 6 | 1.7574 | 107.740 | 34.460 | 0.121750 | 0.162710 |
| 413 | 5 | 1 | 0.5 | 4 | 2.0 | 7 | 1 | 59.9401 | 78.804 | 56.515 | 0.491060 | 0.429070 |
| 2 | 6 | 4 | 0.5 | 1 | 0.5 | 3 | 1 | 4.8789 | 81.309 | 28.527 | 0.627580 | 0.539830 |
| 49 | 7 | 1 | 0.5 | 1 | 0.5 | 7 | 6 | 0.6309 | 83.123 | 50.633 | 0.398340 | 0.294550 |
| 229 | 8 | 1 | 0.5 | 4 | 0.5 | 3 | 6 | 0.8867 | 145.910 | 68.655 | 0.012770 | 0.033490 |
| 213 | 9 | 1 | 0.5 | 4 | 0.5 | 7 | 1 | 17.0276 | 82.350 | 77.214 | 0.585070 | 0.492370 |
| 556 | 10 | 4 | 3.0 | 1 | 2.0 | 3 | 6 | 11.3154 | 84.503 | 21.928 | 0.551120 | 0.503800 |
| 241 | 11 | 1 | 0.5 | 1 | 0.5 | 7 | 6 | 1.3652 | 83.906 | 50.656 | 0.390680 | 0.290640 |
| 386 | 12 | 4 | 0.5 | 1 | 0.5 | 3 | 1 | 5.1996 | 80.847 | 28.047 | 0.631580 | 0.536000 |
| 405 | 13 | 1 | 0.5 | 4 | 0.5 | 7 | 1 | 0.0000 | 93.329 | 325.340 | 0.812520 | 0.828270 |
| 1 | 14 | 1 | 0.5 | 1 | 0.5 | 3 | 1 | 2.7783 | 101.450 | 52.728 | 0.203450 | 0.160100 |
| 70 | 15 | 4 | 0.5 | 4 | 0.5 | 3 | 1 | 77.8486 | 77.940 | 25.759 | 0.674210 | 0.625380 |
| 406 | 16 | 4 | 0.5 | 4 | 0.5 | 7 | 1 | 0.0000 | 82.384 | 72.586 | 0.812690 | 0.774560 |
| 226 | 17 | 4 | 0.5 | 1 | 0.5 | 3 | 6 | 4.2868 | 80.835 | 20.673 | 0.529650 | 0.441980 |
| 343 | 18 | 1 | 3.0 | 4 | 0.5 | 7 | 1 | 4.5945 | 78.116 | 57.659 | 0.622350 | 0.546010 |
| 538 | 19 | 4 | 0.5 | 1 | 2.0 | 7 | 1 | 19.0770 | 79.040 | 57.727 | 0.817320 | 0.749170 |
| 402 | 20 | 4 | 0.5 | 1 | 0.5 | 7 | 1 | 26.7307 | 86.964 | 100.130 | 0.864360 | 0.836350 |
| 183 | 21 | 1 | 3.0 | 4 | 0.5 | 7 | 6 | 4.6264 | 77.683 | 45.182 | 0.548850 | 0.478010 |
| 396 | 22 | 4 | 3.0 | 1 | 2.0 | 3 | 1 | 9.8605 | 80.420 | 24.005 | 0.609920 | 0.549750 |
| 118 | 23 | 4 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 74.404 | 44.168 | 0.749910 | 0.679780 |
| 572 | 24 | 4 | 3.0 | 1 | 2.0 | 7 | 6 | 4.4298 | 79.571 | 44.471 | 0.762190 | 0.691040 |
| 598 | 25 | 4 | 0.5 | 4 | 0.5 | 7 | 1 | 0.0000 | 82.393 | 72.593 | 0.814230 | 0.774580 |
| 549 | 26 | 1 | 0.5 | 4 | 0.5 | 3 | 6 | 0.7593 | 148.070 | 69.757 | 0.008130 | 0.020990 |
| 627 | 27 | 1 | 3.0 | 1 | 0.5 | 7 | 6 | 0.0183 | 82.392 | 50.025 | 0.526950 | 0.441580 |
| 198 | 28 | 4 | 0.5 | 4 | 0.5 | 3 | 1 | 77.3114 | 77.774 | 26.211 | 0.684740 | 0.634530 |
| 310 | 29 | 4 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 76.059 | 45.103 | 0.749910 | 0.680050 |
| 341 | 30 | 1 | 0.5 | 4 | 0.5 | 7 | 1 | 0.0142 | 88.922 | 207.760 | 0.765640 | 0.752990 |
| 52 | 31 | 4 | 3.0 | 1 | 0.5 | 7 | 6 | 3.0054 | 80.161 | 45.981 | 0.762360 | 0.695820 |
| 305 | 32 | 1 | 0.5 | 1 | 0.5 | 7 | 6 | 1.1052 | 83.685 | 51.058 | 0.393520 | 0.291800 |
| 551 | 33 | 1 | 3.0 | 4 | 0.5 | 3 | 6 | 5.1265 | 110.330 | 35.998 | 0.152040 | 0.213350 |
| 338 | 34 | 4 | 0.5 | 1 | 0.5 | 7 | 1 | 20.0588 | 82.757 | 67.654 | 0.819720 | 0.770440 |
| 536 | 35 | 4 | 3.0 | 4 | 0.5 | 7 | 1 | 2.3630 | 77.502 | 69.021 | 0.808010 | 0.788780 |
| 176 | 36 | 4 | 3.0 | 4 | 2.0 | 3 | 6 | 17.6707 | 83.457 | 22.874 | 0.582260 | 0.547290 |
| 6 | 37 | 4 | 0.5 | 4 | 0.5 | 3 | 1 | 78.3500 | 77.746 | 25.705 | 0.676750 | 0.626660 |
| 466 | 38 | 4 | 0.5 | 1 | 0.5 | 7 | 1 | 0.0763 | 89.101 | 125.290 | 0.844340 | 0.852990 |
| 153 | 39 | 1 | 0.5 | 1 | 2.0 | 7 | 1 | 19.3221 | 84.683 | 80.037 | 0.584200 | 0.495450 |
| 47 | 40 | 1 | 3.0 | 4 | 2.0 | 3 | 6 | 7.5775 | 105.600 | 35.799 | 0.197930 | 0.259040 |
| 166 | 41 | 4 | 0.5 | 4 | 0.5 | 3 | 6 | 68.3359 | 84.915 | 21.710 | 0.556720 | 0.518960 |
| 316 | 42 | 4 | 3.0 | 1 | 2.0 | 7 | 6 | 6.4031 | 79.261 | 43.108 | 0.763870 | 0.689920 |
| 233 | 43 | 1 | 0.5 | 1 | 2.0 | 3 | 6 | 0.3957 | 147.800 | 69.993 | 0.002850 | 0.007240 |
| 48 | 44 | 4 | 3.0 | 4 | 2.0 | 3 | 6 | 18.1376 | 83.452 | 23.032 | 0.581350 | 0.549850 |
| 304 | 45 | 4 | 3.0 | 4 | 2.0 | 3 | 6 | 17.9548 | 83.733 | 22.783 | 0.572750 | 0.542160 |
| 432 | 46 | 4 | 3.0 | 4 | 2.0 | 3 | 6 | 17.8759 | 83.168 | 22.959 | 0.587240 | 0.551930 |
| 172 | 47 | 4 | 3.0 | 1 | 2.0 | 3 | 6 | 10.0166 | 83.763 | 21.631 | 0.550550 | 0.502500 |
| 37 | 48 | 1 | 0.5 | 4 | 0.5 | 3 | 6 | 0.7311 | 148.020 | 70.299 | 0.008770 | 0.022140 |
| 244 | 49 | 4 | 3.0 | 1 | 0.5 | 7 | 6 | 1.3901 | 80.998 | 47.034 | 0.753230 | 0.691750 |
| 199 | 50 | 1 | 3.0 | 4 | 0.5 | 3 | 1 | 9.1442 | 91.422 | 36.921 | 0.358960 | 0.384200 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 261 | 51 | 1 | 0.5 | 4 | 0.5 | 3 | 1 | 18.5055 | 102.150 | 49.194 | 0.178510 | 0.207550 |
| 236 | 52 | 4 | 3.0 | 1 | 2.0 | 3 | 6 | 11.2797 | 84.028 | 21.686 | 0.548240 | 0.499580 |
| 330 | 53 | 4 | 0.5 | 1 | 2.0 | 3 | 1 | 37.1567 | 79.699 | 23.381 | 0.613200 | 0.538830 |
| 593 | 54 | 1 | 0.5 | 1 | 0.5 | 7 | 1 | 0.0000 | 85.762 | 76.371 | 0.562320 | 0.455320 |
| 510 | 55 | 4 | 0.5 | 4 | 2.0 | 7 | 6 | 38.8099 | 74.310 | 40.916 | 0.790760 | 0.702360 |
| 431 | 56 | 1 | 3.0 | 4 | 2.0 | 3 | 6 | 7.0142 | 105.410 | 36.158 | 0.201610 | 0.267320 |
| 573 | 57 | 1 | 0.5 | 4 | 2.0 | 7 | 6 | 72.7242 | 83.019 | 50.627 | 0.389820 | 0.377500 |
| 96 | 58 | 4 | 3.0 | 4 | 2.0 | 7 | 1 | 12.7483 | 73.682 | 47.747 | 0.810710 | 0.743810 |
| 329 | 59 | 1 | 0.5 | 1 | 2.0 | 3 | 1 | 13.8532 | 96.358 | 45.028 | 0.167240 | 0.191650 |
| 63 | 60 | 1 | 3.0 | 4 | 2.0 | 7 | 6 | 14.2539 | 79.593 | 46.941 | 0.566680 | 0.522060 |
| 581 | 61 | 1 | 0.5 | 4 | 0.5 | 3 | 1 | 14.7547 | 102.280 | 48.141 | 0.167090 | 0.188470 |
| 521 | 62 | 1 | 0.5 | 1 | 2.0 | 3 | 1 | 10.2494 | 100.500 | 46.350 | 0.134950 | 0.150650 |
| 208 | 63 | 4 | 3.0 | 4 | 2.0 | 3 | 1 | 17.7821 | 77.033 | 26.650 | 0.682690 | 0.635230 |
| 435 | 64 | 1 | 3.0 | 1 | 0.5 | 7 | 6 | 1.3241 | 83.175 | 50.233 | 0.545940 | 0.465360 |
| 452 | 65 | 4 | 3.0 | 1 | 0.5 | 3 | 1 | 3.4016 | 80.323 | 25.706 | 0.587710 | 0.523390 |
| 328 | 66 | 4 | 3.0 | 4 | 0.5 | 3 | 1 | 19.4297 | 78.928 | 26.966 | 0.671440 | 0.634600 |
| 177 | 67 | 1 | 0.5 | 1 | 0.5 | 7 | 6 | 2.2165 | 83.624 | 51.160 | 0.399990 | 0.303140 |
| 215 | 68 | 1 | 3.0 | 4 | 0.5 | 7 | 1 | 5.3755 | 77.800 | 58.359 | 0.625820 | 0.553710 |
| 377 | 69 | 1 | 0.5 | 1 | 2.0 | 7 | 6 | 15.6610 | 85.558 | 50.865 | 0.376520 | 0.312810 |
| 88 | 70 | 4 | 3.0 | 4 | 0.5 | 7 | 1 | 2.4604 | 81.641 | 104.560 | 0.830830 | 0.848860 |
| 163 | 71 | 1 | 3.0 | 1 | 0.5 | 3 | 6 | 1.8653 | 109.750 | 35.539 | 0.124550 | 0.163130 |
| 116 | 72 | 4 | 3.0 | 1 | 0.5 | 7 | 6 | 0.5826 | 80.797 | 47.196 | 0.749300 | 0.689030 |
| 516 | 73 | 4 | 3.0 | 1 | 0.5 | 3 | 1 | 3.6141 | 80.609 | 24.657 | 0.581140 | 0.511590 |
| 477 | 74 | 1 | 0.5 | 4 | 2.0 | 7 | 1 | 55.8153 | 79.373 | 58.226 | 0.496470 | 0.432540 |
| 638 | 75 | 4 | 0.5 | 4 | 2.0 | 7 | 6 | 41.6819 | 74.781 | 40.792 | 0.789300 | 0.699930 |
| 200 | 76 | 4 | 3.0 | 4 | 0.5 | 3 | 1 | 18.6757 | 78.871 | 26.516 | 0.666290 | 0.629920 |
| 250 | 77 | 4 | 0.5 | 1 | 2.0 | 7 | 6 | 13.2363 | 79.062 | 43.671 | 0.771320 | 0.687190 |
| 8 | 78 | 4 | 3.0 | 4 | 0.5 | 3 | 1 | 17.2473 | 78.960 | 26.463 | 0.667530 | 0.625210 |
| 282 | 79 | 4 | 0.5 | 1 | 2.0 | 7 | 1 | 6.1602 | 82.248 | 84.710 | 0.845270 | 0.810910 |
| 18 | 80 | 4 | 0.5 | 1 | 0.5 | 7 | 1 | 0.0000 | 96.077 | 335.960 | 0.875010 | 0.938490 |
| 531 | 81 | 1 | 3.0 | 1 | 0.5 | 7 | 1 | 2.6265 | 84.488 | 81.517 | 0.665860 | 0.625340 |
| 171 | 82 | 1 | 3.0 | 1 | 2.0 | 3 | 6 | 3.1426 | 110.860 | 36.633 | 0.131280 | 0.178650 |
| 76 | 83 | 4 | 3.0 | 1 | 2.0 | 3 | 1 | 10.0259 | 80.899 | 23.600 | 0.609190 | 0.541970 |
| 268 | 84 | 4 | 3.0 | 1 | 2.0 | 3 | 1 | 9.6902 | 80.812 | 24.041 | 0.609920 | 0.549950 |
| 234 | 85 | 4 | 0.5 | 1 | 2.0 | 3 | 6 | 45.4386 | 82.998 | 21.330 | 0.550830 | 0.495500 |
| 451 | 86 | 1 | 3.0 | 1 | 0.5 | 3 | 1 | 2.7010 | 92.185 | 33.885 | 0.271710 | 0.256660 |
| 340 | 87 | 4 | 3.0 | 1 | 0.5 | 7 | 1 | 0.0000 | 91.610 | 160.500 | 0.841570 | 0.884010 |
| 122 | 88 | 4 | 0.5 | 1 | 2.0 | 7 | 6 | 17.0591 | 79.312 | 43.398 | 0.771040 | 0.687480 |
| 194 | 89 | 4 | 0.5 | 1 | 0.5 | 3 | 1 | 4.0827 | 80.802 | 29.173 | 0.633250 | 0.548770 |
| 639 | 90 | 1 | 3.0 | 4 | 2.0 | 7 | 6 | 12.6860 | 79.538 | 46.741 | 0.564300 | 0.518570 |
| 220 | 91 | 4 | 3.0 | 1 | 2.0 | 7 | 1 | 5.0789 | 81.080 | 64.373 | 0.802480 | 0.768150 |
| 433 | 92 | 1 | 0.5 | 1 | 0.5 | 7 | 6 | 1.4779 | 83.859 | 51.093 | 0.397020 | 0.297870 |
| 398 | 93 | 4 | 0.5 | 4 | 2.0 | 3 | 1 | 80.8311 | 76.116 | 26.879 | 0.697110 | 0.645800 |
| 548 | 94 | 4 | 3.0 | 1 | 0.5 | 3 | 6 | 3.2121 | 82.163 | 20.904 | 0.527690 | 0.457750 |
| 327 | 95 | 1 | 3.0 | 4 | 0.5 | 3 | 1 | 10.0834 | 90.652 | 36.901 | 0.379960 | 0.408710 |
| 205 | 96 | 1 | 0.5 | 4 | 2.0 | 3 | 1 | 20.2754 | 97.691 | 45.016 | 0.155270 | 0.190040 |
| 485 | 97 | 1 | 0.5 | 4 | 0.5 | 3 | 6 | 0.6762 | 146.970 | 69.390 | 0.010500 | 0.026410 |
| 506 | 98 | 4 | 0.5 | 1 | 2.0 | 7 | 6 | 20.9653 | 78.895 | 42.427 | 0.773700 | 0.686480 |
| 535 | 99 | 1 | 3.0 | 4 | 0.5 | 7 | 1 | 4.4747 | 78.145 | 61.843 | 0.631620 | 0.569400 |
| 586 | 100 | 4 | 0.5 | 1 | 2.0 | 3 | 1 | 41.2823 | 79.656 | 23.368 | 0.616580 | 0.541240 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 317 | 101 | 1 | 0.5 | 4 | 2.0 | 7 | 6 | 71.7531 | 81.819 | 50.336 | 0.401130 | 0.387120 |
| 449 | 102 | 1 | 0.5 | 1 | 0.5 | 3 | 1 | 0.1666 | 102.620 | 49.129 | 0.140550 | 0.105780 |
| 284 | 103 | 4 | 3.0 | 1 | 2.0 | 7 | 1 | 4.6665 | 81.930 | 70.483 | 0.808960 | 0.784730 |
| 100 | 104 | 4 | 3.0 | 1 | 0.5 | 3 | 6 | 3.0173 | 81.919 | 20.696 | 0.522010 | 0.454140 |
| 575 | 105 | 1 | 3.0 | 4 | 2.0 | 7 | 6 | 13.8809 | 79.301 | 46.913 | 0.568300 | 0.521260 |
| 543 | 106 | 1 | 3.0 | 4 | 2.0 | 7 | 1 | 13.6412 | 77.653 | 53.251 | 0.616960 | 0.555510 |
| 498 | 107 | 4 | 0.5 | 1 | 0.5 | 7 | 6 | 8.9400 | 80.575 | 45.938 | 0.771070 | 0.691930 |
| 444 | 108 | 4 | 3.0 | 1 | 2.0 | 7 | 6 | 7.1858 | 79.257 | 42.813 | 0.769090 | 0.692760 |
| 370 | 109 | 4 | 0.5 | 1 | 0.5 | 7 | 6 | 20.3517 | 80.432 | 44.751 | 0.780740 | 0.695710 |
| 326 | 110 | 4 | 0.5 | 4 | 0.5 | 3 | 1 | 71.6529 | 78.469 | 26.017 | 0.673000 | 0.621370 |
| 602 | 111 | 4 | 0.5 | 1 | 2.0 | 7 | 1 | 1.1524 | 84.852 | 104.870 | 0.836910 | 0.836660 |
| 64 | 112 | 4 | 3.0 | 4 | 2.0 | 7 | 6 | 12.3153 | 74.619 | 41.511 | 0.792620 | 0.709680 |
| 110 | 113 | 4 | 0.5 | 4 | 2.0 | 3 | 6 | 79.5810 | 82.780 | 22.499 | 0.578100 | 0.540660 |
| 618 | 114 | 4 | 0.5 | 1 | 2.0 | 3 | 6 | 46.3812 | 83.095 | 21.232 | 0.549330 | 0.494940 |
| 239 | 115 | 1 | 3.0 | 4 | 2.0 | 3 | 6 | 7.2333 | 106.340 | 36.686 | 0.194110 | 0.260660 |
| 16 | 116 | 4 | 3.0 | 4 | 2.0 | 3 | 1 | 17.7773 | 76.906 | 27.218 | 0.694410 | 0.646240 |
| 465 | 117 | 1 | 0.5 | 1 | 0.5 | 7 | 1 | 13.0425 | 84.327 | 71.714 | 0.549850 | 0.453540 |
| 148 | 118 | 4 | 3.0 | 1 | 0.5 | 7 | 1 | 0.0061 | 85.094 | 84.506 | 0.803520 | 0.802410 |
| 427 | 119 | 1 | 3.0 | 1 | 2.0 | 3 | 6 | 2.9892 | 111.530 | 36.817 | 0.126900 | 0.173660 |
| 591 | 120 | 1 | 3.0 | 4 | 2.0 | 3 | 1 | 10.8097 | 89.379 | 37.441 | 0.387090 | 0.413550 |
| 486 | 121 | 4 | 0.5 | 4 | 0.5 | 3 | 6 | 76.6571 | 84.843 | 21.714 | 0.560790 | 0.523370 |
| 59 | 122 | 1 | 3.0 | 1 | 2.0 | 7 | 6 | 4.4243 | 83.162 | 48.903 | 0.547630 | 0.476950 |
| 238 | 123 | 4 | 0.5 | 4 | 2.0 | 3 | 6 | 87.2767 | 82.474 | 22.543 | 0.583020 | 0.541990 |
| 38 | 124 | 4 | 0.5 | 4 | 0.5 | 3 | 6 | 76.3788 | 84.992 | 21.348 | 0.554080 | 0.513390 |
| 325 | 125 | 1 | 0.5 | 4 | 0.5 | 3 | 1 | 17.7560 | 104.410 | 50.402 | 0.172080 | 0.203440 |
| 523 | 126 | 1 | 3.0 | 1 | 2.0 | 3 | 1 | 4.5733 | 93.755 | 35.364 | 0.295060 | 0.300920 |
| 507 | 127 | 1 | 3.0 | 1 | 2.0 | 7 | 6 | 5.5376 | 83.897 | 48.123 | 0.537950 | 0.477870 |
| 577 | 128 | 1 | 0.5 | 1 | 0.5 | 3 | 1 | 0.1742 | 100.550 | 47.710 | 0.139470 | 0.107270 |
| 230 | 129 | 4 | 0.5 | 4 | 0.5 | 3 | 6 | 72.8762 | 85.065 | 21.500 | 0.555160 | 0.515560 |
| 222 | 130 | 4 | 0.5 | 4 | 2.0 | 7 | 1 | 44.0143 | 73.407 | 47.169 | 0.819100 | 0.736730 |
| 530 | 131 | 4 | 0.5 | 1 | 0.5 | 7 | 1 | 23.0049 | 87.321 | 103.670 | 0.862860 | 0.839070 |
| 278 | 132 | 4 | 0.5 | 4 | 0.5 | 7 | 1 | 0.0987 | 83.697 | 83.738 | 0.813930 | 0.799030 |
| 289 | 133 | 1 | 0.5 | 1 | 0.5 | 3 | 6 | 0.1816 | 148.260 | 70.131 | 0.000623 | 0.001530 |
| 412 | 134 | 4 | 3.0 | 1 | 2.0 | 7 | 1 | 6.5978 | 78.785 | 55.753 | 0.800720 | 0.749330 |
| 372 | 135 | 4 | 3.0 | 1 | 0.5 | 7 | 6 | 1.4227 | 81.263 | 46.784 | 0.748780 | 0.690010 |
| 499 | 136 | 1 | 3.0 | 1 | 0.5 | 7 | 6 | 0.1296 | 83.245 | 50.221 | 0.528710 | 0.444850 |
| 489 | 137 | 1 | 0.5 | 1 | 2.0 | 3 | 6 | 0.5841 | 147.690 | 69.853 | 0.003420 | 0.008470 |
| 440 | 138 | 4 | 3.0 | 4 | 0.5 | 7 | 6 | 0.6695 | 74.651 | 43.554 | 0.751850 | 0.690510 |
| 419 | 139 | 1 | 3.0 | 1 | 0.5 | 3 | 6 | 1.7291 | 110.110 | 35.691 | 0.118460 | 0.161000 |
| 608 | 140 | 4 | 3.0 | 4 | 2.0 | 7 | 1 | 13.0221 | 73.647 | 47.343 | 0.812440 | 0.739510 |
| 30 | 141 | 4 | 0.5 | 4 | 2.0 | 7 | 1 | 42.6967 | 73.371 | 47.301 | 0.820510 | 0.737480 |
| 27 | 142 | 1 | 3.0 | 1 | 2.0 | 7 | 1 | 7.4552 | 82.153 | 59.800 | 0.619040 | 0.553390 |
| 381 | 143 | 1 | 0.5 | 4 | 2.0 | 7 | 6 | 72.2388 | 81.714 | 50.400 | 0.401590 | 0.385510 |
| 80 | 144 | 4 | 3.0 | 4 | 2.0 | 3 | 1 | 18.1235 | 76.810 | 26.900 | 0.689410 | 0.643180 |
| 109 | 145 | 1 | 0.5 | 4 | 2.0 | 3 | 6 | 1.2827 | 141.900 | 66.813 | 0.014680 | 0.036310 |
| 57 | 146 | 1 | 0.5 | 1 | 2.0 | 7 | 6 | 18.6828 | 85.231 | 50.619 | 0.376190 | 0.311250 |
| 237 | 147 | 1 | 0.5 | 4 | 2.0 | 3 | 6 | 1.2766 | 141.880 | 66.807 | 0.016110 | 0.040260 |
| 178 | 148 | 4 | 0.5 | 1 | 0.5 | 7 | 6 | 0.9373 | 80.593 | 47.301 | 0.757210 | 0.685000 |
| 361 | 149 | 1 | 0.5 | 1 | 2.0 | 3 | 6 | 0.3755 | 148.360 | 70.802 | 0.002180 | 0.005380 |
| 323 | 150 | 1 | 3.0 | 1 | 0.5 | 3 | 1 | 2.8117 | 92.585 | 33.356 | 0.256670 | 0.244910 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 359 | 151 | 1 | 3.0 | 4 | 0.5 | 3 | 6 | 4.5018 | 112.770 | 37.393 | 0.139550 | 0.204660 |
| 429 | 152 | 1 | 0.5 | 4 | 2.0 | 3 | 6 | 1.3545 | 142.560 | 67.447 | 0.014620 | 0.037740 |
| 569 | 153 | 1 | 0.5 | 1 | 2.0 | 7 | 6 | 23.2634 | 86.497 | 51.084 | 0.368590 | 0.319570 |
| 119 | 154 | 1 | 3.0 | 4 | 0.5 | 7 | 6 | 4.3659 | 77.614 | 44.734 | 0.540700 | 0.471650 |
