A Critical Evaluation of Empirical Non-linear Control System and System Dynamics Modeling Theories for Mitigating Risks Arising From Bullwhip Effect

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Dedication

I dedicate this dissertation in memory of my late uncle, Kwame Fosu, who took me in at the age of six and sent me to a boarding secondary school where I learned the most in all my young adult life. I also dedicate this to my late mother, Obaapanin Dorcas Akua Afriyie, who passed away while I was pursuing this doctoral degree and wished she had lived three years longer to see my greatest academic achievement.

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Abstract of Dissertation

A Critical Evaluation of Empirical Non-linear Control System and System Dynamics Modeling Theories for Mitigating Risks Arising From Bullwhip Effect

Bullwhip effect is a dysfunctional phenomenon in supply chains. It occurs primarily because of disruptions and delays in information sharing, lead-time delays in supplier order processing, panic stocking (beer game), lack of coordination, and gaps between echelon-level ordering and actual consumption at the customers' end. Bullwhip effect causes propagation of demand variations upstream that gradually amplifies in the form of tidal waves. This effect can cause significant losses because of excess in inventory, wastage and obsolescence of inventory. Bullwhip effect is one of the major indicators of inefficiencies in a supply chain. Its probability of occurrence is more in multi-echelon supply chains.

The bullwhip effect was formally recognized by Jay W. Forrester. This effect results in demand waves with false demand amplification that travel upstream in a supply chain with gradually increasing amplitudes at every echelon the wave crosses. The false amplification is caused by multiple factor variables, causing inefficiencies in the supply chain. Each factor variable may have its own causes that cannot be standardized as they may vary significantly in different supply chains depending upon the local conditions. These conditions are normally known to the supply chain managers, but they lack visibility into the bigger picture to make strategic decisions. In this research, based on review of theories on such factor variables and system dynamics modeling of the bullwhip effect, a six-step process has been designed to support supply chain managers with creating a system dynamics model specific to their supply chains and investigating all significant relationships that can be controlled

in their environments. This six-step process has been tested using a test database having 1,000 records generated in MATLAB. Based on the modeling efforts and test results, a detailed account is presented on how these steps can be carried out and interpreted with the help of surveys conducted in their respective supply chains such that they can choose and execute the most appropriate and effective control strategies. The optimum model obtained from the random records using factor analysis and structural equation modeling techniques has been modeled in Vensim and simulated using its random data generator. The records were created for 730 days (two years) making one day as a unit. The simulations of the 730 days in Vensim and the output data have been used to conduct 730 Taguchi's experiments using twelve by sixteen orthogonal arrays. The Taguchi methods helped in analyzing the signal-to-noise ratio characteristics of the factor variables in the Vensim model. In the end, this dissertation presents a discussion of applying the model for real-world strategic decision-making to counter bullwhip dynamics and enhancement of the model for including interaction effects of moderator variables.

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Chapter 1. Introduction

This research investigates the system dynamics occurring in supply chains because of bullwhip effect. In this chapter, this research is introduced, providing the background review of literatures (expanded later in Chapter 2), the aim and objectives, the research questions, and significance of this research. Based on the review of bullwhip factors and their interrelationships, this research presents a six-step process for defining the system dynamics model in a supply chain reflecting the changes in variables because of bullwhip effect prevailing in the supply chain. This process has been tested using randomly generated test data in MATLAB. Based on the test results, recommendations have been made on how this process can be executed for any specific supply chain to understand the influence of bullwhip effect on all other variables and define strategies to curb it.

1.1 Background of the Research

Jay W. Forrester, the inventor of system dynamics of non-linear systems in the 1950s, formally recognized the bullwhip effect while investigating system dynamics in supply chains in a simulation environment called DYNAMO (Christopher, 2011; Disney *et al*., 2009; Forrester, 1961; Geary, Disney, & Towill, 2006). Jay Forrester was analyzing the reordering and inventory replenishment activities in a supply chain (Forrester, 1961). Forrester modeled three levels of inventory in a supply chain and interconnected them through streams of materials flow downstream and information flow upstream (Forrester, 1961). The inventory levels modeled were at the factories, at the distributors, and at the retailers (Forrester, 1961). Further, he modeled lead times of various activities in the supply chain based on the actual data collected from

real-world supply chain relationships (Forrester, 1961). During his investigations, he found that variability of demand is amplified as it flows upstream in a supply chain, caused primarily by distortions of information and disruptions in information flow, along with multiple other disruptive factors (discussed in Chapter 2) (Christopher, 2011; Disney *et al*., 2009; Forrester, 1961; Geary, Disney, & Towill, 2006; Lee *et al.*, 1997). This effect was originally termed the Forrester effect and later termed the bullwhip effect (although it is unclear who coined these terms, they were popularized through a highly cited paper by Lee *et al.*, 1997). A time-series representation of ordering variations flowing through echelons of a supply chain is presented in Figure 1.1.

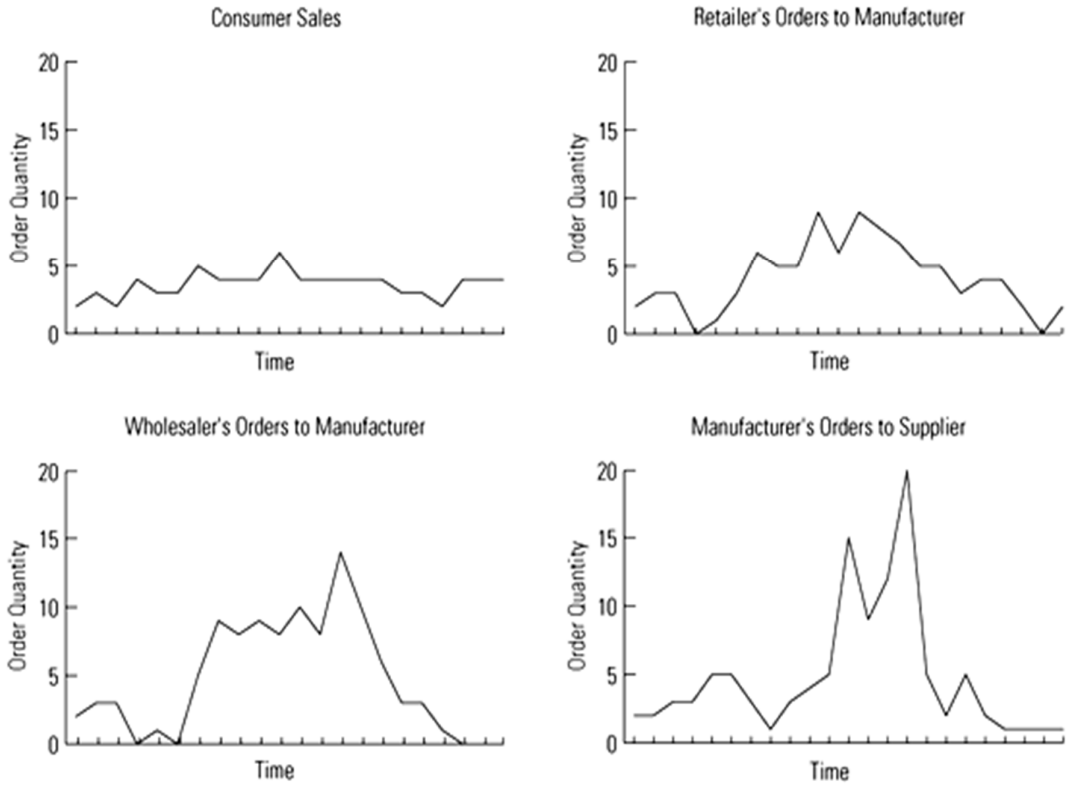

Figure 1.1: Time Series Showing How Order Varies Occur Between Any Two Echelons (MIT Sloan Management Review, 2008)

It may be observed in Figure 1.1 that there are considerable changes in ordering from consumers to retailers, from retailers to wholesalers, from wholesalers to

manufacturers, and from manufacturers to suppliers (Lee *et al.*, 1997). There are many reasons for the differences in ordering between the adjacent echelons. The key reasons are information gaps and beer gaming (a mechanism to create local safety stocks amidst visibility of stock-out risks) (Lee *et al.*, 1997).

Bullwhip effect is interpreted through indicators occurring within the supply chain (Dejonckheere *et al.*, 2003; Disney *et al*., 2009; Geary, Disney, & Towill, 2006). For example, if the variations in ordering at the suppliers' end are found to be significantly larger than the variations in consumption by the end customers, it may be interpreted that the demand waves might have amplified while propagating upstream (Disney *et al*., 2009; Geary, Disney, & Towill, 2006; Lee *et al.*, 1997). Similarly, if false demand peaks are discovered at retailer sites because of discounts or promotions, there is a chance that the actual consumption is lower, resulting in inventory accumulation in the stores (Disney *et al*., 2009; Geary, Disney, & Towill, 2006; Lee *et al.*, 1997). Such demand peaks are caused by false demand information gathered from the customer interfaces (Disney *et al*., 2009; Geary, Disney, & Towill, 2006; Lee *et al.*, 1997). Cachon, Randall, and Schmidt (2007) proposed measuring of amplification ratio and amplification difference. The former is the ratio of production variance to demand variance, and the latter is the difference between production variance and demand variance. The demand variance needs to be adjusted for seasonality.

The risks caused by bullwhip effect can be mitigated through five strategies: ad-hocacy, what-if simulation, control theory, filter theory, and operations research theory (Geary, Disney, & Towill, 2006). This research represents a critical investigation of system dynamics models applied in the control theory. The control system approach is modeled as a transfer function, and the supply chain is structured in the form of a system for ensuring stability and response (Agrawal, Sengupta, and

Shanker, 2009; Dejonckheere *et al.*, 2003; Frank & Disney, 2003; Geary, Disney, & Towill, 2006; Machuca & Barajas, 2004; Ouyang & Li, 2010; Wu & Katok, 2006). One of the approaches used in system dynamics is to model the system through a causal loop, which shows the interrelationships among active variables within a business setting with the direction of changes in the affected variables (indicated by + and – signs) (Burns & Janamanchi, 2007; Campuzano-Bolarin *et al.*, 2013; Jeong & Hing, 2015; Rodrigues, Hebbar, & Herle, 2011; Xu, 2013). The controllers may be centralized or decentralized with a finite allowance of degrees of freedom (Sancedo *et al.*, 2013).

1.2 Research Problem

Bullwhip effect is a known problem in supply chains that causes significant wastage of products, efforts to maintain inventories, and costs of inventories at different echelons of a supply chain because of false demand waves propagating upstream. In complex supply chains having multiple echelons, detecting bullwhip effect and its impacts occurring within the supply chain is a major challenge. The supply chain managers may detect bullwhip effect by comparing demand information at multiple echelons but may not be able to curb it unless a clear picture of its effects on the variables active in the supply chain could be visualized. Many researchers have stated this problem in the past (Christopher, 2011; Disney *et al.*, 2009; Forrester, 1961; Geary, Disney, & Towill, 2006; Lee *et al.*, 1997; Cachon, Randall, & Schmidt, 2007). To address this problem, system dynamics modeling may be a good approach because it can reflect the interrelationships among key variables in a research setting related to a problem area. With this motivation, and knowledge of factor analysis techniques, a process for conducting system dynamics modeling for investigating bullwhip effect in a supply chain has been proposed in this research. With the help of

this process, the primary and secondary variables active within a specific supply chain under study is found, and the significant loadings (including both positive and negative loadings) are highlighted. To gain confidence on the resulting system dynamics model, reliability and validity tests have been conducted. In this context, the aim and objectives of this research are presented in Section 1.3.

1.3 Aim and Objectives

The aim of this research is to design and test an approach for creating system dynamics modeling in a supply chain for addressing the problem of bullwhip effect. The objectives of the research include to:

- Critically examine the systems dynamics modeling in the control theory approach for mitigating bullwhip effect risks.
- Present a standardized approach for reducing bullwhip effect through systems dynamics modeling represented as path models.
- Test the approach in using a test database representing a real supply chain to verify its effectiveness.
- Make recommendations on how practitioners can use the standardized approach to begin their modeling and later add variables from their local settings for controlling bullwhip effect, knowing all the active variables related to bullwhip effect.

1.4 Research Questions

The following research questions have been addressed in this research:

(1) What are the factors causing bullwhip effect in a supply chain?

(2) How can system dynamics modeling in a supply chain be conducted for defining the system dynamics model in a supply chain to identify the dynamics caused by bullwhip effect?

(3) How can practitioners use this modeling as a standardized approach for investigating bullwhip effect in a supply chain?

1.5 Significance

Bullwhip effect is a known problem in supply chains, causing inefficiencies leading to loss of materials and obsolescence, money, efforts, services, and customers. Many past studies have investigated bullwhip effect and attempts to curb its influence on other variables. System dynamics is one such approach. In fact, bullwhip effect was originally discovered through a system dynamics model by Forrester (1961). System dynamics as a subject has matured significantly, as well, since it was introduced by J. Forrester and other contributors. Research using multivariate statistical modeling methods for deriving the relationships in a system dynamics model (showing both positive and negative relationships) specific to a supply chain, with reliability and validity verified, can be very useful for the managers of the supply chain to identify the problem areas caused by bullwhip effect and curb them through interpretations. This is a method of informed decision-making for supply chain managers. The approach designed in this research may be useful for supply chain practitioners and future researchers to visualize a supply chain deeply and explore hidden phenomena specific to a supply chain. This approach also affirms that the problems in every supply chain may be different and localized, and application of

known theories may not always be successful. Research of each supply chain may be needed to investigate the dynamics *causing* bullwhip effect and also the dynamics *caused by* bullwhip effect. The knowledge gained from this study is expected to be disseminated through conference proceedings and journal publications.

1.6 Limitations

This research has presented an approach of system dynamics modeling by integrating the knowledge of bullwhip causes and multivariate factor loading analysis (a combination of principal component analysis with VARIMAX rotation, confirmatory factor analysis, and structural equation modeling). This approach is in theory and has been tested with the help of a test database created through the RAND (N) function in MATLAB, in which test records were generated for ten factor variables found from the literature review. A total number of 1,000 records were generated from the RAND (N) function with the help of rules (defined and explained in Chapter 3) and were applied in the approach to build the system dynamics model. The limitation of this research is that the study has been carried out using a test database and academic (student) versions of the Statistical Package for Social Studies (SPSS) and LISREL(which stands for linear structural relations), which have some limitations. For example, the SPSS student version cannot import more than 1,000 records, and LISREL student version cannot model more than fifteen variables. Thus, this approach needs to be tested in additional future studies using data collected from mass surveys before it can be accredited as an empirical approach. In this research, at the most this approach can be treated as conceptually tested in the research that created it. Time, cost, and resource restrictions prevented the conduct of a wider study. This is left for expanded research for future works.

Another limitation is lack of sufficiently detailed research studies in application of system dynamics modeling for investigating bullwhip effect dynamics. Although the bullwhip effect itself was discovered through a system dynamics experiment by Forrester (1961), other researchers have not contributed much to the literary dialogue conducted significant research in developing the system dynamics modeling theory pertaining to bullwhip effect dynamics. A few studies have been reviewed in Chapter 2. The approach designed in this research has limited scope of theory-based verification given that there are few research studies to support this method. Additional study is needed in this largely untouched domain. This research is expected to be a significant addition.

The last limitation of this research is that the path modeling method (confirmatory factor analysis and structural equation modeling) does not accept variables with negative correlation values because the model cannot converge if there are negative values. Hence, the proposed approach ends with two system dynamics models: the first one with all significant correlations with a high Cronbach alpha value (model reliability score) obtained from principal component analysis with VARIMAX rotation (exploratory factor analysis); and the second one with only the positive significant correlations (after testing Cronbach alpha for the reduced model) and testing all the model fitment (validity) scores of confirmatory factor analysis and structural equation modeling. Hence, the supply chain managers may have to consult two models for decision support, taking the first model as baseline (with only model reliability tested) and the second model as the further reduced model (with reliability as well as model fitment tested).

1.7 Structure of the Dissertation

This dissertation is presented in five chapters. In the first chapter, the theory background, context, problem statement, aim, objectives, research questions, significance, and limitations are discussed. This content has been presented to set the expectations of the reader and his/her directions of thoughts before reading the rest of the paper. It also helps in knowing the positioning of this paper and how this paper can be used. The second chapter expands the theoretical study of this research. It presents a detailed review of literature on the factor variables influencing bullwhip effect in a supply chain and a review of system dynamics for modeling a supply chain facing the bullwhip problem. The third chapter presents the methodology used for conducting the primary sampling and data collection of this research such that a system dynamics model can be produced based on real supply chain inputs. The fourth chapter presents the data collected, its analysis, and the system dynamics modeling steps (based on the proposed six-step approach) using principal component analysis with VARIMAX rotation, confirmatory factor analysis, and structural equation modeling. The model reliability and goodness of fitment (validity) have been tested, and results are discussed in this chapter. The fifth chapter is the final chapter of this dissertation presenting the conclusions of this research and the recommendations arising from this research as well as the recommendations for future research.

Chapter 2. Literature Review

2.1 Introduction

This chapter presents a review of literature pertaining to bullwhip effect, its causes, its consequences, and the prominent empirical control theory approaches in mitigating bullwhip effect. The existing models of system dynamics modeling of bullwhip effect have been reviewed to produce a draft theoretical model (detailed later in Chapter 4).

2.2 Literature Review on the Bullwhip Effect

In supply chains, the order fulfillment deadlines are defined through appropriate communication of demand information (Ouyang & Li, 2010). However, in practice, there is a lag between the deadlines and actual dates of order fulfillment (Ouyang & Li, 2010). This is because of uncertainty in lead times associated in propagation of orders upstream and flow of materials downstream (Ouyang & Li, 2010). While the orders are in transit, there may be variations in actual demands not timely communicated to the echelons of the supply chain engaged in the order fulfillment procedures (Geary, Disney, & Towill, 2006; Lee *et al.*, 1997). Such variations increase with time if the information gap is not bridged and the discrepancies between order fulfillment and demand changes are not corrected in a timely manner (Ouyang and Li, 2010). If plotted, these variations appear as a tidal wave with gradually increasing amplitude, referred to as the Forrester effect or bullwhip effect (Disney, Geary, and Towill, 2006; Luong, 2007; Makui and Madadi, 2007). In addition to the problems of ineffective lead-time management and an information gap, there are other factors that contribute to amplification of the demand variance in bullwhip effect.

Key factors in the bullwhip effect include:

- Lead-time variations because of uncertainties in the supply chain, resulting in variations of safety stocks at all the echelons of the supply chain (Kelepouris, Miliotis, & Pramatari, 2008);
- Shortage gaming, also called beer gaming, in which supply chain actors maintain localized safety stocks as per their respective visibility or perceptions of risks (Hadaya & Cassivi, 2009; Makui & Madadi, 2007; Potter & Disney, 2006; Zhang & Burke, 2011);
- Order rationing, in which the small portions of the products are distributed among all customers in a phased manner given the uncertainties and delays occurring in order fulfillment (Hadaya & Cassivi, 2009; Lee, Padmanabhan, & Whang, 2004; Makui & Madadi, 2007; Potter & Disney, 2006; Shukla, Naim, & Yaseen, 2009; Zhang & Burke, 2011);
- Batch processing of orders (Hadaya & Cassivi, 2009; Lee, Padmanabhan, & Whang, 2004; Makui & Madadi, 2007; Potter & Disney, 2006; Shukla, Naim, & Yaseen, 2009; Zhang & Burke, 2011);
- Ineffective or absent information enrichment and communication protocols (Agrawal, Sengupta, & Shanker, 2009; Dejonckheere *et al.*, 2004; Machuca & Barajas, 2004; Ouyang, 2007; Wu & Katok, 2006);
- Ineffective or absent self-learning systems (Wu & Katok, 2006);
- Ineffective inter-echelon coordination (Boute *et al.*, 2010);
- Ineffective or absent demand forecasting (Hadaya & Cassivi, 2009; Makui & Madadi, 2007; Potter & Disney, 2006; Shukla, Naim, & Yaseen, 2009; Zhang & Burke, 2011);

- Wastage or obsolescence of inventories in the work-in-progress stages (Srinivasan, Mukherjee, & Gaur, 2011);
- Poor utilization of capacities (Puigjaner & Lainez, 2008; Srinivasan, Mukherjee, & Gaur, 2011);
- Disruptions in production (Puigjaner & Lainez, 2008; Srinivasan, Mukherjee, & Gaur, 2011);
- Ineffective environmental risk management (Puigjaner & Lainez, 2008; Srinivasan, Mukherjee, & Gaur, 2011); and
- Price fluctuations caused by uncertainties in the market demands and by promotions (Hadaya & Cassivi, 2009; Lee, Padmanabhan, & Whang, 2004; Makui & Madadi, 2007; Potter & Disney, 2006; Shukla, Naim, & Yaseen, 2009; Zhang & Burke, 2011).

Each of these factors makes a contribution to amplification of demand waves, resulting in amplification of order processing volumes (Shukla, Naim, & Yaseen, 2009). When the difference between order fulfillment and actual consumption significantly increases, there is significant unused inventory at each echelon of the supply chain, where the last echelon downstream receives the maximum unused inventory (Shukla, Naim, & Yaseen, 2009). The overall impacts of bullwhip effect are reduced supply chain efficiency, high inventory costs, significant wastage resulting in inventory writing-off, reduced business profits because the actual demands remain unfulfilled, and risk of loss of customers (Lee, Padmanabhan, & Whang, 2004; Kim *et al.*, 2006). In the case study of Cisco Systems, a leading network equipment manufacturer, unused inventory valued at US $2.1 billion was written off in 2001 (Lee, Padmanabhan, & Whang, 2004). This happened because Cisco operates a highly complex multi-echelon supply chain, and there were significant beer gaming (shortage

gaming) by individual echelons amidst numerous uncertainties in global supply chains. Each echelon manager had visibility of local risks and, hence, created a local cushion of safety stock to meet the customer demands arriving in a stochastic manner. The demand information progressively amplified, and the gap with actual ordering by end customers continuously increased. With advancements in technologies and obsolescence of products of certain part numbers stocked by echelon managers, the unused inventory became obsolete at some stage and had to be written off due to obsolescence. The key lesson from this case study is that there needs to be appropriate collaborative controls for making small but effective adjustments in demand information and inventory reordering such that the bullwhip tidal waves can be gradually dampened. This is the primary strategy related to control theory.

Disney *et al.* (2009), Kim *et al.* (2006), Luong & Phien (2007), and Luong (2007) researched the control theory based on systemic modeling of supply chains. Disney *et al.* (2009) and Luong & Phien (2007) discovered that the exponential nature of demand variance is inversely proportional to the level of information shared from demand end to supply end. Thus, if no information is shared, the amplitudes of demand tidal waves progressively increase exponentially. However, the increase of amplitudes tends toward linearity progressively as gradually increasing small bits of information are shared with the suppliers from the demand side, resulting in a proportionately increasing number of corrections. With increased linearity, the bullwhip waves tend to dampen with time. This is the theory used in the control theory approach using systemic models to reduce bullwhip effect tidal waves. The basic models begin with simplistic control systems. The advancements in these control systems lead to design of complex system dynamics modeling. Section 2.3 is a detailed review of system dynamics models for reducing bullwhip effect. Each of

these models is designed to ensure that the bullwhip tidal waves tend toward linearity (are flattened) to a certain degree.

2.3 Review of Non-linear Control Systems and System Dynamics Modeling for Examining Risks Arising from Bullwhip Effect

Before reviewing the system dynamics modeling for mitigating the risks arising from bullwhip effect, a review of the fundamentals is presented. Control system represents the modeling of a real machine in universal applications (Nise, 2011). A control system may be represented by a state transition table showing the present states, the next states, and the feedback/feed forward control mechanisms responsible for introducing the control functions that control the state transitions (Nise, 2011). By design, each control system machine has inputs, a coupling system, the outputs, and the controls in the form of feedbacks/feed forwards, depending upon the machine logic design (Nise, 2011).

With an initial understanding of the control system, the focus is now switched to system dynamics. The concept of system dynamics was developed in the 1950s by the Massachusetts Institute of Technology (MIT) and was popularized through the Systems Dynamics Society (Marquez, 2010). Jay Forrester was a major contributor to its development, as interpreted from his experience sharing lectures (Forrester, 1989, 2010). Hence, for this paper, Jay Forrester has a dual significance: in the identities of the inventor of the Forrester (bullwhip) effect and of the founder contribution to system dynamics. One of the key approaches in system dynamics involves the creation of causal chain diagrams in which the effect of one variable on another can be investigated (Sterman, 2000). A positive effect on the affected variable is represented by a plus (+) sign, and a negative effect on the affected variable is represented by a minus (–) sign (Sterman, 2000). System dynamics comprises cause

effect investigations within a systemic framework (Sterman, 2000). The knowledge of causes and effects can enhance decision-making by applying appropriate controls (Wu, 2002). Hence, there is a scope for integrating a control system and system dynamics (Wu, 2002). For example, a table comprising plus (+) and minus (–) relationships can serve as a decision-making engine for a control system machine in a manufacturing process (Wu, 2002).

In supply chains, system dynamics can be used to investigate causal relationships among key variables that may have an overall impact on supply chain efficiency and customer services (Marquez, 2010). For example, the impacts of capacity constraints, lead-time delays, and signaling (communication) gaps on delivery ineffectiveness can be investigated by studying influence of hidden variables linked with structural inefficiencies and contractual gaps within a supply chain (Marquez, 2010). These inefficiencies may lead to unwanted inventories at the supply chain echelons, while the customers do not receive the desired products as per their demands (Marquez, 2010). As discussed in Section 2.2, this is one of the major impacts of bullwhip effect. The next step to this dissertation research was to review models on the bullwhip effect.

The traditional method of ordering in supply chain management is ordering-up-to policy (Frank & Disney, 2003). This policy is based on an assumption that the demand variation is linear or near linear (Dejonckheere, 2003). However, in real life, the variations in demand may be non-linear to highly stochastic (Dejonckheere, 2003). If the demands are non-linear and there are no adjustments made over and above the routine order-up-to policy, functional inefficiencies may begin in the supply chain. When the demands become stochastic, then order-up-to policy can induce the bullwhip effect.

While the bullwhip effect can be dampened, losing business from stock outs should be reduced (Agrawal, Sengupta, and Shanker, 2009; Ouyang & Li, 2010). In this context, a number of researchers presented their studies on factor loading on decision-making, such that both bullwhip effect and business losses due to stock outs can be effectively controlled by making stock adjustments in each echelon based on upstream feedback loops on both finished goods and work-in-progress inventories (Agrawal, Sengupta, and Shanker, 2009; Dejonckheere *et al.*, 2003; Machuca & Barajas, 2004; Ouyang & Li, 2010; Wu & Katok, 2006).

The approach of factor loading is a multivariate method for testing the influence of certain factors on a measured variable such that the significantly impacting factors can be considered in the analysis and the non-significant factors may be eliminated (Hair *et al.*, 2009). This method integrates with the decision logic of a control system approach of operating proportionate controllers. System dynamics study is an effective way of graphically plotting the significant factors and also observing the direction of influence on the variables under study. A review of system dynamics study for damping bullwhip effect is presented in the following paragraphs.

System dynamics modeling of the bullwhip effect involves formation of a relationship diagram showing interactions of all the variables in action (Jeong & Houston, 2015). By integrating system dynamics with a control system, the proportionate controllers can be made more effective by virtue of informed choice of their values. In the dissertation by Jeong & Houston (2015), the relationship diagram was created using a software tool named iThink (as shown in Figure 2.1).

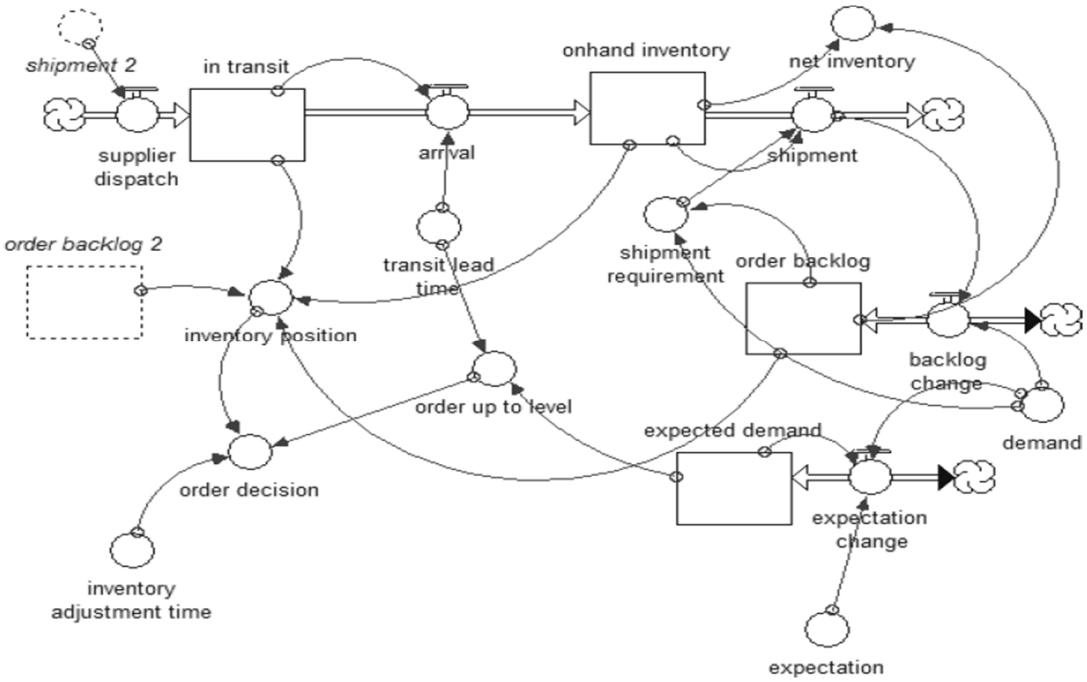

Figure 2.1: Systems Dynamics Model for Investigating and Controlling Factors Causing Bullwhip Effect (Jeong & Houston, 2015)

As observed from Figure 2.1, there are a number of feedback and feed forward loops that are integrated at nodal points. There are five controllers in this system: supplier dispatch, arrival, shipment, backlog change, and expectation change. The first three controllers are regular supply chain controllers, whereas the last two are proportionate controllers. By changing the backlogs and expectations, Jeong and Houston (2015) expected to control bullwhip tidal waves. The signals helping in modifying the expectation change controller arrive from demand feedback, expectation feedback, and expected demand feedback. The backlog change controller retrieves inputs from actual demand and actual shipments. The expected demand change alters the ordering-up-to-threshold, and the backlog change triggers the backlog ordering. In this way, both the bullwhip effect threat and stock out threat have been mitigated. This next figure introduces system dynamics model to investigate controlling factors causing the bullwhip effect.

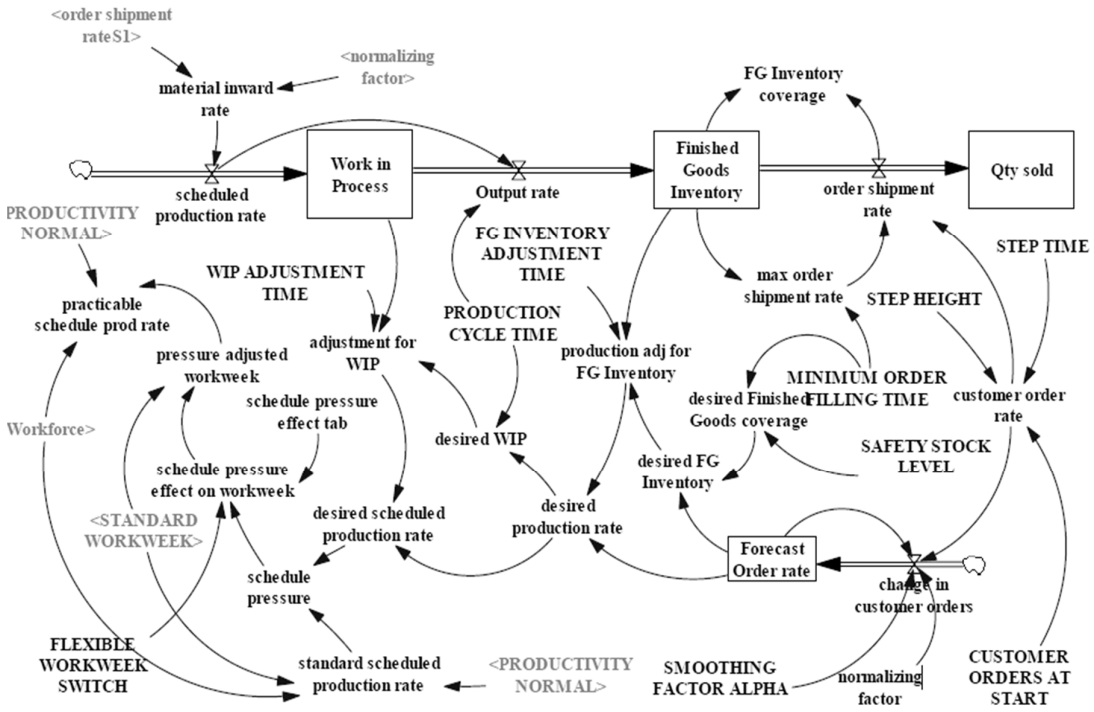

Figure 2.2: System Dynamics Model for Investigating and Controlling Factors Causing Bullwhip Effect (Burns & Janamanchi, 2007)

Figure 2.2 presents another integrated model of system dynamics with cybernetic controls (Burns & Janamanchi, 2007). This model accounts for multiple variables for estimating the desired work-in-progress inventory and desired finished goods inventory. These two estimates are varied through continuous feedbacks of work-in-progress and finished goods adjustment information coming from the actual inventory status. The change in customer orders is used as a control by feeding the two varying estimates after alpha smoothing and normalizing. The model is designed to achieve dual objectives of reducing information flow and material flow delays.

From these two system dynamics models, it may be interpreted that system dynamics modeling has been used to introduce on-the-ground variables, their interrelationships, and the feedback and feed forward loops to ensure informed and just-in-time decision-making for operating the proportionate controllers. However, both these models have completely different sets of variables and interrelationships. A

review of other research studies revealed that there is a lack of empirical standardization for choosing variables and establishing their interrelationships (Campuzano-Bolarin *et al.*, 2013; Rodrigues, Hebbar, & Herle, 2011; Xu, 2013). Therefore, where do these variables originate? Where do these interrelationships originate? Does every new research study reflect a different model for curbing bullwhip effect? These questions point toward the fact that the approach and methodology of integrating system dynamics modeling with control system machine formation needs to be standardized for practitioners such that they know where and how to begin. Once the basic approach is ready, additional variables may be added depending upon local conditions within an industrial setting. The actual problems resulting in bullwhip effect are driven by local challenges of an industry. The modeling outcomes demonstrated in two organizational case studies may not be empirically comparable. The comparisons may occur only by coincidence. Keeping this fact in mind, a critical examination of the approach and methodology of integrating system dynamics and a control system for controlling bullwhip effect and also ensuring minimal stock out situations is presented in Section 2.4. Following this approach, standardization of variables and their interrelationships has been attempted such that practitioners can map with their real environment and choose the ones applicable. The proposed approach will help in choosing and correlating the fundamental variables that may be applicable in every scenario. Thereafter, the practitioner may add more variables as per the real existing scenario.

2.4 Critical Examination and Modeling

In this section, a detailed examination of integrating control system modeling and system dynamics modeling for controlling bullwhip effect without causing stock outs is presented. This section comprises the original contribution of this research. The

method used to present this section is inductive theory analysis using interpretations of three fields of study: control system engine formation, causal loop analysis (system dynamics), and multivariate path modeling method. The examination begins with a brief review of multi-echelon systems in supply chains, given that bullwhip effect is prevalent in complex multi-echelon systems where environmental corruption of flow of information (white noise) and lead-time delays contribute to demand amplification (as per the original theory of Forrester, 1961 and also described by Christopher 2011, Disney *et al*., 2009, Geary, Disney, & Towill, 2006, and Lee *et al.*, 1997).

In a supply chain management system, there are two main approaches to its design: the multi-echelon approach and the single-echelon approach (as shown in Figure 2.3) (Napalkova, 2009). The multi-echelon approach considers the planning and management of the supply chain as an entirety, thus making any supply firm perform at the global level (Napalkova, 2009). In the case of the single echelon approach, the multi-echelon approach is broken down into separate stages, and every stage operates as an independent entity (Napalkova, 2009). In contemporary supply chain structure, the multi-echelon is more commonly used by every supply chain because of its applicability to deal with change and competitiveness at the international level (Napalkova, 2009). Although the single-echelon models traditionally delivered effective results, the problems of communication gaps because of echelon-level hierarchical organizational structure and strong organizational boundaries between echelons existed (Muckstadt & Thomas, 1980). Modern supply chain managers prefer smooth information flows and effective coordination structures through the echelons (Muckstadt & Thomas, 1980). Hence, multi-echelon systems gradually replaced single-echelon systems (Muckstadt & Thomas, 1980).