| 17 | 155 | 1 | 0.5 | 1 | 0.5 | 7 | 1 | 0.0144 | 90.667 | 211.630 | 0.768380 | 0.752760 |
| 161 | 156 | 1 | 0.5 | 1 | 0.5 | 3 | 6 | 0.1388 | 147.370 | 69.592 | 0.000467 | 0.001150 |
| 610 | 157 | 4 | 0.5 | 1 | 0.5 | 3 | 6 | 5.9790 | 80.812 | 20.758 | 0.537590 | 0.450080 |
| 362 | 158 | 4 | 0.5 | 1 | 2.0 | 3 | 6 | 46.9162 | 83.013 | 21.458 | 0.553420 | 0.498890 |
| 588 | 159 | 4 | 3.0 | 1 | 2.0 | 3 | 1 | 9.7389 | 80.706 | 23.851 | 0.609960 | 0.547990 |
| 482 | 160 | 4 | 0.5 | 1 | 0.5 | 3 | 6 | 5.9398 | 81.092 | 20.736 | 0.533370 | 0.449710 |
| 636 | 161 | 4 | 3.0 | 1 | 2.0 | 7 | 6 | 5.3913 | 80.127 | 44.523 | 0.764730 | 0.692590 |
| 632 | 162 | 4 | 3.0 | 4 | 0.5 | 7 | 6 | 0.0985 | 76.209 | 44.914 | 0.741410 | 0.687680 |
| 365 | 163 | 1 | 0.5 | 4 | 2.0 | 3 | 6 | 1.7601 | 143.500 | 67.872 | 0.012040 | 0.031850 |
| 355 | 164 | 1 | 3.0 | 1 | 0.5 | 3 | 6 | 1.6093 | 109.470 | 35.011 | 0.114680 | 0.151350 |
| 24 | 165 | 4 | 3.0 | 4 | 0.5 | 7 | 1 | 1.9695 | 83.270 | 95.995 | 0.822810 | 0.829610 |
| 235 | 166 | 1 | 3.0 | 1 | 2.0 | 3 | 6 | 3.1524 | 110.030 | 36.436 | 0.137850 | 0.188400 |
| 585 | 167 | 1 | 0.5 | 1 | 2.0 | 3 | 1 | 10.4629 | 102.950 | 48.405 | 0.139600 | 0.156230 |
| 469 | 168 | 1 | 0.5 | 4 | 0.5 | 7 | 1 | 8.6080 | 82.665 | 85.285 | 0.611470 | 0.518320 |
| 502 | 169 | 4 | 0.5 | 4 | 0.5 | 7 | 6 | 0.1098 | 74.352 | 43.726 | 0.752900 | 0.680850 |
| 540 | 170 | 4 | 3.0 | 1 | 2.0 | 7 | 1 | 3.5362 | 80.706 | 85.168 | 0.821990 | 0.820950 |
| 283 | 171 | 1 | 3.0 | 1 | 2.0 | 7 | 1 | 6.7621 | 82.845 | 62.589 | 0.626700 | 0.560890 |
| 275 | 172 | 1 | 3.0 | 1 | 0.5 | 7 | 1 | 0.1041 | 84.724 | 87.083 | 0.666860 | 0.634110 |
| 86 | 173 | 4 | 0.5 | 4 | 0.5 | 7 | 1 | 1.7679 | 80.318 | 72.347 | 0.813440 | 0.782450 |
| 364 | 174 | 4 | 3.0 | 1 | 2.0 | 3 | 6 | 9.9535 | 83.715 | 21.579 | 0.549200 | 0.501330 |
| 286 | 175 | 4 | 0.5 | 4 | 2.0 | 7 | 1 | 42.0326 | 73.387 | 46.404 | 0.817310 | 0.733670 |
| 66 | 176 | 4 | 0.5 | 1 | 0.5 | 3 | 1 | 5.1857 | 80.443 | 27.601 | 0.627160 | 0.535270 |
| 428 | 177 | 4 | 3.0 | 1 | 2.0 | 3 | 6 | 10.9008 | 84.136 | 21.818 | 0.555440 | 0.505310 |
| 245 | 178 | 1 | 0.5 | 4 | 0.5 | 7 | 6 | 0.4397 | 78.504 | 45.124 | 0.360550 | 0.250200 |
| 603 | 179 | 1 | 3.0 | 1 | 2.0 | 7 | 1 | 6.1908 | 81.984 | 62.590 | 0.625770 | 0.563680 |
| 358 | 180 | 4 | 0.5 | 4 | 0.5 | 3 | 6 | 77.4587 | 84.988 | 21.622 | 0.560250 | 0.519970 |
| 189 | 181 | 1 | 0.5 | 4 | 2.0 | 7 | 6 | 69.8125 | 82.718 | 50.080 | 0.382370 | 0.364510 |
| 103 | 182 | 1 | 3.0 | 4 | 0.5 | 3 | 6 | 4.6365 | 110.800 | 36.453 | 0.149070 | 0.214250 |
| 441 | 183 | 1 | 0.5 | 1 | 2.0 | 7 | 6 | 19.2711 | 85.420 | 50.779 | 0.378410 | 0.319580 |
| 524 | 184 | 4 | 3.0 | 1 | 2.0 | 3 | 1 | 10.2736 | 80.497 | 24.137 | 0.615480 | 0.555670 |
| 416 | 185 | 4 | 3.0 | 4 | 2.0 | 7 | 1 | 12.3649 | 73.696 | 46.514 | 0.806370 | 0.734150 |
| 403 | 186 | 1 | 3.0 | 1 | 0.5 | 7 | 1 | 2.4662 | 85.651 | 111.440 | 0.709570 | 0.706160 |
| 3 | 187 | 1 | 3.0 | 1 | 0.5 | 3 | 1 | 2.4704 | 93.084 | 33.951 | 0.257030 | 0.240720 |
| 348 | 188 | 4 | 3.0 | 1 | 2.0 | 7 | 1 | 5.7992 | 80.922 | 65.840 | 0.808630 | 0.776060 |
| 228 | 189 | 4 | 3.0 | 1 | 0.5 | 3 | 6 | 3.4501 | 82.251 | 20.954 | 0.528250 | 0.458840 |
| 295 | 190 | 1 | 3.0 | 4 | 0.5 | 3 | 6 | 5.5317 | 109.720 | 35.928 | 0.164390 | 0.224850 |
| 462 | 191 | 4 | 0.5 | 4 | 2.0 | 3 | 1 | 73.5599 | 76.671 | 26.745 | 0.689600 | 0.636360 |
| 494 | 192 | 4 | 0.5 | 4 | 2.0 | 3 | 6 | 85.9811 | 82.517 | 22.409 | 0.585440 | 0.542160 |
| 104 | 193 | 4 | 3.0 | 4 | 0.5 | 3 | 6 | 19.2767 | 85.484 | 22.105 | 0.561330 | 0.529370 |
| 571 | 194 | 1 | 3.0 | 1 | 2.0 | 7 | 6 | 6.1151 | 83.203 | 47.753 | 0.539530 | 0.476400 |
| 197 | 195 | 1 | 0.5 | 4 | 0.5 | 3 | 1 | 14.0728 | 101.700 | 48.936 | 0.180890 | 0.196050 |
| 169 | 196 | 1 | 0.5 | 1 | 2.0 | 3 | 6 | 0.4350 | 148.000 | 69.945 | 0.002490 | 0.006850 |
| 309 | 197 | 1 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 76.622 | 46.730 | 0.398140 | 0.280010 |
| 634 | 198 | 4 | 0.5 | 1 | 2.0 | 7 | 6 | 6.5067 | 80.128 | 44.901 | 0.761750 | 0.682900 |
| 408 | 199 | 4 | 3.0 | 4 | 0.5 | 7 | 1 | 1.5065 | 84.114 | 96.141 | 0.821140 | 0.828530 |
| 111 | 200 | 1 | 3.0 | 4 | 2.0 | 3 | 6 | 7.4499 | 106.130 | 35.930 | 0.189350 | 0.255020 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 567 | 201 | 1 | 3.0 | 4 | 0.5 | 7 | 6 | 5.1763 | 77.364 | 45.307 | 0.556300 | 0.488180 |
| 623 | 202 | 1 | 3.0 | 4 | 2.0 | 3 | 6 | 7.5389 | 106.180 | 36.092 | 0.201100 | 0.262130 |
| 23 | 203 | 1 | 3.0 | 4 | 0.5 | 7 | 1 | 4.2261 | 77.509 | 64.660 | 0.648190 | 0.587720 |
| 467 | 204 | 1 | 3.0 | 1 | 0.5 | 7 | 1 | 3.8158 | 84.078 | 77.361 | 0.659240 | 0.615890 |
| 532 | 205 | 4 | 3.0 | 1 | 0.5 | 7 | 1 | 0.5411 | 84.605 | 72.318 | 0.796750 | 0.774010 |
| 479 | 206 | 1 | 3.0 | 4 | 2.0 | 7 | 1 | 11.9186 | 78.158 | 55.825 | 0.629510 | 0.567980 |
| 347 | 207 | 1 | 3.0 | 1 | 2.0 | 7 | 1 | 4.4097 | 81.993 | 63.253 | 0.620520 | 0.558430 |
| 337 | 208 | 1 | 0.5 | 1 | 0.5 | 7 | 1 | 0.0000 | 86.123 | 76.759 | 0.560730 | 0.454560 |
| 270 | 209 | 4 | 0.5 | 4 | 2.0 | 3 | 1 | 81.3843 | 76.940 | 27.021 | 0.692360 | 0.638540 |
| 247 | 210 | 1 | 3.0 | 4 | 0.5 | 7 | 6 | 4.7595 | 77.846 | 45.588 | 0.543850 | 0.478000 |
| 505 | 211 | 1 | 0.5 | 1 | 2.0 | 7 | 6 | 11.9389 | 85.334 | 50.843 | 0.381340 | 0.310810 |
| 219 | 212 | 1 | 3.0 | 1 | 2.0 | 7 | 1 | 6.3139 | 81.652 | 58.511 | 0.608880 | 0.546980 |
| 375 | 213 | 1 | 3.0 | 4 | 0.5 | 7 | 6 | 4.7711 | 77.809 | 45.206 | 0.553110 | 0.487600 |
| 69 | 214 | 1 | 0.5 | 4 | 0.5 | 3 | 1 | 15.5713 | 101.130 | 48.205 | 0.177710 | 0.199180 |
| 224 | 215 | 4 | 3.0 | 4 | 2.0 | 7 | 1 | 12.2029 | 73.533 | 46.655 | 0.807910 | 0.737780 |
| 124 | 216 | 4 | 3.0 | 1 | 2.0 | 7 | 6 | 5.4647 | 79.626 | 43.947 | 0.764630 | 0.692870 |
| 28 | 217 | 4 | 3.0 | 1 | 2.0 | 7 | 1 | 5.9367 | 82.671 | 72.814 | 0.818230 | 0.795140 |
| 303 | 218 | 1 | 3.0 | 4 | 2.0 | 3 | 6 | 8.3062 | 105.460 | 36.056 | 0.201080 | 0.271580 |
| 527 | 219 | 1 | 3.0 | 4 | 2.0 | 3 | 1 | 9.8347 | 89.579 | 37.027 | 0.388090 | 0.412050 |
| 217 | 220 | 1 | 0.5 | 1 | 2.0 | 7 | 1 | 32.4589 | 83.378 | 70.221 | 0.542760 | 0.463440 |
| 595 | 221 | 1 | 3.0 | 1 | 0.5 | 7 | 1 | 2.2469 | 83.801 | 109.950 | 0.714080 | 0.712200 |
| 67 | 222 | 1 | 3.0 | 1 | 0.5 | 3 | 1 | 2.6040 | 92.800 | 33.863 | 0.268750 | 0.246250 |
| 378 | 223 | 4 | 0.5 | 1 | 2.0 | 7 | 6 | 16.4721 | 79.393 | 43.182 | 0.770330 | 0.685320 |
| 342 | 224 | 4 | 0.5 | 4 | 0.5 | 7 | 1 | 0.0056 | 83.730 | 84.236 | 0.841500 | 0.800070 |
| 563 | 225 | 1 | 3.0 | 1 | 0.5 | 7 | 6 | 0.8651 | 83.522 | 50.345 | 0.540980 | 0.465030 |
| 94 | 226 | 4 | 0.5 | 4 | 2.0 | 7 | 1 | 44.4644 | 73.407 | 48.855 | 0.825550 | 0.746120 |
| 491 | 227 | 1 | 3.0 | 1 | 2.0 | 3 | 6 | 3.7602 | 109.260 | 36.202 | 0.151680 | 0.201740 |
| 89 | 228 | 1 | 0.5 | 1 | 2.0 | 7 | 1 | 19.8400 | 85.832 | 87.969 | 0.607560 | 0.521250 |
| 379 | 229 | 1 | 3.0 | 1 | 2.0 | 7 | 6 | 5.5433 | 83.583 | 46.879 | 0.537210 | 0.469660 |
| 609 | 230 | 1 | 0.5 | 1 | 0.5 | 3 | 6 | 0.2147 | 148.310 | 70.372 | 0.000208 | 0.000513 |
| 383 | 231 | 1 | 3.0 | 4 | 2.0 | 7 | 6 | 11.9596 | 79.657 | 46.722 | 0.566150 | 0.513790 |
| 360 | 232 | 4 | 3.0 | 4 | 0.5 | 3 | 6 | 20.2310 | 85.572 | 22.021 | 0.553940 | 0.527070 |
| 258 | 233 | 4 | 0.5 | 1 | 0.5 | 3 | 1 | 6.3433 | 80.384 | 26.942 | 0.626030 | 0.528330 |
| 22 | 234 | 4 | 0.5 | 4 | 0.5 | 7 | 1 | 0.0886 | 85.843 | 118.960 | 0.872790 | 0.851480 |
| 604 | 235 | 4 | 3.0 | 1 | 2.0 | 7 | 1 | 4.0724 | 80.040 | 64.956 | 0.801850 | 0.771640 |
| 522 | 236 | 4 | 0.5 | 1 | 2.0 | 3 | 1 | 42.5553 | 80.082 | 23.756 | 0.620590 | 0.545080 |
| 13 | 237 | 1 | 0.5 | 4 | 2.0 | 3 | 1 | 22.4426 | 98.172 | 46.081 | 0.171250 | 0.208410 |
| 322 | 238 | 4 | 0.5 | 1 | 0.5 | 3 | 1 | 5.7837 | 80.978 | 28.243 | 0.632280 | 0.541350 |
| 185 | 239 | 1 | 0.5 | 1 | 2.0 | 7 | 6 | 20.1103 | 85.712 | 51.559 | 0.387770 | 0.329750 |
| 492 | 240 | 4 | 3.0 | 1 | 2.0 | 3 | 6 | 10.7090 | 83.589 | 21.534 | 0.551090 | 0.502020 |
| 298 | 241 | 4 | 0.5 | 1 | 2.0 | 3 | 6 | 44.7623 | 82.598 | 21.399 | 0.556190 | 0.499810 |
| 558 | 242 | 4 | 0.5 | 4 | 2.0 | 3 | 6 | 83.8127 | 82.709 | 22.700 | 0.587850 | 0.545300 |
| 321 | 243 | 1 | 0.5 | 1 | 0.5 | 3 | 1 | 0.1627 | 96.140 | 42.721 | 0.114290 | 0.090120 |
| 180 | 244 | 4 | 3.0 | 1 | 0.5 | 7 | 6 | 1.1453 | 81.948 | 47.805 | 0.753530 | 0.692800 |
| 154 | 245 | 4 | 0.5 | 1 | 2.0 | 7 | 1 | 4.8756 | 83.008 | 82.475 | 0.833890 | 0.803650 |
| 542 | 246 | 4 | 0.5 | 4 | 2.0 | 7 | 1 | 42.2866 | 73.257 | 47.148 | 0.821320 | 0.736250 |
| 188 | 247 | 4 | 3.0 | 1 | 2.0 | 7 | 6 | 7.4407 | 79.400 | 43.607 | 0.767830 | 0.697920 |
| 271 | 248 | 1 | 3.0 | 4 | 2.0 | 3 | 1 | 10.6148 | 89.903 | 37.172 | 0.379800 | 0.407310 |
| 350 | 249 | 4 | 0.5 | 4 | 2.0 | 7 | 1 | 47.9972 | 73.042 | 47.561 | 0.823820 | 0.741420 |
| 439 | 250 | 1 | 3.0 | 4 | 0.5 | 7 | 6 | 4.8241 | 77.622 | 45.867 | 0.557760 | 0.490370 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 423 | 251 | 1 | 3.0 | 4 | 0.5 | 3 | 6 | 5.4111 | 110.740 | 36.311 | 0.166000 | 0.227510 |
| 223 | 252 | 1 | 3.0 | 4 | 2.0 | 7 | 1 | 13.3041 | 77.642 | 53.126 | 0.615940 | 0.560080 |
| 32 | 253 | 4 | 3.0 | 4 | 2.0 | 7 | 1 | 12.1250 | 74.084 | 47.735 | 0.809280 | 0.740210 |
| 251 | 254 | 1 | 3.0 | 1 | 2.0 | 7 | 6 | 6.8522 | 83.430 | 48.234 | 0.548790 | 0.491530 |
| 561 | 255 | 1 | 0.5 | 1 | 0.5 | 7 | 6 | 10.0010 | 84.881 | 51.696 | 0.399670 | 0.320880 |
| 335 | 256 | 1 | 3.0 | 4 | 2.0 | 3 | 1 | 10.8844 | 90.049 | 37.761 | 0.392360 | 0.416150 |
| 193 | 257 | 1 | 0.5 | 1 | 0.5 | 3 | 1 | 0.2135 | 99.570 | 47.801 | 0.157880 | 0.124590 |
| 500 | 258 | 4 | 3.0 | 1 | 0.5 | 7 | 6 | 4.0557 | 81.034 | 46.135 | 0.765800 | 0.696370 |
| 273 | 259 | 1 | 0.5 | 1 | 0.5 | 7 | 1 | 0.0000 | 92.367 | 162.040 | 0.720200 | 0.684610 |
| 395 | 260 | 1 | 3.0 | 1 | 2.0 | 3 | 1 | 4.8394 | 93.490 | 35.195 | 0.299320 | 0.304520 |
| 41 | 261 | 1 | 0.5 | 1 | 2.0 | 3 | 6 | 0.3345 | 147.520 | 69.914 | 0.003530 | 0.008610 |
| 495 | 262 | 1 | 3.0 | 4 | 2.0 | 3 | 6 | 6.0578 | 107.590 | 36.502 | 0.174120 | 0.235540 |
| 56 | 263 | 4 | 3.0 | 4 | 0.5 | 7 | 6 | 0.8479 | 74.866 | 43.342 | 0.751850 | 0.688280 |
| 145 | 264 | 1 | 0.5 | 1 | 0.5 | 7 | 1 | 0.2134 | 90.798 | 159.600 | 0.727930 | 0.684680 |
| 285 | 265 | 1 | 0.5 | 4 | 2.0 | 7 | 1 | 54.7727 | 79.700 | 57.004 | 0.486180 | 0.423470 |
| 446 | 266 | 4 | 0.5 | 4 | 2.0 | 7 | 6 | 32.8191 | 74.126 | 41.113 | 0.791250 | 0.702120 |
| 514 | 267 | 4 | 0.5 | 1 | 0.5 | 3 | 1 | 6.3972 | 80.635 | 26.146 | 0.615910 | 0.515020 |
| 82 | 268 | 4 | 0.5 | 1 | 0.5 | 7 | 1 | 6.2257 | 83.835 | 71.666 | 0.814010 | 0.773290 |
| 130 | 269 | 4 | 0.5 | 1 | 0.5 | 3 | 1 | 6.5111 | 80.307 | 26.494 | 0.624070 | 0.523410 |
| 144 | 270 | 4 | 3.0 | 4 | 2.0 | 3 | 1 | 17.4598 | 76.947 | 27.110 | 0.691860 | 0.645800 |
| 112 | 271 | 4 | 3.0 | 4 | 2.0 | 3 | 6 | 18.0516 | 83.351 | 22.945 | 0.580550 | 0.549860 |
| 518 | 272 | 4 | 0.5 | 4 | 0.5 | 3 | 1 | 71.6112 | 78.580 | 25.652 | 0.670350 | 0.616830 |
| 376 | 273 | 4 | 3.0 | 4 | 0.5 | 7 | 6 | 2.3000 | 75.267 | 43.294 | 0.760980 | 0.693250 |
| 269 | 274 | 1 | 0.5 | 4 | 2.0 | 3 | 1 | 26.7698 | 98.027 | 47.120 | 0.184000 | 0.230330 |
| 207 | 275 | 1 | 3.0 | 4 | 2.0 | 3 | 1 | 10.6427 | 89.756 | 37.310 | 0.388200 | 0.418790 |
| 461 | 276 | 1 | 0.5 | 4 | 2.0 | 3 | 1 | 21.0405 | 98.283 | 46.379 | 0.172880 | 0.204490 |
| 481 | 277 | 1 | 0.5 | 1 | 0.5 | 3 | 6 | 0.1428 | 147.910 | 69.857 | 0.000415 | 0.001020 |
| 614 | 278 | 4 | 0.5 | 4 | 0.5 | 3 | 6 | 73.2957 | 85.166 | 21.424 | 0.551050 | 0.512520 |
| 212 | 279 | 4 | 3.0 | 1 | 0.5 | 7 | 1 | 2.8071 | 82.620 | 64.430 | 0.797600 | 0.760900 |
| 184 | 280 | 4 | 3.0 | 4 | 0.5 | 7 | 6 | 0.4690 | 76.008 | 44.302 | 0.749240 | 0.687600 |
| 256 | 281 | 4 | 3.0 | 4 | 2.0 | 7 | 6 | 12.8583 | 74.931 | 41.764 | 0.784700 | 0.710160 |
| 25 | 282 | 1 | 0.5 | 1 | 2.0 | 7 | 1 | 16.2121 | 84.777 | 84.775 | 0.599860 | 0.517290 |
| 87 | 283 | 1 | 3.0 | 4 | 0.5 | 7 | 1 | 5.7189 | 77.373 | 56.780 | 0.623680 | 0.553530 |
| 211 | 284 | 1 | 3.0 | 1 | 0.5 | 7 | 1 | 2.4391 | 87.815 | 105.800 | 0.696960 | 0.684710 |
| 19 | 285 | 1 | 3.0 | 1 | 0.5 | 7 | 1 | 1.9747 | 84.103 | 89.886 | 0.682990 | 0.654090 |
| 92 | 286 | 4 | 3.0 | 1 | 2.0 | 7 | 1 | 5.1210 | 79.696 | 59.750 | 0.799090 | 0.759730 |
| 159 | 287 | 1 | 3.0 | 4 | 2.0 | 7 | 1 | 13.4532 | 77.856 | 54.120 | 0.630000 | 0.566650 |
| 114 | 288 | 4 | 0.5 | 1 | 0.5 | 7 | 6 | 2.0687 | 80.644 | 46.481 | 0.758520 | 0.683290 |
| 127 | 289 | 1 | 3.0 | 4 | 2.0 | 7 | 6 | 13.0269 | 79.043 | 46.331 | 0.574790 | 0.520830 |
| 232 | 290 | 4 | 3.0 | 4 | 0.5 | 3 | 6 | 19.6353 | 85.643 | 21.907 | 0.552510 | 0.520780 |
| 196 | 291 | 4 | 3.0 | 1 | 0.5 | 3 | 1 | 3.2785 | 80.829 | 26.122 | 0.589970 | 0.526210 |
| 414 | 292 | 4 | 0.5 | 4 | 2.0 | 7 | 1 | 39.7112 | 73.610 | 46.293 | 0.816540 | 0.731260 |
| 113 | 293 | 1 | 0.5 | 1 | 0.5 | 7 | 6 | 0.0685 | 83.208 | 50.669 | 0.394540 | 0.283100 |
| 165 | 294 | 1 | 0.5 | 4 | 0.5 | 3 | 6 | 0.7250 | 147.750 | 69.489 | 0.008340 | 0.021450 |
| 384 | 295 | 4 | 3.0 | 4 | 2.0 | 7 | 6 | 11.9320 | 74.693 | 41.546 | 0.787570 | 0.707870 |
| 480 | 296 | 4 | 3.0 | 4 | 2.0 | 7 | 1 | 13.1242 | 73.274 | 47.316 | 0.814290 | 0.744430 |
| 253 | 297 | 1 | 0.5 | 4 | 2.0 | 7 | 6 | 79.9033 | 81.993 | 50.416 | 0.401330 | 0.385920 |
| 430 | 298 | 4 | 0.5 | 4 | 2.0 | 3 | 6 | 78.8831 | 82.758 | 22.374 | 0.578310 | 0.538040 |
| 134 | 299 | 4 | 0.5 | 4 | 0.5 | 3 | 1 | 70.6623 | 77.722 | 26.181 | 0.681100 | 0.630900 |
| 459 | 300 | 1 | 3.0 | 1 | 2.0 | 3 | 1 | 5.0059 | 93.708 | 35.184 | 0.291090 | 0.298290 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 525 | 301 | 1 | 0.5 | 4 | 2.0 | 3 | 1 | 22.2770 | 95.393 | 44.489 | 0.175090 | 0.212140 |
| 616 | 302 | 4 | 3.0 | 4 | 0.5 | 3 | 6 | 18.0816 | 86.072 | 21.986 | 0.551630 | 0.522000 |
| 292 | 303 | 4 | 3.0 | 1 | 0.5 | 3 | 6 | 2.9950 | 81.833 | 20.982 | 0.533090 | 0.459970 |