The multi-echelon system employs both cyclical and non-cyclical planning to model the supply chain environment, although cyclical planning is more favored given its ability to develop causal chains (Napalkova, 2009). The main feature of the multi-echelon system by using a cyclical schedule is that all the processes involved in the supply chain, such as purchasing, production, packing, or transportation, are synchronized and related to each other through causal relationships (Napalkova, 2009). This system is also viewed as favorable to model the supply chain as per the contemporary market demands (Napalkova, 2009).

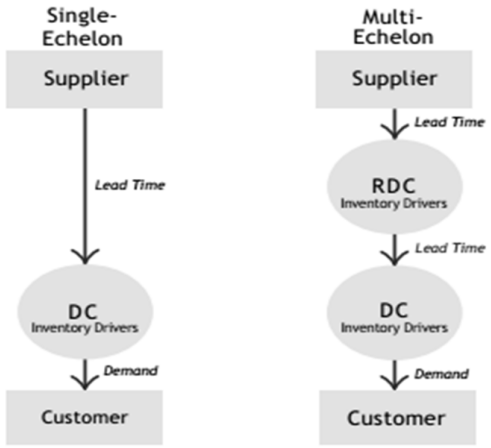

Figure 2.3: Single and Multi-Echelon Systems: A Structural Comparison (Napalkova, 2009)

While multi-echelon systems have become popular in modern businesses, there is a significant gap that causes dysfunctional threats like bullwhip effect. The supply chains are shaped as complex supply networks when businesses grow, causing challenges in network visualization, integrity and accuracy of information flow, lead-time delays in supply chain processes, and delays in the flow of information (Kenneth, 2010). The multi-echelon approach relies on multiple forecasts conducted for each echelon in the network with intent to solve the lead-time delays and synchronize the

strategies across echelons (Kenneth, 2010). However, forecasting errors tend to contribute to bullwhip effect as one of the fundamental causes (Kenneth, 2010).

Many academic scholars have developed fundamental ideas, model designs, and solutions to mitigate forecasting error, process delays, and communication gap problems in multi-echelon supply chains (Agrawal, Sengupta, & Shanker, 2009; Axsater, 2007; Dejonckheere *et al.*, 2003; Klingebiel, 2011; Machuca & Barajas, 2004; Ouyang & Li, 2010; Sherbrooke, 1968; Tempelmeier, 2011; Wu & Katok, 2006; Zipkin, 2000). The primary idea in their approaches is to know the exact variables active in the supply chain and the way the variables are interrelated. The scholars have applied mathematical modeling and statistical techniques to derive the significantly influencing variables and their interrelationships. Some of the techniques used are multivariate regression modeling (multiple variables modeled in linear equations with regression coefficients), correlation analysis, analysis of variance (ANOVA), multivariate ANOVA (MANOVA), principal component analysis (a technique to explore the highest influencing factors through Eigen value filtering after orthogonally rotating the factors), and path modeling and analysis (also known as structural equation modeling, which involves covariance investigation among cause and effect variables).

When the variables are known, control system and system dynamics modeling can be conducted by using the relationships as decision-making logic and establishing right proportionate controllers at the right places. A control system comprises control logic commissioned as transfer functions between cause and effect variables. The feedback and feed forward controls are commissioned to energize the proportionate controllers. Positioning of the transfer functions and controllers can be derived from the interpretations of the problem areas. There are six steps in completing the

modeling exercise (designed with the help of multivariate regression analysis, path modeling, principal component analysis, and structural equation modeling steps explained by Anderson, 2003, Beins & McCarthy, 2012, Hair *et al.*, 2009, Hooper, Coughlan, & Mullen, 2008, and Rencher, 2002):

(1) The first step is to conduct a literature study to discover all the key variables active in a multi-echelon supply chain. This step will require consultations from on-the-job field managers, inventory managers, and procurement managers. One may seek help from academic and professional research studies to compile a list of possible variables such that it can be reduced after knowing relevance in the supply chain.

(2) The second step is to identify the interrelationships among the variables discovered. This again can be derived with the help of on-the-job managers and from relevant academic and professional relationships. The relationships may be plotted in the form of a path diagram in Microsoft Visio. The path diagram comprises branches between nodes, whereby the nodes represent variables and the branches represent relationships (Hair *et al.*, 2009). A node may be a junction of multiple branches, indicating its relationships with multiple variables in the specific supply chain environment (Hair *et al.*, 2009). It should be noted that the significance and directions (+ or –) of the relationships are not yet known. Hence, at this stage, the path diagram should be treated merely as an initial measurement model.

(3) The third step is to collect data against each identified variable and relationship. The data should be collected with the help of a carefully designed instrument that can be used not only to collect data but also to map the data

with pre-designed levels. A structured questionnaire with the Likert scale (or similar five-level scale) is a preferred choice for this purpose.

(4) After collecting the data, the nodes (variables) with two or more interrelationships may be identified and subjected to principal component analysis in the SPSS tool [the method uses VARIMAX orthogonal factor rotation, which is cited as the most reliable by Hair *et al.*, (2009)]. Principal component analysis uses VARIMAX orthogonal factor rotation results in significance ratings of the relationships and also the sign of the relationships (+ or –). The number of variables related with these nodes may be reduced based on significance levels. However, there may be situations when the number of variables needs to be increased because the orthogonal factor rotation failed to converge. In such a scenario, the path diagram (initial measurement model) may have to be revisited. A reliability testing using Cronbach Alpha or Split Half testing shall approve the significance of the relationships.

(5) Step (4) could be treated as the final step that derived the system dynamics model (the reliability-tested version of the initial measurement model or the initial path model). However, one may investigate potential additional path model structures that are more valid than the finalized model in Step (4). Structural equation modeling can be conducted in the LISREL tool. The tool has built-in analytics to run an optimization process and suggest alternate models with enhanced validity. Some of the statistics it uses for deriving construct validity are the ratio of Chi square to degrees of freedom, root mean

square residual, standardized root mean square residual, normed and non-normed fit indices, incremental fit index, and comparative fit index.

(6) The sixth and final step is to introduce controllers in the model. This will require careful analysis of the finalized causal model through simulations and Taguchi's method such that the proportionate controllers can be positioned at appropriate locations on the chart. The controllers need to be positioned in such a way that the most influencing variables can be controlled.

In the traditional approach, system dynamics is concerned with creating a model of a system by examining the interaction of individual components of the system through observations only. Once an adequate model has been developed, observers can see how the system is affected when changes are made to different independent variables and the corresponding effect on dependent variables. Simulation provides a way to understand the behavior arising from a specific system structure without having to create the entire existing structure or without interrupting it. This method may be effective but is highly speculative and prone to human interpretation errors. This six-step process does not account for any speculation. The model will be tested for reliability and validity using credible methods. The only risks may be of sample bias and respondent bias, which are standard challenges of any survey-based modeling. These biases can be tackled using standard research protocols explained in research methodology books (not covered here because they require a very detailed review that is out of the scope of this research).

2.5 Summary

Bullwhip effect is a dysfunctional phenomenon in supply chains. It occurs primarily because of disruptions and delays in information sharing, lead-time delays

in supplier order processing, panic stocking (beer game), lack of coordination, and gaps between echelon-level ordering and actual consumption at the customers' end. Bullwhip effect causes propagation of demand variations upstream that gradually amplifies in the form of tidal waves. This effect can cause significant losses because of excess in inventory, wastage of inventory, and obsolescence of inventory. Bullwhip effect is one of the major indicators of inefficiencies in a supply chain. Its probability of occurrence is more in multi-echelon supply chains.

Bullwhip effect can be curbed through a control theory approach, working on the principle that gradual sharing of demand information and minor corrections at all the echelons can dampen the bullwhip tidal waves by forcing them toward linearity. A control system controls modeling and system dynamics modeling are two approaches under control theory to curb bullwhip effect. The two approaches can be integrated to create a hybrid modeling. In such a model, the systems dynamics model (causal chain analysis) serves as the decision-making logic for control system transfer functions. A control system works with state transition tables controlled by feed forward and feedback rules, whereas system dynamics works with causal diagrams that can be used for formulating the transition rules.

Appropriate proportionate controllers can be employed in the model to execute small-scale controls and adjustments based on feedbacks and feed forwards. These controls can be highly effective in making the bullwhip waves close to linear by damping them as much as possible. A strategy for integrating control system controls with system dynamics modeling has been proposed in this research. The strategy comprises a six-step standard process, beginning with a systematic approach of creating the initial measurement model and then applying a combination of multivariate techniques to refine it with optimum reliability and validity. The six-step

approach involves formation of an initial system dynamics model (initial measurement model) with the help of an initial survey of all echelons in the supply chain, collecting data in a second survey pertaining to each variable and relationship in the initial measurement model, applying the data to a principal component analysis process for reducing/increasing the model as needed to achieve reliability, creating the modified model in LISREL in the form of a path diagram (only if the sample was greater than or equal to 100), conducting validity analysis to achieve the optimum structural construct of the model (having optimum validity scores), and finally, applying control system to the model.

Further in this research, the six-step model has been tested with the help of test data generated from the RAND (N) function in MATLAB. The data from real-world supply chains could not be collected because of time, cost, and resource constraints. The six-step process has been illustrated based on test data generated with the help of the RAND (N) function described in Chapter 3. Each data unit has five levels as defined in the data modeling description in Appendix B. The process has been tested by generating the test data in MATLAB and importing it into SPSS. The methodology for conducting the primary research and the method analysis of primary data using the six-step process are discussed in Chapter 3, and the actual data presentation and analysis are presented in Chapter 4.

Chapter 3. Research Methodology

3.1 Introduction

In this chapter, the methodology and methods used for generating test data, statistical modeling, and results analysis are discussed. The methods and decision criteria chosen have been backed by a review of literature. The chapter is divided into four sections. Section 3.2 is a review of literature pertaining to general research design, and the choices made in this research with justifications are presented. Section 3.3 presents the test data generation method used in this research. Section 3.4 presents the statistical modeling methods used for arriving at the final relationships for creating the system dynamics model specific to the test database studied in this research. Section 3.5 presents the process of modeling, and Section 3.6 presents the Taguchi's method. Both these methods are used for the sixth step of the six-step process defined in Section 2.4. Finally, Section 3.7 discuses the ethical conduct of this research.

3.2 Research Philosophy, Approach, and Methodology

Research is designed to achieve epistemological and ontological objectives for gaining new knowledge for interested communities (Bryman & Bell, 2007). The principle of epistemology accounts for the interest of stakeholders (people and communities interested in the knowledge gained) in a study. Epistemology does not allow knowledge to be gained in silos. Hence, peer reviews and superior reviews are integral parts of a study that is targeted in an area of interest of the reviewers (Saunders *et al.*, 2011). Ontology is focused on whether the subjects of research are independent or dependent of the social construct in which they reside. In other words,

ontology is a study of whether a society construct is independent or dependent upon habits, customs, and behaviors of its people (Bryman & Bell, 2007).

This research is a structural study independent from the habits, customs, and behaviors of its people. Bryman and Bell (2007) classified such a study as following the objectivism philosophy. In epistemology, this is related with positivism philosophy (Bryman & Bell, 2007). Objectivism and positivism employ a deductive approach of learning. The opposite of objectivism is constructivism in ontology, and the opposite of positivism is interpretivism in epistemology. Constructivism and interpretivism employ an inductive approach of learning (Bryman & Bell, 2007).

This study is based on positivism and objectivism philosophies and a deductive approach of learning. A deductive learning approach is mostly conducted through a quantitative methodology that retrieves numbers as inputs and produces statistical/mathematical models, formulae, and relationships as outputs. Quantitative studies can be conducted through short surveys to collect useful data about the variables influencing decision-making. Quantitative studies can also be conducted through controlled experimentations or simulations conducted on test databases. With modern computers and statistical/mathematical modeling tools, quantitative studies have become easier, given that such tools can quickly generate powerful computations on data collected, visualization of data and reports, and integration of data and reports (Cooper & Schindler, 2014). Some tools can generate test databases for simulations if field collection is not feasible (Cooper & Schindler, 2014; Sekaran, 2003). For example, MATLAB has multiple functions for generating arrays of random numbers. The SPSS tool can run a variety of statistical analysis reports on the data collected and also can help in forming complex structural models (called constructs) (Landau & Everitt, 2004). SPSS has been chosen in this research along with LISREL. LISREL is

a software package for multivariate path modeling and conducting confirmatory factor analysis and structural equation modeling (Cortina, Chen, & Dunlap, 2001). The reports drawn from these packages and the analysis conducted are presented in Chapter 4. These packages helped in applying the test data generated from the RAND (N) function in MATLAB to test the six-step process explained in Chapter 2.

3.3 Test Data Generation

All scientific research should be testable (Sekaran, 2003). Testing is conducted to ensure repeatability, confidence, precision, generalizability, and objectivity of results (Sekaran, 2003). The process of the test should be repeatable in the future by other researchers. The confidence on outcomes should be based on a target confidence level (example, 95% confidence at $p < 0.05$), which is a required attribute in hypotheses testing. Precision refers to the closeness of the results with the reality (Sekaran, 2003). In quantitative research, data for testing can be collected from a sampling of the population and collecting data from surveys, retrieval of archives (such as econometric databases), or creating test databases for conducting model testing and simulations (Sekaran, 2003; Tuffery, 2008).

Test data generation is conducted for generating test cases for black box testing of processes, algorithms, programs, and subroutines (Edvardsson, 1999). Generating test data is a tedious process that can be expensive, biased, full of duplicates, and error-prone (Harman, Lakhotia, & McMinn, 2007). It is recommended to generate test data using software programs with built-in algorithms, rather than trying to generate data manually (Edvardsson, 1999; Harman, Lakhotia, & McMinn, 2007). Test data generation through software programs can be conducted using one of the following methods:

- Multi-objective evolutionary algorithms (such as genetic algorithms, weighted genetic algorithms, Pareto genetic algorithms, and ant colony algorithms) (Edvardsson, 1999; McMinn, 2004; Harman, Lakhotia, & McMinn, 2007);
- Random test data generation providing upper and lower bounds of the data (Edvardsson, 1999; Tsoi, Leung, & Leong, 2007; Martinez & Martinez, 2005);
- Goal-oriented test data generation (Edvardsson, 1999);
- Path-oriented test data generation (Edvardsson, 1999);
- Constrained test data generation (Edvardsson, 1999);
- Probabilistic data generation with linkage algorithms and de-duplication (Edvardsson, 1999; Christen, 2006); and
- Meta-modeling test data generation (Brottier *et al.,* 2006).

The requirements of test data in this research are the following:

- Each data unit should be in the range 1 to 5; the range 1 to 5 has been defined for each variable in Appendix B (which could be used as a survey questionnaire if an actual survey is performed).
- There should be no bias in the data.
- There should be no duplicate rows in the data.
- The data should be randomly generated with no predictability.

To meet these requirements, the random test data generation with upper and lower bounds method has been chosen. A random data set can never be generated manually (Edvardsson, 1999; Tsoi, Leung, & Leong, 2007; Martinez & Martinez, 2005). A software program is capable of generating truly random data with almost negligible predictability (Edvardsson, 1999; Tsoi, Leung, & Leong, 2007; Martinez & Martinez,

2005). In this research, the software chosen is MATLAB. Random data with upper and lower bounds can be generated in MATLAB using the following syntax:

$$r = a + (b - a)*RAND(N,M) \quad (3.1)$$

In Equation (3.1), *a* and *b* are the lower and upper bounds, respectively, *N* represents the number of rows, and *M* represents the number of columns. This research has ten factor variables. Given the limit of a student's version of SPSS (included in a book on SPSS available at the university bookstore), a total of 1,000 rows were generated in MATLAB and imported into Microsoft Excel. The syntax used for generating random numbers in 1,000 rows under ten columns within a range of 1 to 5 is the following:

$$r = 1 + (5-1)*RAND(1000,10) \quad (3.2)$$

The data table generated is presented in Appendix C. MATLAB generates data with four decimal places. For appropriate analysis in SPSS and LISREL, the data set was rounded to the nearest whole number in Microsoft Excel before exporting to SPSS.

3.4 Statistical Modeling and Analysis

In the system dynamics approach proposed in Chapter 2, it is very difficult to create an initial measurement model for a supply chain because there is no way to guess the other dependent variables active in the system apart from demand amplification (bullwhip effect). The variables will depend upon the supply chain problems and inefficiencies prevailing in a particular supply chain. In a scenario where the initial measurement model cannot be created with confidence, the exploratory factor analysis method using principal component analysis is proposed by Hair *et al.* (2009) and Rencher (2002). As a ground rule, the number of dependent

variables should not exceed the number of rotated components having Eigen values of at least unity (Hair *et al.*, 2009; Rencher, 2002). Keeping this rule in mind, it was decided that a number of dependent variables be extracted and named after reviewing the factor variables loaded upon them and matching with literature. The set of factor variables loading a dependent variable constitutes a scale, and hence scale reliability testing comes in the picture (Hair *et al.*, 2009; Rencher, 2002). The loading by factor variables is decided based on the following decision criteria:

(1) The loading is significant if the loading coefficient (correlation coefficient) is from 0.7 to 0.9.

(2) The loading is somewhat significant if the loading coefficient is from 0.5 to 0.699.

(3) The loading is not very significant if the loading coefficient is from 0.0 to 0.499.

The factors with significant and moderate loadings were identified and entered in the respective scales. The scales were tested for reliability using Cronbach alpha testing. The Cronbach alpha should be between 0.75 and 0.9 for acceptable reliability (Dougherty & Hunter, 2003; Lin, 2014; Tavakol & Dennick, 2011). Values above 0.9 reflect data redundancies that should be eliminated (Tavakol & Dennick, 2011). It was later observed that the reliability scales could be achieved within the acceptable range only after including a few low loading factor variables as well. The reliability and factor loading analysis is detailed in Chapter 4.

After achieving reliable scales, the model comprises all the relationships between the factor variables and the dependent variables. To make the model more comprehensive, a separate correlation test was conducted only among the factor variables and the medium to high loading relationships. Plotting all these relationships

returned a completed system dynamics model after exploratory factor analysis and scale reliability testing. Further tests of the model were conducted using confirmatory factor analysis (CFA) and structural equation modeling (SEM). CFA and SEM are path analysis methods for determining the validity of relationships in a hypothesized structural construct (Schreiber *et al.,* 2006). If the relationships of the reduced model after reliability testing returns acceptable validity scores in CFA, the model can be accepted with good fitment (Schreiber et al., 2006).

CFA and SEM employ a number of statistical tests to verify model fitment. The key tests and their values in CFA are shown as the following (Hair *et al.*, 2009; Schreiber *et al.,* 2006; Schumacker & Lomax, 2010):

- Ratio of chi-square to degrees of freedom: should be less than 3.
- Goodness of fitment: should be greater than or equal to 0.90.
- Adjusted goodness of fitment: should be greater than or equal to 0.90.
- Root mean squared error of approximation (RMSEA): should be between 0.01 and 0.08.
- Root mean squared residual (RMR): should be between 0.01 and 0.08.
- Standardized RMR = 0.042: should be between 0.01 and 0.08.
- Normed fit index: should be greater than or equal to 0.90 (preferred for large sample sizes).
- Non-normed fit index: should be greater than or equal to 0.90 (preferred for small sample sizes).
- Comparative fit index (specific to SEM only): should be greater than or equal to 0.90 (preferred for large sample sizes).
- Incremental fit index (specific to SEM only): should be greater than or equal to 0.90 (preferred for large sample sizes).

3.5 Simulations

Simulations help with creating linkages between perception and action (Decety & Grezes, 2006). A simulation is an approximate representation of the variables and their interactions in software by applying data collected from field study (deterministic data inputs) or by generating data using random generators in probabilistic distributions (stochastic data inputs) within the software (Berends & Romme, 1999). Simulations are conducted to verify actual dynamics, performance, and behaviors of the specifications of a system designs using virtual software-based experiments instead of actual physical experiments (Sinha *et al.*, 2000). Every component of a design is represented by a mathematical expression created in the software, and the dynamics of the design are studied in terms of actual measurement data of pre-determined attributes that may be later used in testing the physical system as well (Sinha *et al.*, 2000). However, the overall model in simulation is not solved through mathematical modeling; albeit it is solved by computation of the time paths of the dependent variables based on change of states of the independent variables (Kleijnen, 2004). Simulation helps in conducting sensitivity and what-if analysis under different scenarios (Kleijnen, 2004).

The design of a system is represented in graphical format with complexities equivalent to those built in the design of the system (Sinha *et al.*, 2000). The graphical design should be validated using structural validation methods (see Section 3.4) (Berends & Romme, 1999). Once the structural validation of the system is completed, the behavioral validation can be conducted using longitudinal simulation over a period of time (Berends & Romme, 1999).

In supply chains, the collaborative processes can be studied through discrete event simulation (Chan & Chan, 2005; Ramanathan, 2014). Discrete event simulation is

programmed to understand the effects of events flowing through a system at discrete times (Tako & Robinson, 2012). The events flow in the form of queues of events that trigger activities at their points of incident in the flow (Tako & Robinson, 2012). The flexibility and change in degree of freedoms in collaborative processes can be studied by identifying the variables and their interactions by simulating different decision-making scenarios (Ramanathan, 2014). Certain reflections are defined in the study to find out how the collaborations are performing (Ramanathan, 2014). For example, the performance of forecasting accuracy can be judged by studying the changes in inventory levels at different inventory points (Ramanathan, 2014). A decision-flow chart can be modeled with initiation, steps of the process, decision-making points, branching out (from decision-making options), processing boxes (such as manufacturing units), and ending steps (Chan & Chan, 2005).

Discrete event simulations are advantageous for investigating the performances of individual process steps by visualizing its effects on the flowing events. Hence, one can delve deep into the processes to explore the realities (Tako & Robinson, 2012). Discrete event simulations normally work for deterministic data inputs. System dynamics simulations offer a holistic picture of what is happening in the entire system, running multiple processes at the same time (Tako & Robinson, 2012). System dynamics simulations can receive both deterministic and stochastic data feeds. Unlike discrete events simulation, system dynamics simulations are executed over long horizons with continuous generation of data through probabilistic distribution random generators. It uses the concept of stock and flow and provides reflections on causal relationships (Tako & Robinson, 2012). The system dynamics simulation is an excellent approach to conduct scenario analysis for testing alternate designs (Ramanathan, 2014).

Building the model for a system dynamics simulation may be conducted in the following steps as explained in the Vensim modeling guide (Ventana Systems, 2003):

(1) Define the statement of model objectives and goals.

(2) Identify the variables.

(3) Check the realities related to the variables identified.

(4) Define the hypotheses and the corresponding relationships in the model.

(5) Check the consistency of the model (whether all equations have been defined correctly).

(6) Run the simulation, and analyze the reports.

In the six-step process defined in Section 2.4, this is the sixth and final step, in which the controllers are identified and tested for curbing bullwhip effect. The tests can be conducted through simulations and through Taguchi's method. A review of Taguchi's method is presented in Section 3.6.

3.6 Taguchi Methods

A Taguchi method involves a holistic view of quality in a system for assessing the loss function and its relationship with the limits of specifications. The loss function is quadratic and relates directly with the targeted value of a specification. The lowest value of the loss function is at nil variability from the target value of the specification. Reduction in variability can only be achieved through quality by design in a system, which incorporates design of the system, design of the parameters, and design of the tolerance limits (SAS, 2014). Under design of the system, a design of functionalities under nominal conditions of operation is prepared (SAS, 2014). The design of parameters comprises controllable parameters of the system and the control factors that control the parameters (SAS, 2014). Tolerance design defines the upper and lower limits of variability of the parameters (Zhang, Friswell, & Mottershead, 2005).

Taguchi method involves testing of these three designs of a system through a small number of experiments spanning all the known control factors on the parameters under testing and judging the noise factors influencing the control factors (SAS, 2014). Noise factors are externally influencing factor variables that are either impossible or too expensive to control (Simpson, 2000; Zhang, Friswell, & Mottershead, 2005). Small experiments are achieved through orthogonal arrays and their linear graphs (Zhang, Friswell, & Mottershead, 2005). The orthogonal arrays assist with testing the influence of multiple factor variables on the parameter (under testing) within a small number of experiments (Schwaninger & Hadjis, 1998). The

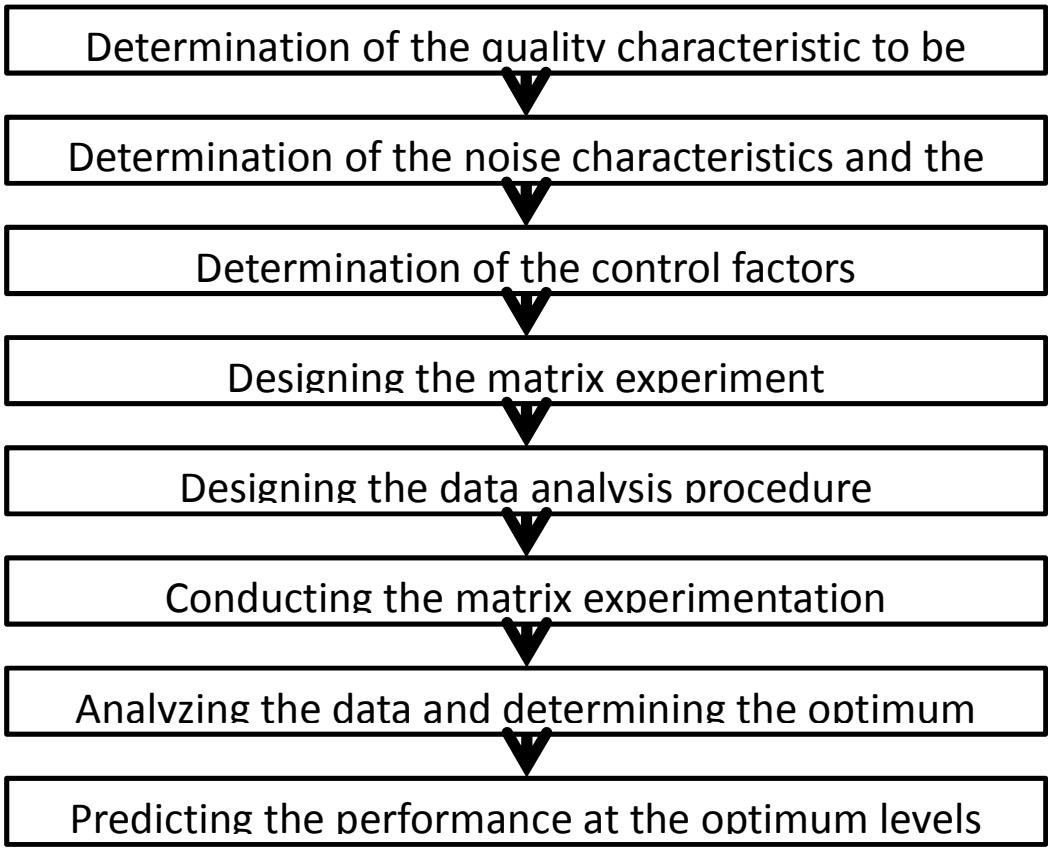

Figure 3.1: Taguchi's Method (Unal & Dean, 1991)

In Taguchi's experimentation technique, there are two arrays within the orthogonal array setup, called inner and outer arrays (Simpson, 2000; Zhang, Friswell, & Mottershead, 2005). The inner array has the orthogonal array with the control factor variables, and the outer array has the orthogonal array with noise factors (Simpson, 2000; Zhang, Friswell, & Mottershead, 2005). The experimental setup of the entire parameter design comprises both inner and outer arrays (Simpson, 2000; Zhang, Friswell, & Mottershead, 2005). The mean and standard deviations of the noise factors after each experimental run are estimated using the following equations (Simpson, 2000; Zhang, Friswell, & Mottershead, 2005):

$$\bar{Y} = \frac{1}{n} \sum_{i=1}^{n} y_i \qquad (3.3)$$

$$S = \sqrt{\sum_{i=1}^{n} \frac{(y-\bar{y})^2}{n-1}} \qquad (3.4)$$

The preferred settings of the parameter under testing are determined by analyzing the signal-to-noise ratio (SNR) (Simpson, 2000; Zang, Friswell, & Mottershead, 2005). The optimal parameter settings are determined at the points of highest signal-to-noise ratios (Simpson, 2000; Zang, Friswell, & Mottershead, 2005). The signal-to-noise ratio is determined under one of the following three preferences (Simpson, 2000; Zang, Friswell, & Mottershead, 2005):

(1) Smaller is better: The response of the system parameter because of the factor variations should be as small as possible.

$$S_s/N_s = -10log\left(\frac{1}{n} \sum_{i=1}^{n} {y_i}^2\right) \qquad (3.5)$$

(2) Nominal is best: The variability of the parameter is focused around a target value.

$$S_N/N_N = 10log\left(\bar{y}^2/S^2\right) \quad (3.6)$$

(3) Largest is better: The response of the system parameter because of the factor variations should be as large as possible.

$$S_L/N_L = -10log\left(\frac{1}{n}\sum_{i=1}^{n} 1/{y_i}^2\right) \quad (3.7)$$

The concept of SNR has been taken from communication engineering fundamentals and is expressed in decibels (SAS, 2014). The SNR is computed for each executed experiment and plotted in graphs (SAS, 2014). With the help of the graphs, the factors causing significant impacts on the tested parameter are identified and special controls applied for their optimization (SAS, 2014). The report on Taguchi's method in this research is presented in Section 4.7.

3.7 Ethics

Ethics in research is linked with protection of human subjects (Cooper & Schindler, 2014; Saunders, Lewis, & Thornhill, 2011). The respondents should not be harmed in any way during and after the research is conducted. In this research, this challenge does not exist because there are no human subjects. The six-step process for system dynamics formation has been created through extensive review of literature, and the process itself has been tested using test data generated in MATLAB.

3.8 Summary

This research has been designed with positivism and objectivism philosophies and deductive approach of learning. The methodology chosen is quantitative, and the methods chosen are exploratory factor analysis using principal component analysis

and VARIMAX rotation, Cronbach Alpha reliability testing, confirmatory factor analysis, and structural equation modeling. There was no sampling and data collection conducted in this research. The test database (of 1,000 records) was generated in MATLAB using its random generator function RAND (N). This chapter also reviewed the methods of the six-step process defined in Section 2.4.

Chapter 4. Data Analysis

4.1 Introduction

In this chapter, the six-step process for modeling system dynamics in a specific supply chain (Section 2.4) is tested using the test data generated in MATLAB (explained in Section 3.3). The steps involve presentation of the data and data normality testing, exploratory factor analysis, Cronbach Alpha reliability testing, confirmatory factor analysis, structural equation modeling, simulations, and Taguchi's analysis for applying controllers to curb bullwhip effect. A system dynamics model emerges after reliability testing by using the Pearson correlation table among all factor variables, using factor loadings on the dependent variables, and the correlation table among all dependent variables. A significant positive correlation indicates a positive (+) dynamic relationship, and a significant negative correlation indicates a negative (–) dynamic relationship. After completing this step, the model is tested further in the confirmatory factor analysis and structural equation modeling steps that also evaluate and confirm the validity of the model. Once reliability and validity are acceptable, the system dynamics model can be used to apply controllers such that the influence of bullwhip effect can be curbed.

4.2 Presenting the Data

The descriptive statistics of the testing data set is presented in Table 4.1. It may be noticed that the mean of all variables is between 3.0 and 3.5, while the standard deviations vary considerably. This may be because the data is randomly generated in MATLAB and has no bias in it. In data collected from real-world supply chains, the means may vary significantly, as well. In addition, the data in real-world supply chains may be non-normally distributed, while in this data set, the data of all variables

have perfect normal distributions (see Table 4.2; all variables have a *p*-value exactly at 0.000 in both the tests).

Table 4.1: Descriptive Statistics of the Test Data

	N	Mean	Std. Deviation	Skewness	Kurtosis
	Statistic	Statistic	Statistic	Statistic	Statistic
Demand variation	1000	3.5310	.99299	-.252	-.615
Actual Sales	1000	3.4950	1.01834	-.194	-.687
Coordination	1000	3.3420	.92514	-.219	-.492
Supplier Relationships	1000	3.3610	1.00483	-.147	-.560
Disruptions	1000	3.0940	1.09470	-.086	-.731
Demand Forecasting	1000	3.4060	1.03742	-.187	-.634
Information Processing	1000	3.3200	1.06430	-.196	-.550
Ordering Policy (size of batches)	1000	3.1510	1.05892	-.101	-.659
Order Rationing	1000	3.2070	1.11687	-.160	-.688
Lead-time variations	1000	3.5210	1.05578	-.352	-.462
Valid N (listwise)	1000				

Table 4.2: Normality of the Test Data

	Kolmogorov-Smirnov			**Shapiro-Wilk**		
	Statistic	Df	Sig.	Statistic	df	Sig.
Demand variation	.219	1000	.000	.896	1000	.000
Actual Sales	.201	1000	.000	.899	1000	.000
Coordination	.231	1000	.000	.890	1000	.000
Supplier Relationships	.194	1000	.000	.905	1000	.000
Disruptions	.177	1000	.000	.915	1000	.000
Demand Forecasting	.196	1000	.000	.905	1000	.000
Information Processing	.181	1000	.000	.910	1000	.000
Ordering Policy (size of batches)	.182	1000	.000	.913	1000	.000
Order Rationing	.175	1000	.000	.915	1000	.000
Lead-time variations	.201	1000	.000	.900	1000	.000

These differences are reflected when a researcher uses randomly generated test data versus actual survey data, and therefore, this trend needs to be taken into account. Future researchers may observe these differences when they apply these methods to data sets collected from the two surveys, as described in the six-step process in Chapter 2.

The next step is to obtain the Pearson correlation table among all the factor variables (see Table 4.3). The correlation values are classified as significant (0.7 to 1.0) and as moderate (0.5 to 0.699) as described in Section 3.4 (Hair *et al.*, 2009; Rencher, 2002). Keeping these ranges in mind, all correlations above 0.5 have been highlighted in grey and accepted as part of the system dynamics model. There are no significant-to-moderate negative correlations. In real supply chains, negative correlations may be evident that need to be input into the system dynamics model with a negative (–) dynamics sign.

Table 4.3: Pearson Correlation Values Among the Factor Variables

	Demand Variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of	Order Rationing	Lead-Time Variations
Demand Variation	1.000	.602	.559	.657	.491	.627	.487	.574	.456	.453
Actual Sales	.602	1.000	.626	.702	.756	.640	.494	.611	.481	.452
Coordination	.559	.626	1.000	.643	.595	.504	.645	.551	.520	.512
Supplier Relationships	.657	.702	.643	1.000	.671	.515	.493	.646	.501	.508
Disruptions	.491	.756	.595	.671	1.000	.614	.514	.590	.378	.464
Demand Forecasting	.627	.640	.504	.515	.614	1.000	.491	.586	.456	.467
Information Processing	.487	.494	.645	.493	.514	.491	1.000	.417	.366	.556

	Demand Variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of	Order Rationing	Lead-Time Variations
Ordering Policy (size of batches)	.574	.611	.551	.646	.590	.586	.417	1.000	.489	.448
Order Rationing	.456	.481	.520	.501	.378	.456	.366	.489	1.000	.585
Lead-Time Variations	.453	.452	.512	.508	.464	.467	.556	.448	.585	1.000

With these steps completed, the system dynamics among all the factor variables are now evident. However, the model is not complete because the hidden variables also have to be discovered and accounted. For this purpose, the next step is to conduct exploratory factor analysis, as explained in Section 4.3.

4.3 Exploratory Factor Analysis with Reliability Testing

In this step, the hidden variables (called components or latent variables) will be extracted through exploratory factor analysis, involving principal component analysis with VARIMAX rotation of factor variables (the method explained in the six-step process and reviewed in Chapter 3). There are two decisions to be made at this stage: define the number of hidden variables based on local knowledge or simply trust the model to explore them through internal analysis. If left to the model, it will extract hidden variables equal to the number of components having Eigen-values of at least unity. The higher the number of variables with high Eigen-values, the more reliable the extracted model (Hair *et al.*, 2009).

Completing this step resulted in the model shown in Table 4.4. The moderate-to-significant loadings are highlighted in grey, and the less-than-moderate loadings are

highlighted in yellow. The factor rotation (VARIMAX) converged in six iterations. This may again vary depending upon the number of records in the data set.

Table 4.4: Rotated Matrix Showing the Factor Variables' Loadings on the Extracted Latent Variables

Rotated Component Matrix				
	Component			
	1	2	3	4
Demand variation	.333	.749	.242	.223
Actual Sales	.770	.364	.181	.210
Coordination	.567	.161	.318	.545
Supplier Relationships	.738	.277	.326	.204
Disruptions	.809	.244	.074	.304
Demand Forecasting	.337	.789	.165	.242
Information Processing	.255	.257	.137	.868
Ordering Policy (size of batches)	.611	.455	.346	.031
Order Rationing	.256	.212	.872	.092
Lead-time variations	.169	.200	.664	.518
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.				
a. Rotation converged in 6 iterations.				

Now the initial model with factor variables as well as hidden variables has been explored. The next step is to extract the combination of factor variables for each hidden variable (called a component scale) in such a way that the maximum reliability score (Cronbach's Alpha) can be achieved. This can be conducted by starting with only significant loading variables and gradually including variables with moderate and lower than moderate loading values (Dougherty & Hunter, 2003; Lin, 2014; Tavakol & Dennick, 2011). To evaluate that the scale is optimal, the "Cronbach's Alpha if item deleted" statistic should be included. This statistic helps in knowing whether the scale reliability can be enhanced further by dropping a few factor

variables. The Cronbach's Alpha scale should be between 0.75 and 0.9 (Dougherty & Hunter, 2003; Lin, 2014; Tavakol & Dennick, 2011). Scales above 0.90 indicate redundant values, which are expected in real surveys (Lin, 2014; Tavakol & Dennick, 2011). Such values should be eliminated from the data set in the beginning. The data set is ideal and has no redundant values because the random generator in MATLAB generates it.

Table 4.5 presents the scale of the first component variable. It has a Cronbach's Alpha reliability score of 0.898, which is impressive. It may be observed from the last column that Cronbach's Alpha will not increase further if any of the items are deleted.

Table 4.5: Reliability Statistics of the First Latent Variable Decided as "Demand Amplification" with the Help of Literature Review

Cronbach's Alpha		N of Items		
.898		5		
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Actual Sales	12.9480	11.883	.800	.864
Coordination	13.1010	13.024	.698	.886
Supplier Relationships	13.0820	12.047	.786	.867
Disruptions	13.3490	11.607	.769	.871
Ordering Policy (size of batches)	13.2920	12.279	.692	.888

The variables in the scale indicate a close relationship with "demand amplification" because disruptions, supplier relationships, actual sales, coordination, and ordering policy (for batch sizing) are in the same scale (five major factors of bullwhip effect, as per Potter & Disney, 2006, Disney *et al*., 2009, and Lee *et al.*, 1997), and from the descriptive statistics, it is known that all five are at equal levels (mean values varying from 3.0 to 3.5). This is not a definitive decision. This decision

results from the experiences and perceptions of the supply chain manager. Considering the role of a supply chain manager, it may be assumed that this scale indicates demand amplification.

Table 4.6: Reliability Statistics of the First Latent Variable Decided as "Forecasting Accuracy" with the Help of Literature Review

Cronbach's Alpha		N of Items		
.815		**3**		
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Demand Variation	6.5570	3.484	.674	.739
Demand Forecasting	6.6820	3.314	.683	.728
Ordering Policy (size of batches)	6.9370	3.354	.643	.770

The Cronbach's Alpha reliability score for the second hidden variable is 0.815 (see Table 4.6), which, per the last column, cannot be increased further by dropping any factor variable from the scale. The three factor variables in the scale are strongly correlated with forecasting accuracy, per the theory study described in Chapter 2 (Hadaya & Cassivi, 2009; Makui & Madadi, 2007; Potter & Disney, 2006; Shukla, Naim, & Yaseen, 2009; Zhang & Burke, 2011). Again, this has to be based on the local experience of the supply chain manager, and hence the decision may vary.

Table 4.7: Reliability Statistics of the First Latent Variable Decided as "Beer Gaming" with the Help of Literature Review

Cronbach's Alpha		N of Items		
.756		**3**		
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Order Rationing	6.6720	3.238	.631	.619
Lead-Time Variations	6.3580	3.525	.601	.656
Ordering Policy (size of batches)	6.7280	3.742	.527	.737

The third scale has Cronbach's Alpha value at 0.756. This is clearly "beer game" because all the variables reported in the study by Lee *et al.* (1997) exist in this scale.

Table 4.8: Reliability Statistics of the First Latent Variable Decided as "Information Sharing" with the Help of Literature Review

Cronbach's Alpha		N of Items		
.797		**3**		
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Coordination	6.8410	3.497	.656	.715
Information Processing	6.8630	2.971	.687	.674
Lead-time variations	6.6620	3.259	.590	.780

Finally, the fourth scale sets a Cronbach's Alpha value of 0.797 (see Table 4.8) and is designated as "information sharing" because coordination, information processing, and lead-time variations are loaded on the same hidden variable (Ouyang & Li, 2010).

The summary of the four hidden variables and their scales (with reliability scores) is presented in Table 4.9. All of the variables with non-highlighted loadings are

discarded because their inclusion resulted in lower Cronbach's Alpha reliability scores. Testing the scale combinations may require substantial time. In the case of data sets collected from real-world supply chains, there may be negative significant loadings as well as resulting in highly reliable scales when grouped with the positive significant loadings. Thus, the resultant system dynamics model will have both positive and negative dynamics reported from this modeling procedure. In summary, this method brings to the forefront all of the hidden dynamics in a supply chain, which can be plotted in a system dynamics model. Table 4.10, finally, reveals the interactions between the hidden variables found through this process.

Table 4.9: The Finalized Loading Table after Reliability Tests of the Four Latent Variables

Rotated Component Matrix				
	Component			
	Demand Amplification (Cronbach Alpha: 0.898)	Forecasting accuracy (Cronbach Alpha: 0.815)	Beer Gaming (Cronbach Alpha: 0.756)	Information Sharing (Cronbach Alpha: 0.797)
Demand Variation	.333	.749	.242	.223
Actual Sales	.770	.364	.181	.210
Coordination	.567	.161	.318	.545
Supplier Relationships	.738	.277	.326	.204
Disruptions	.809	.244	.074	.304
Demand Forecasting	.337	.789	.165	.242
Information Processing	.255	.257	.137	.868
Ordering Policy (size of batches)	.611	.455	.346	.031
Order Rationing	.256	.212	.872	.092
Lead-Time Variations	.169	.200	.664	.518

Table 4.10: Relationships Among the Latent Variables

Component	Demand Amplification	Forecasting Accuracy	Beer Gaming	Information Sharing
Demand Amplification	NA	.485	.417	.414
Forecasting Accuracy	-.516	NA	.695	.422
Beer Gaming	-.028	.240	NA	-.796
Information Sharing	-.560	.797	-.186	NA

The system dynamics model showing all the relationships, positive and negative, is shown in Figure 4.1. The model is very complex given that all the dynamics are shown. For a better viewing, links indicating relationships have been shown in different colors, and the relationship with (+) and (–) signs are shown on the links. One-way loadings are shown as unidirectional arrows, and two-way correlations are shown as bidirectional arrows.

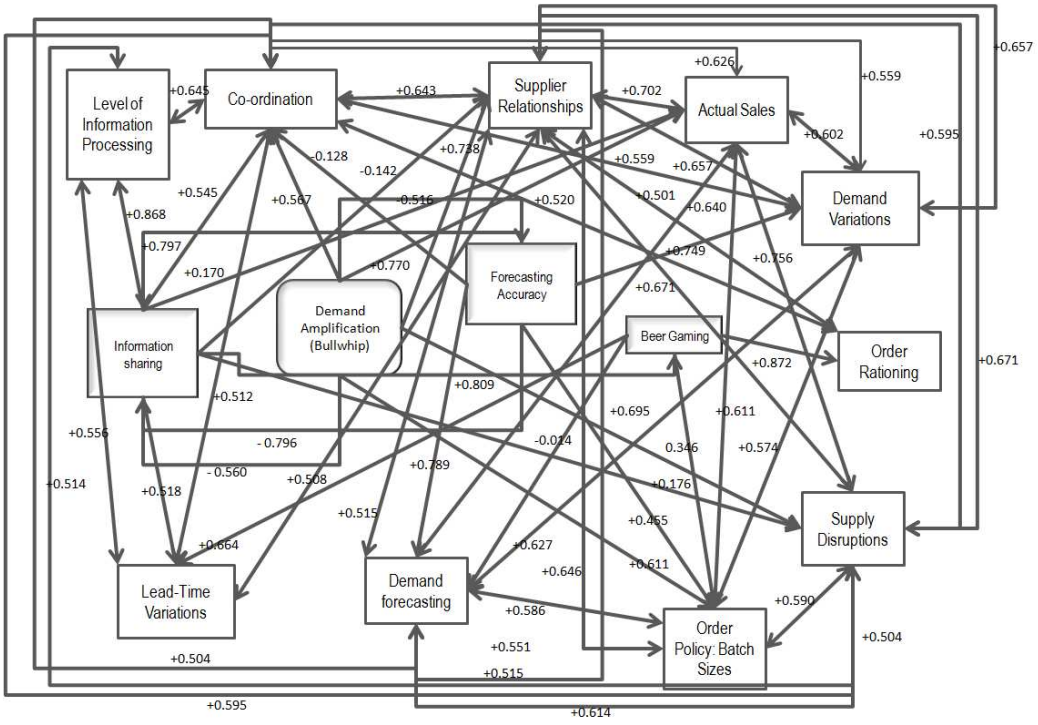

Figure 4.1: The System Dynamics Model Obtained After Correlation Analysis, Principal Component Analysis, and Reliability Testing

The model is already revealed. However, there should be further testing to ascertain validity. This can be conducted through confirmatory factor analysis and structural equation modeling.

4.4 Confirmatory Factor Analysis and Structural Equation Modeling (Model Fitment Tests)

The confirmatory factor analysis and structural equation modeling tests are conducted in LISREL. The SPSS data file is imported into LISREL, and the path model, depicted in Table 4.10, is created in the tool. It may be noted that a LISREL test is not for correlation analysis. It only verifies the validity of loadings between the extracted components (hidden or latent variables) and the factor variables. The test result is shown in Figure 4.2 (screenshot taken from LISREL).

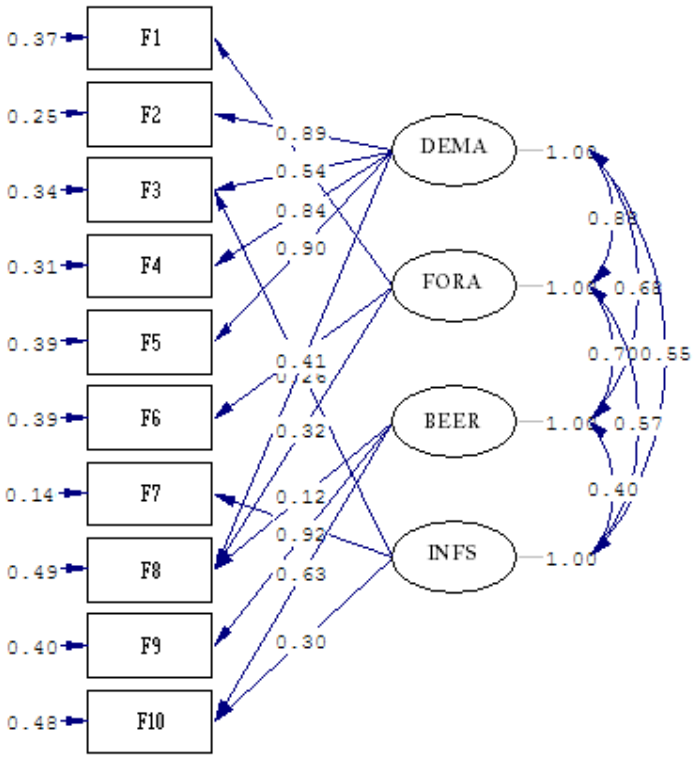

Figure 4.2: The Final Reduced Construct After Structural Equation Modeling

In Figure 4.2, F1 through F10 are the ten factor variables, DEMA represents demand amplification, FORA is forecasting accuracy, BEER is beer gaming, and INFS is information sharing. The values shown in the links between the four extracted components (hidden or latent variables) are modified correlations (internally estimated by LISREL for better model fitment, which reflects that these changes in correlations should replace the previous correlation values in the model derived from exploratory factor analysis and reliability testing), the values shown in the links from extracted components to factor variables (F1 to F10) are R2 statistics, and the arrows pointing toward the factor variables F1 to F10 indicate error variance. Overall, this model returned good fitment as per the values reviewed below (full LISREL outcome is in Appendix A):

- Chi square to degrees of freedom ratio = 45.35/25 = 1.814 (is less than 3.0)
- Root mean squared error of approximation (RMSEA) = 0.11 (is less than 3.0)

- Root mean squared residual (RMR) = 0.034 (is less than 3.0)
- Goodness of fitment index = 0.94 (should be above 0.90)
- Adjusted goodness of fitment = 0.86 (should be above 0.90); this is slightly lower but is more suitable for small sample sizes. As explained by Hair *et al.* (2009), this statistic is better for surveys having sample sizes between 100 and 200.
- SEM goodness for fitment statistics (Hair *et al.*, 2009; Schreiber *et al.,* 2006; Schumacker & Lomax, 2010):
    - Normed fit index = 0.97 (should be above 0.90)
    - Non-normed fit index = 0.96 (should be above 0.90)
    - Comparative fit index = 0.98 (should be above 0.90)
    - Incremental fit index = 0.98 (should be above 0.90)
    - Relative fit index = 0.95 (should be above 0.90)

4.5 Discussion

The validity testing processes in confirmatory factor analysis and structural equation modeling have reflected good model fitment. In real supply chains, if the model fitment is not good but the model converges successfully (i.e., no negative error variances), LISREL recommends changes in the model in the form of addition/deletion of loading relationships and adding/neutralizing error variances (Hair *et al.*, 2009; Schreiber *et al.,* 2006; Schumacker & Lomax, 2010). LISREL is a very transparent tool as it provides a projected change in model fitment with each change made in the loading relationships or in error variances. Hence, the supply chain manager can pick and choose the appropriate changes and stop at a point when the model seems to be reliable. After receiving acceptable validity scores, the system dynamics model obtained through exploratory factor analysis and reliability testing

can be modified, accordingly. In extremely rare cases, if the model does not converge because of negative error variances, the primary data collected from surveys needs to be revisited. There may be issues with responses from some respondents that need to be identified and deleted (Schreiber *et al.,* 2006; Schumacker & Lomax, 2010). The six-step process comprises only non-parametric tests such that the issue of normality may not affect the reliability and validity of the results.

The six-step process has been designed with the help of a collection of statistical processes to be conducted, one after another, to arrive at a reliable and valid relationship construct, which serves as the system dynamics model in supply chains by including (+) and (–) relationships. To the best of my knowledge, this is the first study ever that has proposed this approach and tested it using a test database generated in MATLAB. This approach requires further research and testing using data collected from real-world supply chains. The final step of applying controls is presented in Sections 4.6 and 4.7.

4.6 Simulation Results

The system dynamics model depicted in Figure 4.1 is the result of Steps 1 to 5 (of the six-step process presented in Section 2.4) using the randomly generated data set in MATLAB. This model demonstrates the interrelationships between factor variables (blue boxes) and the core variables related with bullwhip effect (boxes in the center). The model also provides Pearson correlations among the factor variables. However, it may be noted that Pearson correlations do not provide information on the direction of the relationships, leading to the assumption of bidirectional relationships. Hence, while building the model for simulation, one may interpret the direction of relationships based on experiences in the supply chain.

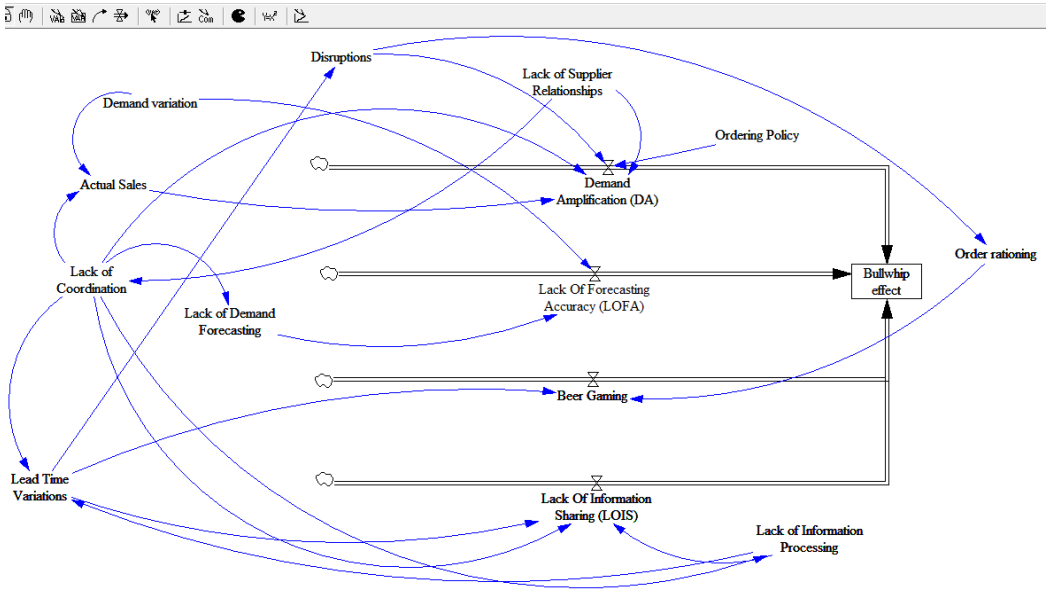

Figure 4.3: The System Dynamics Model Created for Simulation

The system dynamics model created using the Vensim software is depicted in Figure 4.3. It is in line with Figure 4.1, except that only the high correlations (0.8 and above) have been retained, and the direction of relationships is ascertained by applying the logical assumptions of causal relationships, as presented in Figure 4.3. The blue boxes of Figure 4.1 are modeled as auxiliary variables (factor variables that can also be used as control variables in this simulation, as well as Taguchi's method), and the boxes in the center are modeled as box variables causing stock and flow toward bullwhip effect. Reversing the causal relationship also makes sense, but the direction retained in the model is the better choice. For example, there is a high chance that lack of coordination and demand variations affect the actual sales. Similarly, there is a high chance that the lack of supplier relationships causes a lack of coordination, which in turn causes a lack of demand forecasting. This chain of relationships is reported in the studies of Srinivasan, Mukherjee, & Gaur (2011), Puigjaner, & Lainez (2008), and Christopher (2011). In addition, the influence of the lack of information processing on the lack of information sharing and lead-time

variations is reported by Geary, Disney, and Towill (2006), Lee, Padmanabhan, and Whang (1997b), and Ouyang and Li (2010). Overall, the relationships modeled among the factor variables as shown in Figure 4.3 are derived from literature and also apply general interpretations. As per the six-step process presented in Section 2.4, the causal relationships may also be formed with the help of primary data collection from the supply chain agents. The goal is to create a simulation environment with a replica model of a specific supply chain for which this analysis is conducted.

When the relationships are established in the model, the next step is to prepare the model for simulations. Figure 4.4 shows the basic settings for running the simulations. The unit of time is configured as day, and the total time horizon for simulation is two years (730 days). The time step is configured as one day, thus capturing the changes in the variables on a daily basis. The details of configurations of equations for running the model are presented after Figure 4.4. It may be noted from Figure 4.3 and the set of equations presented after Figure 4.4, the primary inputs to the model are demand variation, lack of supplier relationship, and ordering policy. As explained by Geary, Disney, and Towill (2006) and Lee *et al.* (1997), demand variation in all echelons of a supply chain is an initial indicator that bullwhip effect may exist if the echelons are broken (inadequately integrated). Thus, a company having a lack of supplier relationships is expected to have bullwhip effect if the demand variations are high. A number of scholars indicated that batch mode processing of orders should be explored if doubtful variations in demands are evident (Hadaya & Cassivi, 2009; Lee, Padmanabhan, & Whang, 2004; Makui & Madadi, 2007; Potter & Disney, 2006; Shukla, Naim, & Yaseen, 2009; Zhang & Burke, 2011). Therefore, the ordering policy is also included as a primary input to the model. All other variables have secondary inputs from other variables plus noise inputs from its inherent sources

(environmental noise). To simulate a scenario of high uncertainties in the model, the noise factor has been associated with each auxiliary (factor) variable and the box variables, except the primary input variables.

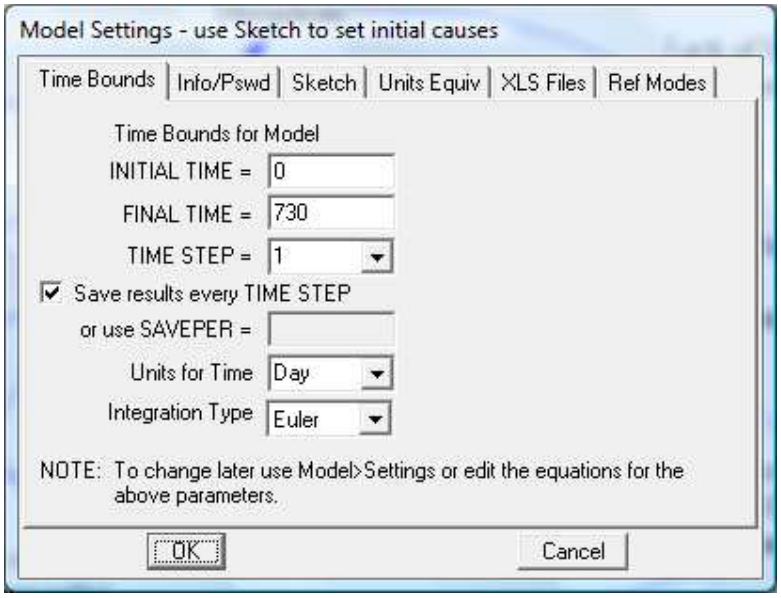

Figure 4.4: The Basic Settings of the Simulation (Unit of Time: Day; Time Horizon 0, 730, I.E., Almost Two Years; Time Step = 1)

The formulas used for generating noise in the model are the following:

RANDOM NORMAL ({min} , {max} , {mean} , {stdev} , {seed})

RANDOM UNIFORM({min} , {max} , {seed})

The RANDOM NORMAL function was used to generate noise with normal distribution, and the RANDOM UNIFORM function was used to generate noise with uniform variations. The formulas used for invoking all dynamics in the model are as follows. In case of demand variation, lack of supplier relationship, and ordering policy variables (primary inputs), the RANDOM NORMAL function was used to generate signal. For the rest of auxiliary (factor) variables, the RANDOM NORMAL function was used to generate noise (assumed as the sum of internal and white noises). The

RANDOM UNIFORM function was used to generate noise. The data range is (1, 5) based on the levels defined in Appendix B.

```
(01)    Actual Sales=
            RANDOM NORMAL( 1 , 5 , 2 , 2 , 1 )+Demand variation+Lack of Coordination
        Units: Dmnl

(02)    Beer Gaming= ACTIVE INITIAL (
            Order rationing+Lead Time Variations,
                +RANDOM UNIFORM(1, 5 , 1 ))
        Units: Dmnl

(03)    Bullwhip effect= INTEG (
            Beer Gaming+"Demand Amplification (DA)"+"Lack Of Forecasting Accuracy
(LOFA)"
        +"Lack Of Information Sharing (LOIS)",
                RANDOM NORMAL(1, 5 , 3 , 2 , 1 ))
        Units: Dmnl

(04)    "Demand Amplification (DA)"= ACTIVE INITIAL (
            Actual Sales+Lack of Coordination+Lack of Supplier Relationships+Disruptions
        +Ordering Policy,
                +RANDOM UNIFORM(1, 5 , 1 ))
        Units: Dmnl

(05)    Demand variation=
            RANDOM NORMAL( 1 , 5 , 4 , 2 , 1 )
        Units: Dmnl

(06)    Disruptions=
            RANDOM NORMAL( 1 , 5 , 4 , 1 , 1 )+Lead Time Variations
        Units: Dmnl

(07)    FINAL TIME  = 730
        Units: Day
        The final time for the simulation.

(08)    INITIAL TIME  = 0
        Units: Day
        The initial time for the simulation.

(09)    Lack of Coordination=
            RANDOM NORMAL( 1 , 5 , 3 , 2 , 1 )+Lack of Supplier Relationships
        Units: Dmnl

(10)    Lack of Demand Forecasting=
            RANDOM NORMAL( 1 , 5 , 4 , 2 , 1 )+Lack of Coordination
        Units: Dmnl

(11)    "Lack Of Forecasting Accuracy (LOFA)"=
            Demand variation+Lack of Demand Forecasting
        Units: Dmnl [1,5,1]

(12)    Lack of Information Processing=
            RANDOM NORMAL( 1 , 5 , 4 , 3 , 2 )+Lack of Coordination
        Units: Dmnl
```

(13) "Lack Of Information Sharing (LOIS)"= ACTIVE INITIAL (
+Lack of Coordination+Lack of Information Processing+Lead Time Variations
,
+RANDOM UNIFORM(1, 5 , 1))
Units: Dmnl [1,5,1]

(14) Lack of Supplier Relationships=
RANDOM NORMAL(1 , 5 , 3 , 2 , 1)
Units: Dmnl

(15) Lead Time Variations=
RANDOM NORMAL(1 , 5 , 4 , 2 , 1)+Lack of Coordination+Lack of Information Processing
Units: Dmnl

(16) Order rationing=
RANDOM NORMAL(1 , 5 , 2 , 3 , 1)+Disruptions
Units: Dmnl

(17) Ordering Policy=
RANDOM NORMAL(1 , 5 , 3 , 3 , 1)
Units: Dmnl

(18) SAVEPER =
TIME STEP
Units: Day
The frequency with which output is stored.

(19) TIME STEP = 1
Units: Day
The time step for the simulation.

The model is simulated for 730 days of activities. The causes' strip of lack of coordination is presented in Figure 4.5. It may be noted that the overall variations in the lack of coordination is the sum of variations in the lack of supplier relationships and inherent noise associated with the lack of coordination. This means that the lack of strategic supplier relationships resulted in a lack of coordination, but there may be some other environmental effects for a lack of coordination modeled as noise. It may be observed that the source of signal is the lack of supplier relationships. However, the variation in the lack of coordination is not identical to the lack of supplier relationships because of the noise added to the signal. The concept of noise and SNR is used in Taguchi's method as well (presented in Section 3.6).

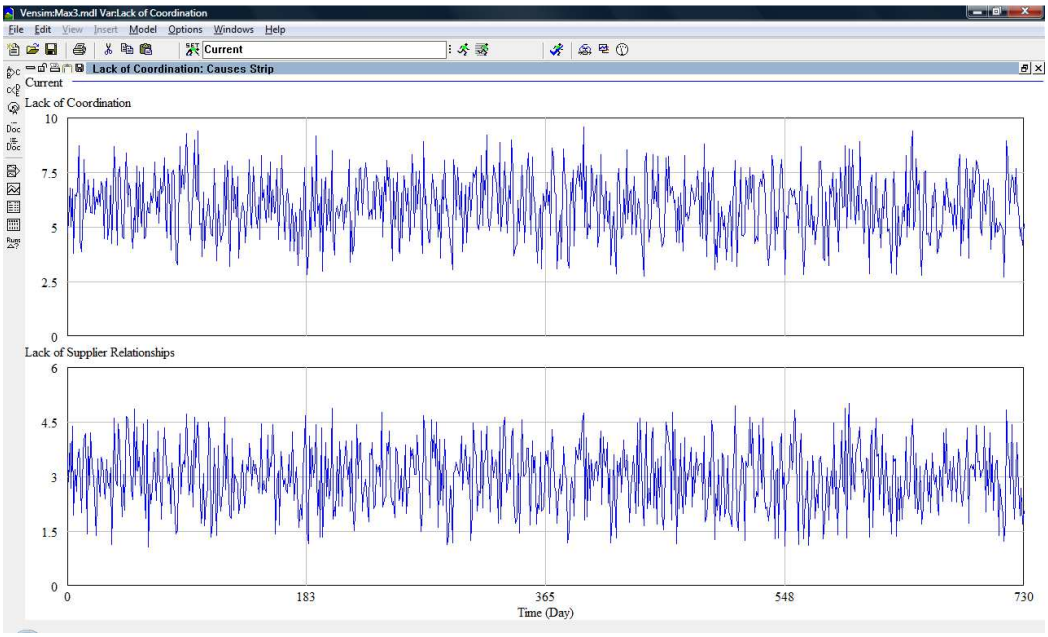

Figure 4.5: The Causes' Strip of Lack of Coordination as a Function of its Noise Variations and the Variation in Lack of Supplier Relationships

Figure 4.6 presents the causes' strip of lead-time variations. The sources of signal of lead-time variations are the lack of coordination and lack of information processing. Adding the variations in the two signal sources with the inherent environmental noise, the variations in lead time are recorded in Figure 4.6. This may be viewed as the result of disintegrated supply chain echelons and a lack of information processed because of the disintegration. Variations in lead times are due to complete and accurate information "not reaching in time" when needed.

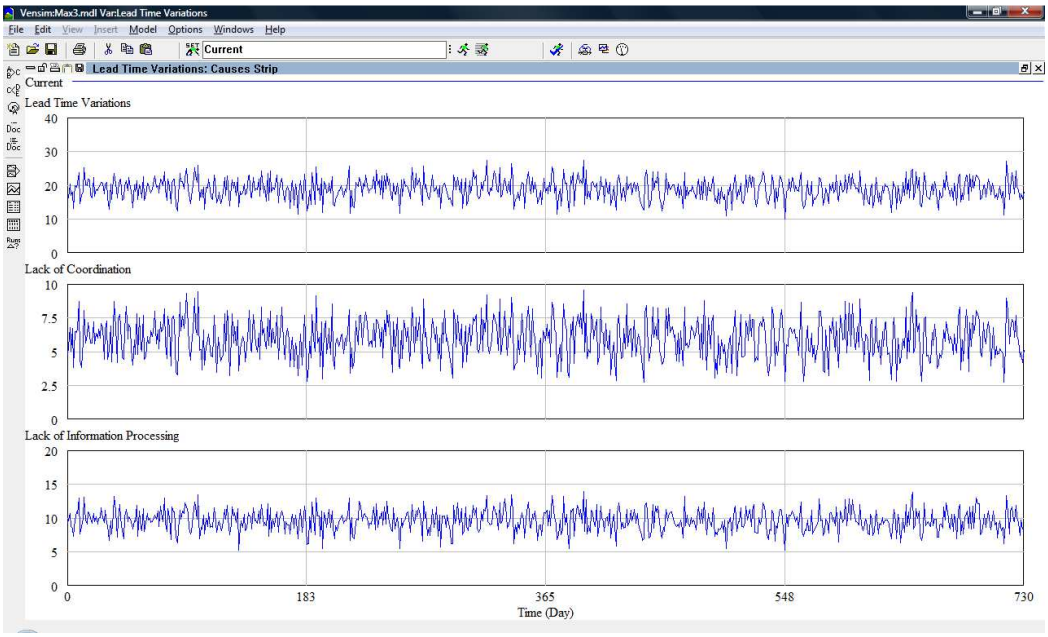

Figure 4.6: The Causes' Strip of Lead-Time Variation as a Function of its Noise Variation and the Variations in Lack of Coordination and Lack of Information Processing

Demand amplification is a box variable (output variable) that receives signals from five auxiliary (factor) variables. It should be noted that the signal sources may have noises added in the previous hops. Demand amplification also has its own sources of noise. Hence, the output variations in demand amplification as shown in Figure 4.7 constitute a signal mixed with noise. The five variables feeding signals to demand amplification are actual sales, disruptions, lack of coordination, lack of supplier relationships, and ordering policy. The variables disruptions, ordering policy, and lack of supplier relationships are primary inputs to the model and therefore do not have noises mixed with signals. The remaining two variables have signal and noise mixed. Demand amplification is the most important input to bullwhip effect.

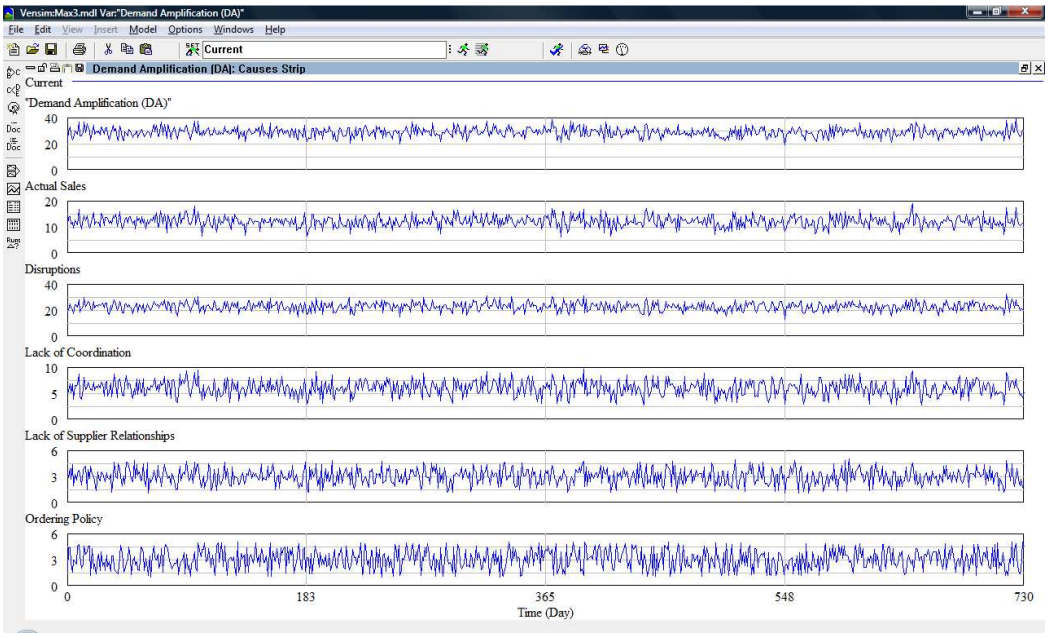

Figure 4.7: The Causes' Strip of Demand Amplification Variation as a Function of its Noise Variation and the Variations in Actual Sales, Disruptions, Lack of Coordination, Lack of Supplier Relationships, and Ordering Policy (Variation in the Size of Batches)

The next most important input to bullwhip effect is beer gaming (see Figure 4.9). Existence of beer gaming in a supply chain almost confirms bullwhip effect. In this model, it is the sum of inputs from order rationing and lead-time variations. It is discussed that lead-time variations are secondary variables with inputs from the lack of coordination and lack of information processing. Order rationing is also a secondary variable receiving input disruptions, which again is a secondary variable receiving inputs from disruptions and lead-time variations. Thus, beer gaming is a complex secondary variable receiving inputs from a cascade of secondary variables before it. Such cascades are evident in the model, making it quite complex and difficult to control. Given that noises are mixed at each cascade stage, the signal of order rationing may demonstrate significant noise. If beer gaming exists in an organization, a number of factors may be causing it, acting in cascades and making it very difficult to reduce or eliminate the practice unless major enhancements in operations are carried out related to the associated variables.