| 552 | 304 | 4 | 3.0 | 4 | 0.5 | 3 | 6 | 17.9183 | 85.970 | 21.941 | 0.554010 | 0.521930 |
| 624 | 305 | 4 | 3.0 | 4 | 2.0 | 3 | 6 | 17.4161 | 82.690 | 22.621 | 0.582130 | 0.548460 |
| 520 | 306 | 4 | 3.0 | 4 | 0.5 | 3 | 1 | 18.8663 | 78.384 | 26.388 | 0.671850 | 0.632750 |
| 417 | 307 | 1 | 0.5 | 1 | 0.5 | 3 | 6 | 0.1929 | 147.730 | 69.676 | 0.001040 | 0.002540 |
| 349 | 308 | 1 | 0.5 | 4 | 2.0 | 7 | 1 | 56.7007 | 79.957 | 58.983 | 0.501720 | 0.438140 |
| 550 | 309 | 4 | 0.5 | 4 | 0.5 | 3 | 6 | 78.0824 | 85.083 | 21.587 | 0.555570 | 0.518140 |
| 487 | 310 | 1 | 3.0 | 4 | 0.5 | 3 | 6 | 4.9428 | 112.030 | 37.367 | 0.153110 | 0.215310 |
| 11 | 311 | 1 | 3.0 | 1 | 2.0 | 3 | 1 | 4.8433 | 93.851 | 35.571 | 0.293070 | 0.302440 |
| 182 | 312 | 4 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0065 | 75.963 | 44.854 | 0.750230 | 0.679520 |
| 216 | 313 | 4 | 3.0 | 4 | 0.5 | 7 | 1 | 1.5368 | 84.421 | 108.320 | 0.828300 | 0.847080 |
| 5 | 314 | 1 | 0.5 | 4 | 0.5 | 3 | 1 | 19.2013 | 98.612 | 47.264 | 0.193840 | 0.219860 |
| 77 | 315 | 1 | 0.5 | 4 | 2.0 | 3 | 1 | 28.4710 | 96.146 | 46.524 | 0.201710 | 0.243490 |
| 537 | 316 | 1 | 0.5 | 1 | 2.0 | 7 | 1 | 9.6192 | 84.774 | 79.703 | 0.581000 | 0.487680 |
| 102 | 317 | 4 | 0.5 | 4 | 0.5 | 3 | 6 | 75.0402 | 85.234 | 21.706 | 0.558580 | 0.518450 |
| 123 | 318 | 1 | 3.0 | 1 | 2.0 | 7 | 6 | 3.7300 | 83.266 | 47.448 | 0.531970 | 0.463520 |
| 457 | 319 | 1 | 0.5 | 1 | 2.0 | 3 | 1 | 9.5680 | 98.934 | 45.199 | 0.134560 | 0.151080 |
| 404 | 320 | 4 | 3.0 | 1 | 0.5 | 7 | 1 | 0.0415 | 90.244 | 158.480 | 0.838490 | 0.883960 |
| 559 | 321 | 1 | 3.0 | 4 | 2.0 | 3 | 6 | 7.9198 | 106.170 | 36.084 | 0.193500 | 0.258090 |
| 580 | 322 | 4 | 3.0 | 1 | 0.5 | 3 | 1 | 3.2326 | 81.104 | 25.971 | 0.588080 | 0.522550 |
| 280 | 323 | 4 | 3.0 | 4 | 0.5 | 7 | 1 | 0.3127 | 81.469 | 84.116 | 0.812930 | 0.810690 |
| 374 | 324 | 4 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 74.410 | 44.177 | 0.750030 | 0.679970 |
| 143 | 325 | 1 | 3.0 | 4 | 2.0 | 3 | 1 | 10.7539 | 89.548 | 36.693 | 0.379720 | 0.403520 |
| 594 | 326 | 4 | 0.5 | 1 | 0.5 | 7 | 1 | 12.6650 | 89.997 | 135.960 | 0.872050 | 0.866070 |
| 162 | 327 | 4 | 0.5 | 1 | 0.5 | 3 | 6 | 7.9633 | 80.664 | 20.718 | 0.542830 | 0.460890 |
| 458 | 328 | 4 | 0.5 | 1 | 2.0 | 3 | 1 | 37.5171 | 79.559 | 23.136 | 0.614060 | 0.536030 |
| 399 | 329 | 1 | 3.0 | 4 | 2.0 | 3 | 1 | 10.4986 | 89.205 | 37.295 | 0.384430 | 0.415880 |
| 547 | 330 | 1 | 3.0 | 1 | 0.5 | 3 | 6 | 1.6624 | 108.480 | 34.432 | 0.119730 | 0.158310 |
| 121 | 331 | 1 | 0.5 | 1 | 2.0 | 7 | 6 | 19.8463 | 86.005 | 51.561 | 0.377810 | 0.319540 |
| 442 | 332 | 4 | 0.5 | 1 | 2.0 | 7 | 6 | 11.0854 | 79.785 | 43.415 | 0.765080 | 0.680830 |
| 267 | 333 | 1 | 3.0 | 1 | 2.0 | 3 | 1 | 4.8639 | 93.902 | 34.477 | 0.281120 | 0.288310 |
| 631 | 334 | 1 | 3.0 | 4 | 0.5 | 7 | 6 | 5.1199 | 77.541 | 44.898 | 0.556800 | 0.487180 |
| 147 | 335 | 1 | 3.0 | 1 | 0.5 | 7 | 1 | 1.1559 | 86.065 | 152.380 | 0.740540 | 0.773250 |
| 578 | 336 | 4 | 0.5 | 1 | 0.5 | 3 | 1 | 4.8230 | 80.392 | 26.956 | 0.620510 | 0.523940 |
| 625 | 337 | 1 | 0.5 | 1 | 0.5 | 7 | 6 | 2.1087 | 83.297 | 51.043 | 0.399330 | 0.305190 |
| 393 | 338 | 1 | 0.5 | 1 | 2.0 | 3 | 1 | 11.3289 | 99.850 | 46.446 | 0.146190 | 0.166570 |
| 496 | 339 | 4 | 3.0 | 4 | 2.0 | 3 | 6 | 17.1469 | 83.842 | 23.059 | 0.583440 | 0.546530 |
| 218 | 340 | 4 | 0.5 | 1 | 2.0 | 7 | 1 | 16.9645 | 78.961 | 57.012 | 0.813310 | 0.746560 |
| 394 | 341 | 4 | 0.5 | 1 | 2.0 | 3 | 1 | 42.0157 | 79.600 | 23.743 | 0.624070 | 0.549190 |
| 421 | 342 | 1 | 0.5 | 4 | 0.5 | 3 | 6 | 0.7711 | 146.800 | 68.996 | 0.010810 | 0.027290 |
| 478 | 343 | 4 | 0.5 | 4 | 2.0 | 7 | 1 | 42.2660 | 73.279 | 46.648 | 0.819020 | 0.733550 |
| 391 | 344 | 1 | 3.0 | 4 | 0.5 | 3 | 1 | 9.8316 | 91.703 | 37.286 | 0.361500 | 0.392690 |
| 407 | 345 | 1 | 3.0 | 4 | 0.5 | 7 | 1 | 4.4950 | 77.041 | 56.698 | 0.618910 | 0.549520 |
| 564 | 346 | 4 | 3.0 | 1 | 0.5 | 7 | 6 | 6.1408 | 80.803 | 44.926 | 0.768800 | 0.694780 |
| 630 | 347 | 4 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 74.396 | 44.153 | 0.750030 | 0.680500 |
| 68 | 348 | 4 | 3.0 | 1 | 0.5 | 3 | 1 | 2.8866 | 80.494 | 26.521 | 0.592230 | 0.531000 |
| 319 | 349 | 1 | 3.0 | 4 | 2.0 | 7 | 6 | 13.1963 | 79.628 | 47.138 | 0.569630 | 0.524370 |
| 475 | 350 | 1 | 3.0 | 1 | 2.0 | 7 | 1 | 6.6368 | 81.460 | 66.638 | 0.646970 | 0.591300 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 274 | 351 | 4 | 0.5 | 1 | 0.5 | 7 | 1 | 3.1410 | 83.983 | 72.493 | 0.814300 | 0.774620 |
| 257 | 352 | 1 | 0.5 | 1 | 0.5 | 3 | 1 | 0.2171 | 98.030 | 45.373 | 0.142190 | 0.115730 |
| 436 | 353 | 4 | 3.0 | 1 | 0.5 | 7 | 6 | 4.9145 | 81.013 | 46.202 | 0.765240 | 0.697810 |
| 633 | 354 | 1 | 0.5 | 1 | 2.0 | 7 | 6 | 22.9228 | 86.205 | 51.533 | 0.381260 | 0.326440 |
| 128 | 355 | 4 | 3.0 | 4 | 2.0 | 7 | 6 | 10.5586 | 74.843 | 41.488 | 0.786630 | 0.707690 |
| 400 | 356 | 4 | 3.0 | 4 | 2.0 | 3 | 1 | 17.3487 | 77.094 | 27.564 | 0.689960 | 0.649010 |
| 142 | 357 | 4 | 0.5 | 4 | 2.0 | 3 | 1 | 75.2939 | 76.497 | 26.975 | 0.696310 | 0.641250 |
| 332 | 358 | 4 | 3.0 | 1 | 2.0 | 3 | 1 | 9.9095 | 80.423 | 24.045 | 0.614800 | 0.551860 |
| 476 | 359 | 4 | 3.0 | 1 | 2.0 | 7 | 1 | 6.5193 | 79.524 | 58.761 | 0.801420 | 0.759030 |
| 133 | 360 | 1 | 0.5 | 4 | 0.5 | 3 | 1 | 18.3211 | 103.050 | 49.476 | 0.170860 | 0.203140 |
| 117 | 361 | 1 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 78.261 | 47.664 | 0.394300 | 0.278720 |
| 108 | 362 | 4 | 3.0 | 1 | 2.0 | 3 | 6 | 10.8700 | 83.848 | 21.707 | 0.548720 | 0.502570 |
| 320 | 363 | 4 | 3.0 | 4 | 2.0 | 7 | 6 | 11.2882 | 74.833 | 41.584 | 0.787490 | 0.710620 |
| 409 | 364 | 1 | 0.5 | 1 | 2.0 | 7 | 1 | 22.1638 | 83.163 | 81.629 | 0.595670 | 0.512030 |
| 141 | 365 | 1 | 0.5 | 4 | 2.0 | 3 | 1 | 22.7394 | 98.183 | 46.444 | 0.170570 | 0.203870 |
| 501 | 366 | 1 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 78.220 | 47.674 | 0.397110 | 0.280580 |
| 488 | 367 | 4 | 3.0 | 4 | 0.5 | 3 | 6 | 18.9684 | 85.775 | 21.829 | 0.558160 | 0.523820 |
| 346 | 368 | 4 | 0.5 | 1 | 2.0 | 7 | 1 | 12.9867 | 79.865 | 63.004 | 0.822580 | 0.765400 |
| 312 | 369 | 4 | 3.0 | 4 | 0.5 | 7 | 6 | 1.0388 | 75.138 | 43.749 | 0.757980 | 0.693990 |
| 555 | 370 | 1 | 3.0 | 1 | 2.0 | 3 | 6 | 3.4427 | 111.000 | 36.492 | 0.135220 | 0.184390 |
| 179 | 371 | 1 | 3.0 | 1 | 0.5 | 7 | 6 | 0.7209 | 83.636 | 50.554 | 0.540870 | 0.462640 |
| 366 | 372 | 4 | 0.5 | 4 | 2.0 | 3 | 6 | 86.8066 | 82.980 | 22.526 | 0.583370 | 0.541620 |
| 288 | 373 | 4 | 3.0 | 4 | 2.0 | 7 | 1 | 12.0930 | 74.183 | 47.935 | 0.810010 | 0.740800 |
| 570 | 374 | 4 | 0.5 | 1 | 2.0 | 7 | 6 | 17.2453 | 79.480 | 43.542 | 0.773130 | 0.688860 |
| 131 | 375 | 1 | 3.0 | 1 | 0.5 | 3 | 1 | 2.5963 | 92.399 | 33.945 | 0.272200 | 0.257720 |
| 387 | 376 | 1 | 3.0 | 1 | 0.5 | 3 | 1 | 2.7492 | 92.674 | 33.252 | 0.263550 | 0.248480 |
| 339 | 377 | 1 | 3.0 | 1 | 0.5 | 7 | 1 | 0.0448 | 88.750 | 140.320 | 0.731680 | 0.749720 |
| 259 | 378 | 1 | 3.0 | 1 | 0.5 | 3 | 1 | 2.8079 | 92.112 | 33.820 | 0.264520 | 0.256130 |
| 287 | 379 | 1 | 3.0 | 4 | 2.0 | 7 | 1 | 13.9964 | 77.336 | 53.170 | 0.625960 | 0.564450 |
| 497 | 380 | 1 | 0.5 | 1 | 0.5 | 7 | 6 | 2.3027 | 84.080 | 51.004 | 0.393690 | 0.301250 |
| 351 | 381 | 1 | 3.0 | 4 | 2.0 | 7 | 1 | 13.3872 | 77.495 | 52.332 | 0.617690 | 0.555580 |
| 493 | 382 | 1 | 0.5 | 4 | 2.0 | 3 | 6 | 1.5546 | 142.280 | 66.944 | 0.013620 | 0.033680 |
| 344 | 383 | 4 | 3.0 | 4 | 0.5 | 7 | 1 | 0.8680 | 78.570 | 80.183 | 0.813440 | 0.809060 |
| 388 | 384 | 4 | 3.0 | 1 | 0.5 | 3 | 1 | 3.2572 | 80.723 | 25.658 | 0.588380 | 0.522960 |
| 545 | 385 | 1 | 0.5 | 1 | 0.5 | 3 | 6 | 0.2082 | 147.280 | 69.530 | 0.000934 | 0.002300 |
| 448 | 386 | 4 | 3.0 | 4 | 2.0 | 7 | 6 | 12.3909 | 74.651 | 41.576 | 0.789490 | 0.712560 |
| 301 | 387 | 1 | 0.5 | 4 | 2.0 | 3 | 6 | 1.1898 | 142.770 | 67.188 | 0.012580 | 0.033090 |
| 276 | 388 | 4 | 3.0 | 1 | 0.5 | 7 | 1 | 1.9038 | 84.925 | 187.770 | 0.848690 | 0.909590 |
| 81 | 389 | 1 | 0.5 | 1 | 0.5 | 7 | 1 | 4.2781 | 89.303 | 172.830 | 0.744410 | 0.713120 |
| 622 | 390 | 4 | 0.5 | 4 | 2.0 | 3 | 6 | 82.6445 | 82.261 | 22.458 | 0.584730 | 0.543300 |
| 290 | 391 | 4 | 0.5 | 1 | 0.5 | 3 | 6 | 5.7825 | 81.087 | 20.653 | 0.534870 | 0.451180 |
| 582 | 392 | 4 | 0.5 | 4 | 0.5 | 3 | 1 | 76.5607 | 78.089 | 25.555 | 0.672280 | 0.620760 |
| 389 | 393 | 1 | 0.5 | 4 | 0.5 | 3 | 1 | 16.2789 | 101.080 | 49.768 | 0.201610 | 0.218490 |
| 242 | 394 | 4 | 0.5 | 1 | 0.5 | 7 | 6 | 10.1827 | 80.266 | 45.470 | 0.771150 | 0.691740 |
| 126 | 395 | 4 | 0.5 | 4 | 2.0 | 7 | 6 | 39.0390 | 74.656 | 41.873 | 0.795390 | 0.707220 |
| 590 | 396 | 4 | 0.5 | 4 | 2.0 | 3 | 1 | 77.5331 | 75.979 | 27.480 | 0.705240 | 0.651620 |
| 357 | 397 | 1 | 0.5 | 4 | 0.5 | 3 | 6 | 1.1398 | 144.420 | 68.274 | 0.016730 | 0.043530 |
| 434 | 398 | 4 | 0.5 | 1 | 0.5 | 7 | 6 | 25.4490 | 79.970 | 44.244 | 0.787200 | 0.700180 |
| 596 | 399 | 4 | 3.0 | 1 | 0.5 | 7 | 1 | 1.1766 | 83.821 | 68.988 | 0.796600 | 0.768980 |
| 587 | 400 | 1 | 3.0 | 1 | 2.0 | 3 | 1 | 5.1420 | 93.685 | 34.985 | 0.303120 | 0.307410 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 248 | 401 | 4 | 3.0 | 4 | 0.5 | 7 | 6 | 0.0008 | 74.765 | 44.498 | 0.739080 | 0.686880 |
| 93 | 402 | 1 | 0.5 | 4 | 2.0 | 7 | 1 | 69.5396 | 79.955 | 57.478 | 0.489300 | 0.431990 |
| 137 | 403 | 1 | 0.5 | 1 | 2.0 | 3 | 1 | 10.9796 | 101.720 | 47.648 | 0.147740 | 0.162530 |
| 101 | 404 | 1 | 0.5 | 4 | 0.5 | 3 | 6 | 0.7468 | 148.470 | 70.027 | 0.007100 | 0.018940 |
| 426 | 405 | 4 | 0.5 | 1 | 2.0 | 3 | 6 | 47.4780 | 82.984 | 21.265 | 0.551610 | 0.495320 |
| 620 | 406 | 4 | 3.0 | 1 | 2.0 | 3 | 6 | 11.2805 | 83.855 | 21.765 | 0.556640 | 0.505610 |
| 26 | 407 | 4 | 0.5 | 1 | 2.0 | 7 | 1 | 12.9580 | 81.217 | 65.059 | 0.827310 | 0.767920 |
| 415 | 408 | 1 | 3.0 | 4 | 2.0 | 7 | 1 | 12.3318 | 77.047 | 54.459 | 0.627600 | 0.567090 |
| 53 | 409 | 1 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0001 | 78.285 | 47.641 | 0.396150 | 0.281380 |
| 392 | 410 | 4 | 3.0 | 4 | 0.5 | 3 | 1 | 18.4830 | 79.024 | 26.705 | 0.668590 | 0.634650 |
| 175 | 411 | 1 | 3.0 | 4 | 2.0 | 3 | 6 | 7.7742 | 106.970 | 36.595 | 0.197460 | 0.265120 |
| 513 | 412 | 1 | 0.5 | 1 | 0.5 | 3 | 1 | 0.1919 | 98.890 | 45.283 | 0.121710 | 0.097110 |
| 422 | 413 | 4 | 0.5 | 4 | 0.5 | 3 | 6 | 71.6970 | 85.184 | 21.582 | 0.554790 | 0.515110 |
| 204 | 414 | 4 | 3.0 | 1 | 2.0 | 3 | 1 | 9.8458 | 80.611 | 23.649 | 0.604250 | 0.543160 |
| 629 | 415 | 1 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0024 | 78.226 | 47.441 | 0.393990 | 0.277890 |
| 62 | 416 | 4 | 0.5 | 4 | 2.0 | 7 | 6 | 41.1060 | 74.700 | 40.615 | 0.787840 | 0.699120 |
| 136 | 417 | 4 | 3.0 | 4 | 0.5 | 3 | 1 | 18.8875 | 78.578 | 26.439 | 0.670140 | 0.630140 |
| 626 | 418 | 4 | 0.5 | 1 | 0.5 | 7 | 6 | 2.9757 | 81.172 | 47.177 | 0.760930 | 0.687170 |
| 583 | 419 | 1 | 3.0 | 4 | 0.5 | 3 | 1 | 8.7802 | 91.236 | 36.086 | 0.351430 | 0.383640 |
| 308 | 420 | 4 | 3.0 | 1 | 0.5 | 7 | 6 | 5.9649 | 81.304 | 45.956 | 0.769430 | 0.769430 |
| 353 | 421 | 1 | 0.5 | 1 | 0.5 | 3 | 6 | 0.1832 | 147.750 | 69.926 | 0.000415 | 0.001020 |
| 484 | 422 | 4 | 3.0 | 1 | 0.5 | 3 | 6 | 3.6334 | 82.022 | 20.748 | 0.531700 | 0.462380 |
| 107 | 423 | 1 | 3.0 | 1 | 2.0 | 3 | 6 | 3.2619 | 111.030 | 36.838 | 0.139210 | 0.185030 |
| 40 | 424 | 4 | 3.0 | 4 | 0.5 | 3 | 6 | 18.8278 | 85.763 | 22.005 | 0.557720 | 0.525010 |
| 168 | 425 | 4 | 3.0 | 4 | 0.5 | 3 | 6 | 19.9009 | 85.342 | 21.921 | 0.559680 | 0.527570 |
| 307 | 426 | 1 | 3.0 | 1 | 0.5 | 7 | 6 | 1.3696 | 82.545 | 49.741 | 0.543290 | 0.469330 |
| 574 | 427 | 4 | 0.5 | 4 | 2.0 | 7 | 6 | 40.1876 | 74.704 | 40.915 | 0.790500 | 0.701770 |
| 221 | 428 | 1 | 0.5 | 4 | 2.0 | 7 | 1 | 63.3797 | 79.756 | 56.836 | 0.487950 | 0.428850 |
| 255 | 429 | 1 | 3.0 | 4 | 2.0 | 7 | 6 | 13.3330 | 79.937 | 46.940 | 0.562840 | 0.511650 |
| 473 | 430 | 1 | 0.5 | 1 | 2.0 | 7 | 1 | 22.7503 | 84.469 | 77.522 | 0.576260 | 0.484630 |
| 20 | 431 | 4 | 3.0 | 1 | 0.5 | 7 | 1 | 0.9658 | 82.803 | 72.340 | 0.802660 | 0.780800 |
| 36 | 432 | 4 | 3.0 | 1 | 0.5 | 3 | 6 | 3.2849 | 82.067 | 20.950 | 0.527460 | 0.463010 |
| 529 | 433 | 1 | 0.5 | 1 | 0.5 | 7 | 1 | 0.5713 | 88.550 | 124.410 | 0.686360 | 0.620380 |
| 611 | 434 | 1 | 3.0 | 1 | 0.5 | 3 | 6 | 1.8975 | 107.650 | 34.365 | 0.126120 | 0.166200 |
| 115 | 435 | 1 | 3.0 | 1 | 0.5 | 7 | 6 | 0.1460 | 82.754 | 49.792 | 0.533900 | 0.445800 |
| 410 | 436 | 4 | 0.5 | 1 | 2.0 | 7 | 1 | 6.9376 | 81.800 | 73.243 | 0.833850 | 0.784630 |
| 158 | 437 | 4 | 0.5 | 4 | 2.0 | 7 | 1 | 41.9521 | 73.086 | 45.829 | 0.816480 | 0.730640 |
| 390 | 438 | 4 | 0.5 | 4 | 0.5 | 3 | 1 | 74.3062 | 77.672 | 26.138 | 0.681990 | 0.633180 |
| 201 | 439 | 1 | 0.5 | 1 | 2.0 | 3 | 1 | 11.2146 | 99.115 | 45.851 | 0.143070 | 0.163750 |
| 125 | 440 | 1 | 0.5 | 4 | 2.0 | 7 | 6 | 79.1437 | 82.427 | 51.096 | 0.405150 | 0.389660 |
| 336 | 441 | 4 | 3.0 | 4 | 2.0 | 3 | 1 | 17.5986 | 77.011 | 26.905 | 0.686620 | 0.642040 |
| 146 | 442 | 4 | 0.5 | 1 | 0.5 | 7 | 1 | 1.0934 | 84.087 | 79.958 | 0.825020 | 0.792520 |
| 512 | 443 | 4 | 3.0 | 4 | 2.0 | 7 | 6 | 13.4868 | 74.793 | 41.896 | 0.792490 | 0.712110 |
| 210 | 444 | 4 | 0.5 | 1 | 0.5 | 7 | 1 | 7.1471 | 83.279 | 69.312 | 0.817630 | 0.770630 |
| 98 | 445 | 4 | 0.5 | 1 | 0.5 | 3 | 6 | 5.9698 | 80.772 | 20.672 | 0.537020 | 0.453800 |
| 369 | 446 | 1 | 0.5 | 1 | 0.5 | 7 | 6 | 12.5213 | 85.053 | 52.037 | 0.398020 | 0.334360 |
| 155 | 447 | 1 | 3.0 | 1 | 2.0 | 7 | 1 | 5.4636 | 81.662 | 63.426 | 0.627100 | 0.568790 |
| 607 | 448 | 1 | 3.0 | 4 | 2.0 | 7 | 1 | 11.7057 | 77.264 | 55.588 | 0.630620 | 0.573190 |
| 324 | 449 | 4 | 3.0 | 1 | 0.5 | 3 | 1 | 3.0386 | 80.939 | 25.160 | 0.579040 | 0.510020 |
| 60 | 450 | 4 | 3.0 | 1 | 2.0 | 7 | 6 | 4.1993 | 80.417 | 45.507 | 0.755720 | 0.692360 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 508 | 451 | 4 | 3.0 | 1 | 2.0 | 7 | 6 | 7.2717 | 79.600 | 43.652 | 0.770790 | 0.695450 |