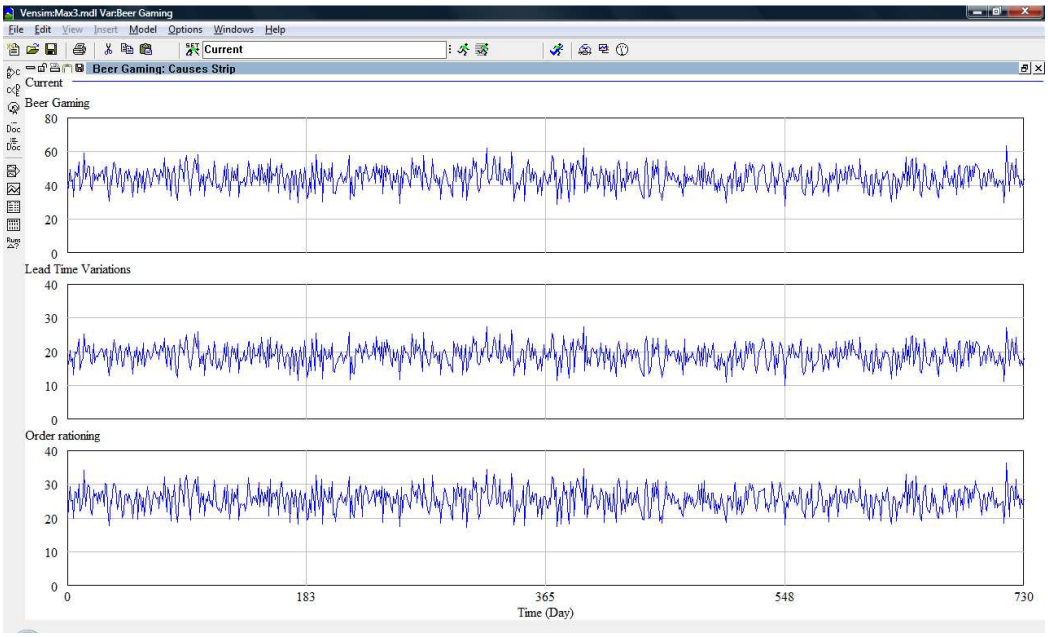

Figure 4.8: The Causes' Strip of Beer Gaming as a Function of its Noise Variation and the Variation in Lead Time and Order Rationing

Finally, the graph of bullwhip effect is revealed. It linearly increased as a sum of all the box variables. It started from NIL and increased to extremely high levels because all the variables causing it are in action, and none of them are controlled. To damp the continuous increase in bullwhip effect, some of the variables need to be controlled. The effects of applying controls are depicted in Figures 4.10 and 4.11.

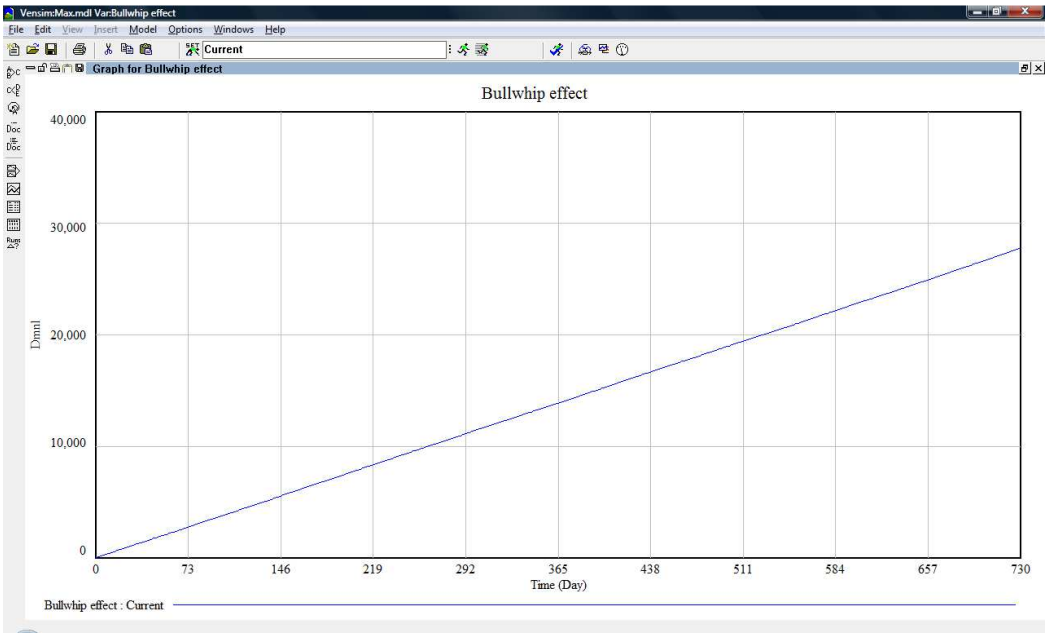

Figure 4.9: The Overall Variation in Bullwhip Effect as an Outcome of the Overall Variations in the Four Box Variables Viz., Beer Gaming, Demand Amplification, Lack of Forecasting Accuracy, and Lack of Information Sharing

The following variables are controlled through change of their formulas. Given that they are complex secondary variables, the only control in hand is to reduce the noise associated with them, as demonstrated in the respective formulas:

Lack of Information Processing=
RANDOM NORMAL(-5 , 0 , -4 , -3 , -2)+Lack of Coordination
Units: Dmnl

Lack of Coordination=
RANDOM NORMAL(-5 , 0 , -3 , -2 , -1)+Lack of Supplier Relationships
Units: Dmnl

Lack of Supplier Relationships=
RANDOM NORMAL(-5 , 0 , -3 , -2 , -1)
Units: Dmnl

It may be noted that the normal distribution of noise has been shifted left along the *x*-axis. In general terms, the strategies and processes associated with these variables

were enhanced without bothering about the variables affecting them. The effect on bullwhip effect is shown in Figure 4.11.

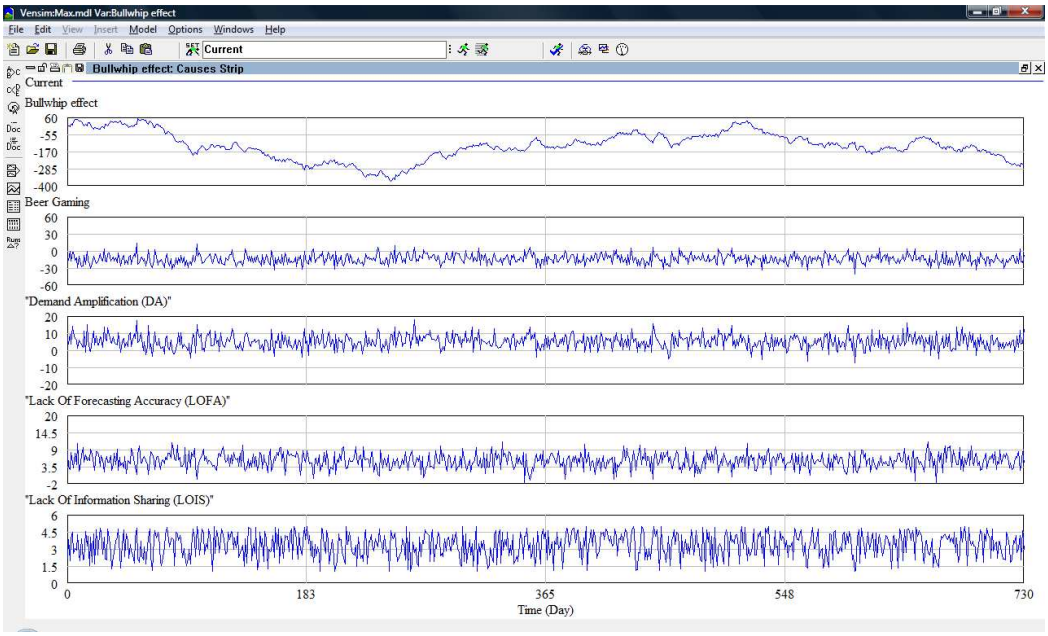

Figure 4.10:The Overall Change in Variation in Bullwhip Effect and the Overall Change in Variations in the Four Box Variables When Changes in Lack of Information Sharing, Lack of Coordination, and Lack of Supplier Relationships are Executed Treating Them as the Control Variables

It may be observed that while the bullwhip effect is intermittently reaching moderate peaks, it is struggling to sustain. The levels are nowhere close to those depicted in Figure 4.9, and the ramp is converted into an oscillating waveform. Thus, reducing noise in the three factor variables (lack of information processing, lack of coordination, and lack of supplier relationships) caused significant damping of the bullwhip effect, although it is not completely eliminated yet. To completely eliminate bullwhip effect, further controls are needed. In the next stage, ordering policy has been controlled using the formula shown below:

Ordering Policy=
RANDOM NORMAL(-5 , 0 , -3 , -3 , -1)
Units: Dmnl

The signal input of ordering policy is now a normal distribution shifted left on the *x*-axis. In effect, it is the reduction of average batch sizes. The result is complete elimination of bullwhip effect. As expected, beer gaming is the most reduced variable. The two steps prove how manipulation of noises and signals used as strategic controls can eliminate bullwhip effect from a supply chain.

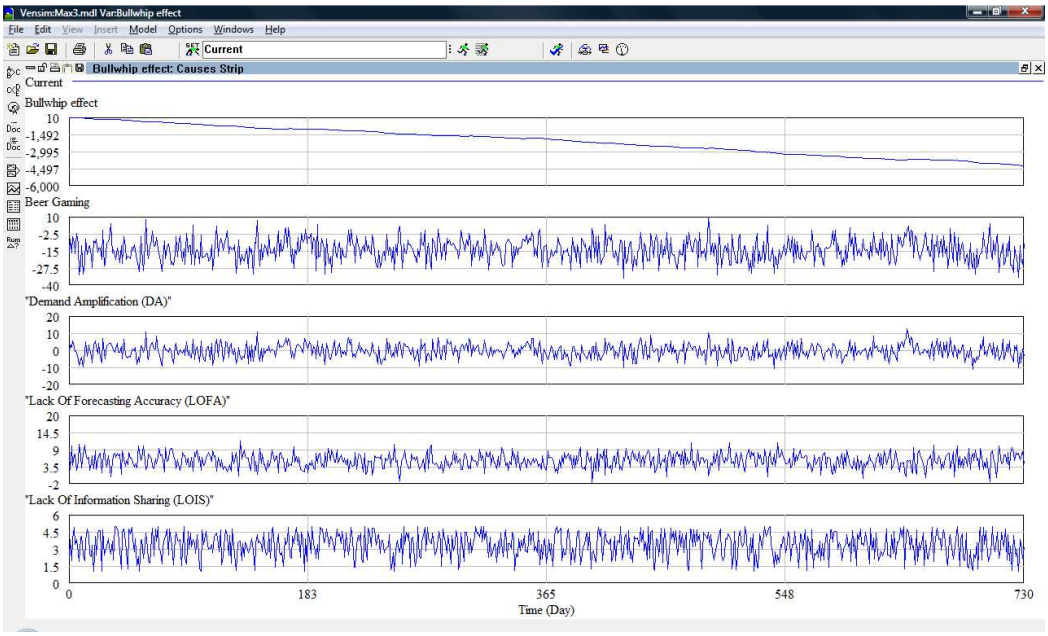

Figure 4.11:The Elimination of Bullwhip Effect and the Overall Change in Variations in the Four Box Variables When Changes in Ordering Policy, Lack of Information Sharing, Lack of Coordination, and Lack of Supplier Relationships are Executed Treating Them as the Control Variables

4.7 Results of Taguchi's Method

The next set of tests is conducted using Taguchi methods. In this method, the output data generated in Vensim simulations has been used as experimentation data. In Vensim, the simulations have been conducted for 730 days (Section 4.6). Taguchi's method advocates conducting smaller sets of experiments to test the influence of a number of factor variables simultaneously on the parameter under testing under different noise scenarios using the SNR formulations of smaller-the-better, nominal-the-best, or larger-the-better scenarios (as reviewed in Section 3.6). The experimental

sets are configured using orthogonal arrays comprising a small set of experiments, involving all the factor variables together. In this research, the twelve by sixteen orthogonal arrays have been used, comprising sixteen experiments each in one array involving all the factor variables modeled in the Vensim simulations. Hence, a total number of forty-six orthogonal arrays have been created for covering all 730 simulations conducted in Vensim. These arrays are presented in Appendices D.1 to D.46. The output data from the Vensim simulations have been loaded in these orthogonal arrays, taking sixteen experiments per array.

The templates generated by Dr. P. R. Apte of Indian Institute of Technology, Bombay (Apte, 2007) have been used for calculating and plotting SNR. Dr. Apte's templates offer orthogonal arrays of L9, L12, L18, and L36. In this research, the L12 template was chosen because it receives exactly twelve signal inputs (eleven factors and one parameter, that is the bullwhip effect), which is the requirement of this research. Dr. Apte's L12 template allows testing of SNR for two noise levels, L1 and L2 (estimates of low and high white noise modeled within the template). This researcher decided to use both the levels for each factor variable in each of the 730 experiments to test how the factor variables vary from the mean within a particular set of sixteen experiments. In this way, forty-six sets of experiments have been conducted by loading sixteen simulation outputs from Vensim into the Taguchi Methods template and plotting the SNR at L1 and L2. All the plots are presented in Appendices D.1 to D.46. Table 4.11 presents a summary of effects of all the factor variables on the parameter. The parameter chosen is bullwhip effect, and the criterion chosen is smaller-the-better. Dr. Apte chose three different effects of the factor variables:

- Dominant: if the mean value of SNR of the factor variable (between L1 and L2) is significantly higher than the overall mean SNR.

- Significant: if the mean value of SNR of the factor variable (between L1 and L2) is significantly lower than the overall mean SNR.
- Neutral/negligible: if the mean value of SNR of the factor variable (between L1 and L2) is closer to the overall mean SNR.

These three effects have been tabulated for all the factor variables on the bullwhip effect based on observations from 730 experiments. The data shown in Table 4.11 comprises outcomes of forty-six sets of Taguchi experimental settings, each comprising sixteen experiments. The state of a factor variable as dominant, significant, and neutral/negligible varied, as shown in the table. As discussed in Section 4.6 the data generated from the Vensim simulations has been loaded into the Taguchi method templates. The input data for the simulations is internally generated by Vensim using a random generator. In real supply chain research, the data can be collected from the echelons of a real supply chain and then loaded in the professional version of Vensim (the student version only allows internal data generation by the random generators). In such a scenario, the outcomes of Taguchi experiments presented in Appendices D.1 to D.46 and summarized in Table 4.11 will represent actual actions by these factors. Given that the simulations have been conducted for a two-year period, the observations can reflect longitudinal behaviors of the factors and can also reflect seasonal patterns.

Table 4.11: Summary of Findings in Taguchi Experiments (Details in Appendices D.1 to D.46)

S. No.	Factor Variables	Dominant	Significant	Neutral/negligible
1	Coordination	2	19	25
2	Demand forecasting	1	7	38
3	Lead time variations	1	10	35
4	Ordering policy (batch size variations)	3	5	38

5	Supplier relationships	5	21	20
6	Information sharing	43	3	0
7	Information processing	1	13	32
8	Order rationing	0	13	33
9	Beer gaming	14	21	11
10	Forecasting accuracy	2	9	35
11	Actual sales	33	11	2

Ideally, a supply chain manager would like to see the SNR of all the factors at neutral/negligible level. If the observations in these tables are perceived as from a real supply chain, the following statements may be made:

- Information sharing and actual sales tracking are the most dominant factors. These variables tend to stretch the SNR to an extreme significantly above the mean.
- Supplier relationships, coordination, and beer gaming are the most significant factors. These variables tend to stretch the SNR to an extreme significantly below the mean.
- Beer gaming and actual sales tracking tend to vary between dominance and significance levels during different parts of the year. This indicates the existence of pressure from seasonal variations.
- Demand forecasting, lead-time variations, ordering policy (batch size variations), information processing, order rationing, and forecasting accuracy are the most stable factors. They have their respective SNR closer to the overall mean (of SNR) at most parts of the year.

It may be observed that these observations from a large set of Taguchi experimental settings can provide definitive leads into the future strategies of a supply chain.

Essentially, strategic directions can be set and investments made with a lot of confidence.

4.8 Summary

In this chapter, the six-step model presented in Chapter 2 for forming the system dynamics model based on the existing dynamics in a supply chain has been tested. This model has been tested using a test database generated through the RAND (N) function in MATLAB. The sequence of steps comprised correlation analysis, exploratory factor analysis, reliability testing, confirmatory factor analysis for validity testing, and structural equation modeling for model fitment testing. The final reliability and validity test results have been found as satisfactory. Thereafter, the output model was created in Vensim and simulated for 730 simulation days using internally generated data in Vensim (independent of the factor analysis step). The outcomes of Vensim simulations were loaded into Taguchi's templates, and a number of definitive observations have been made that can potentially determine the future strategic changes in the supply chain (if the random data was instead collected from a real-world supply chain).

Chapter 5. Conclusions

5.1 Introduction

This research is an investigation of system dynamics modeling for investigating the effects of bullwhip effect in a supply chain and curbing its harmful effects on supply chain performance. Based on a detailed review of literature on bullwhip factors and on system dynamics modeling of a supply chain, a six-step process was presented in this research, which is based on a combination of statistical modeling and tests conducted in a series. This process, described in Chapter 2, developed a system dynamics model specific to active variables in a supply chain and their interaction with bullwhip effect. The process involved two surveys in the supply chain: the first survey for learning about the variables active in the supply chain under study and the second survey for collecting quantitative data about the variables mapped in five levels of a scale.

This research tested the six-step process, but without conducting surveys due to time, cost, and resource constraints. In the data analytics portion of the process, a test database was created using MATLAB's RAND (N) function to generate 1,000 records pertaining to ten bullwhip-related variables chosen from the literature review findings. The definition of the five levels in each variable is presented in Appendix B (which can also serve as a survey questionnaire if a real survey is conducted), and the RAND function was used with 1 as the lowest level and 5 as the highest level for each variable. The six-step analytics process was completed using this data set and described in Chapter 4 such that it can be used by users of this research in supply chains where data is collected through actual surveys. This research has been concluded and the objectives have been met as discussed in Section 5.2.

5.2 Conclusions

In this section, the answers to the research questions have been summarized to present the conclusions of this dissertation. The research questions have been replicated below for ready reference:

(1) What are the factors causing bullwhip effect in a supply chain?

(2) How can system dynamics modeling in a supply chain be conducted for defining the system dynamics model in a supply chain to identify the dynamics caused by bullwhip effect?

(3) How can practitioners use this modeling as a standardized approach for investigating bullwhip effect in a supply chain?

In the response to the first question, the first aspect one needs to keep in mind is that bullwhip effect is not a variable that is directly measurable. In the absence of knowledge of factor variables causing bullwhip effect, it is largely a hidden phenomenon. This is one of the reasons why it exists so prominently in supply chains having inefficiencies but is not strategically mitigated by the supply chain managers. In search for an answer to this question, the prominent factor variables causing bullwhip effect reported by existing studies were reviewed in Chapter 2. In addition, methods and strategies for curbing bullwhip effect were also reviewed. In this space, the review of these factor variables is not repeated. However, a conclusion on how this knowledge could be used by supply chain managers is presented. By looking at the review of bullwhip factor variables in Chapter 2, one may interpret that not all of them may exist in every supply chain. Also, the extent of influence of action of these bullwhip factor variables may vary in different supply chains. The third aspect is to consider that all of these factor variables are not primary variables because they may have underlying causes in different supply chains, which cannot be generalized. For

example, lead-time delays in the United States may depend upon motorway congestions as one of the underlying causes. However, lead-time delays in South Asia may be dependent upon lack of good roads, and the same in parts of Africa and central America may be dependent upon lack of good roads on the shortest paths. In the United States, rain may not cause supply disruptions, but in other parts of the world, rain may be the cause of supply disruptions. This may also be true in some parts of south America. However, in the United States, hailstorms and twisters may be major causes of supply disruptions. Such causes cannot be generalized in theory and the supply chain manager may have to find them through local knowledge and experience. Hence, knowing the active bullwhip factor variables in a supply chain may open windows of analysis but may not be self-sufficient.

In response to the second question, once the bullwhip factor variables and their underlying causes are known, the supply chain manager may need to know how these variables interact. This is where system dynamics modeling is useful. A review of fundamentals of system dynamics (causal loop diagrams and stock and flow diagrams) has been presented in Chapter 2. The existing studies on causal loop diagrams for identifying bullwhip effect and its interaction with other variables in a supply chain have been studied. They are based on the concept of identifying prominent factor variables active in the studied supply chains. However, there is one gap in this approach. The prominent factor variables found to be active in a supply chain may not be directly interacting, albeit they may be interacting through some hidden nodes (latent variables unknown to the local supply chain knowledge base). If such hidden factors exist and are not included in the system dynamics model, the model may be inaccurate, and the governors introduced in the model at strategic places may not return expected results. In such cases, one may incorrectly conclude

that system dynamics is not a reliable approach to study the dynamics caused by bullwhip effect such that they could be controlled. Identifying this gap, this research presented a six-step process for creating a system dynamics model specific to a supply chain using a set of statistical modeling and tests conducted in series.

This six-step process is part of a response to the second research question. This process comprises two surveys: one for learning about all the factor variables prominent in a supply chain and another for collecting data about the extent the factor variables are active in the supply chain (using five-level scales, as presented in Appendix B). In this research, these two surveys could not be performed due to time, cost, and resource constraints. Hence, a test database was generated in MATLAB comprising 1,000 records for ten factor variables chosen to operate the six-step process. The ten factor variables chosen for operating the six-step process represent the data collected in the first survey from a supply chain, and the 1,000 records (presented in Appendix C) represent the data collected about the factor variables discovered from the supply chain using five-level scales, as presented in Appendix B. It may be noted that these levels are tentative and may be set up independently by the supply chain managers based on their local knowledge of the supply chains.

To address the need for exploring the hidden variables existing in the supply chain, the process of exploratory factor analysis is proposed. This process helps in finding hidden (latent) variables in the supply chain and their loadings on the factor variables. The factor variables affected by the hidden variables can be explored by grouping their loading coefficients and testing their reliability scores. After a number of efforts, the groups (called scales) with acceptable reliability scores can be achieved. SPSS is a good tool for exploring such hidden variables and the groups of factor variables associated with them. Additional relationships may be explored by verifying

the correlation coefficients among the factor variables (bypassing the hidden variables) and also verifying the correlation coefficients among the hidden variables. Typically, a correlation coefficient of 0.5 and above is treated as reflecting significant relationship. When all the significant coefficients are known, they can be plotted on a drawing showing (+) signs for positive coefficients and (–) signs for negative coefficients, as well as directions of the relationships. In this way, all the prerequisites of creating the system dynamics model (in the form of causal loops) can be derived. To show stock and flow diagrams, governors for controlling magnitudes of variables may be applied at places where multiple relationships either converge or diverge, and also the strategic controlling objectives of the supply chain can be met. Applying controllers in this way was recommended by Burns and Janamanchi (2007) and Jeong and Houston (2015). To gain further confidence on the derived system dynamics model, the confirmatory factor analysis approach using a path modeling technique may be conducted. Additionally, if there are chances of getting alternate configurations of the system dynamics model with better reliability and validity, one may consider conducting structural equation modeling. These steps are included in the six-step process. The entire process execution was demonstrated in Chapter 4 using the test database of 1,000 records generated in MATLAB. After arriving at the optimum model with high reliability and validity, this system dynamics model was recreated in Vensim simulation tool. The model was simulated for 730 simulation days (two years) in Vensim using internally generated random data. The output data of the simulation was loaded in the L12 Taguchi experimentation setting with sixteen experiments at a time. The 730 simulated days were covered by forty-six Taguchi experimentation settings. The impacts of the factor variables on bullwhip effect were tested through the 730 Taguchi experiments. The SNR values were categorized as

dominant, significant, and neutral/negligible. By summarizing the effects of all the factors and categorizing as dominant, significant, and neutral/negligible, a supply chain manager can obtain definitive leads and directions into the appropriate actions for controlling the unstable factors.

The third research question is about generalization of the proposed six-step process for investigating bullwhip-related dynamics in real supply chains. This process can be followed by conducting the two surveys explained in the process and following the steps discussed in Chapter 4. It is essential to find all underlying causes of the factor variables explored such that realistic, on-the-ground actions could be taken. For example, if motorway congestions are found to be frequent deterrents in maintaining lead times, the suppliers can be instructed to explore alternative transportation paths. If there is a stretch privately created for transportation but becomes unusable during rainy seasons causing supplies disruptions, agents in all the echelons using that path can create a temporary road for trucks that can face rainy seasons, and water logging can be avoided. Such examples allude that the proposed six-step process can be used by supply chain agents to formulate and execute even low-level strategies such as these. When the six-step process is completed (as per the demonstration in Chapter 4 using the test database) and the finalized system dynamics model is evident, such ground-level information will help in identifying the exact strategies to operate the controls defined on the model.

5.3 Recommendations from this Research

This study is unique for two reasons:

- There have been few studies on creating system dynamics models for investigating the dynamics associated with a supply chain.
- The approach presented in this research is based on multivariate statistical modeling and testing processes for identifying correlations with acceptable reliability and validity.

This study presented the six-step process, which can be executed through advanced knowledge of multivariate factor analysis techniques and using tools like SPSS and LISREL. There are additional tools to achieve the same results, like R, Stata, IBM AMOS, and MATLAB. The proposed method comprises empirically proven statistical modeling and testing methods. However, the entire process requires more testing using real data collected from supply chains. It is recommended that this method may be used by researchers and supply chain analysts for ascertaining practical feasibility. Given the involvement of advanced statistical modeling techniques, the role of a statistician would add value on the analysis team. This process may also be combined with scenario analysis techniques to predict how the supply chain is expected to behave when the loadings or relationships change. These are extended and involve analytics projecting the usage of the six-step process in predicting changes in the supply chain. The dynamics of loadings and relationships may be driven by internal and external factors learned through additional research and investigation. Similarly, alternative tools can be used in addition to Vensim for simulating the output system dynamics model of the multivariate analysis.

5.4 Recommendations for Future Study and Analysis

In this research, the effects of interaction variables have not been explored. Interaction variables are moderators that can influence the significance and loadings of each variable on the overall system dynamics model. Interaction variables can be introduced in the proposed process as steps for investigating the impact of interaction variables separately, by forming a multiple regression model using the factor variables and the hidden variables found through exploratory factor analysis. A third survey will have to be added to collect data about the hidden variables such that the dependent variable field of the regression model can be populated in SPSS. Given that there can be only one dependent variable in multiple regression modeling, the impact of interaction variables on the factor variables will have to be tested, assessing one hidden variable at a time in the model. This method means that the number of multiple regression models to be tested for interaction will be equal to the number of hidden variables explored through exploratory factor analysis. The six-step process may be expanded into a seven-step process, whereby the new step added will test interactions in the multiple regression models, which will also help in testing *p*-value significance.

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Appendix A: LISREL Output

```
DATE: 10/11/2015
                                    TIME:  6:59

                                L I S R E L  8.80

                                      BY

                             Karl G. Jöreskog & Dag Sörbom


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The following lines were read from file C:\RESEARCH\Max
Taylor\Max_Path_Diagram_1000_Records.SPJ:

 Path Diagram for Systems Dynamics Model
 Raw Data from file 'C: \RESEARCH\Max
Taylor\Max_PHD_Primary_Data_1000_Records.psf'
 Latent Variables DEMA FORA BEER INFS
 Relationships
 F1 = FORA
 F2 = DEMA
 F3 = DEMA INFS
 F4 = DEMA
 F5 = DEMA
 F6 = FORA
 F7 = INFS
 F8 = DEMA FORA BEER
 F9 = BEER
 F10 = BEER INFS
 Path Diagram
 End of Problem

 Sample Size = 1000

 Path Diagram for Systems Dynamics Model


 Path Diagram for Systems Dynamics Model

 Number of Iterations = 13
```

LISREL Estimates (Maximum Likelihood)

Measurement Equations

F1 = 0.79*FORA, Errorvar. = 0.37, R^2 = 0.63
(0.028) (0.023)
28.10 15.89

F2 = 0.89*DEMA, Errorvar. = 0.25, R^2 = 0.76
(0.026) (0.016)
33.76 15.80

F3 = 0.54*DEMA + 0.26*INFS, Errorvar. = 0.34, R^2 = 0.61
(0.045) (0.049) (0.019)
11.88 5.42 17.56

F4 = 0.84*DEMA, Errorvar. = 0.31, R^2 = 0.69
(0.027) (0.018)
31.55 17.59

F5 = 0.90*DEMA, Errorvar. = 0.39, R^2 = 0.68
(0.029) (0.022)
31.02 17.93

F6 = 0.83*FORA, Errorvar. = 0.39, R^2 = 0.64
(0.029) (0.025)
28.31 15.64

F7 = 1.13*INFS, Errorvar. = 0.14, R^2 = 1.12
(0.095) (0.21)
11.93 0.67

F8 = 0.41*DEMA + 0.32*FORA + 0.12*BEER, Errorvar. = 0.49, R^2 = 0.57
(0.079) (0.085) (0.045) (0.024)
5.20 3.77 2.65 20.16

F9 = 0.92*BEER, Errorvar. = 0.40, R^2 = 0.68
(0.044) (0.064)
21.03 6.21

F10 = 0.63*BEER + 0.30*INFS, Errorvar. = 0.48, R^2 = 0.57
(0.057) (0.058) (0.030)
10.89 5.13 15.94

Correlation Matrix of Independent Variables

	DEMA	FORA	BEER	INFS
DEMA	1.00			
FORA	0.88	1.00		
	(0.02)			
	55.00			
BEER	0.68	0.70	1.00	
	(0.03)	(0.03)		

	20.99	20.24		
INFS	0.55	0.57	0.40	1.00
	(0.05)	(0.05)	(0.04)	
	11.11	10.90	10.24	

Goodness of Fit Statistics

Degrees of Freedom = 25
Minimum Fit Function Chi-Square = 40.35 (P = 0.0)
Normal Theory Weighted Least Squares Chi-Square = 40.52 (P = 0.0)
Estimated Non-centrality Parameter (NCP) = 315.52
90 Percent Confidence Interval for NCP = (259.62; 378.88)

Minimum Fit Function Value = 0.34
Population Discrepancy Function Value (F0) = 0.32
90 Percent Confidence Interval for F0 = (0.26; 0.38)
Root Mean Square Error of Approximation (RMSEA) = 0.11
90 Percent Confidence Interval for RMSEA = (0.10; 0.12)
P-Value for Test of Close Fit (RMSEA < 0.05) = 0.00

Expected Cross-Validation Index (ECVI) = 0.40
90 Percent Confidence Interval for ECVI = (0.34; 0.46)
ECVI for Saturated Model = 0.11
ECVI for Independence Model = 13.57

Chi-Square for Independence Model with 45 Degrees of Freedom = 13540.23
Independence AIC = 13560.23
Model AIC = 400.52
Saturated AIC = 110.00
Independence CAIC = 13619.31
Model CAIC = 577.76
Saturated CAIC = 434.93

Normed Fit Index (NFI) = 0.97
Non-Normed Fit Index (NNFI) = 0.96
Parsimony Normed Fit Index (PNFI) = 0.54
Comparative Fit Index (CFI) = 0.98
Incremental Fit Index (IFI) = 0.98
Relative Fit Index (RFI) = 0.95

Critical N (CN) = 131.07

Root Mean Square Residual (RMR) = 0.034
Standardized RMR = 0.031
Goodness of Fit Index (GFI) = 0.94
Adjusted Goodness of Fit Index (AGFI) = 0.86
Parsimony Goodness of Fit Index (PGFI) = 0.43

Time used: 0.016 Seconds

Appendix B: Data Modeling for Generating Test Data

Factor Variable 1: demand variations

1. Never occurred
2. Minor (less than 5%)
3. Moderate (more than 5% but less than 15%)
4. High (more than 15% but less than 25%)
5. Significant (above 25%)

Factor Variable 2: extent of actual sales when compared with forecasts of demands

1. Low (less than 20%)
2. Moderate (20% or more but less than 40%)
3. Good (40% or more but less than 60%)
4. High (60% or more but less than 80%)
5. Significant (above 80%)

Factor variable 3: extent of coordination among supply chain echelons

1. Poor (hardly coordinate)
2. Fair (coordinate occasionally on a need basis)
3. Average (coordinate periodically)
4. Good (coordinate in real time)
5. Excellent (work as partners)

Factor variable 4: supplier relationships within the supply chain

1. Poor (hardly coordinate)
2. Fair (coordinate occasionally on a need basis)
3. Average (coordinate periodically)
4. Good (coordinate in real time)
5. Excellent (work as partners)

Factor variable 5: Extent of disruptions in supplies

1. Low (once to thrice in a demand period)
2. Minor (> 3 to 5 times in a demand period)
3. Moderate (> 5 to 10 times in a demand period)
4. High (>10 times to 15 times in a demand period)
5. Significant (>15 times in a demand period)

Factor variable 6: extent of demand forecasting

1. Poor (nil to negligible demand forecasting)
2. Fair (demand forecasting is carried out subjectively through meetings and discussions)
3. Average (demand forecasting is manual)
4. Good (demand forecasting is semi-automated)
5. Excellent (demand forecasting is automated)

Factor variable 7: extent of information processing

1. Poor (inadequate details)
2. Fair (abstract information only)
3. Average (important details only)
4. Good (detailed)
5. Excellent (highly detailed)

Factor variable 8: extent of order batches in the supply chain (as per the ordering policy)

1. Small (less than 20% of the total order quantity)
2. Moderate (20% or more but less than 40% of the total order quantity)
3. Large (40% or more but less than 60% of the total order quantity)
4. Very Large (60% or more but less than 80% of the total order quantity)
5. Significant (above 80% of the total order quantity)

Factor variable 9: order rationing (again as per ordering policy)

1. Low (< 5%)
2. Moderate (>5% to 15%)
3. High (> 15% to 25%)
4. Very high (> 25% to 50%)
5. Significant (> 50%)

Factor variable 10: overall lead time variations

1. Low (< 5%)
2. Moderate (>5% to 15%)
3. High (> 15% to 25%)
4. Very high (> 25% to 50%)
5. Significant (> 50%)

Appendix C: Test Data Generated from RAND (N) Function in MATLAB

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
1	3	3	4	3	2	4	3	3	5	4
2	4	3	3	4	3	4	3	3	3	3
3	2	4	3	4	2	3	3	2	4	4
4	3	3	4	3	2	4	4	3	3	4
5	5	3	4	3	3	5	4	3	3	4
6	4	2	3	3	2	4	4	2	5	4
7	5	3	4	3	3	3	3	2	4	4
8	4	2	3	4	2	4	4	2	5	4
9	3	3	4	3	2	3	4	2	4	5
10	4	3	3	3	3	2	4	3	4	3
11	3	2	3	3	2	3	4	3	4	4
12	3	4	4	3	3	3	5	2	5	5
13	5	4	3	4	2	2	3	3	5	4
14	4	3	4	4	2	2	3	3	4	4
15	5	3	3	4	3	4	5	3	5	4
16	5	3	3	3	2	3	3	2	3	3
17	5	3	3	3	2	4	3	2	3	3
18	5	3	3	3	2	3	3	2	3	3
19	5	2	3	4	2	3	3	2	4	4
20	4	4	4	3	2	4	4	2	4	4
21	5	3	4	3	2	2	4	3	5	4
22	5	3	4	3	2	4	5	3	5	3
23	5	3	3	4	3	4	4	4	5	4
24	3	2	3	4	3	2	4	3	4	5
25	4	4	3	4	2	2	4	4	3	5
26	4	3	3	3	3	3	3	4	2	5
27	4	2	4	3	3	4	5	3	2	5
28	4	4	3	4	3	3	3	3	2	5
29	5	4	4	4	2	3	4	3	2	3
30	4	4	4	4	2	3	3	4	5	5
31	4	3	3	4	3	2	4	4	2	4
32	4	3	4	3	3	4	4	4	2	4
33	3	3	4	3	2	4	4	3	3	4
34	4	3	3	3	3	2	4	3	4	3
35	3	3	4	3	2	4	3	3	5	4
36	3	4	4	3	3	3	5	2	5	5
37	4	3	4	3	3	4	4	4	2	4
38	4	4	4	3	2	4	4	2	4	4
39	3	4	4	3	3	3	5	2	5	5
40	3	3	4	3	2	4	4	3	3	4
41	4	4	3	4	3	3	3	3	2	5
42	4	2	4	3	3	4	5	3	2	5
43	3	3	4	3	2	4	3	3	5	4
44	3	3	4	3	2	4	3	3	5	4
45	5	4	4	4	2	3	4	3	2	3
46	5	3	4	3	2	4	5	3	5	3
47	5	3	4	3	3	5	4	3	3	4
48	4	4	4	4	2	3	3	4	5	5
49	2	4	3	4	2	3	3	2	4	4
50	4	3	4	4	2	2	3	3	4	4
51	2	2	5	2	3	2	3	3	2	4
52	3	2	3	4	3	2	4	3	4	5
53	3	4	4	3	3	3	5	2	5	5
54	4	3	3	3	3	3	3	4	2	5
55	5	3	3	3	2	3	3	2	3	3
56	5	3	3	3	2	3	3	2	3	3
57	5	2	3	4	2	3	3	2	4	4
58	2	3	3	3	2	3	3	2	4	4
59	2	2	4	2	4	2	4	3	3	4
60	3	3	4	3	2	4	3	3	5	4
61	3	3	4	3	2	4	4	3	3	4
62	4	3	3	3	3	3	3	4	2	5
63	5	3	4	3	3	3	3	2	4	4
64	4	2	3	3	2	4	4	2	5	4
65	5	2	3	4	2	3	3	2	4	4
66	3	4	4	3	3	3	5	2	5	5
67	4	3	3	4	3	2	4	4	2	4
68	4	3	3	3	3	3	3	4	2	5
69	5	3	4	3	3	3	3	2	4	4
70	3	3	4	3	2	3	4	2	4	5
71	4	4	3	4	2	2	4	4	3	5

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
72	3	3	4	3	2	4	4	3	3	4
73	3	2	3	4	3	2	4	3	4	5
74	5	3	3	4	3	4	4	4	5	4
75	3	3	4	3	2	4	4	3	3	4
76	4	3	4	4	3	3	3	3	3	4
77	3	4	4	4	5	3	5	4	3	2
78	4	4	5	4	4	3	3	3	3	4
79	4	3	3	4	3	4	4	5	4	3
80	3	4	3	3	4	4	4	3	3	4
81	4	4	5	4	3	4	5	4	3	4
82	4	3	4	3	4	4	4	3	5	5
83	5	4	4	4	4	4	3	5	4	4
84	4	5	4	5	4	3	4	3	3	4
85	5	4	4	4	4	5	3	5	4	3
86	3	4	4	4	4	5	5	5	4	4
87	4	5	5	5	5	3	4	5	5	5
88	4	4	4	4	4	5	4	4	3	5
89	5	5	4	3	3	5	3	4	5	4
90	4	4	4	3	4	4	5	4	4	3
91	4	4	5	4	4	3	5	4	3	5
92	3	4	4	4	5	5	3	3	4	5
93	4	4	5	5	3	4	4	4	4	3
94	4	5	4	4	4	4	4	3	4	4
95	5	4	4	4	4	5	5	4	3	5
96	4	4	5	4	3	4	3	4	5	4
97	5	5	4	4	4	5	5	3	4	5
98	4	5	4	3	4	4	4	4	3	3
99	4	5	4	5	5	4	4	4	5	4
100	5	5	4	5	5	5	3	4	3	3
101	4	4	3	4	3	4	3	5	5	5
102	5	4	4	5	4	4	5	4	3	4
103	4	4	4	4	5	5	4	4	3	4
104	5	5	4	4	4	5	5	4	4	5
105	4	5	5	5	4	3	4	3	4	4
106	4	5	3	4	4	4	5	5	5	5
107	4	4	4	5	5	5	5	4	3	4
108	3	4	5	4	5	4	5	5	4	5
109	4	5	4	4	4	3	5	4	5	5
110	5	5	4	5	3	3	4	5	4	4
111	3	4	4	4	4	4	4	4	4	5
112	5	5	4	5	3	5	5	5	5	5
113	3	4	3	4	4	4	4	3	4	4
114	4	4	4	3	4	5	5	4	4	5
115	4	4	5	3	4	4	3	5	4	4
116	5	4	5	4	3	5	5	4	5	4
117	4	5	4	4	4	4	4	4	3	3
118	4	4	4	4	4	4	5	5	5	4
119	4	5	5	4	3	4	5	4	5	5
120	5	4	5	4	4	4	4	5	4	3
121	3	4	4	5	4	5	4	5	4	4
122	5	4	4	3	4	4	5	5	3	4
123	4	3	4	4	4	4	4	3	3	4
124	4	5	4	3	4	5	3	4	4	5
125	4	5	4	4	5	4	4	5	4	3
126	5	5	4	3	4	4	4	5	4	5
127	4	4	5	4	5	4	4	4	3	4
128	5	5	4	5	4	5	5	4	5	5
129	4	5	4	4	4	5	4	5	5	4
130	4	4	5	5	3	4	4	4	4	5
131	5	4	4	4	4	3	4	5	4	5
132	4	4	5	5	4	5	4	5	4	5
133	4	5	4	4	5	4	4	3	3	4
134	4	4	4	4	5	3	3	4	5	5
135	5	3	4	5	4	4	4	3	4	3
136	5	4	5	3	4	5	4	4	3	4
137	4	4	3	5	4	4	4	4	5	5
138	5	4	4	4	3	4	4	4	4	3
139	5	5	4	4	5	3	3	4	5	5
140	4	5	4	5	4	5	4	5	4	3
141	4	5	4	4	5	4	4	5	3	4
142	5	5	4	5	4	4	4	3	4	4
143	4	5	5	4	4	3	5	4	4	5
144	4	4	4	4	3	5	3	5	4	4
145	4	5	4	5	4	4	4	4	4	3

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
146	4	4	5	5	5	3	3	4	5	5
147	5	4	4	5	3	4	5	4	5	4
148	3	4	4	4	5	3	3	4	4	5
149	5	5	5	5	5	3	3	4	5	4
150	5	3	4	4	4	4	5	4	5	5
151	5	4	4	5	3	4	5	4	5	4
152	3	4	4	4	5	3	3	4	4	5
153	5	5	5	5	5	3	3	4	5	4
154	5	3	4	4	4	4	5	4	5	5
155	4	4	4	4	3	4	4	3	4	4
156	3	3	3	3	2	3	3	2	3	3
157	5	5	5	5	4	5	5	4	5	5
158	4	4	4	4	3	4	4	4	4	4
159	4	4	4	4	3	4	4	4	4	4
160	3	3	3	3	2	3	3	3	3	3
161	5	5	5	5	4	5	5	5	5	5
162	4	4	4	4	3	4	4	3	4	4
163	4	3	3	4	2	3	4	3	4	3
164	2	3	3	3	4	2	2	3	3	4
165	4	4	4	4	4	2	2	3	4	3
166	4	2	3	3	3	3	4	3	4	4
167	4	3	3	4	2	3	4	3	4	3
168	2	3	3	3	4	2	2	3	3	4
169	4	4	4	4	4	2	2	3	4	3
170	4	2	3	3	3	3	4	3	4	4
171	3	3	3	3	2	3	3	2	3	3
172	2	2	2	2	1	2	2	1	2	2
173	4	4	4	4	3	4	4	3	4	4
174	3	3	3	3	2	3	3	3	3	3
175	3	3	3	3	2	3	3	3	3	3
176	2	2	2	2	1	2	2	2	2	2
177	2	2	3	2	1	3	2	2	4	3
178	3	2	2	3	2	3	2	2	2	2
179	1	3	2	3	1	2	2	1	3	3
180	2	2	3	2	1	3	3	2	2	3
181	4	2	3	2	2	4	3	2	2	3
182	3	1	2	2	1	3	3	1	4	3
183	4	2	3	2	2	2	2	1	3	3
184	3	1	2	3	1	3	3	1	4	3
185	2	2	3	2	1	2	3	1	3	4
186	3	2	2	2	2	1	3	2	3	2
187	2	1	2	2	1	2	3	2	3	3
188	2	3	3	2	2	2	4	1	4	4
189	4	3	2	3	1	1	2	2	4	3
190	3	2	3	3	1	1	2	2	3	3
191	4	2	2	3	2	3	4	2	4	3
192	4	2	2	2	1	2	2	1	2	2
193	4	2	2	2	1	3	2	1	2	2
194	4	2	2	2	1	2	2	1	2	2
195	4	1	2	3	1	2	2	1	3	3
196	3	3	3	2	1	3	3	1	3	3
197	4	2	3	2	1	1	3	2	4	3
198	4	2	3	2	1	3	4	2	4	2
199	4	2	2	3	2	3	3	3	4	3
200	2	1	2	3	2	1	3	2	3	4
201	3	3	2	3	1	1	3	3	2	4
202	3	2	2	2	2	2	2	3	1	4
203	3	1	3	2	2	3	4	2	1	4
204	3	3	2	3	2	2	2	2	1	4
205	4	3	3	3	1	2	3	2	1	2
206	3	3	3	3	1	2	2	3	4	4
207	3	2	2	3	2	1	3	3	1	3
208	3	2	3	2	2	3	3	3	1	3
209	2	2	3	2	1	3	3	2	2	3
210	3	2	2	2	2	1	3	2	3	2
211	2	2	3	2	1	3	2	2	4	3
212	2	3	3	2	2	2	4	1	4	4
213	3	2	3	2	2	3	3	3	1	3
214	3	3	3	2	1	3	3	1	3	3
215	2	3	3	2	2	2	4	1	4	4
216	2	2	3	2	1	3	3	2	2	3
217	3	3	2	3	2	2	2	2	1	4
218	3	1	3	2	2	3	4	2	1	4
219	2	2	3	2	1	3	2	2	4	3

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
220	2	2	3	2	1	3	2	2	4	3
221	4	3	3	3	1	2	3	2	1	2
222	4	2	3	2	1	3	4	2	4	2
223	4	2	3	2	2	4	3	2	2	3
224	3	3	3	3	1	2	2	3	4	4
225	1	3	2	3	1	2	2	1	3	3
226	3	2	3	3	1	1	2	2	3	3
227	1	1	4	1	2	1	2	2	1	3
228	2	1	2	3	2	1	3	2	3	4
229	2	3	3	2	2	2	4	1	4	4
230	3	2	2	2	2	2	2	3	1	4
231	4	2	2	2	1	2	2	1	2	2
232	4	2	2	2	1	2	2	1	2	2
233	4	1	2	3	1	2	2	1	3	3
234	1	2	2	2	1	2	2	1	3	3
235	1	1	3	1	3	1	3	2	2	3
236	2	2	3	2	1	3	2	2	4	3
237	2	2	3	2	1	3	3	2	2	3
238	3	2	2	2	2	2	2	3	1	4
239	4	2	3	2	2	2	2	1	3	3
240	3	1	2	2	1	3	3	1	4	3
241	4	1	2	3	1	2	2	1	3	3
242	2	3	3	2	2	2	4	1	4	4
243	3	2	2	3	2	1	3	3	1	3
244	3	2	2	2	2	2	2	3	1	4
245	4	2	3	2	2	2	2	1	3	3
246	2	2	3	2	1	2	3	1	3	4
247	3	3	2	3	1	1	3	3	2	4
248	2	2	3	2	1	3	3	2	2	3
249	2	1	2	3	2	1	3	2	3	4
250	4	2	2	3	2	3	3	3	4	3
251	2	2	3	2	1	3	3	2	2	3
252	3	2	3	3	2	2	2	2	2	3
253	2	3	3	3	4	2	4	3	2	1
254	3	3	4	3	3	2	2	2	2	3
255	3	2	2	3	2	3	3	4	3	2
256	2	3	2	2	3	3	3	2	2	3
257	3	3	4	3	2	3	4	3	2	3
258	3	2	3	2	3	3	3	2	4	4
259	4	3	3	3	3	3	2	4	3	3
260	3	4	3	4	3	2	3	2	2	3
261	4	3	3	3	3	4	2	4	3	2
262	2	3	3	3	3	4	4	4	3	3
263	3	4	4	4	4	2	3	4	4	4
264	3	3	3	3	3	4	3	3	2	4
265	4	4	3	2	2	4	2	3	4	3
266	3	3	3	2	3	3	4	3	3	2
267	3	3	4	3	3	2	4	3	2	4
268	2	3	3	3	4	4	2	2	3	4
269	3	3	4	4	2	3	3	3	3	2
270	3	4	3	3	3	3	3	2	3	3
271	4	3	3	3	3	4	4	3	2	4
272	3	3	4	3	2	3	2	3	4	3
273	4	4	3	3	3	4	4	2	3	4
274	3	4	3	2	3	3	3	3	2	2
275	3	4	3	4	4	3	3	3	4	3
276	4	4	3	4	4	4	2	3	2	2
277	3	3	2	3	2	3	2	4	4	4
278	4	3	3	4	3	3	4	3	2	3
279	3	3	3	3	4	4	3	3	2	3
280	4	4	3	3	3	4	4	3	3	4
281	3	4	4	4	3	2	3	2	3	3
282	3	4	2	3	3	3	4	4	4	4
283	4	4	4	4	2	3	3	4	5	5
284	2	4	3	4	2	3	3	2	4	4
285	4	3	4	4	2	2	3	3	4	4
286	2	2	5	2	3	2	3	3	2	4
287	3	2	3	4	3	2	4	3	4	5
288	3	4	4	3	3	3	5	2	5	5
289	4	3	3	3	3	3	3	4	2	5
290	5	3	3	3	2	3	3	2	3	3
291	5	3	3	3	2	3	3	2	3	3
292	5	2	3	4	2	3	3	2	4	4
293	2	3	3	3	2	3	3	2	4	4

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
294	2	2	4	2	4	2	4	3	3	4
295	3	3	4	3	2	4	3	3	5	4
296	3	3	4	3	2	4	4	3	3	4
297	4	3	3	3	3	3	3	4	2	5
298	5	3	4	3	3	3	3	2	4	4
299	4	2	3	3	2	4	4	2	5	4
300	5	2	3	4	2	3	3	2	4	4
301	3	4	4	3	3	3	5	2	5	5
302	4	3	3	4	3	2	4	4	2	4
303	4	3	3	3	3	3	3	4	2	5
304	5	3	4	3	3	3	3	2	4	4
305	3	3	4	3	2	3	4	2	4	5
306	4	4	3	4	2	2	4	4	3	5
307	3	3	4	3	2	4	4	3	3	4
308	3	2	3	4	3	2	4	3	4	5
309	5	3	3	4	3	4	4	4	5	4
310	3	3	4	3	2	4	4	3	3	4
311	4	3	4	4	3	3	3	3	3	4
312	3	4	4	4	5	3	5	4	3	2
313	4	4	5	4	4	3	3	3	3	4
314	4	3	3	4	3	4	4	5	4	3
315	3	4	3	3	4	4	4	3	3	4
316	4	4	5	4	3	4	5	4	3	4
317	4	3	4	3	4	4	4	3	5	5
318	5	4	4	4	4	4	3	5	4	4
319	4	5	4	5	4	3	4	3	3	4
320	5	4	4	4	4	5	3	5	4	3
321	3	4	4	4	4	5	5	5	4	4
322	4	5	5	5	5	3	4	5	5	5
323	4	4	4	4	4	5	4	4	3	5
324	5	5	4	3	3	5	3	4	5	4
325	4	4	4	3	4	4	5	4	4	3
326	4	4	5	4	4	3	5	4	3	5
327	3	4	4	4	5	5	3	3	4	5
328	4	4	5	5	3	4	4	4	4	3
329	4	5	4	4	4	4	4	3	4	4
330	5	4	4	4	4	5	5	4	3	5
331	4	4	5	4	3	4	3	4	5	4
332	5	5	4	4	4	5	5	3	4	5
333	4	5	4	3	4	4	4	4	3	3
334	4	5	4	5	5	4	4	4	5	4
335	5	5	4	5	5	5	3	4	3	3
336	4	4	3	4	3	4	3	5	5	5
337	5	4	4	5	4	4	5	4	3	4
338	4	4	4	4	5	5	4	4	3	4
339	5	5	4	4	4	5	5	4	4	5
340	4	5	5	5	4	3	4	3	4	4
341	4	5	3	4	4	4	5	5	5	5
342	5	5	5	5	3	4	4	5	3	3
343	3	5	4	5	3	4	4	3	5	5
344	5	4	5	5	3	3	4	4	5	5
345	3	3	4	3	4	3	4	4	3	5
346	3	2	3	3	2	2	2	2	2	3
347	2	3	3	3	4	2	4	3	2	1
348	3	3	4	3	3	2	2	2	2	3
349	3	2	2	3	2	3	3	4	3	2
350	2	3	2	2	3	3	3	2	2	3
351	3	3	4	3	2	3	4	3	2	3
352	3	2	3	2	3	3	3	2	4	4
353	4	3	3	3	3	3	2	4	3	3
354	3	4	3	4	3	2	3	2	2	3
355	4	3	3	3	3	4	2	4	3	2
356	2	3	3	3	3	4	4	4	3	3
357	3	4	4	4	4	2	3	4	4	4
358	3	3	3	3	3	4	3	3	2	4
359	4	4	3	2	2	4	2	3	4	3
360	3	3	3	2	3	3	4	3	3	2
361	3	3	4	3	3	2	4	3	2	4
362	2	3	3	3	4	4	2	2	3	4
363	3	3	4	4	2	3	3	3	3	2
364	3	4	3	3	3	3	3	2	3	3
365	4	3	3	3	3	4	4	3	2	4
366	3	3	4	3	2	3	2	3	4	3
367	4	4	3	3	3	4	4	2	3	4

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
368	3	4	3	2	3	3	3	3	2	2
369	3	4	3	4	4	3	3	3	4	3
370	4	4	3	4	4	4	2	3	2	2
371	3	3	2	3	2	3	2	4	4	4
372	4	3	3	4	3	3	4	3	2	3
373	3	3	3	3	4	4	3	3	2	3
374	4	4	3	3	3	4	4	3	3	4
375	3	4	4	4	3	2	3	2	3	3
376	3	4	4	4	5	3	5	4	3	2
377	4	4	5	4	4	3	3	3	3	4
378	4	3	3	4	3	4	4	5	4	3
379	3	4	3	3	4	4	4	3	3	4
380	4	4	5	4	3	4	5	4	3	4
381	4	3	4	3	4	4	4	3	5	5
382	5	4	4	4	4	4	3	5	4	4
383	4	5	4	5	4	3	4	3	3	4
384	5	4	4	4	4	5	3	5	4	3
385	3	4	4	4	4	5	5	5	4	4
386	4	5	5	5	5	3	4	5	5	5
387	4	4	4	4	4	5	4	4	3	5
388	5	5	4	3	3	5	3	4	5	4
389	4	4	4	3	4	4	5	4	4	3
390	4	4	5	4	4	3	5	4	3	5
391	3	4	4	4	5	5	3	3	4	5
392	4	4	5	5	3	4	4	4	4	3
393	4	5	4	4	4	4	4	3	4	4
394	5	4	4	4	4	5	5	4	3	5
395	4	4	5	4	3	4	3	4	5	4
396	5	5	4	4	4	5	5	3	4	5
397	4	5	4	3	4	4	4	4	3	3
398	4	5	4	5	5	4	4	4	5	4
399	5	5	4	5	5	5	3	4	3	3
400	4	4	3	4	3	4	3	5	5	5
401	5	4	4	5	4	4	5	4	3	4
402	4	4	4	4	5	5	4	4	3	4
403	5	5	4	4	4	5	5	4	4	5
404	4	5	5	5	4	3	4	3	4	4
405	4	5	5	5	4	4	4	5	4	3
406	5	5	4	5	5	4	4	4	4	5
407	5	4	4	5	4	5	5	3	5	4
408	4	5	4	4	5	5	5	4	4	5
409	5	5	3	5	4	5	3	5	4	5
410	5	4	5	4	5	5	5	4	3	3
411	5	5	5	5	5	5	4	4	5	5
412	3	3	4	3	3	2	2	2	2	3
413	3	2	2	3	2	3	3	4	3	2
414	2	3	2	2	3	3	3	2	2	3
415	3	3	4	3	2	3	4	3	2	3
416	3	2	3	2	3	3	3	2	4	4
417	4	3	3	3	3	3	2	4	3	3
418	3	4	3	4	3	2	3	2	2	3
419	4	3	3	3	3	4	2	4	3	2
420	2	3	3	3	3	4	4	4	3	3
421	3	4	4	4	4	2	3	4	4	4
422	3	3	3	3	3	4	3	3	2	4
423	4	4	3	2	2	4	2	3	4	3
424	3	3	3	2	3	3	4	3	3	2
425	3	3	4	3	3	2	4	3	2	4
426	2	3	3	3	4	4	2	2	3	4
427	3	3	4	4	2	3	3	3	3	2
428	3	4	3	3	3	3	3	2	3	3
429	4	3	3	3	3	4	4	3	2	4
430	3	3	4	3	2	3	2	3	4	3
431	4	4	3	3	3	4	4	2	3	4
432	3	4	3	2	3	3	3	3	2	2
433	3	4	3	4	4	3	3	3	4	3
434	4	4	3	4	4	4	2	3	2	2
435	3	3	2	3	2	3	2	4	4	4
436	4	3	3	4	3	3	4	3	2	3
437	3	3	3	3	4	4	3	3	2	3
438	4	4	3	3	3	4	4	3	3	4
439	3	4	4	4	3	2	3	2	3	3
440	3	4	4	4	3	3	3	4	3	2
441	4	4	3	4	4	3	3	3	3	4

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
442	4	3	3	4	3	4	4	2	4	3
443	3	4	3	3	4	4	4	3	3	4
444	4	4	2	4	3	4	2	4	3	4
445	4	3	4	3	4	4	4	3	2	2
446	4	4	4	4	4	4	3	3	4	4
447	2	2	3	2	2	1	1	1	1	2
448	2	1	1	2	1	2	2	3	2	1
449	1	2	1	1	2	2	2	1	1	2
450	2	2	3	2	1	2	3	2	1	2
451	4	4	5	4	4	3	3	3	3	4
452	4	3	3	4	3	4	4	5	4	3
453	3	4	3	3	4	4	4	3	3	4
454	4	4	5	4	3	4	5	4	3	4
455	4	3	4	3	4	4	4	3	5	5
456	5	4	4	4	4	4	3	5	4	4
457	4	5	4	5	4	3	4	3	3	4
458	5	4	4	4	4	5	3	5	4	3
459	3	4	4	4	4	5	5	5	4	4
460	4	5	5	5	5	3	4	5	5	5
461	4	4	4	4	4	5	4	4	3	5
462	5	5	4	3	3	5	3	4	5	4
463	4	4	4	3	4	4	5	4	4	3
464	4	4	5	4	4	3	5	4	3	5
465	3	4	4	4	5	5	3	3	4	5
466	4	4	5	5	3	4	4	4	4	3
467	4	5	4	4	4	4	4	3	4	4
468	5	4	4	4	4	5	5	4	3	5
469	4	4	5	4	3	4	3	4	5	4
470	5	5	4	4	4	5	5	3	4	5
471	4	5	4	3	4	4	4	4	3	3
472	4	5	4	5	5	4	4	4	5	4
473	5	5	4	5	5	5	3	4	3	3
474	4	4	3	4	3	4	3	5	5	5
475	5	4	4	5	4	4	5	4	3	4
476	4	4	4	4	5	5	4	4	3	4
477	5	5	4	4	4	5	5	4	4	5
478	4	5	5	5	4	3	4	3	4	4
479	4	5	5	5	4	4	4	5	4	3
480	5	5	4	5	5	4	4	4	4	5
481	5	4	4	5	4	5	5	3	5	4
482	4	5	4	4	5	5	5	4	4	5
483	5	5	4	5	4	5	3	5	4	5
484	5	4	5	4	5	5	5	4	3	3
485	5	5	5	5	5	5	4	4	5	5
486	3	3	4	3	3	2	2	2	2	3
487	3	2	2	3	2	3	3	4	3	2
488	2	3	2	2	3	3	3	2	2	3
489	3	3	4	3	2	3	4	3	2	3
490	5	5	3	5	5	4	4	4	4	5
491	5	4	4	5	4	5	5	3	5	4
492	1	2	1	1	2	2	2	1	1	2
493	2	2	3	2	1	2	3	2	1	2
494	2	1	2	1	2	2	2	1	3	3
495	3	2	2	2	2	2	1	3	2	2
496	2	3	2	3	2	1	2	1	1	2
497	3	2	2	2	2	3	1	3	2	1
498	1	2	2	2	2	3	3	3	2	2
499	2	3	3	3	3	1	2	3	3	3
500	2	2	2	2	2	3	2	2	1	3
501	3	3	2	1	1	3	1	2	3	2
502	2	2	2	1	2	2	3	2	2	1
503	2	2	3	2	2	1	3	2	1	3
504	1	2	2	2	3	3	1	1	2	3
505	2	2	3	3	1	2	2	2	2	1
506	2	3	2	2	2	2	2	1	2	2
507	3	2	2	2	2	3	3	2	1	3
508	2	2	3	2	1	2	1	2	3	2
509	3	3	2	2	2	3	3	1	2	3
510	2	3	2	1	2	2	2	2	1	1
511	2	3	2	3	3	2	2	2	3	2
512	3	3	2	3	3	3	1	2	1	1
513	2	2	1	2	1	2	1	3	3	3
514	3	2	2	3	2	2	3	2	1	2
515	2	3	2	2	3	3	3	2	2	3

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
516	3	3	4	3	2	3	4	3	2	3
517	3	2	3	2	3	3	3	2	4	4
518	4	3	3	3	3	3	2	4	3	3
519	3	4	3	4	3	2	3	2	2	3
520	4	3	3	3	3	4	2	4	3	2
521	2	3	3	3	3	4	4	4	3	3
522	3	4	4	4	4	2	3	4	4	4
523	3	3	3	3	3	4	3	3	2	4
524	4	4	3	2	2	4	2	3	4	3
525	3	3	3	2	3	3	4	3	3	2
526	3	3	4	3	3	2	4	3	2	4
527	2	3	3	3	4	4	2	2	3	4
528	3	3	4	4	2	3	3	3	3	2
529	3	4	3	3	3	3	3	2	3	3
530	4	3	3	3	3	4	4	3	2	4
531	3	3	4	3	2	3	2	3	4	3
532	4	4	3	3	3	4	4	2	3	4
533	3	4	3	2	3	3	3	3	2	2
534	3	4	3	4	4	3	3	3	4	3
535	4	4	3	4	4	4	2	3	2	2
536	3	3	2	3	2	3	2	4	4	4
537	4	3	3	4	3	3	4	3	2	3
538	3	4	3	3	4	4	4	3	3	4
539	4	4	5	4	3	4	5	4	3	4
540	4	3	4	3	4	4	4	3	5	5
541	5	4	4	4	4	4	3	5	4	4
542	4	5	4	5	4	3	4	3	3	4
543	5	4	4	4	4	5	3	5	4	3
544	3	4	4	4	4	5	5	5	4	4
545	4	5	5	5	5	3	4	5	5	5
546	4	4	4	4	4	5	4	4	3	5
547	5	5	4	3	3	5	3	4	5	4
548	4	4	4	3	4	4	5	4	4	3
549	4	4	5	4	4	3	5	4	3	5
550	3	4	4	4	5	5	3	3	4	5
551	4	4	5	5	3	4	4	4	4	3
552	4	5	4	4	4	4	4	3	4	4
553	5	4	4	4	4	5	5	4	3	5
554	4	4	5	4	3	4	3	4	5	4
555	5	5	4	4	4	5	5	3	4	5
556	4	5	4	3	4	4	4	4	3	3
557	4	5	4	5	5	4	4	4	5	4
558	5	5	4	5	5	5	3	4	3	3
559	4	4	3	4	3	4	3	5	5	5
560	5	4	4	5	4	4	5	4	3	4
561	4	5	4	4	5	5	5	4	4	5
562	5	5	4	5	4	5	4	5	4	5
563	3	3	2	2	2	3	3	1	2	3
564	2	3	2	1	2	2	2	2	1	1
565	2	3	2	3	3	2	2	2	3	2
566	3	3	2	3	3	3	1	2	1	1
567	2	2	1	2	1	2	1	3	3	3
568	3	2	2	3	2	2	3	2	1	2
569	2	3	2	2	3	3	3	2	2	3
570	3	3	4	3	2	3	4	3	2	3
571	3	2	3	2	3	3	3	2	4	4
572	4	3	3	3	3	3	2	4	3	3
573	3	4	3	4	3	2	3	2	2	3
574	4	3	3	3	3	4	2	4	3	2
575	2	3	3	3	3	4	4	4	3	3
576	3	4	4	4	4	2	3	4	4	4
577	3	3	3	3	3	4	3	3	2	4
578	4	4	3	2	2	4	2	3	4	3
579	3	3	3	2	3	3	4	3	3	2
580	3	3	4	3	3	2	4	3	2	4
581	2	3	3	3	4	4	2	2	3	4
582	3	3	4	4	2	3	3	3	3	2
583	3	4	3	3	3	3	3	2	3	3
584	4	3	3	3	3	4	4	3	2	4
585	3	3	4	3	2	3	2	3	4	3
586	4	4	3	3	3	4	4	2	3	4
587	3	4	3	2	3	3	3	3	2	2
588	3	4	3	4	4	3	3	3	4	3
589	4	4	3	4	4	4	2	3	2	2

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
590	3	3	2	3	2	3	2	4	4	4
591	4	3	3	4	3	3	4	3	2	3
592	3	4	3	3	4	4	4	3	3	4
593	4	4	3	4	3	4	3	4	3	4
594	4	4	3	3	3	4	4	2	3	4
595	3	4	3	2	3	3	3	3	2	2
596	3	4	3	4	4	3	3	3	4	3
597	4	4	3	4	4	4	2	3	2	2
598	3	3	2	3	2	3	2	4	4	4
599	4	3	3	4	3	3	4	3	2	3
600	3	4	3	3	4	4	4	3	3	4
601	4	4	5	4	3	4	5	4	3	4
602	4	3	4	3	4	4	4	3	5	5
603	5	4	4	4	4	4	3	5	4	4
604	4	5	4	5	4	3	4	3	3	4
605	5	4	4	4	4	5	3	5	4	3
606	3	4	4	4	4	5	5	5	4	4
607	4	5	5	5	5	3	4	5	5	5
608	4	4	4	4	4	5	4	4	3	5
609	5	5	4	3	3	5	3	4	5	4
610	4	4	4	3	4	4	5	4	4	3
611	4	4	5	4	4	3	5	4	3	5
612	3	4	4	4	5	5	3	3	4	5
613	4	4	5	5	3	4	4	4	4	3
614	4	5	4	4	4	4	4	3	4	4
615	5	4	4	4	4	5	5	4	3	5
616	4	4	5	4	3	4	3	4	5	4
617	5	5	4	4	4	5	5	3	4	5
618	4	5	4	3	4	4	4	4	3	3
619	4	5	4	5	5	4	4	4	5	4
620	5	5	4	5	5	5	3	4	3	3
621	4	4	3	4	3	4	3	5	5	5
622	5	4	4	5	4	4	5	4	3	4
623	4	5	4	4	5	5	5	4	4	5
624	5	5	4	5	4	5	4	5	4	5
625	5	5	4	4	4	5	5	3	4	5
626	4	5	4	3	4	4	4	4	3	3
627	4	5	4	5	5	4	4	4	5	4
628	5	5	4	5	5	5	3	4	3	3
629	4	4	3	4	3	4	3	5	5	5
630	5	4	4	5	4	4	5	4	3	4
631	4	5	4	4	5	5	5	4	4	5
632	5	5	3	5	4	5	3	5	4	5
633	2	2	3	2	1	2	3	2	1	2
634	2	1	2	1	2	2	2	1	3	3
635	3	2	2	2	2	2	1	3	2	2
636	2	3	2	3	2	1	2	1	1	2
637	3	2	2	2	2	3	1	3	2	1
638	1	2	2	2	2	3	3	3	2	2
639	2	3	3	3	3	1	2	3	3	3
640	2	2	2	2	2	3	2	2	1	3
641	3	3	2	1	1	3	1	2	3	2
642	2	2	2	1	2	2	3	2	2	1
643	2	2	3	2	2	1	3	2	1	3
644	1	2	2	2	3	3	1	1	2	3
645	2	2	3	3	1	2	2	2	2	1
646	2	3	2	2	2	2	2	1	2	2
647	3	2	2	2	2	3	3	2	1	3
648	2	2	3	2	1	2	1	2	3	2
649	3	3	2	2	2	3	3	1	2	3
650	2	3	2	1	2	2	2	2	1	1
651	2	3	2	3	3	2	2	2	3	2
652	3	3	2	3	3	3	1	2	1	1
653	2	2	1	2	1	2	1	3	3	3
654	3	2	2	3	2	2	3	2	1	2
655	2	3	2	2	3	3	3	2	2	3
656	3	3	2	3	2	3	2	3	2	3
657	3	3	2	2	2	3	3	1	2	3
658	2	3	2	1	2	2	2	2	1	1
659	2	3	2	3	3	2	2	2	3	2
660	3	3	2	3	3	3	1	2	1	1
661	2	2	1	2	1	2	1	3	3	3
662	3	2	2	3	2	2	3	2	1	2
663	2	3	2	2	3	3	3	2	2	3

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
664	3	3	1	3	2	3	1	3	2	3
665	3	3	4	3	2	3	4	3	2	3
666	3	2	3	2	3	3	3	2	4	4
667	4	3	3	3	3	3	2	4	3	3
668	3	4	3	4	3	2	3	2	2	3
669	4	3	3	3	3	4	2	4	3	2
670	2	3	3	3	3	4	4	4	3	3
671	3	4	4	4	4	2	3	4	4	4
672	3	3	3	3	3	4	3	3	2	4
673	4	4	3	2	2	4	2	3	4	3
674	3	3	3	2	3	3	4	3	3	2
675	3	3	4	3	3	2	4	3	2	4
676	2	3	3	3	4	4	2	2	3	4
677	3	3	4	4	2	3	3	3	3	2
678	3	4	3	3	3	3	3	2	3	3
679	4	3	3	3	3	4	4	3	2	4
680	3	3	4	3	2	3	2	3	4	3
681	4	4	3	3	3	4	4	2	3	4
682	3	4	3	2	3	3	3	3	2	2
683	3	4	3	4	4	3	3	3	4	3
684	4	4	3	4	4	4	2	3	2	2
685	3	3	2	3	2	3	2	4	4	4
686	4	3	3	4	3	3	4	3	2	3
687	3	4	3	3	4	4	4	3	3	4
688	4	4	3	4	3	4	3	4	3	4
689	4	4	3	3	3	4	4	2	3	4
690	3	4	3	2	3	3	3	3	2	2
691	3	4	3	4	4	3	3	3	4	3
692	4	4	3	4	4	4	2	3	2	2
693	3	3	2	3	2	3	2	4	4	4
694	4	3	3	4	3	3	4	3	2	3
695	3	4	3	3	4	4	4	3	3	4
696	4	4	2	4	3	4	2	4	3	4
697	4	4	5	4	3	4	5	4	3	4
698	4	3	4	3	4	4	4	3	5	5
699	5	4	4	4	4	4	3	5	4	4
700	4	5	4	5	4	3	4	3	3	4
701	5	4	4	4	4	5	3	5	4	3
702	3	4	4	4	4	5	5	5	4	4
703	4	5	5	5	5	3	4	5	5	5
704	4	4	4	4	4	5	4	4	3	5
705	5	5	4	3	3	5	3	4	5	4
706	4	4	4	3	4	4	5	4	4	3
707	4	4	5	4	4	3	5	4	3	5
708	3	4	4	4	5	5	3	3	4	5
709	4	4	5	5	3	4	4	4	4	3
710	4	5	4	4	4	4	4	3	4	4
711	5	4	4	4	4	5	5	4	3	5
712	4	4	5	4	3	4	3	4	5	4
713	5	5	4	4	4	5	5	3	4	5
714	4	5	4	3	4	4	4	4	3	3
715	4	5	4	5	5	4	4	4	5	4
716	5	5	4	5	5	5	3	4	3	3
717	4	4	3	4	3	4	3	5	5	5
718	5	4	4	5	4	4	5	4	3	4
719	4	5	4	4	5	5	5	4	4	5
720	5	5	4	5	4	5	4	5	4	5
721	5	5	4	4	4	5	5	3	4	5
722	4	5	4	3	4	4	4	4	3	3
723	4	5	4	5	5	4	4	4	5	4
724	5	5	4	5	5	5	3	4	3	3
725	4	4	3	4	3	4	3	5	5	5
726	5	4	4	5	4	4	5	4	3	4
727	4	5	4	4	5	5	5	4	4	5
728	5	5	3	5	4	5	3	5	4	5
729	2	2	3	2	1	2	3	2	1	2
730	2	1	2	1	2	2	2	1	3	3
731	3	2	2	2	2	2	1	3	2	2
732	2	3	2	3	2	1	2	1	1	2
733	3	2	2	2	2	3	1	3	2	1
734	1	2	2	2	2	3	3	3	2	2
735	2	3	3	3	3	1	2	3	3	3
736	2	2	2	2	2	3	2	2	1	3
737	3	3	2	1	1	3	1	2	3	2