| 138 | 452 | 4 | 0.5 | 1 | 2.0 | 3 | 1 | 38.2348 | 79.773 | 23.505 | 0.617500 | 0.542080 |
| 528 | 453 | 4 | 3.0 | 4 | 2.0 | 3 | 1 | 18.2538 | 77.328 | 27.262 | 0.682870 | 0.642520 |
| 576 | 454 | 4 | 3.0 | 4 | 2.0 | 7 | 6 | 11.5285 | 74.778 | 41.301 | 0.787530 | 0.708380 |
| 151 | 455 | 1 | 3.0 | 4 | 0.5 | 7 | 1 | 4.9851 | 78.037 | 59.507 | 0.625950 | 0.557690 |
| 214 | 456 | 4 | 0.5 | 4 | 0.5 | 7 | 1 | 1.8481 | 80.718 | 76.692 | 0.827680 | 0.791990 |
| 605 | 457 | 1 | 0.5 | 4 | 2.0 | 7 | 1 | 66.2344 | 80.486 | 59.269 | 0.495570 | 0.437190 |
| 277 | 458 | 1 | 0.5 | 4 | 0.5 | 7 | 1 | 0.2112 | 89.381 | 159.760 | 0.730490 | 0.690050 |
| 544 | 459 | 4 | 3.0 | 4 | 2.0 | 7 | 1 | 11.5549 | 73.479 | 46.978 | 0.809940 | 0.738900 |
| 314 | 460 | 4 | 0.5 | 1 | 2.0 | 7 | 6 | 21.0173 | 79.247 | 43.061 | 0.776780 | 0.690030 |
| 45 | 461 | 1 | 0.5 | 4 | 2.0 | 3 | 6 | 1.4187 | 143.390 | 67.749 | 0.012800 | 0.032210 |
| 61 | 462 | 1 | 0.5 | 4 | 2.0 | 7 | 6 | 66.5805 | 83.239 | 51.033 | 0.392490 | 0.382110 |
| 354 | 463 | 4 | 0.5 | 1 | 0.5 | 3 | 6 | 6.9733 | 81.394 | 20.876 | 0.534430 | 0.453620 |
| 533 | 464 | 1 | 0.5 | 4 | 0.5 | 7 | 1 | 6.4945 | 83.513 | 102.040 | 0.657870 | 0.579840 |
| 78 | 465 | 4 | 0.5 | 4 | 2.0 | 3 | 1 | 76.8532 | 75.730 | 26.960 | 0.700610 | 0.647440 |
| 380 | 466 | 4 | 3.0 | 1 | 2.0 | 7 | 6 | 5.9109 | 79.977 | 44.191 | 0.764020 | 0.692470 |
| 42 | 467 | 4 | 0.5 | 1 | 2.0 | 3 | 6 | 44.8509 | 83.494 | 21.254 | 0.547230 | 0.490420 |
| 509 | 468 | 1 | 0.5 | 4 | 2.0 | 7 | 6 | 77.4080 | 82.572 | 50.420 | 0.396350 | 0.379720 |
| 302 | 469 | 4 | 0.5 | 4 | 2.0 | 3 | 6 | 77.0041 | 83.172 | 22.548 | 0.578250 | 0.536370 |
| 105 | 470 | 1 | 0.5 | 1 | 2.0 | 3 | 6 | 0.4071 | 148.610 | 70.449 | 0.001660 | 0.004080 |
| 265 | 471 | 1 | 0.5 | 1 | 2.0 | 3 | 1 | 11.0920 | 97.156 | 44.841 | 0.153340 | 0.171930 |
| 192 | 472 | 4 | 3.0 | 4 | 2.0 | 7 | 6 | 11.6380 | 74.624 | 41.416 | 0.789830 | 0.709570 |
| 534 | 473 | 4 | 0.5 | 4 | 0.5 | 7 | 1 | 3.6645 | 78.740 | 65.599 | 0.819660 | 0.768990 |
| 352 | 474 | 4 | 3.0 | 4 | 2.0 | 7 | 1 | 12.3638 | 74.280 | 48.492 | 0.812370 | 0.744490 |
| 227 | 475 | 1 | 3.0 | 1 | 0.5 | 3 | 6 | 1.7741 | 108.610 | 34.438 | 0.115240 | 0.156380 |
| 167 | 476 | 1 | 3.0 | 4 | 0.5 | 3 | 6 | 4.5852 | 110.880 | 36.126 | 0.146310 | 0.210580 |
| 333 | 477 | 1 | 0.5 | 4 | 2.0 | 3 | 1 | 26.6709 | 96.297 | 46.139 | 0.193910 | 0.233750 |
| 191 | 478 | 1 | 3.0 | 4 | 2.0 | 7 | 6 | 11.9220 | 79.026 | 47.170 | 0.571630 | 0.521610 |
| 541 | 479 | 1 | 0.5 | 4 | 2.0 | 7 | 1 | 60.6084 | 79.305 | 58.534 | 0.501520 | 0.439460 |
| 612 | 480 | 4 | 3.0 | 1 | 0.5 | 3 | 6 | 3.1504 | 81.761 | 20.806 | 0.527560 | 0.454870 |
| 95 | 481 | 1 | 3.0 | 4 | 2.0 | 7 | 1 | 12.8694 | 77.921 | 53.469 | 0.624730 | 0.559190 |
| 600 | 482 | 4 | 3.0 | 4 | 0.5 | 7 | 1 | 1.0985 | 83.537 | 86.554 | 0.806600 | 0.813430 |
| 306 | 483 | 4 | 0.5 | 1 | 0.5 | 7 | 6 | 28.0674 | 80.114 | 44.072 | 0.786250 | 0.698570 |
| 420 | 484 | 4 | 3.0 | 1 | 0.5 | 3 | 6 | 3.6461 | 82.307 | 21.028 | 0.528020 | 0.463940 |
| 504 | 485 | 4 | 3.0 | 4 | 0.5 | 7 | 6 | 0.3426 | 75.752 | 44.645 | 0.749030 | 0.690230 |
| 438 | 486 | 4 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 74.483 | 44.214 | 0.750030 | 0.679580 |
| 517 | 487 | 1 | 0.5 | 4 | 0.5 | 3 | 1 | 23.0560 | 103.970 | 50.652 | 0.186900 | 0.222350 |
| 254 | 488 | 4 | 0.5 | 4 | 2.0 | 7 | 6 | 41.3084 | 74.486 | 40.924 | 0.791940 | 0.702130 |
| 15 | 489 | 1 | 3.0 | 4 | 2.0 | 3 | 1 | 10.7370 | 89.300 | 36.666 | 0.385430 | 0.411980 |
| 367 | 490 | 1 | 3.0 | 4 | 2.0 | 3 | 6 | 8.2336 | 104.170 | 35.291 | 0.207150 | 0.276420 |
| 129 | 491 | 1 | 0.5 | 1 | 0.5 | 3 | 1 | 0.1384 | 99.110 | 47.081 | 0.149510 | 0.110670 |
| 373 | 492 | 1 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 78.231 | 47.667 | 0.395470 | 0.278560 |
| 246 | 493 | 4 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 74.388 | 44.154 | 0.749970 | 0.680070 |
| 557 | 494 | 1 | 0.5 | 4 | 2.0 | 3 | 6 | 1.1867 | 142.990 | 67.414 | 0.012120 | 0.030480 |
| 568 | 495 | 4 | 3.0 | 4 | 0.5 | 7 | 6 | 2.7403 | 74.771 | 42.562 | 0.765310 | 0.695220 |
| 300 | 496 | 4 | 3.0 | 1 | 2.0 | 3 | 6 | 11.1275 | 83.899 | 21.979 | 0.557280 | 0.509890 |
| 592 | 497 | 4 | 3.0 | 4 | 2.0 | 3 | 1 | 18.4534 | 77.407 | 27.108 | 0.684600 | 0.640690 |
| 526 | 498 | 4 | 0.5 | 4 | 2.0 | 3 | 1 | 74.8221 | 76.115 | 26.724 | 0.695300 | 0.638620 |
| 149 | 499 | 1 | 0.5 | 4 | 0.5 | 7 | 1 | 7.7827 | 83.975 | 94.862 | 0.637040 | 0.554860 |
| 120 | 500 | 4 | 3.0 | 4 | 0.5 | 7 | 6 | 0.0469 | 74.910 | 44.217 | 0.743830 | 0.687980 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 424 | 501 | 4 | 3.0 | 4 | 0.5 | 3 | 6 | 18.8902 | 85.649 | 21.910 | 0.553650 | 0.523730 |
| 187 | 502 | 1 | 3.0 | 1 | 2.0 | 7 | 6 | 5.2497 | 83.761 | 48.089 | 0.540830 | 0.479420 |
| 628 | 503 | 4 | 3.0 | 1 | 0.5 | 7 | 6 | 3.1449 | 80.378 | 45.680 | 0.765020 | 0.695880 |
| 264 | 504 | 4 | 3.0 | 4 | 0.5 | 3 | 1 | 18.8485 | 78.456 | 26.680 | 0.673190 | 0.636070 |
| 152 | 505 | 4 | 3.0 | 4 | 0.5 | 7 | 1 | 1.8084 | 79.295 | 70.422 | 0.807230 | 0.786240 |
| 139 | 506 | 1 | 3.0 | 1 | 2.0 | 3 | 1 | 4.8079 | 93.149 | 35.080 | 0.301100 | 0.305100 |
| 71 | 507 | 1 | 3.0 | 4 | 0.5 | 3 | 1 | 9.5962 | 91.397 | 36.773 | 0.367610 | 0.401970 |
| 597 | 508 | 1 | 0.5 | 4 | 0.5 | 7 | 1 | 1.6347 | 82.254 | 75.391 | 0.570970 | 0.468410 |
| 106 | 509 | 4 | 0.5 | 1 | 2.0 | 3 | 6 | 46.2368 | 83.075 | 21.282 | 0.551050 | 0.495550 |
| 44 | 510 | 4 | 3.0 | 1 | 2.0 | 3 | 6 | 11.1400 | 84.343 | 21.483 | 0.544330 | 0.495270 |
| 599 | 511 | 1 | 3.0 | 4 | 0.5 | 7 | 1 | 6.1741 | 77.743 | 56.805 | 0.618550 | 0.550830 |
| 617 | 512 | 1 | 0.5 | 1 | 2.0 | 3 | 6 | 0.4182 | 148.200 | 70.412 | 0.003680 | 0.009020 |
| 468 | 513 | 4 | 3.0 | 1 | 0.5 | 7 | 1 | 1.2952 | 84.063 | 114.350 | 0.832490 | 0.854810 |
| 160 | 514 | 4 | 3.0 | 4 | 2.0 | 7 | 1 | 11.3327 | 73.762 | 48.695 | 0.812590 | 0.748020 |
| 368 | 515 | 4 | 3.0 | 4 | 2.0 | 3 | 6 | 18.5852 | 83.328 | 22.897 | 0.580950 | 0.549260 |
| 454 | 516 | 4 | 0.5 | 4 | 0.5 | 3 | 1 | 70.1905 | 77.834 | 25.296 | 0.670630 | 0.616880 |
| 9 | 517 | 1 | 0.5 | 1 | 2.0 | 3 | 1 | 7.8785 | 100.240 | 45.541 | 0.124620 | 0.140540 |
| 296 | 518 | 4 | 3.0 | 4 | 0.5 | 3 | 6 | 18.1653 | 85.323 | 21.904 | 0.559600 | 0.527990 |
| 566 | 519 | 4 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 74.415 | 44.164 | 0.749910 | 0.680140 |
| 601 | 520 | 1 | 0.5 | 1 | 2.0 | 7 | 1 | 31.6103 | 83.770 | 65.422 | 0.514130 | 0.432810 |
| 58 | 521 | 4 | 0.5 | 1 | 2.0 | 7 | 6 | 9.7952 | 79.427 | 44.007 | 0.765350 | 0.683990 |
| 291 | 522 | 1 | 3.0 | 1 | 0.5 | 3 | 6 | 1.8805 | 108.240 | 34.566 | 0.128830 | 0.165760 |
| 39 | 523 | 1 | 3.0 | 4 | 0.5 | 3 | 6 | 5.4752 | 110.280 | 36.174 | 0.160630 | 0.226280 |
| 554 | 524 | 4 | 0.5 | 1 | 2.0 | 3 | 6 | 48.3561 | 83.729 | 21.448 | 0.546570 | 0.494490 |
| 156 | 525 | 4 | 3.0 | 1 | 2.0 | 7 | 1 | 6.4835 | 79.563 | 54.272 | 0.792240 | 0.741990 |
| 437 | 526 | 1 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 78.254 | 47.703 | 0.394780 | 0.280260 |
| 209 | 527 | 1 | 0.5 | 1 | 0.5 | 7 | 1 | 0.6511 | 88.700 | 179.080 | 0.750230 | 0.721790 |
| 266 | 528 | 4 | 0.5 | 1 | 2.0 | 3 | 1 | 39.1292 | 79.419 | 23.439 | 0.618150 | 0.541060 |
| 10 | 529 | 4 | 0.5 | 1 | 2.0 | 3 | 1 | 41.9981 | 80.225 | 23.375 | 0.613060 | 0.538080 |
| 425 | 530 | 1 | 0.5 | 1 | 2.0 | 3 | 6 | 0.5204 | 147.690 | 70.053 | 0.003370 | 0.008490 |
| 560 | 531 | 4 | 3.0 | 4 | 2.0 | 3 | 6 | 18.6367 | 82.873 | 22.646 | 0.585880 | 0.550710 |
| 74 | 532 | 4 | 0.5 | 1 | 2.0 | 3 | 1 | 39.8267 | 79.655 | 23.635 | 0.623850 | 0.548370 |
| 470 | 533 | 4 | 0.5 | 4 | 0.5 | 7 | 1 | 3.6178 | 82.375 | 90.202 | 0.842910 | 0.819880 |
| 164 | 534 | 4 | 3.0 | 1 | 0.5 | 3 | 6 | 3.4103 | 81.774 | 20.996 | 0.536810 | 0.468260 |
| 511 | 535 | 1 | 3.0 | 4 | 2.0 | 7 | 6 | 13.7079 | 79.273 | 46.705 | 0.570250 | 0.521240 |
| 65 | 536 | 1 | 0.5 | 1 | 0.5 | 3 | 1 | 0.1835 | 97.190 | 44.840 | 0.148680 | 0.118210 |
| 363 | 537 | 1 | 3.0 | 1 | 2.0 | 3 | 6 | 3.5322 | 109.690 | 35.997 | 0.139500 | 0.190680 |
| 31 | 538 | 1 | 3.0 | 4 | 2.0 | 7 | 1 | 13.4334 | 77.633 | 53.369 | 0.626850 | 0.562240 |
| 445 | 539 | 1 | 0.5 | 4 | 2.0 | 7 | 6 | 60.9446 | 81.760 | 49.689 | 0.392400 | 0.373990 |
| 483 | 540 | 1 | 3.0 | 1 | 0.5 | 3 | 6 | 1.6410 | 109.160 | 35.006 | 0.117930 | 0.155280 |
| 157 | 541 | 1 | 0.5 | 4 | 2.0 | 7 | 1 | 65.3676 | 79.819 | 60.970 | 0.518490 | 0.457650 |
| 382 | 542 | 4 | 0.5 | 4 | 2.0 | 7 | 6 | 36.9779 | 74.676 | 41.379 | 0.790820 | 0.703470 |
| 206 | 543 | 4 | 0.5 | 4 | 2.0 | 3 | 1 | 72.3174 | 76.455 | 26.953 | 0.692340 | 0.642050 |
| 471 | 544 | 1 | 3.0 | 4 | 0.5 | 7 | 1 | 3.4752 | 78.405 | 63.432 | 0.635130 | 0.572330 |
| 356 | 545 | 4 | 3.0 | 1 | 0.5 | 3 | 6 | 3.1784 | 81.946 | 20.750 | 0.527560 | 0.457030 |
| 73 | 546 | 1 | 0.5 | 1 | 2.0 | 3 | 1 | 10.4813 | 97.789 | 44.615 | 0.142820 | 0.158670 |
| 34 | 547 | 4 | 0.5 | 1 | 0.5 | 3 | 6 | 5.0816 | 80.914 | 20.676 | 0.531130 | 0.443320 |
| 79 | 548 | 1 | 3.0 | 4 | 2.0 | 3 | 1 | 9.9936 | 89.380 | 36.485 | 0.378570 | 0.400360 |
| 46 | 549 | 4 | 0.5 | 4 | 2.0 | 3 | 6 | 82.5376 | 82.601 | 22.524 | 0.584080 | 0.540010 |
| 315 | 550 | 1 | 3.0 | 1 | 2.0 | 7 | 6 | 6.7164 | 83.459 | 47.486 | 0.538930 | 0.486780 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 565 | 551 | 1 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 78.274 | 47.705 | 0.395860 | 0.281200 |
| 85 | 552 | 1 | 0.5 | 4 | 0.5 | 7 | 1 | 0.2790 | 86.350 | 123.560 | 0.692590 | 0.626340 |
| 202 | 553 | 4 | 0.5 | 1 | 2.0 | 3 | 1 | 40.5938 | 79.783 | 23.354 | 0.616340 | 0.541080 |
| 33 | 554 | 1 | 0.5 | 1 | 0.5 | 3 | 6 | 0.1570 | 147.900 | 70.162 | 0.000571 | 0.001410 |
| 443 | 555 | 1 | 3.0 | 1 | 2.0 | 7 | 6 | 6.4111 | 83.964 | 48.774 | 0.541180 | 0.486600 |
| 453 | 556 | 1 | 0.5 | 4 | 0.5 | 3 | 1 | 23.8213 | 100.120 | 48.400 | 0.196200 | 0.235780 |
| 318 | 557 | 4 | 0.5 | 4 | 2.0 | 7 | 6 | 36.5932 | 74.634 | 41.084 | 0.789170 | 0.701800 |
| 21 | 558 | 1 | 0.5 | 4 | 0.5 | 7 | 1 | 0.0000 | 91.261 | 160.760 | 0.721910 | 0.685050 |
| 615 | 559 | 1 | 3.0 | 4 | 0.5 | 3 | 6 | 5.5110 | 109.100 | 35.509 | 0.165170 | 0.234540 |
| 474 | 560 | 4 | 0.5 | 1 | 2.0 | 7 | 1 | 15.7631 | 81.246 | 63.316 | 0.819790 | 0.763360 |
| 203 | 561 | 1 | 3.0 | 1 | 2.0 | 3 | 1 | 5.0953 | 92.900 | 34.632 | 0.298740 | 0.306660 |
| 195 | 562 | 1 | 3.0 | 1 | 0.5 | 3 | 1 | 2.7142 | 92.380 | 33.517 | 0.271980 | 0.255870 |
| 460 | 563 | 4 | 3.0 | 1 | 2.0 | 3 | 1 | 9.6578 | 80.298 | 23.537 | 0.609670 | 0.546950 |
| 584 | 564 | 4 | 3.0 | 4 | 0.5 | 3 | 1 | 19.2169 | 78.703 | 26.222 | 0.667300 | 0.627140 |
| 243 | 565 | 1 | 3.0 | 1 | 0.5 | 7 | 6 | 0.0524 | 83.254 | 50.543 | 0.530600 | 0.444830 |
| 397 | 566 | 1 | 0.5 | 4 | 2.0 | 3 | 1 | 24.8904 | 98.616 | 47.214 | 0.183550 | 0.221680 |
| 519 | 567 | 1 | 3.0 | 4 | 0.5 | 3 | 1 | 8.8158 | 92.169 | 36.399 | 0.342430 | 0.372990 |
| 385 | 568 | 1 | 0.5 | 1 | 0.5 | 3 | 1 | 0.2208 | 97.060 | 43.903 | 0.132610 | 0.104250 |
| 150 | 569 | 4 | 0.5 | 4 | 0.5 | 7 | 1 | 0.3152 | 81.158 | 72.732 | 0.807700 | 0.779190 |
| 334 | 570 | 4 | 0.5 | 4 | 2.0 | 3 | 1 | 76.2224 | 76.577 | 26.719 | 0.688860 | 0.639220 |
| 29 | 571 | 1 | 0.5 | 4 | 2.0 | 7 | 1 | 57.9976 | 79.641 | 58.714 | 0.499140 | 0.436020 |
| 263 | 572 | 1 | 3.0 | 4 | 0.5 | 3 | 1 | 8.0779 | 93.390 | 37.346 | 0.341760 | 0.370070 |
| 55 | 573 | 1 | 3.0 | 4 | 0.5 | 7 | 6 | 4.4234 | 77.834 | 45.478 | 0.551640 | 0.484060 |
| 12 | 574 | 4 | 3.0 | 1 | 2.0 | 3 | 1 | 9.3011 | 79.680 | 23.736 | 0.618290 | 0.552360 |
| 262 | 575 | 4 | 0.5 | 4 | 0.5 | 3 | 1 | 75.8413 | 77.701 | 25.377 | 0.676150 | 0.621240 |
| 313 | 576 | 1 | 0.5 | 1 | 2.0 | 7 | 6 | 21.5141 | 85.524 | 51.338 | 0.383210 | 0.327150 |
| 299 | 577 | 1 | 3.0 | 1 | 2.0 | 3 | 6 | 3.5338 | 109.010 | 36.148 | 0.150650 | 0.198530 |
| 411 | 578 | 1 | 3.0 | 1 | 2.0 | 7 | 1 | 7.4683 | 82.377 | 60.634 | 0.626860 | 0.558450 |
| 464 | 579 | 4 | 3.0 | 4 | 2.0 | 3 | 1 | 17.4027 | 76.856 | 27.379 | 0.690350 | 0.646020 |
| 97 | 580 | 1 | 0.5 | 1 | 0.5 | 3 | 6 | 0.1873 | 147.510 | 69.521 | 0.000622 | 0.001530 |
| 135 | 581 | 1 | 3.0 | 4 | 0.5 | 3 | 1 | 9.1364 | 91.856 | 36.551 | 0.362150 | 0.383750 |
| 272 | 582 | 4 | 3.0 | 4 | 2.0 | 3 | 1 | 17.7121 | 77.123 | 27.203 | 0.688410 | 0.645130 |
| 99 | 583 | 1 | 3.0 | 1 | 0.5 | 3 | 6 | 1.6927 | 109.510 | 35.107 | 0.118560 | 0.158180 |
| 455 | 584 | 1 | 3.0 | 4 | 0.5 | 3 | 1 | 9.9434 | 91.488 | 37.033 | 0.370620 | 0.402010 |
| 54 | 585 | 4 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 74.412 | 44.163 | 0.749910 | 0.680430 |
| 173 | 586 | 1 | 0.5 | 4 | 2.0 | 3 | 6 | 1.3175 | 142.300 | 67.062 | 0.014230 | 0.036460 |
| 4 | 587 | 4 | 3.0 | 1 | 0.5 | 3 | 1 | 3.0599 | 80.485 | 26.610 | 0.595740 | 0.535240 |
| 562 | 588 | 4 | 0.5 | 1 | 0.5 | 7 | 6 | 19.2487 | 80.257 | 44.547 | 0.780970 | 0.695310 |
| 640 | 589 | 4 | 3.0 | 4 | 2.0 | 7 | 6 | 12.4673 | 74.359 | 41.405 | 0.792140 | 0.713050 |
| 140 | 590 | 4 | 3.0 | 1 | 2.0 | 3 | 1 | 9.6249 | 80.674 | 23.885 | 0.609160 | 0.548480 |
| 490 | 591 | 4 | 0.5 | 1 | 2.0 | 3 | 6 | 46.4651 | 83.302 | 21.217 | 0.547160 | 0.491710 |
| 249 | 592 | 1 | 0.5 | 1 | 2.0 | 7 | 6 | 25.0322 | 86.015 | 51.254 | 0.375230 | 0.329410 |
| 297 | 593 | 1 | 0.5 | 1 | 2.0 | 3 | 6 | 0.4945 | 147.650 | 69.650 | 0.002650 | 0.006580 |
| 619 | 594 | 1 | 3.0 | 1 | 2.0 | 3 | 6 | 3.5367 | 108.760 | 35.375 | 0.144660 | 0.192520 |
| 606 | 595 | 4 | 0.5 | 4 | 2.0 | 7 | 1 | 42.9184 | 73.372 | 47.206 | 0.822590 | 0.736920 |
| 91 | 596 | 1 | 3.0 | 1 | 2.0 | 7 | 1 | 6.0610 | 81.988 | 58.237 | 0.607560 | 0.542050 |
| 294 | 597 | 4 | 0.5 | 4 | 0.5 | 3 | 6 | 71.2234 | 85.146 | 21.625 | 0.555240 | 0.515630 |
| 84 | 598 | 4 | 3.0 | 1 | 0.5 | 7 | 1 | 5.4886 | 80.022 | 61.224 | 0.806610 | 0.774350 |
| 186 | 599 | 4 | 0.5 | 1 | 2.0 | 7 | 6 | 17.6387 | 79.421 | 42.950 | 0.769680 | 0.684290 |
| 181 | 600 | 1 | 0.5 | 4 | 0.5 | 7 | 6 | 0.0000 | 76.705 | 46.786 | 0.397800 | 0.280670 |

Appendix A1 Results of simulation runs (continued)

| StdOrder | RunOrder | A | B | C | D | E | F | KPI1 | KPI2 | KPI3 | KPI4 | KPI5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 418 | 601 | 4 | 0.5 | 1 | 0.5 | 3 | 6 | 4.2070 | 80.848 | 20.744 | 0.529740 | 0.442510 |
| 447 | 602 | 1 | 3.0 | 4 | 2.0 | 7 | 6 | 13.1936 | 79.592 | 47.059 | 0.571580 | 0.523140 |
| 463 | 603 | 1 | 3.0 | 4 | 2.0 | 3 | 1 | 10.3489 | 89.220 | 36.736 | 0.391820 | 0.414600 |
| 190 | 604 | 4 | 0.5 | 4 | 2.0 | 7 | 6 | 40.5113 | 74.606 | 41.356 | 0.795450 | 0.705380 |
| 546 | 605 | 4 | 0.5 | 1 | 0.5 | 3 | 6 | 4.5322 | 80.863 | 20.580 | 0.527510 | 0.440500 |
| 345 | 606 | 1 | 0.5 | 1 | 2.0 | 7 | 1 | 30.7433 | 84.047 | 64.383 | 0.506920 | 0.421780 |
| 75 | 607 | 1 | 3.0 | 1 | 2.0 | 3 | 1 | 5.2305 | 94.775 | 35.915 | 0.296030 | 0.305890 |
| 613 | 608 | 1 | 0.5 | 4 | 0.5 | 3 | 6 | 0.6853 | 146.810 | 69.138 | 0.011100 | 0.027940 |
| 539 | 609 | 1 | 3.0 | 1 | 2.0 | 7 | 1 | 5.0656 | 83.635 | 69.206 | 0.640730 | 0.587850 |
| 170 | 610 | 4 | 0.5 | 1 | 2.0 | 3 | 6 | 47.1619 | 83.590 | 21.483 | 0.550750 | 0.495590 |
| 331 | 611 | 1 | 3.0 | 1 | 2.0 | 3 | 1 | 4.8099 | 92.122 | 34.893 | 0.314420 | 0.318340 |
| 279 | 612 | 1 | 3.0 | 4 | 0.5 | 7 | 1 | 4.7827 | 77.210 | 58.380 | 0.625060 | 0.560250 |
| 72 | 613 | 4 | 3.0 | 4 | 0.5 | 3 | 1 | 18.7035 | 78.389 | 26.450 | 0.670590 | 0.634040 |
| 252 | 614 | 4 | 3.0 | 1 | 2.0 | 7 | 6 | 4.5762 | 79.636 | 44.167 | 0.757350 | 0.691340 |
| 240 | 615 | 4 | 3.0 | 4 | 2.0 | 3 | 6 | 18.2680 | 83.252 | 23.014 | 0.587040 | 0.552090 |
| 311 | 616 | 1 | 3.0 | 4 | 0.5 | 7 | 6 | 4.7944 | 77.752 | 45.636 | 0.554310 | 0.488240 |
| 579 | 617 | 1 | 3.0 | 1 | 0.5 | 3 | 1 | 2.8329 | 92.252 | 34.380 | 0.282530 | 0.267930 |
| 401 | 618 | 1 | 0.5 | 1 | 0.5 | 7 | 1 | 4.0705 | 92.663 | 207.060 | 0.769950 | 0.748400 |
| 43 | 619 | 1 | 3.0 | 1 | 2.0 | 3 | 6 | 3.9346 | 108.990 | 35.657 | 0.152330 | 0.197880 |
| 174 | 620 | 4 | 0.5 | 4 | 2.0 | 3 | 6 | 82.9804 | 82.325 | 22.503 | 0.584950 | 0.543200 |
| 589 | 621 | 1 | 0.5 | 4 | 2.0 | 3 | 1 | 22.4789 | 99.593 | 47.397 | 0.173250 | 0.209850 |
| 635 | 622 | 1 | 3.0 | 1 | 2.0 | 7 | 6 | 6.0983 | 83.043 | 47.652 | 0.546660 | 0.484910 |
| 553 | 623 | 1 | 0.5 | 1 | 2.0 | 3 | 6 | 0.7874 | 146.600 | 69.220 | 0.005860 | 0.015570 |
| 472 | 624 | 4 | 3.0 | 4 | 0.5 | 7 | 1 | 0.5252 | 80.791 | 73.241 | 0.803530 | 0.787350 |
| 225 | 625 | 1 | 0.5 | 1 | 0.5 | 3 | 6 | 0.1745 | 148.010 | 69.713 | 0.000570 | 0.001400 |
| 456 | 626 | 4 | 3.0 | 4 | 0.5 | 3 | 1 | 18.1378 | 78.957 | 26.266 | 0.670960 | 0.629090 |
| 14 | 627 | 4 | 0.5 | 4 | 2.0 | 3 | 1 | 86.2767 | 76.398 | 27.088 | 0.698490 | 0.645320 |
| 50 | 628 | 4 | 0.5 | 1 | 0.5 | 7 | 6 | 9.6246 | 80.343 | 45.545 | 0.772210 | 0.691720 |
| 293 | 629 | 1 | 0.5 | 4 | 0.5 | 3 | 6 | 0.8589 | 145.630 | 68.369 | 0.012550 | 0.032230 |
| 260 | 630 | 4 | 3.0 | 1 | 0.5 | 3 | 1 | 3.3178 | 80.969 | 26.509 | 0.597070 | 0.532760 |
| 621 | 631 | 1 | 0.5 | 4 | 2.0 | 3 | 6 | 1.6893 | 141.740 | 66.431 | 0.014140 | 0.035260 |
| 83 | 632 | 1 | 3.0 | 1 | 0.5 | 7 | 1 | 1.5444 | 83.161 | 76.670 | 0.656400 | 0.612380 |
| 7 | 633 | 1 | 3.0 | 4 | 0.5 | 3 | 1 | 8.7809 | 91.699 | 36.712 | 0.357010 | 0.382980 |
| 503 | 634 | 1 | 3.0 | 4 | 0.5 | 7 | 6 | 4.8042 | 77.695 | 45.521 | 0.554390 | 0.483370 |
| 132 | 635 | 4 | 3.0 | 1 | 0.5 | 3 | 1 | 2.9765 | 80.661 | 26.323 | 0.597210 | 0.533030 |
| 515 | 636 | 1 | 3.0 | 1 | 0.5 | 3 | 1 | 2.4988 | 91.799 | 33.294 | 0.277480 | 0.257170 |
| 90 | 637 | 4 | 0.5 | 1 | 2.0 | 7 | 1 | 13.4649 | 79.321 | 61.670 | 0.825760 | 0.763160 |
| 51 | 638 | 1 | 3.0 | 1 | 0.5 | 7 | 6 | 0.2057 | 82.611 | 49.719 | 0.533130 | 0.449820 |
| 450 | 639 | 4 | 0.5 | 1 | 0.5 | 3 | 1 | 5.7401 | 80.767 | 27.380 | 0.625430 | 0.531960 |
| 637 | 640 | 1 | 0.5 | 4 | 2.0 | 7 | 6 | 73.6386 | 82.822 | 51.027 | 0.398430 | 0.386050 |