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
738	2	2	2	1	2	2	3	2	2	1
739	2	2	3	2	2	1	3	2	1	3
740	1	2	2	2	3	3	1	1	2	3
741	2	2	3	3	1	2	2	2	2	1
742	2	3	2	2	2	2	2	1	2	2
743	3	2	2	2	2	3	3	2	1	3
744	2	2	3	2	1	2	1	2	3	2
745	3	3	2	2	2	3	3	1	2	3
746	2	3	2	1	2	2	2	2	1	1
747	2	3	2	3	3	2	2	2	3	2
748	3	3	2	3	3	3	1	2	1	1
749	2	2	1	2	1	2	1	3	3	3
750	3	2	2	3	2	2	3	2	1	2
751	2	3	2	2	3	3	3	2	2	3
752	3	3	2	3	2	3	2	3	2	3
753	3	3	2	2	2	3	3	1	2	3
754	2	3	2	1	2	2	2	2	1	1
755	2	3	2	3	3	2	2	2	3	2
756	3	3	2	3	3	3	1	2	1	1
757	2	2	1	2	1	2	1	3	3	3
758	3	2	2	3	2	2	3	2	1	2
759	2	3	2	2	3	3	3	2	2	3
760	3	3	1	3	2	3	1	3	2	3
761	3	3	4	3	2	3	4	3	2	3
762	3	2	3	2	3	3	3	2	4	4
763	4	3	3	3	3	3	2	4	3	3
764	3	4	3	4	3	2	3	2	2	3
765	4	3	3	3	3	4	2	4	3	2
766	2	3	3	3	3	4	4	4	3	3
767	3	4	4	4	4	2	3	4	4	4
768	3	3	3	3	3	4	3	3	2	4
769	4	4	3	2	2	4	2	3	4	3
770	3	3	3	2	3	3	4	3	3	2
771	3	3	4	3	3	2	4	3	2	4
772	2	3	3	3	4	4	2	2	3	4
773	3	3	4	4	2	3	3	3	3	2
774	3	4	3	3	3	3	3	2	3	3
775	4	3	3	3	3	4	4	3	2	4
776	3	3	4	3	2	3	2	3	4	3
777	4	4	3	3	3	4	4	2	3	4
778	3	4	3	2	3	3	3	3	2	2
779	3	4	3	4	4	3	3	3	4	3
780	4	4	3	4	4	4	2	3	2	2
781	3	3	2	3	2	3	2	4	4	4
782	4	3	3	4	3	3	4	3	2	3
783	3	4	3	3	4	4	4	3	3	4
784	4	4	3	4	3	4	3	4	3	4
785	4	4	3	3	3	4	4	2	3	4
786	3	4	3	2	3	3	3	3	2	2
787	3	4	3	4	4	3	3	3	4	3
788	4	4	3	4	4	4	2	3	2	2
789	3	3	2	3	2	3	2	4	4	4
790	4	3	3	4	3	3	4	3	2	3
791	3	4	3	3	4	4	4	3	3	4
792	4	4	2	4	3	4	2	4	3	4
793	3	3	4	3	2	3	4	3	2	3
794	3	2	3	2	3	3	3	2	4	4
795	4	3	3	3	3	3	2	4	3	3
796	3	4	3	4	3	2	3	2	2	3
797	4	3	3	3	3	4	2	4	3	2
798	2	3	3	3	3	4	4	4	3	3
799	3	4	4	4	4	2	3	4	4	4
800	3	3	3	3	3	4	3	3	2	4
801	4	4	3	2	2	4	2	3	4	3
802	3	3	3	2	3	3	4	3	3	2
803	3	3	4	3	3	2	4	3	2	4
804	2	3	3	3	4	4	2	2	3	4
805	3	3	4	4	2	3	3	3	3	2
806	3	4	3	3	3	3	3	2	3	3
807	4	3	3	3	3	4	4	3	2	4
808	3	3	4	3	2	3	2	3	4	3
809	4	4	3	3	3	4	4	2	3	4
810	3	4	3	2	3	3	3	3	2	2
811	3	4	3	4	4	3	3	3	4	3

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
812	4	4	3	4	4	4	2	3	2	2
813	3	3	2	3	2	3	2	4	4	4
814	4	3	3	4	3	3	4	3	2	3
815	3	4	3	3	4	4	4	3	3	4
816	4	4	3	4	3	4	3	4	3	4
817	4	4	3	3	3	4	4	2	3	4
818	3	4	3	2	3	3	3	3	2	2
819	3	4	3	4	4	3	3	3	4	3
820	4	4	3	4	4	4	2	3	2	2
821	3	3	2	3	2	3	2	4	4	4
822	4	3	3	4	3	3	4	3	2	3
823	3	4	3	3	4	4	4	3	3	4
824	4	4	2	4	3	4	2	4	3	4
825	4	4	5	4	3	4	5	4	3	4
826	4	3	4	3	4	4	4	3	5	5
827	5	4	4	4	4	4	3	5	4	4
828	4	5	4	5	4	3	4	3	3	4
829	5	4	4	4	4	5	3	5	4	3
830	3	4	4	4	4	5	5	5	4	4
831	4	5	5	5	5	3	4	5	5	5
832	4	4	4	4	4	5	4	4	3	5
833	5	5	4	3	3	5	3	4	5	4
834	4	4	4	3	4	4	5	4	4	3
835	4	4	5	4	4	3	5	4	3	5
836	3	4	4	4	5	5	3	3	4	5
837	4	4	5	5	3	4	4	4	4	3
838	4	5	4	4	4	4	4	3	4	4
839	5	4	4	4	4	5	5	4	3	5
840	4	4	5	4	3	4	3	4	5	4
841	5	5	4	4	4	5	5	3	4	5
842	4	5	4	3	4	4	4	4	3	3
843	4	5	4	5	5	4	4	4	5	4
844	5	5	4	5	5	5	3	4	3	3
845	4	4	3	4	3	4	3	5	5	5
846	5	4	4	5	4	4	5	4	3	4
847	4	5	4	4	5	5	5	4	4	5
848	5	5	4	5	4	5	4	5	4	5
849	5	5	4	4	4	5	5	3	4	5
850	4	5	4	3	4	4	4	4	3	3
851	4	5	4	5	5	4	4	4	5	4
852	5	5	4	5	5	5	3	4	3	3
853	4	4	3	4	3	4	3	5	5	5
854	5	4	4	5	4	4	5	4	3	4
855	4	5	4	4	5	5	5	4	4	5
856	5	5	3	5	4	5	3	5	4	5
857	4	4	5	4	3	4	5	4	3	4
858	4	3	4	3	4	4	4	3	5	5
859	5	4	4	4	4	4	3	5	4	4
860	4	5	4	5	4	3	4	3	3	4
861	5	4	4	4	4	5	3	5	4	3
862	3	4	4	4	4	5	5	5	4	4
863	4	5	5	5	5	3	4	5	5	5
864	4	4	4	4	4	5	4	4	3	5
865	5	5	4	3	3	5	3	4	5	4
866	4	4	4	3	4	4	5	4	4	3
867	4	4	5	4	4	3	5	4	3	5
868	3	4	4	4	5	5	3	3	4	5
869	4	4	5	5	3	4	4	4	4	3
870	4	5	4	4	4	4	4	3	4	4
871	5	4	4	4	4	5	5	4	3	5
872	4	4	5	4	3	4	3	4	5	4
873	5	5	4	4	4	5	5	3	4	5
874	4	5	4	3	4	4	4	4	3	3
875	4	5	4	5	5	4	4	4	5	4
876	5	5	4	5	5	5	3	4	3	3
877	4	4	3	4	3	4	3	5	5	5
878	5	4	4	5	4	4	5	4	3	4
879	4	5	4	4	5	5	5	4	4	5
880	5	5	4	5	4	5	4	5	4	5
881	5	5	4	4	4	5	5	3	4	5
882	4	5	4	3	4	4	4	4	3	3
883	4	5	4	5	5	4	4	4	5	4
884	5	5	4	5	5	5	3	4	3	3
885	4	4	3	4	3	4	3	5	5	5

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
886	5	4	4	5	4	4	5	4	3	4
887	4	5	4	4	5	5	5	4	4	5
888	5	5	3	5	4	5	3	5	4	5
889	5	5	3	5	4	5	3	5	4	5
890	2	3	3	3	3	1	2	3	3	3
891	2	2	2	2	2	3	2	2	1	3
892	3	3	2	1	1	3	1	2	3	2
893	2	2	2	1	2	2	3	2	2	1
894	2	2	3	2	2	1	3	2	1	3
895	1	2	2	2	3	3	1	1	2	3
896	2	2	3	3	1	2	2	2	2	1
897	2	3	2	2	2	2	2	1	2	2
898	3	2	2	2	2	3	3	2	1	3
899	2	2	3	2	1	2	1	2	3	2
900	3	3	2	2	2	3	3	1	2	3
901	2	3	2	1	2	2	2	2	1	1
902	2	3	2	3	3	2	2	2	3	2
903	3	3	2	3	3	3	1	2	1	1
904	2	2	1	2	1	2	1	3	3	3
905	3	2	2	3	2	2	3	2	1	2
906	2	3	2	2	3	3	3	2	2	3
907	3	3	2	3	2	3	2	3	2	3
908	3	3	2	2	2	3	3	1	2	3
909	2	3	2	1	2	2	2	2	1	1
910	2	3	2	3	3	2	2	2	3	2
911	3	3	2	3	3	3	1	2	1	1
912	2	2	1	2	1	2	1	3	3	3
913	3	2	2	3	2	2	3	2	1	2
914	2	3	2	2	3	3	3	2	2	3
915	3	3	1	3	2	3	1	3	2	3
916	2	2	3	2	1	2	3	2	1	2
917	2	1	2	1	2	2	2	1	3	3
918	3	2	2	2	2	2	1	3	2	2
919	2	3	2	3	2	1	2	1	1	2
920	3	2	2	2	2	3	1	3	2	1
921	1	2	2	2	2	3	3	3	2	2
922	2	3	3	3	3	1	2	3	3	3
923	2	2	2	2	2	3	2	2	1	3
924	3	3	2	1	1	3	1	2	3	2
925	2	2	2	1	2	2	3	2	2	1
926	2	2	3	2	2	1	3	2	1	3
927	1	2	2	2	3	3	1	1	2	3
928	2	2	3	3	1	2	2	2	2	1
929	2	3	2	2	2	2	2	1	2	2
930	3	2	2	2	2	3	3	2	1	3
931	2	2	3	2	1	2	1	2	3	2
932	3	3	2	2	2	3	3	1	2	3
933	2	3	2	1	2	2	2	2	1	1
934	2	3	2	3	3	2	2	2	3	2
935	3	3	2	3	3	3	1	2	1	1
936	2	2	1	2	1	2	1	3	3	3
937	3	2	2	3	2	2	3	2	1	2
938	2	3	2	2	3	3	3	2	2	3
939	3	3	2	3	2	3	2	3	2	3
940	3	3	2	2	2	3	3	1	2	3
941	2	3	2	1	2	2	2	2	1	1
942	2	3	2	3	3	2	2	2	3	2
943	3	3	2	3	3	3	1	2	1	1
944	2	2	1	2	1	2	1	3	3	3
945	3	2	2	3	2	2	3	2	1	2
946	2	3	2	2	3	3	3	2	2	3
947	3	3	1	3	2	3	1	3	2	3
948	3	3	1	3	2	3	1	3	2	3
949	3	4	4	4	5	5	3	3	4	5
950	4	4	5	5	3	4	4	4	4	3
951	4	5	4	4	4	4	4	3	4	4
952	5	4	4	4	4	5	5	4	3	5
953	4	4	5	4	3	4	3	4	5	4
954	5	5	4	4	4	5	5	3	4	5
955	4	5	4	3	4	4	4	4	3	3
956	4	5	4	5	5	4	4	4	5	4
957	5	5	4	5	5	5	3	4	3	3
958	4	4	3	4	3	4	3	5	5	5
959	5	4	4	5	4	4	5	4	3	4

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
S. No.	Demand variation	Actual Sales	Coordination	Supplier Relationships	Disruptions	Demand Forecasting	Information Processing	Ordering Policy (size of batches)	Order Rationing	Lead-time variations
960	4	5	4	4	5	5	5	4	4	5
961	5	5	4	5	4	5	4	5	4	5
962	5	5	4	4	4	5	5	3	4	5
963	4	5	4	3	4	4	4	4	3	3
964	4	5	4	5	5	4	4	4	5	4
965	5	5	4	5	5	5	3	4	3	3
966	4	4	3	4	3	4	3	5	5	5
967	5	4	4	5	4	4	5	4	3	4
968	4	5	4	4	5	5	5	4	4	5
969	5	5	3	5	4	5	3	5	4	5
970	4	4	5	4	3	4	5	4	3	4
971	4	3	4	3	4	4	4	3	5	5
972	5	4	4	4	4	4	3	5	4	4
973	4	5	4	5	4	3	4	3	3	4
974	5	4	4	4	4	5	3	5	4	3
975	3	4	4	4	4	5	5	5	4	4
976	4	5	5	5	5	3	4	5	5	5
977	4	4	4	4	4	5	4	4	3	5
978	5	5	4	3	3	5	3	4	5	4
979	4	4	4	3	4	4	5	4	4	3
980	4	4	5	4	4	3	5	4	3	5
981	3	4	4	4	5	5	3	3	4	5
982	4	4	5	5	3	4	4	4	4	3
983	4	5	4	4	4	4	4	3	4	4
984	5	4	4	4	4	5	5	4	3	5
985	4	4	5	4	3	4	3	4	5	4
986	5	5	4	4	4	5	5	3	4	5
987	4	5	4	3	4	4	4	4	3	3
988	4	5	4	5	5	4	4	4	5	4
989	5	5	4	5	5	5	3	4	3	3
990	4	4	3	4	3	4	3	5	5	5
991	5	4	4	5	4	4	5	4	3	4
992	4	5	4	4	5	5	5	4	4	5
993	5	5	4	5	4	5	4	5	4	5
994	5	5	4	4	4	5	5	3	4	5
995	4	5	4	3	4	4	4	4	3	3
996	4	5	4	5	5	4	4	4	5	4
997	5	5	4	5	5	5	3	4	3	3
998	4	4	3	4	3	4	3	5	5	5
999	5	4	4	5	4	4	5	4	3	4
1000	4	5	4	4	5	5	5	4	4	5

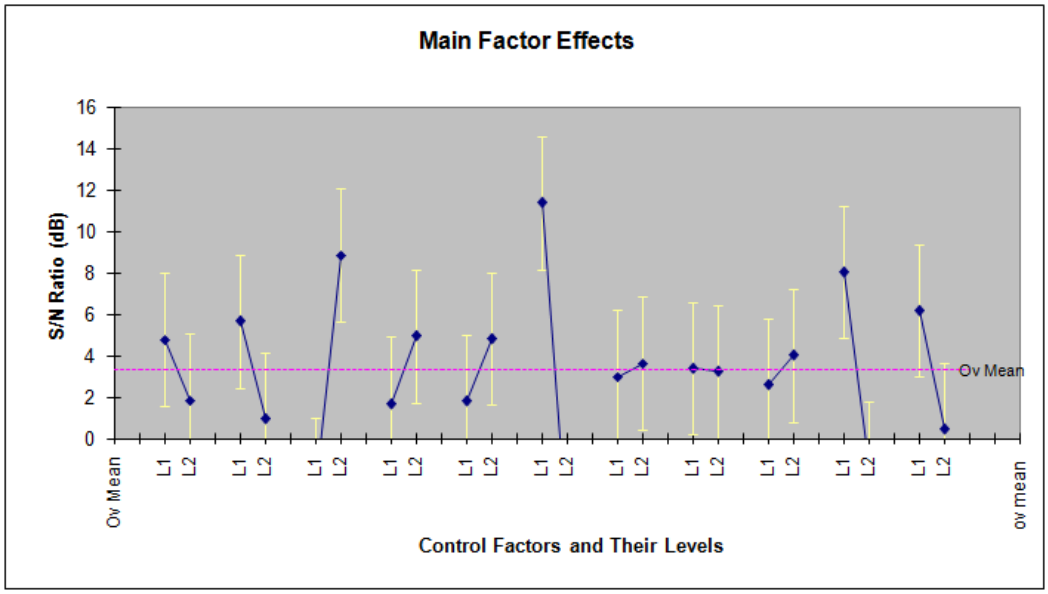
Appendix D: Outputs of Taguchi's Experiments

Total 730 experiments using the twelve by sixteen orthogonal arrays.

Appendix D.1: Outputs of Taguchi's Experiments: 1 to 16

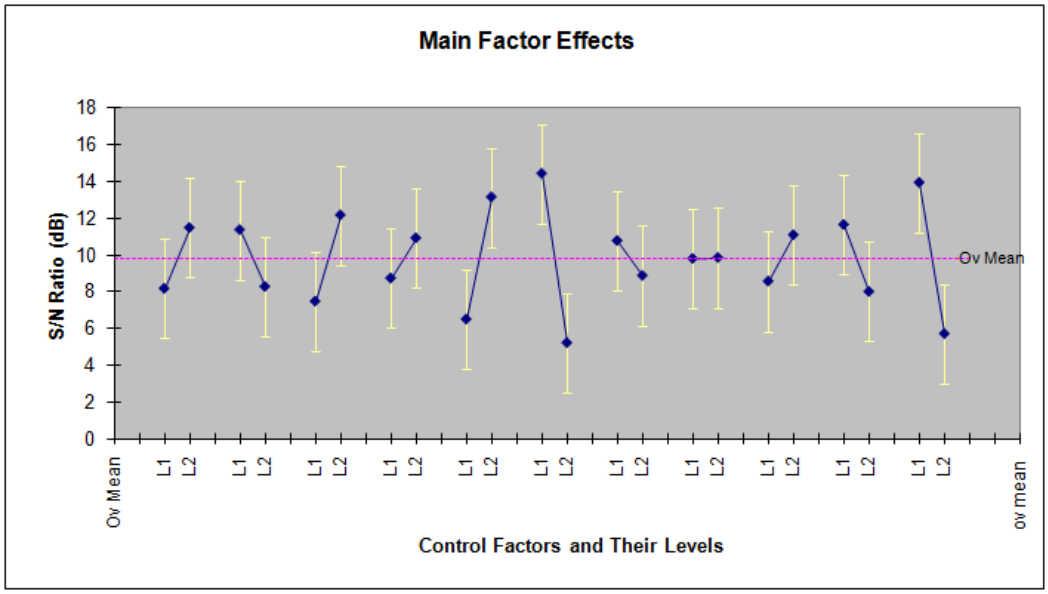
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-5.85289	-3.7483	-10.4324	4.56233	-3.14609	2.21007	-6.78956	-5.3388	-15.7712	7.4551	0.904491	3.14609
2	-5.26065	-0.276248	-11.1693	2.17765	-4.05058	3.85326	-9.7619	-5.40194	-16.5712	3.69934	-0.732704	4.29591
3	-2.94017	-1.29752	-4.45636	4.91878	-1.44483	1.993	-3.50918	4.12214	-0.334218	2.48051	0.175596	-0.955595
4	-6.95567	-4.02222	-12.3188	2.48281	-2.91411	3.88223	-9.24534	-5.69427	-18.0131	7.95459	0.772333	12.6464
5	-3.52769	-0.112479	-3.59486	2.04026	-1.10459	4.46237	-4.52954	2.08868	-1.50618	4.9881	6.06123	9.95258
6	-3.30522	0.0417545	-4.31965	2.26092	-1.20036	2.58764	-3.60208	1.75951	-2.56014	3.15794	3.47352	31.7119
7	-6.21378	-4.32719	-11.5568	4.01275	-2.85326	3.0597	-8.40273	-4.58302	-16.1398	7.69779	0.870992	45.2176
8	-5.17649	-1.20599	-9.03086	3.83314	-2.72473	2.89845	-6.75282	-2.81453	-11.8454	4.06278	-1.30301	46.7422
9	-8.86214	-7.12619	-17.7855	3.13782	-4.87774	4.27172	-13.1951	-11.2079	-28.9934	10.8873	-2.70469	47.8668
10	-3.11577	1.83393	-7.98436	3.43032	-0.182994	2.55609	-7.42469	-1.18146	-9.16583	1.99204	3.74893	35.3577
11	-5.07847	-0.808116	-11.9045	4.33934	-4.08547	1.93865	-8.76471	-5.18793	-17.0925	2.97074	-0.967978	36.8178
12	-8.30526	-3.56529	-16.7312	4.54635	-3.8794	3.85774	-12.2836	-11.0533	-27.7844	7.28892	-0.018817	29.0887
13	-8.62347	-6.38367	-16.6727	3.19309	-4.27919	2.06684	-10.116	-10.0454	-26.7181	9.66623	-1.84813	16.0382
14	-4.74793	-0.413064	-8.02374	3.55267	-4.10528	2.09423	-5.37003	0.40576	-7.61798	4.99303	2.42146	2.87041
15	-7.728	-4.95373	-14.8594	1.97739	-2.93238	4.55698	-11.6884	-9.21675	-24.0762	7.29964	-2.43119	13.6533
16	-3.23474	-2.18449	-4.05785	4.83113	-2.88223	3.23553	-4.05864	3.22565	-0.832209	5.56398	3.35169	0.3037

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
MEAN of sum of reciprocal squares	0.049143	44.914961	0.022112	0.115955 1	2.190101 7	0.126429 2	0.028656	0.520619 1	0.736409 5	0.057897 5	190.95963	0.816244 6
S/N Ratio	13.085379	-16.52391	16.553716	9.357100 5	-3.404643	8.981524 7	15.42639	2.834799 1	1.328806 3	12.373404	-22.80942	0.881796 7



Appendix D.2: Outputs of Taguchi's Experiments: 17 to 32

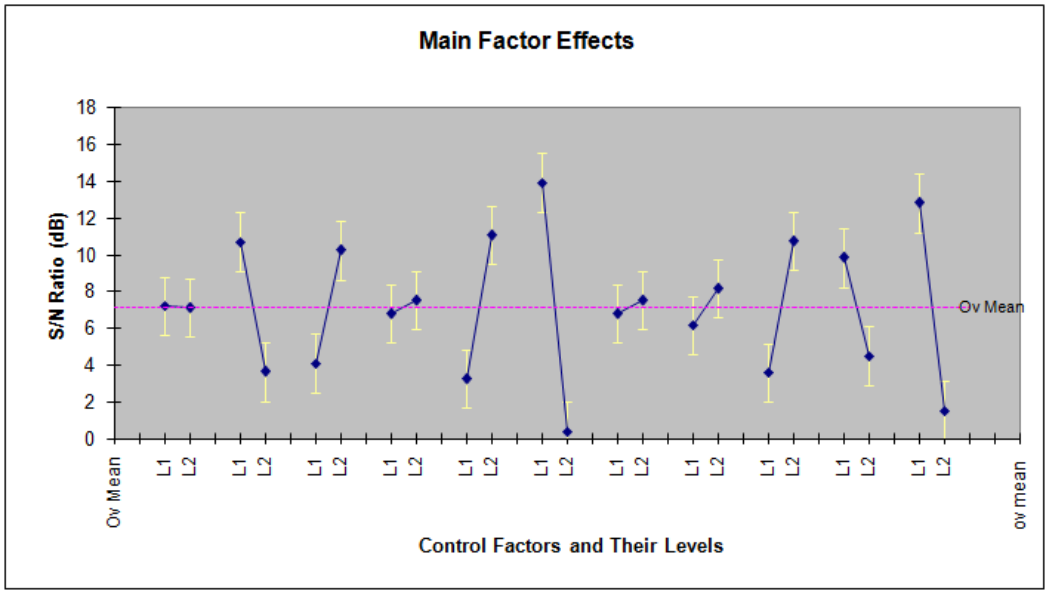
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-6.95405	-2.87075	-12.2269	2.8793	-4.29884	4.12016	-9.393	-3.6153	-15.8422	6.43583	-0.484747	23.4844
2	-6.19226	-2.23152	-15.725	3.00012	-1.93345	1.55684	-11.0896	-6.63682	-22.3618	5.48624	0.38804	24.6115
3	-9.02127	-6.63165	-18.498	3.63971	-4.49911	4.03923	-13.516	-12.9253	-31.4233	9.11533	-3.86561	9.59326
4	-7.33799	-2.73299	-15.7213	4.78136	-3.87562	1.8122	-10.1955	-6.84033	-22.5616	7.61566	1.34949	-9.48664
5	-5.56616	0.952986	-7.63864	2.54868	-4.35224	4.34823	-6.42071	-1.75987	-9.39851	4.47563	1.57438	-16.6867
6	-4.69845	0.218887	-9.8207	2.30536	-2.33828	1.69013	-6.81238	-3.57571	-13.3964	2.3181	0.825309	-6.28906
7	-7.28208	-4.87994	-14.0628	4.70828	-4.86687	4.66598	-11.4467	-8.28154	-22.3443	8.36176	0.971176	-12.595
8	-6.77873	-4.50944	-13.0942	2.22257	-2.1997	2.42992	-8.74543	-6.06486	-19.1591	8.00435	1.12956	-13.7541
9	-5.38742	-4.0568	-10.164	1.84834	-1.58764	3.45357	-8.23018	-4.8681	-15.0321	7.64536	0.201474	-19.2154
10	-3.11312	-0.260297	-6.3475	2.8857	-2.78618	4.83324	-8.06762	1.01362	-5.33388	3.51532	1.50828	-20.0166
11	-7.13979	-3.91855	-9.948	1.92758	-4.63251	4.45627	-7.26449	-3.94268	-13.8907	6.98408	-0.787889	-8.94079
12	-4.71756	-3.06588	-11.3634	2.71575	-2.34697	2.53733	-9.1832	-5.94197	-17.3054	5.9417	0.280609	-3.98268
13	-1.83524	1.9274	-2.54422	4.40279	-1.63851	4.03831	-4.74729	5.75774	3.21352	1.73876	4.96135	-11.3531
14	-6.77388	-3.24794	-11.4489	4.47256	-4.71418	2.10262	-6.77765	-6.7249	-18.1738	5.30437	-1.04055	11.2687
15	-7.33311	-3.11752	-13.152	2.19141	-4.02588	2.06804	-7.8869	-5.98361	-19.1356	6.88586	1.3855	7.30184
16	-4.56175	-0.147345	-6.30789	4.59667	-3.67516	4.76129	-6.50743	1.36244	-4.94545	4.81294	1.90187	2.63211
MEAN of sum of reciprocal squares	0.0509154	5.5997732	0.0194247	0.1230752	0.1454987	0.1535308	0.0165926	0.1488122	0.0144652	0.0606033	3.6510014	0.0208591
S/N Ratio	12.931512	-7.481704	17.116461	9.0982958	8.3714078	8.1380844	17.800859	8.2736139	18.396762	12.172908	-5.624112	16.807054



Appendix D.3: Outputs of Taguchi's Experiments: 33 to 48

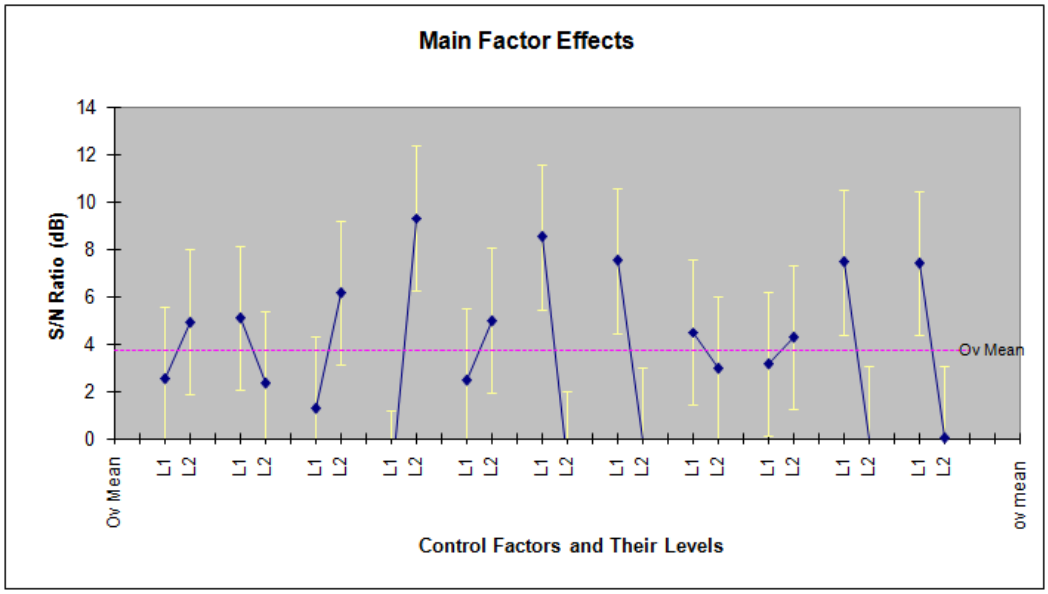
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-3.87348	-0.302868	-4.78387	1.22895	-1.85679	3.99903	-4.90942	1.54628	-3.23758	4.82403	3.17015	20.1269
2	-6.11513	-3.83097	-12.698	3.78383	-1.89845	2.66369	-9.24653	-5.25421	-17.9522	7.01255	1.92255	35.1917
3	-3.91537	-0.180496	-10.951	3.09556	-1.17671	1.21709	-8.25272	-3.64488	-14.5959	2.22498	2.30035	31.7765
4	-4.24215	0.490183	-8.57906	4.01923	-0.686725	2.30165	-6.63856	-2.13451	-10.7136	4.25217	2.99113	24.543
5	-5.7316	-4.23682	-11.9601	1.88724	-2.9705	2.69943	-8.92796	-5.36043	-17.3206	7.79069	2.02463	28.4695
6	-4.61325	-1.4078	-9.1982	2.66017	-1.2169	3.66533	-8.25028	-3.14449	-12.3427	4.23508	0.375567	27.159
7	-8.14728	-4.24292	-14.4762	1.76189	-3.27172	4.07056	-10.3995	-5.76959	-20.2458	9.06703	-0.01776	26.2609
8	-4.22809	0.310686	-5.22718	3.51384	-1.46822	4.77228	-5.77138	2.21969	-3.0075	2.29054	1.2922	22.284
9	-3.82783	-2.018	-9.98075	1.6083	-3.09188	2.55019	-8.70312	-4.32267	-14.3034	6.50871	2.40504	36.5327

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-7.04852	-2.51763	-16.426	2.23895	-4.22254	1.35526	-10.7328	-9.60999	-26.036	3.90548	-1.63837	34.5664
11	-5.70518	-0.744138	-8.94423	2.78941	-1.66646	3.41364	-6.65269	-3.22903	-12.1733	4.55824	-0.560128	12.611
12	-3.72438	-0.646385	-6.94906	3.08638	-1.55609	4.65307	-7.87775	-0.407197	-7.35626	3.03053	1.13895	13.2484
13	-7.09938	-3.03362	-14.1202	1.13892	-3.8125	2.35508	-9.37588	-9.85686	-23.977	6.89067	1.68296	20.6613
14	-5.11232	-0.27835	-10.6906	2.51079	-3.9497	4.30447	-9.88274	-5.13591	-15.8265	1.34114	-0.938801	7.67575
15	-7.26273	-2.95796	-14.9101	3.39627	-2.94787	3.65686	-11.3043	-8.84752	-23.7577	5.41208	-0.772947	1.86009
16	-3.58513	-1.88449	-7.60121	4.62459	-0.938651	2.19431	-6.21039	-3.44442	-11.0456	5.09766	4.16101	-10.567
MEAN of sum of reciprocal squares	0.045197	4.8673489	0.0134686	0.231833 5	0.447518	0.176291 3	0.016695 3	0.490586	0.018356 6	0.096220 7	211.86749	0.022437 2
S/N Ratio	13.448903	-6.872925	18.706785	6.348238	3.491894 9	7.537690 1	17.774056	3.092848 1	17.362087	10.167313	-23.26064	16.490322



Appendix D.4: Outputs of Taguchi's Experiments: 49 to 64

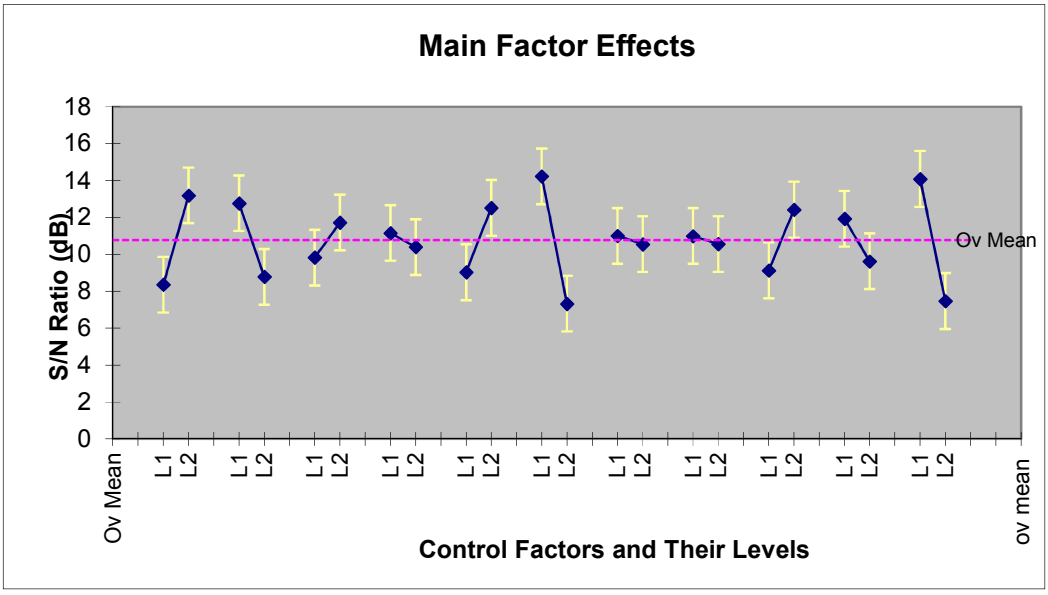
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-4.89997	-0.022914	-7.3463	2.78779	-3.59557	3.36269	-5.80902	-0.162139	-7.50844	4.54307	1.84559	-5.4832
2	-7.16325	-5.07482	15.9184	1.64505	-3.89289	2.79071	-11.5459	-7.48381	-23.4023	9.43483	0.78822	5.1587
3	-5.58138	-3.18705	-10.253	4.34875	-2.72363	2.42856	-7.10018	-2.13902	-12.392	7.69155	0.408065	-4.04754
4	-3.68679	-0.049937	-6.4962	1.49425	-2.21236	1.74931	-4.55872	1.51403	-4.98217	4.72226	5.90506	0.225293
5	-3.79689	-1.52492	8.46846	1.32921	-3.04781	3.96918	-8.64075	-1.72426	-10.1927	3.29341	2.86804	11.5713
6	-1.18008	3.04503	2.31935	2.85857	-0.181879	4.83921	-1.33977	10.6989	13.0182	0.947209	6.61043	15.3217
7	-7.77087	-5.23239	-15.07	4.80793	-4.0309	2.18128	-9.48041	-7.79753	-22.8675	7.62047	-1.16525	51.4835
8	-6.77534	-5.43874	-14.3115	3.29866	-2.28256	1.78804	-9.3242	-6.28888	-20.6004	10.166	2.87549	42.7823
9	-6.04209	-2.90854	-9.48009	3.7283	-4.97525	3.64822	-7.08622	-2.77928	-12.2594	4.70794	0.390976	39.4061
10	-4.53221	0.382652	-8.52096	1.09741	-3.48459	2.38179	-6.37054	-2.20176	-10.7227	4.61479	2.58948	45.7849
11	-6.38535	-3.47647	-12.9317	1.18387	-3.25662	2.04539	-8.59171	-5.35817	-18.2898	6.48623	-1.32074	48.5496
12	-5.3787	-2.83507	-10.0448	1.14338	-4.1389	3.1668	-7.83292	-3.55835	-13.6032	6.85297	1.15316	38.4383
13	-7.16939	-3.79835	-15.7693	2.62138	-3.57996	1.67581	-10.2757	-10.2769	-26.0462	5.47415	-2.86521	40.0378
14	-5.1143	-2.53052	-10.6461	3.05489	-1.09423	3.18337	-8.71518	-4.68868	-15.3348	4.21553	0.284722	18.7524
15	-3.07006	1.89754	-3.06407	4.10942	-1.6161	3.95869	-3.9527	5.26673	2.20267	0.913596	3.84683	13.1712
16	-6.55315	-1.83808	-12.9427	1.92711	-2.27351	4.78083	-11.1704	-5.11792	-18.0606	5.21694	-1.14641	34.7186
MEAN of sum of reciprocal squares	0.086021 2	154.28622	0.028329 8	0.271390 7	2.182936 5	0.150384	0.056915 3	2.642801 9	0.021454 4	0.186196 3	1.977857 8	1.323875 3
S/N Ratio	10.65394 3	-21.88327	15.47756 3	5.664049 6	-3.390411	8.227982 3	12.44770 8	-4.220646	16.68483 8	7.300290 3	-2.961951	-1.218471