**APPENDIX B**

# Minitab Outputs

## Minitab outputs for KPI1

### Factorial Fit: KPI1 versus A, B, C, D, E, F

Estimated Effects and Coefficients for KPI1 (coded units)

| Term | Effect | Coef | SE Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 15.471 | 0.09055 | 170.85 | 0.000 |
| A | 10.227 | 5.113 | 0.09099 | 56.20 | 0.000 |
| B | -16.041 | -8.021 | 0.09055 | -88.57 | 0.000 |
| C | 15.371 | 7.686 | 0.08935 | 86.02 | 0.000 |
| D | 14.252 | 7.126 | 0.08988 | 79.28 | 0.000 |
| E | -7.041 | -3.520 | 0.09026 | -39.00 | 0.000 |
| F | -0.429 | -0.215 | 0.09055 | -2.37 | 0.018 |
| A*B | -7.251 | -3.625 | 0.09099 | -39.85 | 0.000 |
| A*C | 5.075 | 2.537 | 0.09217 | 27.53 | 0.000 |
| A*D | 0.450 | 0.225 | 0.08849 | 2.54 | 0.011 |
| A*E | -15.199 | -7.600 | 0.09099 | -83.52 | 0.000 |
| A*F | 2.768 | 1.384 | 0.09099 | 15.21 | 0.000 |
| B*C | -9.257 | -4.628 | 0.08935 | -51.80 | 0.000 |
| B*D | -9.614 | -4.807 | 0.08988 | -53.48 | 0.000 |
| B*E | 3.729 | 1.864 | 0.09026 | 20.66 | 0.000 |
| B*F | -0.067 | -0.033 | 0.09055 | -0.37 | 0.712 |
| C*D | 2.645 | 1.322 | 0.09137 | 14.47 | 0.000 |
| C*E | -3.943 | -1.972 | 0.08964 | -21.99 | 0.000 |
| C*F | -1.724 | -0.862 | 0.08935 | -9.65 | 0.000 |
| D*E | 6.542 | 3.271 | 0.09018 | 36.27 | 0.000 |
| D*F | -0.270 | -0.135 | 0.08988 | -1.50 | 0.134 |
| E*F | 2.304 | 1.152 | 0.09026 | 12.76 | 0.000 |
| A*B*C | -4.054 | -2.027 | 0.09217 | -21.99 | 0.000 |
| A*B*D | 0.027 | 0.014 | 0.08849 | 0.15 | 0.878 |
| A*B*E | 11.247 | 5.623 | 0.09099 | 61.80 | 0.000 |
| A*B*F | -1.891 | -0.946 | 0.09099 | -10.39 | 0.000 |
| A*C*D | -3.300 | -1.650 | 0.08755 | -18.85 | 0.000 |
| A*C*E | -7.830 | -3.915 | 0.09217 | -42.48 | 0.000 |
| A*C*F | -0.331 | -0.165 | 0.09217 | -1.79 | 0.073 |
| A*D*E | -4.126 | -2.063 | 0.08908 | -23.16 | 0.000 |
| A*D*F | -0.257 | -0.129 | 0.08849 | -1.45 | 0.147 |
| A*E*F | -1.890 | -0.945 | 0.09099 | -10.39 | 0.000 |
| B*C*D | -2.236 | -1.118 | 0.09137 | -12.23 | 0.000 |
| B*C*E | 1.829 | 0.915 | 0.08964 | 10.20 | 0.000 |
| B*C*F | 1.299 | 0.650 | 0.08935 | 7.27 | 0.000 |
| B*D*E | -4.389 | -2.194 | 0.09018 | -24.34 | 0.000 |
| B*D*F | 0.335 | 0.168 | 0.08988 | 1.87 | 0.063 |
| B*E*F | -1.820 | -0.910 | 0.09026 | -10.08 | 0.000 |
| C*D*E | 7.922 | 3.961 | 0.09108 | 43.49 | 0.000 |
| C*D*F | 1.201 | 0.600 | 0.09137 | 6.57 | 0.000 |
| C*E*F | 0.358 | 0.179 | 0.08964 | 1.99 | 0.047 |
| D*E*F | -0.172 | -0.086 | 0.09018 | -0.95 | 0.341 |
| A*B*C*D | 2.817 | 1.409 | 0.08755 | 16.09 | 0.000 |
| A*B*C*E | 5.517 | 2.758 | 0.09217 | 29.93 | 0.000 |
| A*B*C*F | 0.297 | 0.148 | 0.09217 | 1.61 | 0.108 |
| A*B*D*E | 4.020 | 2.010 | 0.08908 | 22.56 | 0.000 |
| A*B*D*F | 0.174 | 0.087 | 0.08849 | 0.98 | 0.327 |
| A*B*E*F | 1.366 | 0.683 | 0.09099 | 7.51 | 0.000 |
| A*C*D*E | 1.491 | 0.745 | 0.08695 | 8.57 | 0.000 |
| A*C*D*F | -0.123 | -0.062 | 0.08755 | -0.70 | 0.481 |
| A*C*E*F | -2.410 | -1.205 | 0.09217 | -13.07 | 0.000 |
| A*D*E*F | -2.050 | -1.025 | 0.08908 | -11.51 | 0.000 |
| B*C*D*E | -5.481 | -2.741 | 0.09108 | -30.09 | 0.000 |
| B*C*D*F | -1.083 | -0.541 | 0.09137 | -5.93 | 0.000 |
| B*C*E*F | -0.118 | -0.059 | 0.08964 | -0.66 | 0.512 |
| B*D*E*F | 0.067 | 0.034 | 0.09018 | 0.37 | 0.709 |

```
C*D*E*F      0.879   0.439  0.09108    4.82  0.000
A*B*C*D*F    0.070   0.035  0.08755    0.40  0.688
A*B*C*E*F    1.870   0.935  0.09217   10.14  0.000
A*B*D*E*F    1.931   0.966  0.08908   10.84  0.000
A*C*D*E*F    0.297   0.148  0.08695    1.71  0.088
B*C*D*E*F   -0.828  -0.414  0.09108   -4.55  0.000


S = 1.55544   R-Sq = 99.51%   R-Sq(adj) = 99.46%


Analysis of Variance for KPI1 (coded units)

Source               DF  Seq SS  Adj SS   Adj MS        F      P
Main Effects          6  119259  127196  21199.3  8762.19  0.000
2-Way Interactions   15   82471   70473   4698.2  1941.87  0.000
3-Way Interactions   20   50968   49763   2488.2  1028.42  0.000
4-Way Interactions   15    9110    9212    614.1   253.82  0.000
5-Way Interactions    5     580     580    115.9    47.92  0.000
Residual Error      529    1280    1280      2.4
  Pure Error        529    1280    1280      2.4
Total               590  263668
```

### Regression Analysis: KPI1 versus A, B, ...

```
The regression equation is
KPI1 = - 10.0 - 14.5 A + 14.8 B + 1.71 C + 9.54 D + 0.458 E - 2.55 F - 0.043
       A*B + 14.0 A*C + 10.2 A*D + 2.59 A*E + 1.79 A*F - 1.60 B*C - 9.76 B*D
       - 1.77 B*E - 7.85 C*D - 0.511 C*E - 0.849 C*F - 0.543 D*E + 0.502 E*F
       - 3.27 A*B*C - 0.171 A*B*E - 0.369 A*B*F - 2.30 A*C*D - 2.13 A*C*E
       - 1.70 A*D*E - 0.335 A*E*F + 3.39 B*C*D + 0.259 B*C*E + 0.249 B*C*F
       + 1.18 B*D*E - 0.0546 B*E*F + 2.56 C*D*E - 0.366 C*D*F + 0.0416 C*E*F
       + 0.0584 A*B*C*D + 0.530 A*B*C*E + 0.0792 A*B*D*E + 0.0852 A*B*E*F
       + 0.256 A*C*D*E + 0.0189 A*C*E*F + 0.0059 A*D*E*F - 0.856 B*C*D*E
       + 0.167 B*C*D*F + 0.0877 C*D*E*F - 0.00948 A*B*C*E*F - 0.00167
       A*B*D*E*F - 0.0377 B*C*D*E*F


S = 3.45774   R-Sq = 97.5%   R-Sq(adj) = 97.3%


Analysis of Variance

Source           DF        SS      MS       F      P
Regression       47  257175.6  5471.8  457.67  0.000
Residual Error  543    6492.1    12.0
Total           590  263667.7
```

## Minitab outputs for KPI2

### Factorial Fit: KPI2 versus A, B, C, D, E, F

Estimated Effects and Coefficients for KPI2 (coded units)

| Term | Effect | Coef | SE Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 88.451 | 0.03863 | 2289.94 | 0.000 |
| A | -16.831 | -8.415 | 0.03863 | -217.86 | 0.000 |
| B | -6.200 | -3.100 | 0.03877 | -79.97 | 0.000 |
| C | -3.069 | -1.534 | 0.03854 | -39.81 | 0.000 |
| D | -1.603 | -0.801 | 0.03842 | -20.86 | 0.000 |
| E | -15.865 | -7.933 | 0.03865 | -205.25 | 0.000 |
| F | 8.171 | 4.085 | 0.03869 | 105.60 | 0.000 |
| A*B | 6.463 | 3.231 | 0.03877 | 83.36 | 0.000 |
| A*C | 0.104 | 0.052 | 0.03854 | 1.35 | 0.177 |
| A*D | -0.535 | -0.267 | 0.03842 | -6.96 | 0.000 |
| A*E | 13.624 | 6.812 | 0.03865 | 176.26 | 0.000 |
| A*F | -7.426 | -3.713 | 0.03869 | -95.98 | 0.000 |
| B*C | -0.057 | -0.029 | 0.03764 | -0.76 | 0.445 |
| B*D | 0.311 | 0.155 | 0.03856 | 4.03 | 0.000 |
| B*E | 4.718 | 2.359 | 0.03879 | 60.82 | 0.000 |
| B*F | -3.261 | -1.631 | 0.03883 | -42.00 | 0.000 |
| C*D | -0.908 | -0.454 | 0.03862 | -11.75 | 0.000 |
| C*E | -2.057 | -1.028 | 0.03836 | -26.81 | 0.000 |
| C*F | 0.484 | 0.242 | 0.03860 | 6.27 | 0.000 |
| D*E | -0.492 | -0.246 | 0.03873 | -6.35 | 0.000 |
| D*F | 1.400 | 0.700 | 0.03849 | 18.19 | 0.000 |
| E*F | -10.031 | -5.015 | 0.03859 | -129.98 | 0.000 |
| A*B*C | 0.218 | 0.109 | 0.03764 | 2.90 | 0.004 |
| A*B*D | -0.136 | -0.068 | 0.03856 | -1.76 | 0.078 |
| A*B*E | -5.127 | -2.563 | 0.03879 | -66.08 | 0.000 |
| A*B*F | 3.569 | 1.785 | 0.03883 | 45.96 | 0.000 |
| A*C*D | -0.129 | -0.064 | 0.03862 | -1.67 | 0.096 |
| A*C*E | -0.287 | -0.144 | 0.03836 | -3.74 | 0.000 |
| A*C*F | 0.648 | 0.324 | 0.03860 | 8.40 | 0.000 |
| A*D*E | -1.026 | -0.513 | 0.03873 | -13.25 | 0.000 |
| A*D*F | 0.298 | 0.149 | 0.03849 | 3.87 | 0.000 |
| A*E*F | 6.393 | 3.196 | 0.03859 | 82.84 | 0.000 |
| B*C*D | -0.018 | -0.009 | 0.03772 | -0.24 | 0.808 |
| B*C*E | 0.090 | 0.045 | 0.03746 | 1.20 | 0.232 |
| B*C*F | 0.239 | 0.120 | 0.03771 | 3.17 | 0.002 |
| B*D*E | 0.069 | 0.035 | 0.03887 | 0.89 | 0.372 |
| B*D*F | -0.561 | -0.281 | 0.03863 | -7.26 | 0.000 |
| B*E*F | 4.136 | 2.068 | 0.03873 | 53.41 | 0.000 |
| C*D*E | 0.968 | 0.484 | 0.03816 | 12.69 | 0.000 |
| C*D*F | 0.035 | 0.017 | 0.03868 | 0.45 | 0.652 |
| C*E*F | -0.350 | -0.175 | 0.03830 | -4.57 | 0.000 |
| D*E*F | 1.386 | 0.693 | 0.03866 | 17.92 | 0.000 |
| A*B*C*D | -0.094 | -0.047 | 0.03772 | -1.25 | 0.213 |
| A*B*C*E | 0.060 | 0.030 | 0.03746 | 0.80 | 0.423 |
| A*B*C*F | -0.495 | -0.247 | 0.03771 | -6.56 | 0.000 |
| A*B*D*E | 0.052 | 0.026 | 0.03887 | 0.67 | 0.502 |
| A*B*D*F | 0.279 | 0.140 | 0.03863 | 3.61 | 0.000 |
| A*B*E*F | -3.935 | -1.967 | 0.03873 | -50.80 | 0.000 |
| A*C*D*E | -0.617 | -0.309 | 0.03816 | -8.09 | 0.000 |
| A*C*D*F | 0.083 | 0.041 | 0.03868 | 1.07 | 0.287 |
| A*C*E*F | -0.790 | -0.395 | 0.03830 | -10.32 | 0.000 |
| A*D*E*F | -0.176 | -0.088 | 0.03866 | -2.27 | 0.023 |
| B*C*D*E | -0.023 | -0.012 | 0.03725 | -0.31 | 0.756 |
| B*C*D*F | -0.121 | -0.060 | 0.03778 | -1.60 | 0.111 |
| B*C*E*F | -0.310 | -0.155 | 0.03739 | -4.14 | 0.000 |
| B*D*E*F | -0.414 | -0.207 | 0.03880 | -5.33 | 0.000 |

| | | | | | |
|---|---|---|---|---|---|
| C*D*E*F | 0.600 | 0.300 | 0.03809 | 7.88 | 0.000 |
| A*B*C*D*E | -0.034 | -0.017 | 0.03725 | -0.45 | 0.651 |
| A*B*C*D*F | 0.265 | 0.133 | 0.03778 | 3.51 | 0.000 |
| A*B*C*E*F | 0.216 | 0.108 | 0.03739 | 2.89 | 0.004 |
| A*B*D*E*F | 0.244 | 0.122 | 0.03880 | 3.14 | 0.002 |
| A*C*D*E*F | 0.373 | 0.186 | 0.03809 | 4.89 | 0.000 |

S = 0.665191 R-Sq = 99.87% R-Sq(adj) = 99.86%

Analysis of Variance for KPI2 (coded units)

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 6 | 106157 | 77935.3 | 12989.2 | 29355.55 | 0.000 |
| 2-Way Interactions | 15 | 62534 | 55958.8 | 3730.6 | 8431.11 | 0.000 |
| 3-Way Interactions | 20 | 15446 | 14203.8 | 710.2 | 1605.03 | 0.000 |
| 4-Way Interactions | 15 | 2215 | 2203.5 | 146.9 | 332.00 | 0.000 |
| 5-Way Interactions | 5 | 40 | 39.8 | 8.0 | 18.00 | 0.000 |
| Residual Error | 532 | 235 | 235.4 | 0.4 | | |
| Pure Error | 532 | 235 | 235.4 | 0.4 | | |
| Total | 593 | 186626 | | | | |

## Regression Analysis: KPI2 versus A, B, ...

The regression equation is

KPI2 = 97.9 - 7.58 A - 1.08 B + 1.99 C + 2.68 D - 0.457 E + 26.0 F + 0.301 A*B + 0.669 A*D + 1.07 A*E - 6.13 A*F + 0.506 B*D - 0.193 B*E - 5.92 B*F - 1.49 C*D - 0.646 C*E - 0.262 C*F - 0.925 D*E - 0.842 D*F - 3.93 E*F - 0.0050 A*B*C + 0.0072 A*B*E + 1.50 A*B*F + 0.0260 A*C*E + 0.156 A*C*F - 0.160 A*D*E + 0.159 A*D*F + 0.864 A*E*F + 0.0808 B*C*F + 0.0486 B*D*F + 0.903 B*E*F + 0.311 C*D*E + 0.0530 C*E*F + 0.268 D*E*F - 0.0187 A*B*C*F - 0.0308 A*B*D*F - 0.222 A*B*E*F - 0.0343 A*C*D*E - 0.0278 A*C*E*F - 0.0322 A*D*E*F - 0.0120 B*C*E*F - 0.0344 B*D*E*F - 0.00906 C*D*E*F - 0.00264 A*B*C*D*F + 0.00349 A*B*C*E*F + 0.00880 A*B*D*E*F + 0.00529 A*C*D*E*F

S = 0.929331 R-Sq = 99.7% R-Sq(adj) = 99.7%

Analysis of Variance

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 46 | 186153.9 | 4046.8 | 4685.69 | 0.000 |
| Residual Error | 547 | 472.4 | 0.9 | | |
| Total | 593 | 186626.3 | | | |

## Minitab outputs for KPI3

### Factorial Fit: lnKPI3 versus A, B, C, D, E, F

Estimated Effects and Coefficients for lnKPI3 (coded units)

| Term | Effect | Coef | SE Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 3.7580 | 0.001550 | 2424.20 | 0.000 |
| A | -0.3349 | -0.1674 | 0.001550 | -108.01 | 0.000 |
| B | -0.1396 | -0.0698 | 0.001094 | -63.82 | 0.000 |
| C | -0.0679 | -0.0340 | 0.001094 | -31.05 | 0.000 |
| D | -0.0868 | -0.0434 | 0.001511 | -28.73 | 0.000 |
| E | 0.5427 | 0.2714 | 0.001549 | 175.19 | 0.000 |
| F | -0.1916 | -0.0958 | 0.001550 | -61.81 | 0.000 |
| A*B | 0.1411 | 0.0705 | 0.001094 | 64.47 | 0.000 |
| A*C | -0.0061 | -0.0030 | 0.001094 | -2.77 | 0.006 |
| A*D | -0.0568 | -0.0284 | 0.001511 | -18.81 | 0.000 |
| A*E | 0.3094 | 0.1547 | 0.001549 | 99.87 | 0.000 |
| A*F | -0.1347 | -0.0673 | 0.001550 | -43.45 | 0.000 |
| B*C | 0.0171 | 0.0086 | 0.001094 | 7.83 | 0.000 |
| B*D | 0.0060 | 0.0030 | 0.001037 | 2.90 | 0.004 |
| B*E | 0.0889 | 0.0444 | 0.001092 | 40.67 | 0.000 |
| B*F | -0.0308 | -0.0154 | 0.001094 | -14.07 | 0.000 |
| C*D | 0.0206 | 0.0103 | 0.001037 | 9.95 | 0.000 |
| C*E | -0.1068 | -0.0534 | 0.001092 | -48.91 | 0.000 |
| C*F | 0.0541 | 0.0270 | 0.001094 | 24.71 | 0.000 |
| D*E | -0.0850 | -0.0425 | 0.001509 | -28.16 | 0.000 |
| D*F | 0.0859 | 0.0430 | 0.001511 | 28.44 | 0.000 |
| E*F | -0.2028 | -0.1014 | 0.001549 | -65.45 | 0.000 |
| A*B*C | -0.0071 | -0.0035 | 0.001094 | -3.23 | 0.001 |
| A*B*D | 0.0027 | 0.0013 | 0.001037 | 1.29 | 0.196 |
| A*B*E | -0.0935 | -0.0468 | 0.001092 | -42.81 | 0.000 |
| A*B*F | 0.0408 | 0.0204 | 0.001094 | 18.66 | 0.000 |
| A*C*D | 0.0144 | 0.0072 | 0.001037 | 6.92 | 0.000 |
| A*C*E | -0.0199 | -0.0099 | 0.001092 | -9.10 | 0.000 |
| A*C*F | 0.0202 | 0.0101 | 0.001094 | 9.23 | 0.000 |
| A*D*E | -0.0557 | -0.0279 | 0.001509 | -18.45 | 0.000 |
| A*D*F | 0.0481 | 0.0240 | 0.001511 | 15.92 | 0.000 |
| A*E*F | 0.0523 | 0.0262 | 0.001549 | 16.89 | 0.000 |
| B*C*D | -0.0024 | -0.0012 | 0.001037 | -1.16 | 0.246 |
| B*C*E | 0.0018 | 0.0009 | 0.001092 | 0.83 | 0.407 |
| B*C*F | -0.0146 | -0.0073 | 0.001094 | -6.68 | 0.000 |
| B*D*E | -0.0083 | -0.0041 | 0.001035 | -3.99 | 0.000 |
| B*D*F | -0.0058 | -0.0029 | 0.001037 | -2.78 | 0.006 |
| B*E*F | 0.0605 | 0.0302 | 0.001092 | 27.68 | 0.000 |
| C*D*E | 0.0111 | 0.0055 | 0.001035 | 5.35 | 0.000 |
| C*D*F | -0.0177 | -0.0088 | 0.001037 | -8.52 | 0.000 |
| C*E*F | 0.0697 | 0.0349 | 0.001092 | 31.92 | 0.000 |
| D*E*F | 0.0646 | 0.0323 | 0.001509 | 21.39 | 0.000 |
| A*B*C*D | -0.0067 | -0.0033 | 0.001037 | -3.21 | 0.001 |
| A*B*C*E | -0.0026 | -0.0013 | 0.001092 | -1.17 | 0.242 |
| A*B*C*F | 0.0020 | 0.0010 | 0.001094 | 0.93 | 0.353 |
| A*B*D*E | 0.0090 | 0.0045 | 0.001035 | 4.33 | 0.000 |
| A*B*D*F | -0.0001 | -0.0001 | 0.001037 | -0.05 | 0.957 |
| A*B*E*F | -0.0591 | -0.0296 | 0.001092 | -27.07 | 0.000 |
| A*C*D*E | -0.0167 | -0.0084 | 0.001035 | -8.07 | 0.000 |
| A*C*D*F | -0.0193 | -0.0096 | 0.001037 | -9.30 | 0.000 |
| A*C*E*F | 0.0079 | 0.0039 | 0.001092 | 3.61 | 0.000 |
| A*D*E*F | 0.0284 | 0.0142 | 0.001509 | 9.42 | 0.000 |
| B*C*D*E | 0.0036 | 0.0018 | 0.001035 | 1.74 | 0.082 |
| B*C*D*F | 0.0031 | 0.0015 | 0.001037 | 1.49 | 0.138 |
| B*C*E*F | -0.0115 | -0.0057 | 0.001092 | -5.25 | 0.000 |
| A*B*C*D*E | 0.0007 | 0.0004 | 0.001035 | 0.36 | 0.718 |

```
A*B*C*D*F   0.0079   0.0040  0.001037     3.83  0.000
A*B*C*E*F   0.0077   0.0039  0.001092     3.53  0.000


S = 0.0185231   R-Sq = 99.77%   R-Sq(adj) = 99.75%


Analysis of Variance for lnKPI3 (coded units)

Source               DF   Seq SS   Adj SS   Adj MS         F      P
Main Effects          6  52.3541  25.0563  4.17604  12171.33  0.000
2-Way Interactions   15  18.3843  10.3471  0.68981   2010.48  0.000
3-Way Interactions   20   3.9147   3.2352  0.16176    471.45  0.000
4-Way Interactions   13   0.5699   0.5797  0.04459    129.96  0.000
5-Way Interactions    3   0.0179   0.0179  0.00595     17.34  0.000
Residual Error      499   0.1712   0.1712  0.00034
  Pure Error        499   0.1712   0.1712  0.00034
Total               556  75.4121
```