Appendix D.5: Outputs of Taguchi's Experiments: 65 to 80

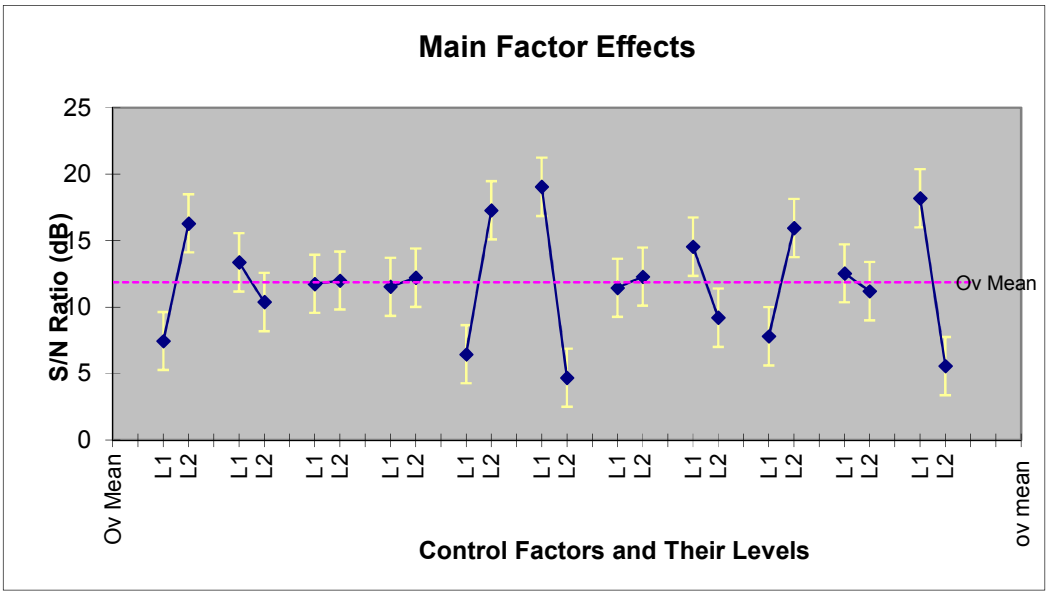
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-8.24859	-4.17612	-14.6397	3.92125	-4.88014	2.34029	-8.73144	-9.66445	-24.3042	8.34904	-2.41436	27.4707
2	-7.8371	-5.85338	-17.7799	2.99821	-3.33486	1.08556	-11.0284	-11.2467	-29.0267	7.53343	-3.16256	17.515
3	-6.15755	-1.52445	-10.6711	1.10573	-4.81165	3.90099	-8.41457	-6.25123	-16.9224	5.70445	2.33692	-6.25014
4	-2.84304	0.696309	-1.33235	1.97772	-0.98943	4.63437	-3.12368	3.82728	2.49493	2.65416	3.23549	-7.10119
5	-5.26789	-3.50442	-9.3861	2.34386	-1.31699	3.94722	-8.06543	-2.0371	-11.4232	6.5083	-1.22187	13.1892
6	-9.11286	-4.23509	-15.7177	2.21726	-4.70176	4.43084	-11.0357	-8.87195	-24.5897	6.72679	-1.91129	15.4174
7	-5.60258	-1.94859	-11.8787	4.95999	-3.55698	4.27093	-10.547	-5.79672	-17.6754	5.78241	1.18563	5.12659
8	-5.39818	-0.418238	-11.7441	2.73914	-3.07992	1.95752	-8.30347	-6.67579	-18.4199	2.50249	-1.97612	4.24783
9	-4.15376	-0.853435	-11.1755	1.72055	-1.7742	1.5158	-8.53752	-3.78594	-14.9614	4.86243	0.955575	-8.59223

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-6.44248	-1.48622	-14.5215	2.89531	-4.20695	2.23113	-10.3102	-8.14502	-22.6665	5.63397	-0.478401	-15.9238
11	-8.15102	-3.22419	-16.9675	2.95534	-4.94304	3.11158	-11.928	-11.7212	-28.6887	4.3435	-4.73269	-28.4123
12	-5.34359	-1.7644	-10.1443	2.17927	-1.12284	4.2358	-9.03648	-5.00891	-15.1532	6.56959	4.36652	-51.5577
13	-4.48178	-1.27608	-6.89283	1.53208	-4.43153	4.90783	-7.31888	1.42581	-5.46702	5.80861	1.07682	-49.0514
14	-6.4693	-3.50429	-11.0983	1.22331	-2.56507	4.42784	-9.05687	-6.07898	-17.1773	7.87308	-0.95679	-35.4542
15	-8.10564	-3.86593	-17.2865	3.16968	-3.12016	3.18205	-12.3629	-9.6039	-26.8904	7.75233	-0.590744	-38.6998
16	-6.99876	-3.5437	-10.8346	2.05328	-4.07923	3.80276	-7.63856	-2.28047	-13.115	6.32786	-0.371836	-54.3516
MEAN of sum of reciprocal squares	0.0347808	0.7790452	0.0448784	0.2605236	0.2359296	0.1684419	0.0183293	0.0843426	0.0158201	0.0416201	1.3354023	0.0115681
S/N Ratio	14.58661	1.0843737	13.479627	5.8415286	6.2721758	7.7354991	17.368539	10.739528	18.00792	13.806967	-1.256121	19.36738



Appendix D.6: Outputs of Taguchi's Experiments: 81 to 96

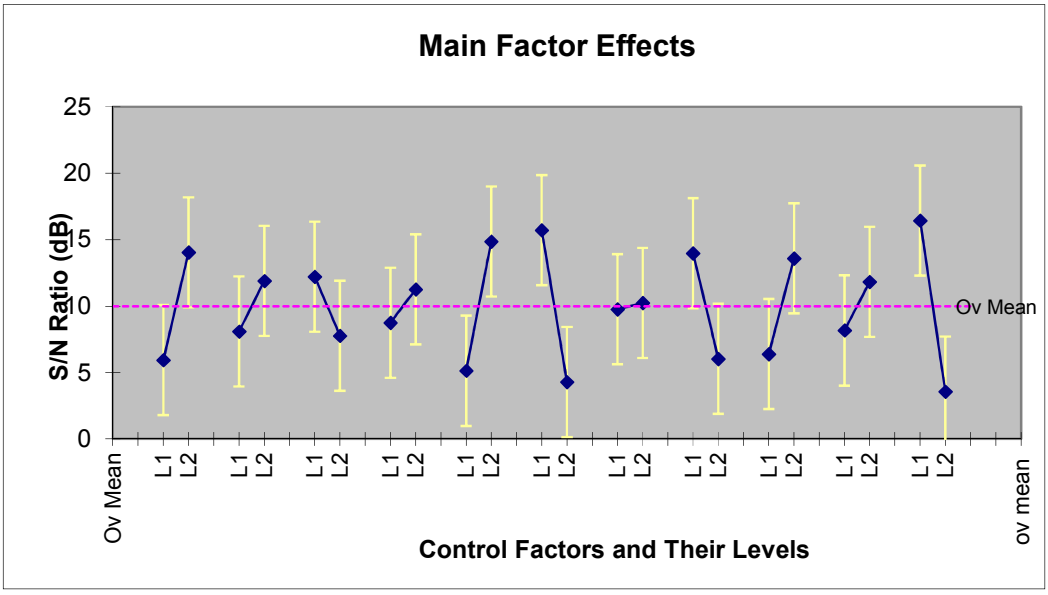
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-9.75625	-7.67587	-19.9674	4.77523	-4.91653	3.94164	-14.1527	-12.5234	-32.4908	11.2102	-2.64876	-51.4314
2	-7.68625	-6.2501	-16.0008	1.47598	-3.08329	3.80629	-12.1208	-8.10277	-24.1036	9.05894	-3.28135	-67.8435
3	-6.5803	-1.75547	-15.6997	1.01979	-2.25471	1.55637	-10.6758	-11.601	-27.3007	6.02832	1.00167	-81.2185
4	-4.58009	-1.53518	-8.71232	1.18767	-0.556837	4.44529	-8.57753	-3.5182	-12.2305	5.47496	0.675929	-103.043
5	-7.71779	-5.61183	-14.9915	3.43298	-4.71771	4.35272	-11.6264	-8.53424	-23.5257	10.4912	-1.10309	-104.457
6	-4.44441	-1.03625	-9.21998	4.0832	-2.96074	3.71571	-8.49127	-3.17294	-12.3929	5.72423	3.65246	-108.421
7	-6.71121	-2.16279	-13.9595	3.36948	-3.67198	4.20061	-11.4489	-6.94311	-20.9026	6.58946	-0.37582	-100.945
8	-4.45841	0.403265	-6.57667	2.38533	-3.78486	3.95492	-6.07318	-1.52591	-8.10258	3.62623	2.13189	-108.104
9	-5.87999	-1.58099	-12.2155	3.64429	-2.45352	2.2573	-8.59282	-7.88669	-20.1022	3.67236	-0.93428 9	-98.4672
10	-5.27228	-1.419	-9.7539	2.82445	-1.38961	3.06359	-7.5452	-0.937948	-10.6918	4.60236	0.146032	-111.437
11	-8.98765	-6.312	-16.0704	4.70649	-4.80481	2.30066	-9.38343	-10.4151	-26.4855	9.68167	-4.24394	-110.712
12	-4.43327	-0.089141	-10.6555	3.08167	-0.8122	1.53697	-7.75915	-6.06911	-16.7246	1.30199	1.0669	-122.614
13	-8.90118	-4.61928	-18.6261	3.30719	-4.7136	2.15701	-11.8819	-10.7693	-29.3954	6.26717	-3.57215	-134.826
14	-6.12765	-4.82147	-13.0848	3.55761	-3.60501	2.93544	-9.89262	-6.9558	-20.0406	8.4834	0.3579	-156.115
15	-5.21858	-1.30225	-13.0992	2.40799	-0.600684	1.66397	-9.54462	-6.35181	-19.451	3.3305	-1.18884	-160.919
16	-7.4871	-4.75096	-15.4773	4.19125	-3.34823	3.17118	-11.1614	-9.63869	-25.116	8.20971	-2.97723	-179.689
MEAN of sum of reciprocal squares	0.0298476	9.0389622	0.0075237	0.2191881	0.6035903	0.1573569	0.0116132	0.1278578	0.0039471	0.0716879	4.61598	0.0001078
S/N Ratio	15.250905	-9.561186	21.235667	6.5918296	2.1925774	8.0311414	19.350475	8.9327264	24.037184	11.445543	-6.642639	39.672958



Appendix D.7: Outputs of Taguchi's Experiments: 97 to 112

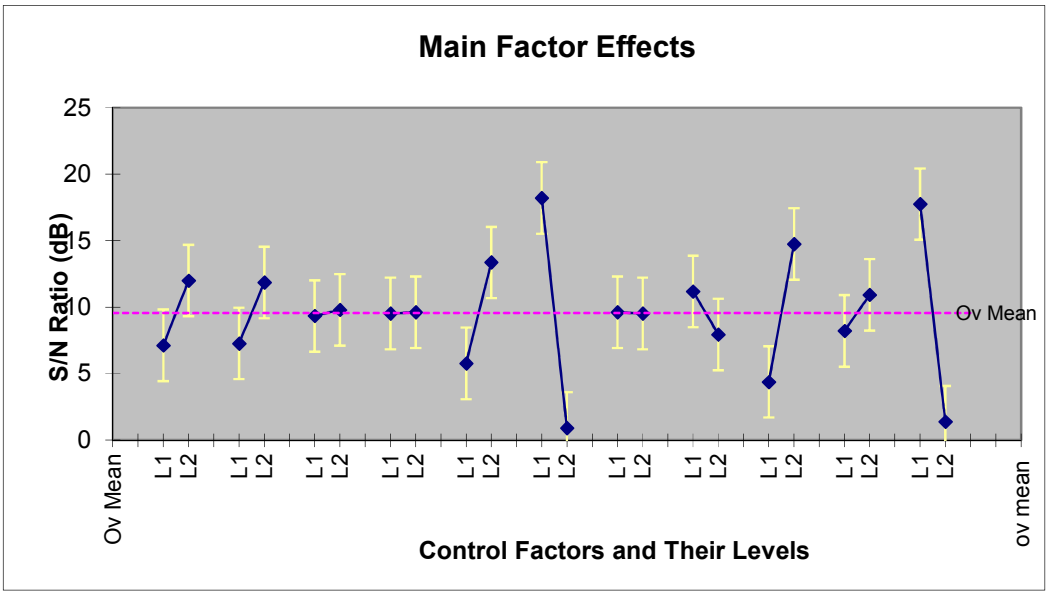
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-5.2386 7	-2.4167	-8.1072 1	4.0623	-2.5395 5	4.7716 1	-7.6401 5	-0.3398 93	-8.4471	6.8932 4	2.6270 9	-192.22 1
2	-8.5522 4	-5.9853 4	-13.724 9	4.6878 2	-4.9390 7	3.8432 4	-9.0158 9	-4.9661 3	-18.691	9.2938 3	-1.8723 9	-179.06 1
3	-5.5237 6	-2.2999 8	-11.899 2	1.3248 3	-1.0992 1	2.3475	-8.7229 8	-5.0288 1	-16.928	3.6969 4	-1.8199 2	-178.03 2
4	-1.1611 8	3.5051 1	2.4626	2.4354 8	-0.6901 31	4.9782	-1.3544 2	9.2464 6	11.709 1	-0.4400 86	3.9364 6	-190.75 7
5	-4.0541 4	0.0785 141	-7.902	3.2540 6	-4.0063 1	4.4649 2	-8.3127 8	-1.3098 2	-9.2118 2	3.3848 9	2.4367 5	-159.58 8
6	-3.4307 5	-0.6764 63	-5.5651 7	1.8610 7	-0.8938 48	2.4721 1	-4.6065 3	2.1219 4	-3.4432 4	5.3842 3	3.0844 3	-150.71 9
7	-5.9613 8	-2.4050 4	-9.7438 6	2.2692 4	-3.4795 6	3.9060 4	-7.6885 2	-2.9436 2	-12.687 5	6.5937 1	2.9295 4	-139.14
8	-7.4497	-4.7811 7	-14.853 3	2.2448 1	-3.6659 8	4.7383 1	-12.141 9	-7.6340 6	-22.487 4	7.1029 4	-2.8687 9	-131.43 7
9	-6.7317 7	-5.1563 2	-13.687 8	2.4526 7	-2.5929 1	4.3574 5	-11.313 5	-7.1028 6	-20.790 7	9.2184 1	-1.3574 8	-141.90 7

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-5.41118	-2.84087	-12.5297	2.25084	-1.40215	2.54888	-9.6674	-7.37384	-19.9035	5.36402	-1.17959	-147.889
11	-4.31718	-2.98856	-9.49113	2.55234	-2.49492	3.44199	-8.61593	-4.37445	-13.8656	6.86174	3.31233	-160.822
12	-4.48428	-0.838094	-8.64392	4.83863	-1.42992	3.0647	-7.22434	-1.97645	-10.6204	4.43057	3.73458	-157.366
13	-4.34869	-1.91602	-6.58083	1.23834	-3.66813	4.7591	-6.99123	-2.41524	-8.99606	5.37283	3.50804	-150.88
14	-3.75101	-0.493671	-5.45535	2.91856	-2.48171	4.19332	-5.89766	0.441895	-5.01345	5.2528	3.12649	-141.03
15	-4.34365	-3.12774	-8.09033	1.25403	-2.58856	3.11612	-6.8628	-3.36133	-11.4517	5.0537	-0.635332	-125.113
16	-5.4539	-0.96675	-13.4681	2.43975	-3.00033	1.06035	-9.07453	-8.35301	-21.8211	3.58299	1.49215	-125.844
MEAN of sum of reciprocal squares	0.088868	11.481641	0.023895	0.239977	0.415845 4	0.137585 8	0.052883 5	1.024989 6	0.013836 8	0.381270 3	0.383 42	4.447 E-05
S/N Ratio	10.512547	-10.60004	16.216931	6.197929 5	3.810681 1	8.614264 1	12.766799	-0.107195	18.589638	4.187670 5	4.163252 9	43.518973



Appendix D.8: Outputs of Taguchi's Experiments: 113 to 128

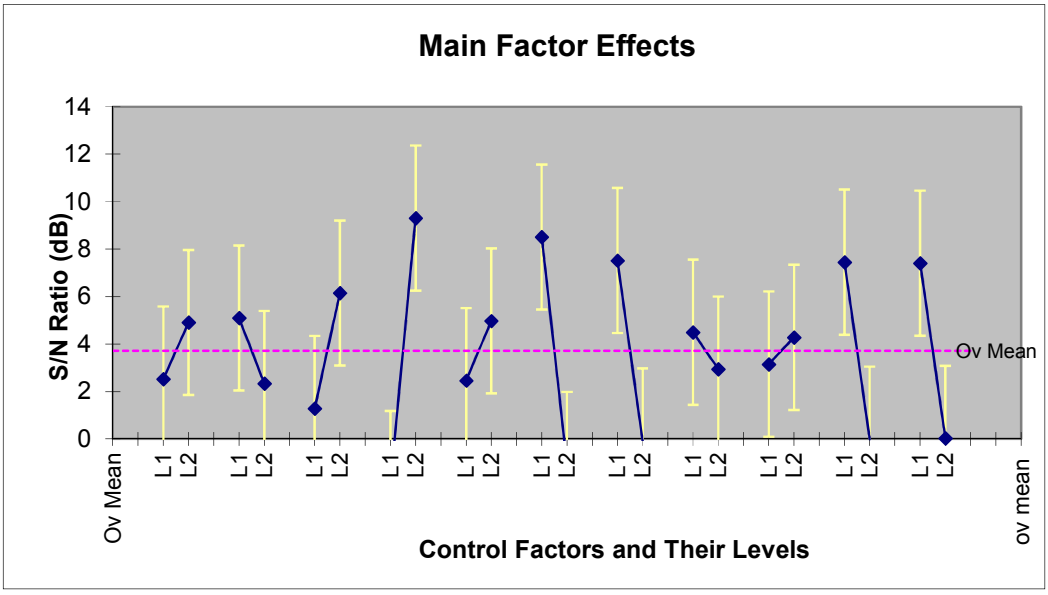
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-5.8922 1	-1.0820 3	-8.5869	1.0456 8	-3.5423 8	4.9985 4	-7.6932 4	-3.5932 6	-12.180 2	3.7925 6	-2.1396 5	-140.29 4
2	-2.5628 4	0.0914 478	-5.3158	3.8996 9	-2.2322 3	2.6281 6	-5.3811 2	0.4112 53	-4.9045 5	3.1378 9	3.7369	-140.57 8
3	-4.6214 1	0.2341 62	-8.0767	1.2770 5	-2.2550 2	4.5867 6	-8.0420 5	-1.0179 8	-9.0946 7	2.2639	0.1256 71	-128.68 4
4	-7.0639 2	-3.1902	-12.282	3.8198 2	-3.8332 4	3.9020 1	-9.1200 4	-8.3844 8	-20.666 4	7.4876 3	0.6632 8	-126.74 3
5	-6.7543 2	-3.8906 1	-15.497	1.3882	-3.8305 2	2.7029 9	-11.445 7	-7.3419 7	-22.839	7.7971 8	-0.3521 77	-130.22 2
6	-6.0683 4	-3.5549 2	-8.8083 9	3.6222 9	-4.2155 1	3.9271 9	-6.6672 4	-1.1256 2	-9.9340 1	6.7968	1.4634 6	-143.05 2
7	-6.6095 5	-3.3956 1	-13.248 8	4.4082 7	-4.5440 1	4.7162 5	-11.355 5	-8.3812 4	-21.630 1	8.3808	0.6905 97	-132.22 8
8	-8.3508	-6.1813	-14.533 8	1.9518 1	-4.2863 7	4.2216 1	-10.404 6	-9.1137 5	-23.647 5	9.8737 7	-1.1084 2	-134.23 4
9	-7.3451 9	-3.0844	-14.600 1	2.3723 8	-3.4562 7	3.2582	-10.513 1	-10.058 5	-24.658 6	6.6174 4	0.4926 55	-141.34 9
10	-4.1361 4	-1.2642 9	-8.8389 4	1.0500 4	-2.2024 3	2.5284 8	-7.2312 9	-3.3377	-12.176 6	4.8133 5	1.1038 5	-154.59 1
11	-4.028	-1.8742 9	-10.294 7	4.8337	-1.3207 6	2.7525	-9.0192 4	-4.9399 6	-15.234 7	5.4368 6	2.9623 7	-155.31 5
12	-7.0714 8	-3.6615 7	-12.181	4.0901 2	-2.2850 5	4.4404 2	-9.5499 3	-4.8282 2	-17.009 2	7.3662 8	1.3673 7	-155.16 1
13	-4.0970 7	-0.3803 08	-6.1709 6	1.2736 3	-2.2212 4	3.8439 8	-5.9178 7	0.2902 12	-5.8807 5	3.5614 7	0.1722 11	-154.57 5
14	-5.0123 1	-3.0965 6	-6.0124 9	3.7570 2	-1.8899 6	4.5662 9	-5.5664 7	0.1092 6	-5.9032 3	7.2554 8	0.7954 01	-148.17 6
15	-2.0543 1	0.1261 01	-3.4349 5	2.1400 9	-1.5373 3	4.4424 7	-5.8231 1	5.1608 8	1.7259 4	4.4313	6.4465 3	-133.42 1
16	-6.2524 8	-3.1852 8	-11.566 9	3.8672 6	-3.4419 8	2.9301 2	-8.2445 8	-4.3817 5	-15.948 7	8.1662 6	3.3822 9	-110.38 6
MEAN of sum of reciprocal squares	0.0528 747	13.989 075	0.0179 183	0.3125 352	0.1495 951	0.0789 933	0.0180 136	6.9117 799	0.0325 204	0.0463 205	7.8805 875	5.358 E-05
S/N Ratio	12.767 518	-11.457 89	17.467 035	5.0510 108	8.2508 276	11.024 097	17.444 006	-8.3958 99	14.878 436	13.342 269	-8.9655 86	42.710 239



Appendix D.9: Outputs of Taguchi's Experiments: 129 to 144

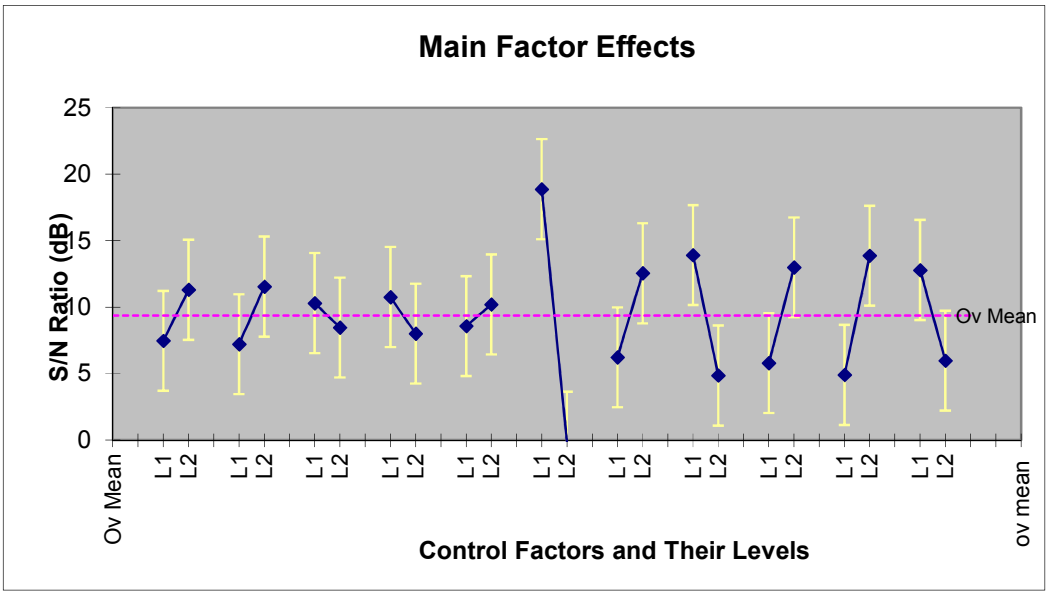
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-4.89997	-0.022914	-7.3463	2.78779	-3.59557	3.36269	-5.80902	-0.162139	-7.50844	4.54307	1.84559	-5.4832
2	-7.16325	-5.07482	-15.9184	1.64505	-3.89289	2.79071	-11.5459	-7.48381	-23.4023	9.43483	0.78822	-5.1587
3	-5.58138	-3.18705	-10.253	4.34875	-2.72363	2.42856	-7.10018	-2.13902	-12.392	7.69155	0.408065	-4.04754
4	-3.68679	-0.049937	-6.4962	1.49425	-2.21236	1.74931	-4.55872	1.51403	-4.98217	4.72226	5.90506	0.225293
5	-3.79689	-1.52492	-8.46846	1.32921	-3.04781	3.96918	-8.64075	-1.72426	-10.1927	3.29341	2.86804	11.5713
6	-1.18008	3.04503	2.31935	2.85857	-0.181879	4.83921	-1.33977	10.6989	13.0182	0.947209	6.61043	15.3217
7	-7.77087	-5.23239	-15.07	4.80793	-4.0309	2.18128	-9.48041	-7.79753	-22.8675	7.62047	-1.16525	51.4835
8	-6.77534	-5.43874	-14.3115	3.29866	-2.82256	1.78804	-9.3242	-6.28888	-20.6004	10.166	2.87549	42.7823
9	-6.04209	-2.90854	-9.48009	3.7283	-4.97525	3.64822	-7.08622	-2.77928	-12.2594	4.70794	0.390976	39.4061

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-4.53221	0.382652	-8.52096	1.09741	-3.48459	2.38179	-6.37054	-2.20176	-10.7227	4.61479	2.58948	45.7849
11	-6.38535	-3.47647	-12.9317	1.18387	-3.25662	2.04539	-8.59171	-5.35817	-18.2898	6.48623	-1.32074	48.5496
12	-5.3787	-2.83507	-10.0448	1.14338	-4.1389	3.1668	-7.83292	-3.55835	-13.6032	6.85297	1.15316	38.4383
13	-7.16939	-3.79835	-15.7693	2.62138	-3.57996	1.67581	-10.2757	-10.2769	-26.0462	5.47415	-2.86521	40.0378
14	-5.1143	-2.53052	-10.6461	3.05489	-1.09423	3.18337	-8.71518	-4.68868	-15.3348	4.21553	0.284722	18.7524
15	-3.07006	1.89754	-3.06407	4.10942	-1.6161	3.95869	-3.9527	5.26673	2.20267	0.913596	3.84683	13.1712
16	-6.55315	-1.83808	-12.9427	1.92711	-2.27351	4.78083	-11.1704	-5.11792	-18.0606	5.21694	-1.14641	34.7186
MEAN of sum of reciprocal squares	0.086021 2	154.28622	0.028329 8	0.271390 7	2.182936 5	0.150384	0.056915 3	2.642801 9	0.021454 4	0.186196 3	1.977857 8	1.323875 3
S/N Ratio	10.653943	-21.88327	15.477563	5.664049 6	-3.390411	8.227982 3	12.447708	-4.220646	16.684838	7.300290 3	-2.961951	-1.218471



Appendix D.10: Outputs of Taguchi's Experiments: 145 to 160

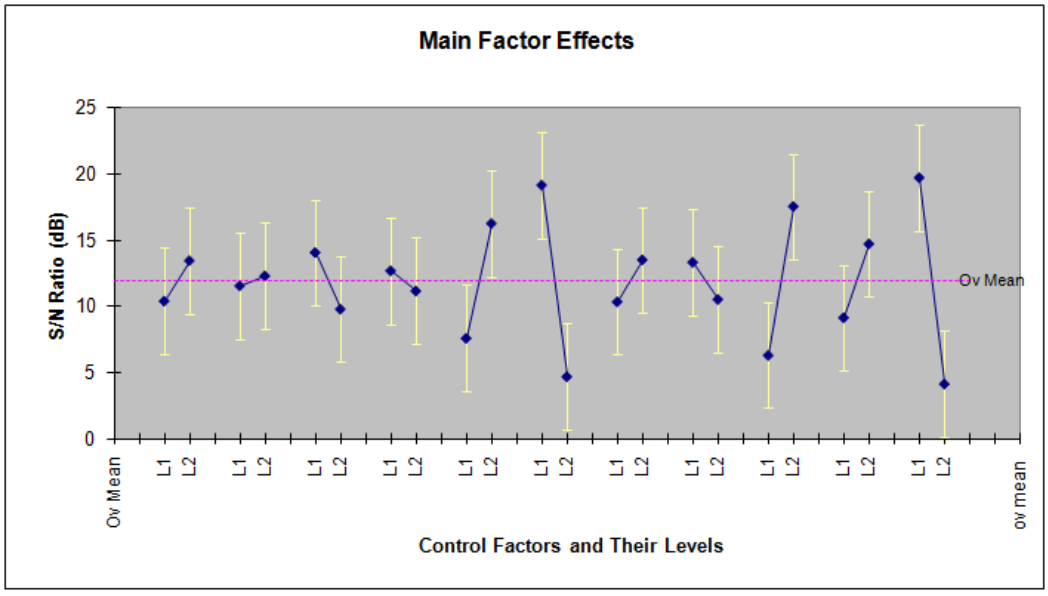
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-7.63829	-5.03415	-12.5336	4.39344	-3.76129	4.90327	-9.79863	-6.98201	-19.5157	6.71879	-2.39005	-152.123
2	-3.39469	1.02497	-8.73928	3.35733	-1.50787	1.14307	-6.48766	0.198462	-8.54081	2.27067	1.73663	-155.336
3	-5.43248	-0.44198	-13.0144	4.82423	-3.82122	1.9968	-9.57874	-5.92617	-18.9406	4.5706	1.57214	-154.974
4	-7.47886	-5.94206	-13.4203	2.18609	-4.06445	4.43009	-10.3715	-5.18615	-18.6064	8.05773	-4.28243	-161.604
5	-8.37235	-3.39555	-15.9607	3.28975	-4.85119	3.19297	-10.7813	-10.3223	-26.283	7.19095	-3.26915	-167.222
6	-2.66371	0.666593	-6.32413	1.16838	-0.77231	3.85982	-7.52024	-0.70356	-7.02808	2.9311	2.16152	-181.396
7	-6.5215	-4.44586	-14.6579	1.44633	-3.52247	1.86714	-10.0035	-8.99416	-23.652	7.2884	-2.0121	-178.004
8	-6.39852	-1.62975	-12.9796	4.03634	-3.26763	4.50375	-11.0848	-6.47785	-19.4574	4.91342	0.53279	-193.802
9	-4.38991	-2.04779	-7.19929	1.97876	-1.8193	3.87859	-6.68797	0.660501	-6.53879	4.60699	1.49826	-197.965
10	-3.84526	1.09428	-11.1669	4.96234	-2.18157	1.22497	-8.54656	-4.29073	-15.4576	1.49619	1.8954	-190.24
11	-6.7475	-3.20496	-14.6764	2.33723	-2.6775	2.96277	-10.8917	-5.92459	-20.601	6.40781	-1.85912	-198.944
12	-7.52872	-5.58236	-15.4325	1.41556	-3.52255	2.75999	-10.6638	-8.91005	-24.3425	9.0558	-0.997059	-210.308
13	-2.32865	2.47239	-4.62174	1.84241	-1.28416	2.79716	-5.09025	4.7599	0.138156	1.98368	6.54542	-222.557
14	-3.9836	-0.555901	-8.54277	1.88032	-0.21709	4.16408	-8.72324	-1.00781	-9.55058	3.75484	1.51824	-205.712
15	-8.52542	-4.66113	-19.563	4.72404	-3.61524	2.25838	-13.2959	-13.5598	-33.1228	6.64452	-4.40867	-203.626
16	-5.79858	-1.64013	-8.15877	2.90954	-3.06371	4.92704	-7.28723	-3.30908	-11.4678	5.40124	-0.525601	-231.195
MEAN of sum of reciprocal squares	0.0524609	0.9217391	0.0120067	0.219502	1.6755914	0.1931305	0.0146567	2.0682165	3.4992222	0.0908909	0.7267565	3.009 E-05
S/N Ratio	12.801644	0.35392	19.205772	6.5856154	-2.241681	7.1414916	18.339632	-3.15596	-5.439715	10.414797	1.3861109	45.216022



Appendix D.11: Outputs of Taguchi's Experiments: 161 to 176

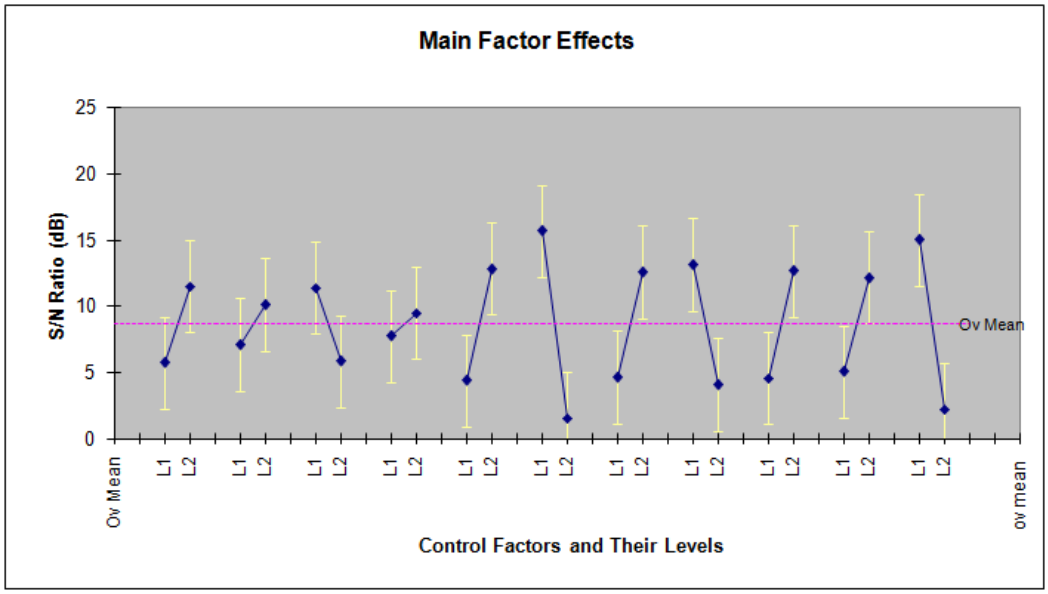
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-7.23329	-3.43467	-15.9579	2.74226	-3.74236	2.93213	-11.6567	-7.16784	-23.1257	8.11012	2.19857	-226.685
2	-5.79199	-4.56118	-9.76366	2.47149	-4.90335	4.77062	-8.74229	-1.44957	-11.2132	7.16364	1.66198	-234.506
3	-7.26453	-5.25007	-12.9109	1.68295	-4.45224	1.71604	-7.36237	-6.32905	-19.2399	9.35115	-1.62907	-224.26
4	-7.41182	-4.98319	-14.8714	1.72238	-3.67949	4.0744	-11.534	-7.09188	-21.9633	9.73615	-0.888662	-230.734
5	-4.25329	-0.368687	-6.54891	3.39838	-2.55386	3.76052	-6.05614	0.161088	-6.38783	5.12184	4.11464	-237.753
6	-7.55465	-4.37542	-15.9304	4.92422	-4.73228	2.1443	-10.52	-9.59102	-25.5214	8.4234	-2.07267	-224.398
7	-2.75294	2.01406	-3.80811	3.19006	-2.25816	4.1966	-5.25177	0.599787	-3.20832	0.625655	1.38856	-235.858
8	-4.98882	-0.937121	-6.59123	1.78506	-1.82728	4.00353	-5.60594	0.836894	-5.75434	3.08588	1.41326	-225.536
9	-7.52418	-5.25179	-14.7248	2.71116	-4.85884	4.11433	-11.315	-9.49401	-24.2189	8.7534	-2.76033	-217.155