## Regression Analysis: lnKPI3 versus A, B, ...

```
The regression equation is
lnKPI3 = 3.34 - 0.314 A - 0.182 B + 0.139 C + 0.122 D + 0.194 E + 0.343 F
         + 0.0327 A*B - 0.0199 A*C - 0.0118 A*D + 0.0692 A*E - 0.0721 A*F
         + 0.0136 B*C + 0.0273 B*D + 0.00778 B*E - 0.0742 B*F - 0.0535 C*D
         - 0.0353 C*E - 0.0170 C*F - 0.0243 D*E - 0.0135 D*F - 0.0649 E*F
         - 0.000280 A*B*C - 0.00137 A*B*E + 0.0198 A*B*F + 0.0270 A*C*D
         - 0.000576 A*C*E + 0.00276 A*C*F - 0.0154 A*D*E + 0.00181 A*D*F
         + 0.00515 A*E*F - 0.00101 B*C*F - 0.00333 B*D*E - 0.00243 B*D*F
         + 0.0133 B*E*F + 0.00865 C*D*E + 0.00253 C*D*F + 0.00392 C*E*F
         + 0.00281 D*E*F - 0.00138 A*B*C*D + 0.000450 A*B*D*E - 0.00326
        A*B*E*F - 0.00248 A*C*D*E - 0.00261 A*C*D*F + 0.000390 A*C*E*F
         + 0.00245 A*D*E*F - 0.000178 B*C*E*F + 0.000189 A*B*C*D*F
         + 0.000000 A*B*C*E*F

S = 0.0202348   R-Sq = 99.7%   R-Sq(adj) = 99.7%


Analysis of Variance

Source           DF       SS      MS        F      P
Regression       48  75.2041  1.5668  3826.49  0.000
Residual Error  508   0.2080  0.0004
Total           556  75.4121
```

## Minitab outputs for KPI4

### Factorial Fit: KPI4 versus A, B, C, D, E, F

Estimated Effects and Coefficients for KPI4 (coded units)

| Term | Effect | Coef | SE Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 0.52253 | 0.000501 | 1043.88 | 0.000 |
| A | 0.35015 | 0.17508 | 0.000500 | 350.35 | 0.000 |
| B | 0.06584 | 0.03292 | 0.000497 | 66.19 | 0.000 |
| C | 0.01754 | 0.00877 | 0.000501 | 17.52 | 0.000 |
| D | 0.00589 | 0.00295 | 0.000496 | 5.95 | 0.000 |
| E | 0.28188 | 0.14094 | 0.000500 | 282.04 | 0.000 |
| F | -0.10796 | -0.05398 | 0.000501 | -107.84 | 0.000 |
| A*B | -0.07481 | -0.03740 | 0.000496 | -75.34 | 0.000 |
| A*C | 0.00684 | 0.00342 | 0.000500 | 6.85 | 0.000 |
| A*D | 0.00609 | 0.00304 | 0.000495 | 6.15 | 0.000 |
| A*E | -0.08875 | -0.04438 | 0.000499 | -88.95 | 0.000 |
| A*F | 0.03655 | 0.01828 | 0.000500 | 36.57 | 0.000 |
| B*C | 0.01294 | 0.00647 | 0.000497 | 13.01 | 0.000 |
| B*D | 0.00582 | 0.00291 | 0.000492 | 5.91 | 0.000 |
| B*E | -0.00859 | -0.00429 | 0.000496 | -8.65 | 0.000 |
| B*F | 0.00888 | 0.00444 | 0.000497 | 8.92 | 0.000 |
| C*D | 0.00891 | 0.00446 | 0.000496 | 8.99 | 0.000 |
| C*E | -0.03031 | -0.01516 | 0.000500 | -30.33 | 0.000 |
| C*F | 0.00080 | 0.00040 | 0.000501 | 0.80 | 0.422 |
| D*E | -0.01060 | -0.00530 | 0.000495 | -10.72 | 0.000 |
| D*F | 0.00938 | 0.00469 | 0.000496 | 9.47 | 0.000 |
| E*F | 0.01987 | 0.00993 | 0.000500 | 19.88 | 0.000 |
| A*B*C | -0.00790 | -0.00395 | 0.000496 | -7.96 | 0.000 |
| A*B*D | -0.00353 | -0.00177 | 0.000491 | -3.59 | 0.000 |
| A*B*E | 0.00733 | 0.00366 | 0.000496 | 7.39 | 0.000 |
| A*B*F | -0.00292 | -0.00146 | 0.000496 | -2.94 | 0.003 |
| A*C*D | -0.00048 | -0.00024 | 0.000495 | -0.49 | 0.627 |
| A*C*E | 0.00496 | 0.00248 | 0.000499 | 4.97 | 0.000 |
| A*C*F | -0.00917 | -0.00459 | 0.000500 | -9.18 | 0.000 |
| A*D*E | 0.00481 | 0.00241 | 0.000494 | 4.87 | 0.000 |
| A*D*F | 0.00008 | 0.00004 | 0.000495 | 0.08 | 0.933 |
| A*E*F | 0.00027 | 0.00013 | 0.000499 | 0.27 | 0.788 |
| B*C*D | -0.00085 | -0.00043 | 0.000492 | -0.86 | 0.388 |
| B*C*E | 0.00031 | 0.00016 | 0.000496 | 0.32 | 0.751 |
| B*C*F | -0.00559 | -0.00279 | 0.000497 | -5.62 | 0.000 |
| B*D*E | -0.00317 | -0.00158 | 0.000491 | -3.22 | 0.001 |
| B*D*F | 0.00036 | 0.00018 | 0.000492 | 0.37 | 0.715 |
| B*E*F | 0.01081 | 0.00541 | 0.000496 | 10.89 | 0.000 |
| C*D*E | 0.00593 | 0.00296 | 0.000495 | 5.99 | 0.000 |
| C*D*F | 0.00028 | 0.00014 | 0.000496 | 0.28 | 0.778 |
| C*E*F | 0.02076 | 0.01038 | 0.000500 | 20.77 | 0.000 |
| D*E*F | 0.00613 | 0.00306 | 0.000495 | 6.19 | 0.000 |
| A*B*C*D | -0.00246 | -0.00123 | 0.000491 | -2.50 | 0.013 |
| A*B*C*E | 0.00060 | 0.00030 | 0.000496 | 0.60 | 0.548 |
| A*B*C*F | 0.00309 | 0.00154 | 0.000496 | 3.11 | 0.002 |
| A*B*D*E | 0.00119 | 0.00060 | 0.000491 | 1.22 | 0.224 |
| A*B*D*F | -0.00153 | -0.00077 | 0.000491 | -1.56 | 0.119 |
| A*B*E*F | -0.01146 | -0.00573 | 0.000496 | -11.56 | 0.000 |
| A*C*D*E | -0.00236 | -0.00118 | 0.000494 | -2.39 | 0.017 |
| A*C*D*F | 0.00276 | 0.00138 | 0.000495 | 2.79 | 0.005 |
| A*C*E*F | -0.00767 | -0.00384 | 0.000499 | -7.69 | 0.000 |
| A*D*E*F | -0.00178 | -0.00089 | 0.000494 | -1.80 | 0.072 |
| B*C*D*E | -0.00018 | -0.00009 | 0.000491 | -0.18 | 0.855 |
| B*C*D*F | 0.00058 | 0.00029 | 0.000492 | 0.59 | 0.558 |
| B*C*E*F | -0.00200 | -0.00100 | 0.000496 | -2.01 | 0.045 |
| B*D*E*F | 0.00179 | 0.00089 | 0.000491 | 1.82 | 0.070 |

| | | | | | |
|---|---|---|---|---|---|
| C*D*E*F | -0.00104 | -0.00052 | 0.000495 | -1.06 | 0.292 |
| A*B*C*D*E | 0.00154 | 0.00077 | 0.000491 | 1.57 | 0.118 |
| A*B*C*D*F | 0.00076 | 0.00038 | 0.000491 | 0.78 | 0.438 |
| A*B*C*E*F | 0.00276 | 0.00138 | 0.000496 | 2.78 | 0.006 |
| A*C*D*E*F | 0.00548 | 0.00274 | 0.000494 | 5.55 | 0.000 |
| B*C*D*E*F | -0.00180 | -0.00090 | 0.000491 | -1.83 | 0.068 |

S = 0.00877544 R-Sq = 99.89% R-Sq(adj) = 99.87%

Analysis of Variance for KPI4 (coded units)

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 6 | 34.7782 | 34.6485 | 5.77474 | 74988.55 | 0.000 |
| 2-Way Interactions | 15 | 2.4884 | 2.4647 | 0.16431 | 2133.72 | 0.000 |
| 3-Way Interactions | 20 | 0.0888 | 0.0841 | 0.00421 | 54.64 | 0.000 |
| 4-Way Interactions | 15 | 0.0290 | 0.0297 | 0.00198 | 25.72 | 0.000 |
| 5-Way Interactions | 5 | 0.0055 | 0.0055 | 0.00110 | 14.33 | 0.000 |
| Residual Error | 549 | 0.0423 | 0.0423 | 0.00008 | | |
| Pure Error | 549 | 0.0423 | 0.0423 | 0.00008 | | |
| Total | 610 | 37.4322 | | | | |

## Regression Analysis: KPI4 versus A, B, ...

The regression equation is

KPI4 = - 0.432 + 0.207 A + 0.0800 B + 0.0280 C + 0.0153 D + 0.147 E - 0.0334 F - 0.0242 A*B + 0.00625 A*C - 0.00045 A*D - 0.0189 A*E + 0.00801 A*F + 0.0102 B*C + 0.0105 B*D - 0.00827 B*E - 0.00169 B*F - 0.00142 C*D - 0.0106 C*E - 0.00786 D*E - 0.00142 D*F - 0.00288 E*F - 0.00182 A*B*C - 0.000646 A*B*D + 0.00211 A*B*E + 0.000189 A*B*F + 0.000244 A*C*E - 0.00201 A*C*F + 0.000737 A*D*E - 0.00199 B*C*F - 0.00101 B*D*E + 0.00128 B*E*F + 0.000936 C*D*E + 0.000782 C*E*F + 0.000583 D*E*F - 0.000165 A*B*C*D + 0.000568 A*B*C*F - 0.000199 A*B*E*F - 0.000013 A*C*D*E + 0.000047 A*C*D*F + 0.000136 A*C*E*F + 0.000167 B*C*E*F - 0.000066 A*B*C*E*F + 0.000014 A*C*D*E*F

S = 0.0110675 R-Sq = 99.8% R-Sq(adj) = 99.8%

Analysis of Variance

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 42 | 37.36258 | 0.88959 | 7262.51 | 0.000 |
| Residual Error | 568 | 0.06957 | 0.00012 | | |
| Total | 610 | 37.43215 | | | |

## Minitab outputs for KPI5

### Factorial Fit: lnKPI5 versus A, B, C, D, E, F

Estimated Effects and Coefficients for lnKPI5 (coded units)

| Term | Effect | Coef | SE Coef | T | P |
|---|---|---|---|---|---|
| Constant | | -1.010 | 0.002354 | -429.01 | 0.000 |
| A | 1.104 | 0.552 | 0.002354 | 234.44 | 0.000 |
| B | 0.580 | 0.290 | 0.002354 | 123.16 | 0.000 |
| C | 0.186 | 0.093 | 0.002308 | 40.37 | 0.000 |
| D | 0.137 | 0.068 | 0.002369 | 28.82 | 0.000 |
| E | 0.962 | 0.481 | 0.002342 | 205.28 | 0.000 |
| F | -0.622 | -0.311 | 0.002351 | -132.31 | 0.000 |
| A*B | -0.570 | -0.285 | 0.002354 | -121.18 | 0.000 |
| A*C | -0.123 | -0.062 | 0.002308 | -26.72 | 0.000 |
| A*D | -0.127 | -0.064 | 0.002369 | -26.85 | 0.000 |
| A*E | -0.654 | -0.327 | 0.002342 | -139.66 | 0.000 |
| A*F | 0.487 | 0.244 | 0.002351 | 103.67 | 0.000 |
| B*C | -0.071 | -0.035 | 0.002308 | -15.30 | 0.000 |
| B*D | -0.100 | -0.050 | 0.002369 | -21.03 | 0.000 |
| B*E | -0.449 | -0.225 | 0.002342 | -95.95 | 0.000 |
| B*F | 0.386 | 0.193 | 0.002351 | 82.15 | 0.000 |
| C*D | 0.003 | 0.001 | 0.002293 | 0.57 | 0.566 |
| C*E | -0.205 | -0.102 | 0.002366 | -43.22 | 0.000 |
| C*F | 0.073 | 0.037 | 0.002357 | 15.59 | 0.000 |
| D*E | -0.174 | -0.087 | 0.002357 | -36.96 | 0.000 |
| D*F | 0.161 | 0.080 | 0.002366 | 33.94 | 0.000 |
| E*F | 0.380 | 0.190 | 0.002363 | 80.36 | 0.000 |
| A*B*C | 0.074 | 0.037 | 0.002308 | 15.96 | 0.000 |
| A*B*D | 0.098 | 0.049 | 0.002369 | 20.70 | 0.000 |
| A*B*E | 0.449 | 0.224 | 0.002342 | 95.84 | 0.000 |
| A*B*F | -0.381 | -0.190 | 0.002351 | -81.01 | 0.000 |
| A*C*D | -0.008 | -0.004 | 0.002293 | -1.83 | 0.068 |
| A*C*E | 0.127 | 0.063 | 0.002366 | 26.82 | 0.000 |
| A*C*F | -0.078 | -0.039 | 0.002357 | -16.59 | 0.000 |
| A*D*E | 0.135 | 0.068 | 0.002357 | 28.66 | 0.000 |
| A*D*F | -0.130 | -0.065 | 0.002366 | -27.53 | 0.000 |
| A*E*F | -0.366 | -0.183 | 0.002363 | -77.50 | 0.000 |
| B*C*D | -0.001 | -0.001 | 0.002293 | -0.23 | 0.814 |
| B*C*E | 0.078 | 0.039 | 0.002366 | 16.59 | 0.000 |
| B*C*F | -0.063 | -0.032 | 0.002357 | -13.44 | 0.000 |
| B*D*E | 0.114 | 0.057 | 0.002357 | 24.12 | 0.000 |
| B*D*F | -0.121 | -0.060 | 0.002366 | -25.55 | 0.000 |
| B*E*F | -0.300 | -0.150 | 0.002363 | -63.49 | 0.000 |
| C*D*E | 0.030 | 0.015 | 0.002351 | 6.36 | 0.000 |
| C*D*F | 0.023 | 0.012 | 0.002342 | 5.01 | 0.000 |
| C*E*F | -0.025 | -0.013 | 0.002299 | -5.48 | 0.000 |
| D*E*F | -0.055 | -0.028 | 0.002377 | -11.63 | 0.000 |
| A*B*C*D | -0.002 | -0.001 | 0.002293 | -0.34 | 0.733 |
| A*B*C*E | -0.076 | -0.038 | 0.002366 | -16.02 | 0.000 |
| A*B*C*F | 0.059 | 0.030 | 0.002357 | 12.56 | 0.000 |
| A*B*D*E | -0.116 | -0.058 | 0.002357 | -24.62 | 0.000 |
| A*B*D*F | 0.120 | 0.060 | 0.002366 | 25.42 | 0.000 |
| A*B*E*F | 0.298 | 0.149 | 0.002363 | 63.07 | 0.000 |
| A*C*D*E | -0.022 | -0.011 | 0.002351 | -4.59 | 0.000 |
| A*C*D*F | -0.020 | -0.010 | 0.002342 | -4.19 | 0.000 |
| A*C*E*F | 0.048 | 0.024 | 0.002299 | 10.54 | 0.000 |
| A*D*E*F | 0.065 | 0.032 | 0.002377 | 13.62 | 0.000 |
| B*C*D*E | -0.005 | -0.002 | 0.002351 | -1.04 | 0.300 |
| B*C*D*F | -0.022 | -0.011 | 0.002342 | -4.66 | 0.000 |
| B*C*E*F | 0.062 | 0.031 | 0.002299 | 13.57 | 0.000 |
| B*D*E*F | 0.074 | 0.037 | 0.002377 | 15.50 | 0.000 |

```
C*D*E*F    -0.010  -0.005  0.002284    -2.26  0.024
A*B*C*D*E   0.006   0.003  0.002351     1.19  0.234
A*B*C*D*F   0.025   0.013  0.002342     5.42  0.000
A*B*C*E*F  -0.063  -0.032  0.002299   -13.79  0.000
A*B*D*E*F  -0.071  -0.035  0.002377   -14.88  0.000
A*C*D*E*F   0.024   0.012  0.002284     5.34  0.000
B*C*D*E*F  -0.002  -0.001  0.002284    -0.43  0.667


S = 0.0408505   R-Sq = 99.81%   R-Sq(adj) = 99.78%


Analysis of Variance for lnKPI5 (coded units)

Source               DF   Seq SS   Adj SS   Adj MS         F      P
Main Effects          6  257.988  211.218  35.2030  21095.29  0.000
2-Way Interactions   15  126.230  140.962   9.3975   5631.42  0.000
3-Way Interactions   20   66.242   71.153   3.5576   2131.90  0.000
4-Way Interactions   15   18.028   18.339   1.2226    732.64  0.000
5-Way Interactions    6    1.507    1.507   0.2512    150.53  0.000
Residual Error      548    0.914    0.914   0.0017
  Pure Error        548    0.914    0.914   0.0017
Total               610  470.909
```

### Regression Analysis: lnKPI5 versus A, B, ...

```
The regression equation is
lnKPI5 = - 2.53 + 0.364 A - 0.0303 B + 0.185 C + 0.0788 D + 0.373 E - 2.69 F
         + 0.0048 A*B - 0.0173 A*C - 0.0070 A*D - 0.0598 A*E + 0.665 A*F
         + 0.0367 B*C + 0.0485 B*D - 0.0163 B*E + 0.844 B*F - 0.0339 C*E
         + 0.187 C*F - 0.0741 D*E + 0.498 D*F + 0.345 E*F - 0.00927 A*B*C
         - 0.0101 A*B*D + 0.00438 A*B*E - 0.210 A*B*F + 0.00402 A*C*E
         - 0.0474 A*C*F + 0.0157 A*D*E - 0.121 A*D*F - 0.0863 A*E*F
         - 0.00516 B*C*E - 0.0638 B*C*F + 0.0102 B*D*E - 0.160 B*D*F
         - 0.112 B*E*F - 0.00024 C*D*E - 0.00258 C*D*F - 0.0270 C*E*F
         - 0.0599 D*E*F + 0.00143 A*B*C*E + 0.0159 A*B*C*F - 0.00299 A*B*D*E
         + 0.0396 A*B*D*F + 0.0278 A*B*E*F - 0.000240 A*C*D*E - 0.00038
        A*C*D*F + 0.00684 A*C*E*F + 0.0145 A*D*E*F - 0.00193 B*C*D*F +
        0.00956 B*C*E*F + 0.0196 B*D*E*F + 0.00193 C*D*E*F + 0.000481
        A*B*C*D*F - 0.00240 A*B*C*E*F - 0.00483 A*B*D*E*F - 0.000233
        A*C*D*E*F


S = 0.0493833   R-Sq = 99.7%   R-Sq(adj) = 99.7%


Analysis of Variance

Source           DF        SS      MS        F      P
Regression       55  469.5556  8.5374  3500.77  0.000
Residual Error  555    1.3535  0.0024
Total           610  470.9091
```