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-5.87112	-2.43823	-9.23092	2.3424	-2.75297	2.76824	-6.12804	-3.05614	-12.2871	6.93246	2.15697	-226.993
11	-6.80489	-3.21466	-13.3535	4.97753	-2.77344	4.29698	-10.8456	-7.89208	-21.2456	7.28941	-0.977188	-221.724
12	-6.02956	-3.7268	-11.8403	1.53976	-2.20545	4.77806	-10.5888	-6.01501	-17.8553	7.43989	1.42574	-228.959
13	-6.06571	-3.06616	-14.5572	3.46429	-1.76032	2.12665	-10.6181	-6.44053	-20.9977	7.16301	-0.114863	-232.099
14	-6.95931	-2.90359	-12.1473	2.32284	-3.07056	4.97621	-10.1642	-6.44809	-18.5954	7.15827	-1.14966	-243.222
15	-6.14592	-4.46689	-9.4448	4.82368	-1.63775	4.54811	-7.84699	-1.91288	-11.3577	6.62828	-1.73999	-246.89
16	-9.56965	-5.56699	-17.2788	3.12211	-4.94892	3.67815	-11.3873	-11.0048	-28.2835	8.39203	-3.88915	-240.831
MEAN of sum of reciprocal squares	0.0326935	0.6391595	0.0129138	0.1787392	0.1440808	0.1056379	0.0157765	2.9180493	0.0129079	0.1930957	5.4206091	1.869 E-05
S/N Ratio	14.855381	1.9439078	18.889472	7.4778026	8.4139391	9.7618023	18.019898	-4.650926	18.891457	7.1422745	-7.340481	47.284656



Appendix D.12: Outputs of Taguchi's Experiments: 177 to 192

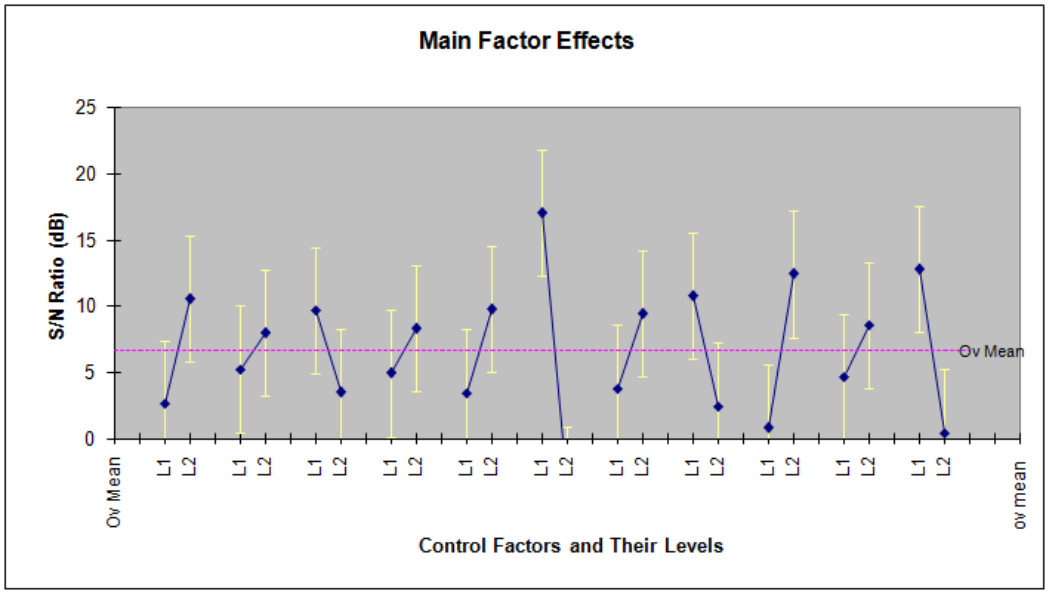
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-5.11058	-3.73986	-9.74485	3.06665	-0.257226	2.07162	-6.70589	-1.0326	-10.7774	7.3368	1.02744	-256.821
2	-6.71957	-1.92257	-10.2083	2.78065	-2.1746	4.37185	-7.86055	-6.16862	-16.3769	5.42956	1.41203	-254.501
3	-4.50558	0.164019	-7.79887	2.28805	-2.90435	2.96872	-6.26202	-0.21235	-8.01122	0.848834	-1.31477	-255.261
4	-7.69134	-3.10719	-17.7267	2.34624	-3.91906	2.43227	-12.4676	-14.0754	-31.8021	6.09655	-2.28267	-254.951
5	-8.18887	-3.83244	-15.6693	4.06892	-4.83643	3.7943	-11.2748	-10.2812	-25.9505	8.71953	0.611149	-282.478
6	-4.80986	-2.01563	-5.11079	1.58357	-4.38652	4.89281	-5.19374	4.23018	-0.88061	5.8313	2.13782	-290.953
7	-5.61914	-1.58182	-9.20773	2.87896	-1.06954	3.85101	-7.4396	-3.88741	-13.0951	5.00854	1.64019	-268.373
8	-8.90862	-4.53049	-14.4805	3.12272	-4.37594	4.96425	-10.5361	-6.8173	-21.2978	8.63803	-0.825524	-268.343
9	-6.88133	-4.00697	-14.4712	1.20527	-3.34256	3.48695	-11.0768	-8.98385	-23.455	5.98178	-2.23015	-270.529
10	-6.23286	-2.49912	-9.16787	4.32056	-3.49071	4.15854	-7.09354	0.820084	-8.34778	4.4896	-0.563917	-287.655
11	-5.43826	-1.06606	-12.4717	4.62988	-1.55019	2.35908	-9.39256	-6.60595	-19.0777	4.60423	-0.403473	-278.048
12	-2.88202	-0.559287	-4.03143	3.87	-2.0722	3.71202	-4.86143	2.66438	-1.36706	4.7237	3.45949	-287.555
13	-0.743113	2.96361	-1.93497	3.22385	-0.387849	1.81391	-3.00576	6.13749	4.20252	-0.203075	4.6731	-268.941
14	-5.70974	-1.1549	-12.9963	1.50459	-1.74857	3.37264	-10.6592	-7.63382	-20.6301	5.68284	1.77273	-252.399
15	-6.02352	-1.90143	-11.3227	4.37884	-2.49264	2.38354	-7.68271	-5.98674	-17.3094	6.31011	0.878979	-262.72
16	-5.14505	-0.783216	-9.52833	4.98718	-2.8141	3.14802	-7.5313	-2.40544	-11.9338	3.86126	0.769533	-265.197
MEAN of sum of reciprocal squares	0.153543 7	2.971302 2	0.031246 3	0.181983 4	1.613095 5	0.111232 2	0.024451 1	1.678895 9	0.129903 2	1.737151 2	0.915384 7	1.397 E-05
S/N Ratio	8.137679 6	-4.729468	15.05200 7	7.399683 1	-2.076601	9.537695 8	16.11701	-2.250238	8.863799 9	-2.398376	0.383963 6	48.54862 1



Appendix D.13: Outputs of Taguchi's Experiments: 193 to 208

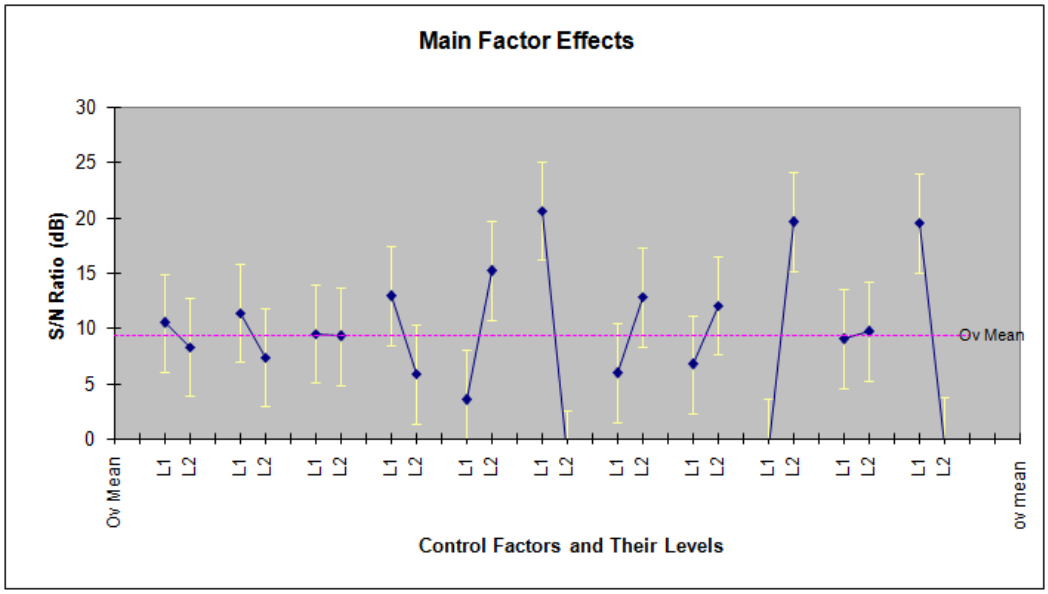
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-5.7777	-3.77515	-9.98194	1.73482	-2.41364	2.58565	-6.7899	-1.79641	-11.7784	7.31557	-0.553548	-261.332
2	-1.94109	1.54121	-6.77148	2.82716	-0.224565	1.00371	-5.8341	-0.084002	-6.85548	2.00909	3.05337	-260.051
3	-4.41137	0.0765133	-8.71813	4.54855	-1.72258	4.83596	-9.14273	-0.82878	-9.54692	3.85889	1.12165	-259.165
4	-2.56858	-0.526799	-4.30629	4.85144	-1.23313	4.72808	-6.4658	3.24546	-1.06084	3.57234	3.17105	-253.075
5	-6.82065	-4.67313	-14.7242	4.19896	-2.85961	3.33803	-11.2416	-10.2856	-25.0099	8.08568	-0.72822	-233.649
6	-4.86333	-0.530065	-11.4769	2.64786	-1.38414	2.61189	-9.2255	-2.81334	-14.2903	4.05338	0.763756	-246.03
7	-7.71068	-5.32792	-12.6275	3.61954	-3.65307	4.59642	-9.51323	-5.53699	-18.1645	8.66907	-2.1126	-251.577
8	-3.26277	-2.12356	-4.27226	1.93378	-0.254061	3.80167	-4.81116	1.52715	-2.74511	5.19475	3.86452	-252.824
9	-1.654	2.32923	-5.17571	3.49534	-0.508592	1.64907	-5.17078	0.611481	-4.56423	0.57242	6.17544	-237.202

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-5.13558	-1.56716	-12.0167	2.59746	-3.05759	2.71348	-9.59454	-4.83516	-16.8518	3.36445	-0.830972	-228.736
11	-4.21213	0.545427	-7.82456	1.67326	-2.85705	3.83345	-7.44588	0.503168	-7.3214	2.84148	1.62942	-237.519
12	-4.8467	-0.565652	-7.76797	1.65987	-3.08742	3.15347	-6.07474	1.3667	-6.40126	2.70468	-0.166152	-231.634
13	-7.50916	-4.04024	-18.9107	4.09339	-3.06576	1.06524	-12.4668	-13.6762	-32.5869	8.26715	-0.714673	-226.204
14	-1.47725	2.71262	-3.10733	1.2377	-0.062794	1.34228	-2.97236	1.74637	-1.36096	1.05598	5.66459	-250.902
15	-7.4152	-3.10974	-16.8934	1.91833	-4.11072	1.97687	-11.455	-9.41217	-26.3055	5.7685	-2.09102	-240.748
16	-6.26553	-2.86399	-10.3754	3.17273	-3.84362	4.33931	-8.44918	-2.00858	-12.384	5.04826	-0.334249	-260.38
MEAN of sum of reciprocal squares	0.1092335	12.194055	0.0234784	0.1845243	19.675047	0.2621283	0.0251654	9.8680771	0.1130003	0.3197412	3.8014961	1.661E-05
S/N Ratio	9.6164409	-10.86148	16.293309	7.3394639	-12.93916	5.8148611	15.991969	-9.942325	9.4692025	4.952014	-5.799545	47.795953



Appendix D.14: Outputs of Taguchi's Experiments: 209 to 224

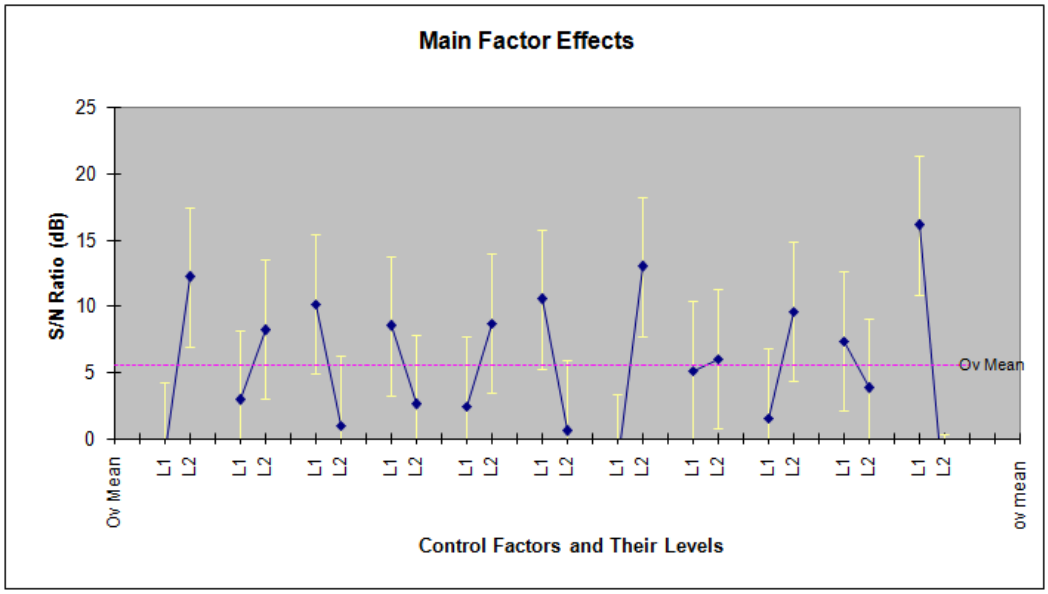
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-6.50783	-2.84539	-12.4119	3.29971	-2.67386	3.78473	-9.68878	-5.49988	-17.9118	7.50975	1.37971	-256.23
2	-4.11099	-1.63911	-8.37586	2.62923	-1.45413	3.83568	-8.10056	0.168131	-8.20773	5.50915	0.940708	-257.343
3	-6.49219	-4.96125	-14.2471	4.2813	-3.67565	2.65875	-10.4137	-8.50718	-22.7543	9.34499	2.17757	-251.581
4	-7.79256	-5.26013	-15.8068	1.25207	-4.52838	2.26545	-10.2797	-10.6915	-26.4983	9.78692	-0.954873	-256.341
5	-5.51795	-1.45328	-11.9261	4.40362	-3.30478	1.70569	-8.11388	-5.8103	-17.7364	4.02494	1.33096	-272.159
6	-5.26266	-1.60784	-6.93725	1.85129	-4.06835	4.9843	-6.65889	0.0722845	-6.86496	2.96034	0.691717	-277.315
7	-3.61028	-1.8954	-6.81933	4.72453	-1.25863	3.3659	-6.57495	1.56122	-5.25811	3.16512	0.962455	-266.683
8	-8.27231	-3.3604	-13.1418	4.799	-4.08306	4.4466	-9.31612	-8.17699	-21.3188	6.23959	-2.04304	-257.012
9	-4.22079	-2.55346	-6.65435	4.83185	-0.700641	3.98509	-6.41864	0.479542	-6.17481	5.28893	1.43865	-262.155
10	-5.5881	-0.82635	-9.79512	2.64552	-3.22541	2.88043	-7.08744	-3.92466	-13.7198	5.17416	1.12341	-251.773
11	-7.40537	-3.74369	-14.6734	4.28512	-3.92389	2.61856	-9.8866	-7.66208	-22.3355	5.15351	-4.94739	-250.932
12	-6.73559	-1.74797	-13.4876	3.06303	-2.85853	2.47932	-9.23133	-4.32912	-17.8167	6.57579	-0.002394	-266.409
13	-7.77426	-5.14616	-13.8299	1.24412	-4.41426	3.28644	-9.34207	-8.6699	-22.4998	9.9087	-1.53855	-271.196
14	-6.38217	-3.27993	-14.8731	2.78736	-4.59146	1.42926	-9.92021	-9.2569	-24.13	5.95727	-0.279542	-279.877
15	-5.90663	-1.73688	-10.2261	4.45213	-3.79905	4.00168	-8.32118	-2.41688	-12.643	4.08778	-2.15197	-294.519
16	-5.90984	-2.47458	-12.1252	1.87671	-4.35674	3.26696	-9.48232	-7.78287	-19.9081	6.64492	1.45978	-293.993
MEAN of sum of reciprocal squares	0.032799	0.291353 8	0.009959 6	0.184130 8	0.270340 6	0.138755 7	0.014671 4	15.463428	0.008749 7	0.039399 7	11636.358	1.406E-05
S/N Ratio	14.842588	5.3557935	20.017564	7.3487366	5.680888	8.5774931	18.335 28	-11.893 06	20.580051	14.045 07	-40.658 17	48.519532



Appendix D.15: Outputs of Taguchi's Experiments: 225 to 240

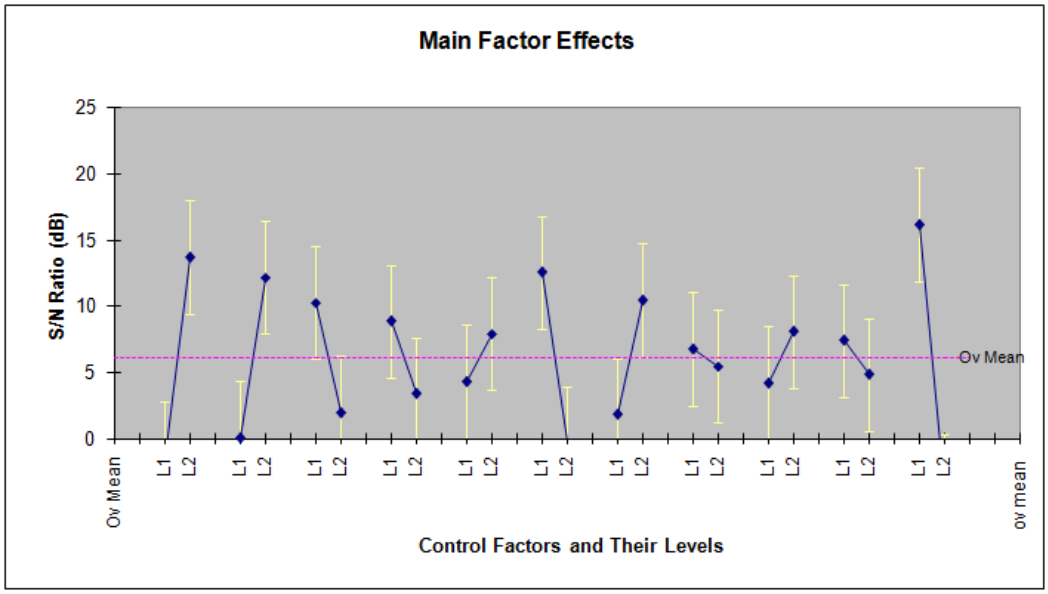
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-6.43106	-2.84066	-13.3924	4.24122	-4.33436	2.146	-9.10736	-8.48748	-21.8799	7.29797	-0.279649	-299.68
2	-5.51959	-0.651429	-13.5447	3.31034	-1.08842	2.47014	-10.4953	-6.41411	-19.9589	2.1252	-2.33807	-307.062
3	-8.62558	-5.7184	-17.0636	4.0279	-4.28122	1.90734	-10.3453	-9.3349	-26.3985	9.92197	-2.96977	-324.472
4	-5.98944	-3.24097	-11.5838	1.24091	-3.5045	4.3291	-9.92351	-5.92914	-17.513	5.71496	0.28412	-337.737
5	-3.90036	-1.70916	-5.57732	4.33308	-1.42856	4.67761	-6.35457	0.283347	-5.29398	5.81208	3.27329	-341.915
6	-5.58682	-3.36696	-11.5721	1.45493	-1.00144	1.6872	-7.67248	-2.3152	-13.8873	6.09231	1.29979	-325.631
7	-5.29349	-1.47244	-9.57139	3.53508	-3.89917	3.64566	-7.92355	-1.3651	-10.9365	5.75615	0.987871	-329.361
8	-4.42163	-1.36961	-10.0008	3.73905	-3.67232	3.61143	-9.19064	-5.40093	-15.4018	3.49914	1.08629	-323.339
9	-6.07924	-4.24672	-9.75992	2.56305	-1.10862	4.25901	-7.93969	-4.10983	-13.8697	7.74259	-0.365388	-327.334

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-6.80737	-4.34641	-11.4777	4.26967	-4.81121	3.36282	-8.03311	-5.12675	-16.6044	8.37885	-0.840365	-326.503
11	-3.40534	1.19288	-8.74244	2.82676	-2.63685	2.79523	-8.13232	-3.1301	-11.8725	1.76831	1.22838	-325.156
12	-6.18323	-2.4921	-11.7719	1.9244	-2.96918	3.90245	-9.49107	-5.39694	-17.1688	4.58634	0.0419536	-328.597
13	-3.87482	-0.158451	-8.18244	1.72694	-0.450039	3.60361	-7.91123	-1.12798	-9.31043	4.39438	2.88186	-335.18
14	-0.548877	3.61915	0.0269504	1.36322	-0.177634	3.20689	-2.63106	6.12616	6.15311	0.975333	6.94325	-331.771
15	-3.15811	0.889189	-4.56717	4.08283	-1.88614	4.75867	-6.16774	1.33138	-3.2358	0.427532	2.86783	-308.791
16	-7.79052	-5.11584	-14.9787	1.24456	-2.99224	3.64375	-10.8319	-6.85855	-21.8372	8.98806	1.02559	-296.216
MEAN of sum of reciprocal squares	0.2573595	3.0339846	91.798067	0.2394154	2.7101823	0.1174081	0.0231905	0.9880478	0.0140339	0.4742776	40.41976	9.641 E-06
S/N Ratio	5.8945987	-4.820134	-19.62834	6.2084789	-4.329985	9.3030189	16.346897	0.0522202	18.528228	3.2396742	-16.06594	50.158658



Appendix D.16: Outputs of Taguchi's Experiments: 241 to 256

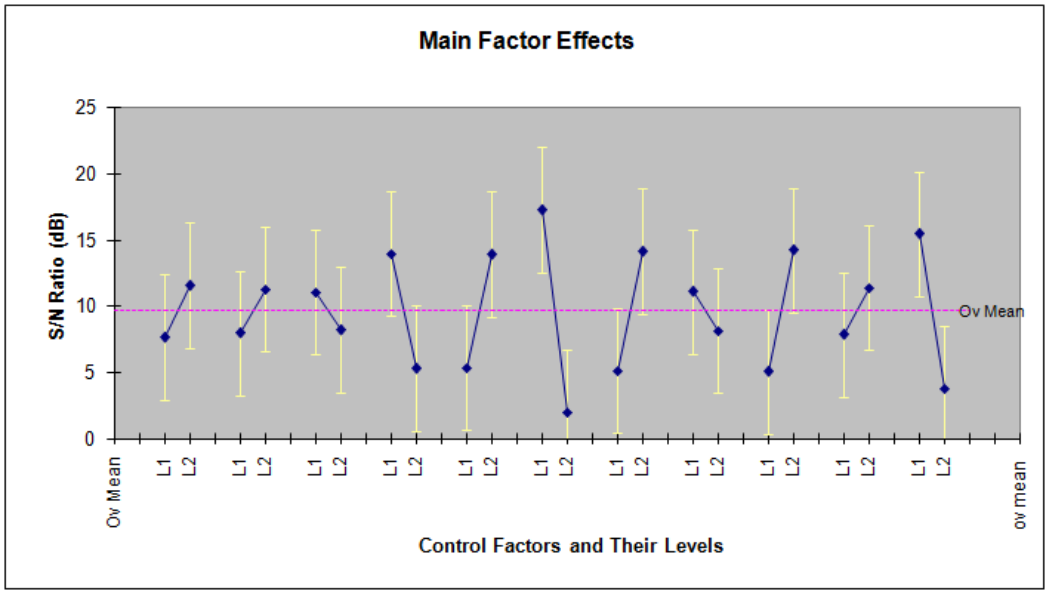
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-7.2531	-2.72617	-15.1783	1.66647	-3.83921	3.53866	-11.4638	-8.0283	-23.2066	5.11348	-1.37912	-302.576
2	-5.33589	-0.665852	-12.2212	2.87979	-4.44837	2.60212	-9.48745	-6.21209	-18.4333	3.05509	-1.75933	-318.426
3	-7.3652	-4.06917	-13.8463	2.64176	-4.45949	4.15664	-10.6378	-11.3332	-25.1795	6.30903	-0.867948	-327.841
4	-4.6132	0.151497	-8.28344	3.13456	-3.22511	2.9235	-6.59374	-3.40198	-11.6854	4.31794	1.02544	-341.448
5	-4.16148	-1.86448	-9.74762	3.25656	-1.18128	2.65145	-8.23759	-2.62235	-12.37	3.54701	1.75664	-339.309
6	-8.0602	-5.24665	-16.3739	1.22738	-3.85491	2.92446	-11.2382	-11.2692	-27.6431	7.25513	-2.33926	-340.853
7	-5.2658	-0.315835	-11.8857	3.12674	-1.53849	1.00493	-7.62488	-6.51292	-18.3987	2.26745	0.170581	-359.932
8	-2.50953	1.41333	-4.6911	1.37793	-1.72149	4.5998	-6.78137	2.83029	-1.86082	2.25091	5.17642	-372.614
9	-4.65133	0.0562854	-6.77412	2.22322	-3.69903	3.97654	-6.09933	-0.97697	-7.75109	3.81843	1.14189	-358.235
10	-7.31451	-4.74552	-13.7605	4.37784	-4.1154	3.87297	-10.319	-6.28051	-20.041	5.90427	-2.26231	-349.31
11	-1.13601	0.108634	0.0274153	3.58084	-0.336603	4.38401	-3.22059	9.17424	9.20166	3.82185	4.20254	-356.399
12	-6.89925	-2.30397	-13.9868	4.48594	-2.64823	3.61688	-10.7044	-8.56901	-22.5558	4.83616	-2.02168	-325.192
13	-3.94356	-1.84197	-8.80032	3.13888	-2.08455	1.88594	-6.74269	-0.161684	-8.962	6.28552	1.53722	-337.649
14	-2.83437	1.39795	-4.56003	3.27583	-0.811886	2.19539	-3.92105	1.15818	-3.40185	3.03238	4.65283	-332.206
15	-2.04923	1.5992	-3.81796	1.82386	-0.82014	2.54885	-4.31758	2.24683	-1.57114	2.86111	4.23831	-319.292
16	-4.73846	-0.948697	-8.46049	3.75112	-1.68827	2.77416	-6.49619	-2.27871	-10.7392	4.50652	2.06997	-305.405
MEAN of sum of reciprocal squares	0.062994 1	25.004245	0.018224 1	0.198890 4	0.377875 4	0.178527 9	0.021435 5	2.727546 9	0.056469	0.077332 5	2.666905 4	8.979 E-06
S/N Ratio	12.007004	-13.98014	17.393 55	7.0138 608	4.2265 143	7.4829 388	16.688 657	-4.357722	12.481 902	11.116 381	-4.260076	50.467 624



Appendix D.17: Outputs of Taguchi's Experiments: 257 to 272

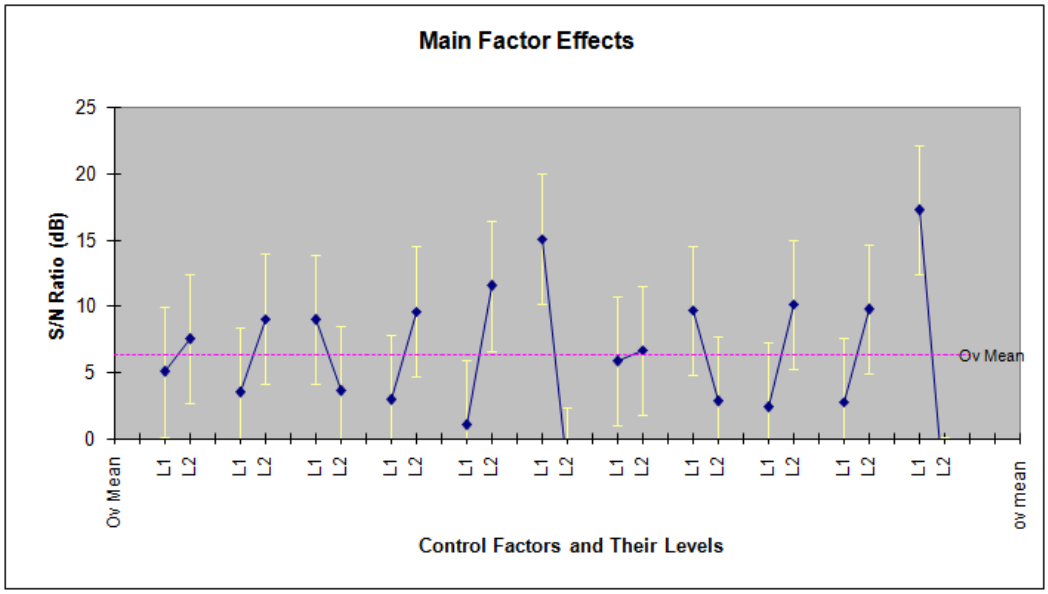
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-7.77209	-3.94602	-13.1262	2.53223	-3.48553	3.86141	-9.21556	-8.1545	-21.2807	5.90292	-1.13757	-300.832
2	-6.28319	-1.48178	-10.7364	2.22248	-2.13356	3.57559	-8.02878	-3.89111	-14.1255	4.16725	-0.055463	-309.979
3	-7.12169	-4.24115	-13.7404	2.39758	-3.99744	2.04732	-8.66604	-8.52609	-22.2665	8.22362	1.24246	-312.469
4	-2.99795	-1.15236	-4.66043	3.61365	-1.38179	4.96229	-6.62478	1.04643	-3.61401	5.64339	3.19577	-320.234
5	-2.2509	2.1216	-3.38969	2.83007	-1.44781	1.17361	-2.3124	2.85855	-0.531135	2.20676	4.19721	-302.375
6	-5.72282	-2.07179	-8.80417	3.38119	-2.04874	4.46916	-7.55051	-4.26618	-13.0703	6.24807	3.3908	-290.08
7	-5.64646	-2.96802	-11.5944	2.17171	-1.7316	1.06842	-7.01638	-4.86161	-16.456	7.1736	0.600853	-283.235
8	-6.41741	-4.41079	-12.6481	4.69969	-4.40766	1.76001	-7.99065	-4.44876	-17.0968	8.71902	0.832029	-290.086
9	-4.10024	-1.3326	-8.79637	2.7097	-3.05485	3.58657	-8.2827	-1.39665	-10.193	5.73338	2.39964	-289.326

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-1.59698	1.53617	-0.82574	3.72535	-1.14705	2.6771	-1.90586	7.48224	6.6565	3.4553	7.71723	-283.625
11	-5.92839	-1.40855	-13.089	3.32608	-4.66665	3.11955	-10.2802	-6.86563	-19.9547	5.23075	-0.758673	-253.132
12	-6.37139	-3.26304	-11.3493	4.73973	-4.58214	1.85689	-6.83483	-3.46795	-14.8173	6.44871	-0.718233	-260.853
13	-4.92678	-0.76063	-11.953	2.49164	-1.90888	1.46229	-8.48854	-5.84298	-17.796	5.27048	0.693627	-259.42
14	-5.33041	-2.99819	-8.09524	3.33085	-1.81646	4.05303	-6.81785	0.430832	-7.66441	7.00945	1.35149	-267.765
15	-3.99392	0.757877	-7.94064	3.74528	-2.1668	2.35592	-6.30264	-2.32964	-10.2703	1.12697	1.725116	-255.77
16	-5.43181	-2.07452	-9.2614	2.26898	-1.71654	3.75504	-7.58462	-4.87962	-14.141	6.77987	1.961007	-257.28
MEAN of sum of reciprocal squares	0.0737076	0.4561481	0.114434	0.1232053	0.2688875	0.2457555	0.0462105	0.5037278	0.2476644	0.0933145	22.420424	1.246E-05
S/N Ratio	11.324879	3.4089409	9.414449	9.0937061	5.7042933	6.0949671	13.352592	2.978041	6.0613646	10.300511	-13.50644	49.044954



Appendix D.18: Outputs of Taguchi's Experiments: 273 to 288

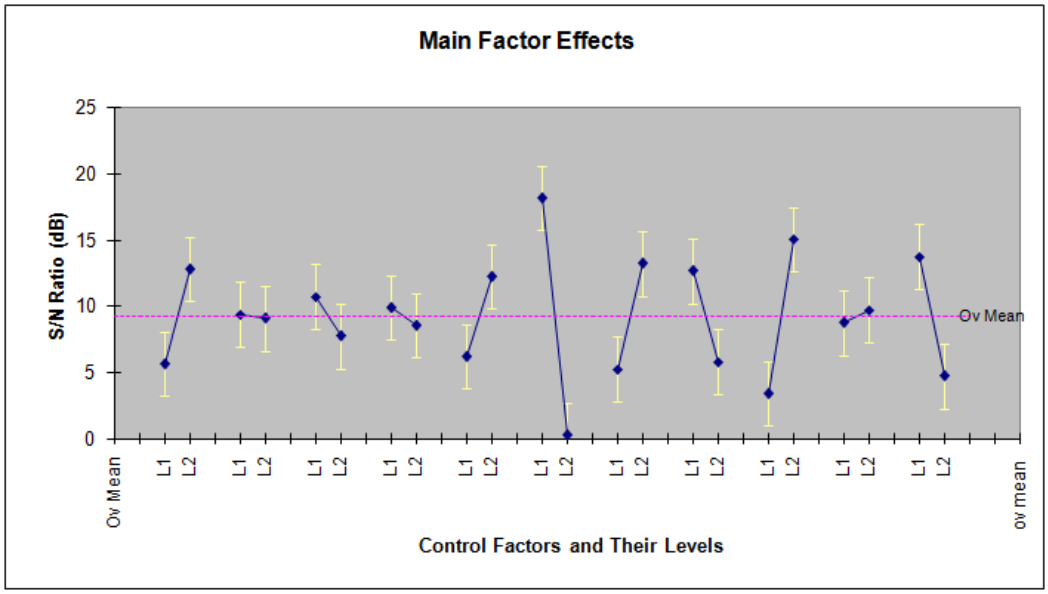
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-2.89092	1.42292	-3.06187	2.03823	-1.12866	3.42934	-3.6003	5.15514	2.09327	-0.117543	1.49556	-255.459
2	-2.21944	0.384168	-4.56883	1.84276	-1.54363	4.70858	-7.05797	0.970673	-3.59816	1.44139	1.80543	-241.645
3	-4.30418	-1.01054	-4.98455	2.99801	-3.62837	4.49609	-5.17646	-0.214212	-5.19876	3.14167	1.00172	-232.257
4	-2.24149	0.279689	-4.53492	3.62928	-0.749319	4.32278	-6.61622	1.41401	-3.1209	3.89397	5.46377	-220.778
5	-6.15938	-4.03249	-10.1914	2.29161	-3.41179	4.15862	-8.19065	-4.41044	-14.6018	8.16865	2.7587	-206.37
6	-3.05605	1.25188	-9.12986	4.68278	-2.37104	1.91894	-7.99275	-1.10357	-10.2334	3.2688	6.32666	-200.052
7	-6.05087	-1.64672	-8.99553	2.53069	-1.33686	4.25063	-7.1953	-2.56882	-11.5644	3.69135	0.91134	-193.336
8	-4.0886	-0.667107	-7.34168	4.19975	-2.18337	4.64345	-7.89654	-0.027284	-7.36897	3.34123	0.14846	-190.371
9	-3.61009	-0.576884	-7.18631	2.22328	-2.23416	1.92125	-5.49747	0.635327	-6.55099	2.76507	1.93801	-183.236
10	-6.37313	-3.89404	-11.204	1.09308	-3.33654	3.30361	-8.13449	-5.28389	-16.4879	8.69417	0.988367	-178.615
11	-6.37441	-2.99032	-11.8795	4.52299	-4.79064	3.02949	-8.53454	-6.2796	-18.1591	6.76259	-0.403328	-177.833
12	-4.76983	0.0282917	-6.80715	3.51866	-1.81114	4.46657	-6.50389	-0.662401	-7.46955	4.62614	1.73716	-180.1
13	-6.1682	-1.54579	-12.0055	2.22291	-4.78833	3.95582	-9.79308	-5.34044	-17.3459	4.32647	-1.06435	-169.51
14	-7.69737	-5.59087	-16.5999	1.18464	-3.95776	2.40844	-11.311	-12.2661	-28.866	10.2433	-0.986056	-174.957
15	-6.34646	-3.03253	-14.1168	4.63116	-3.9676	2.63167	-10.402	-7.18392	-21.3007	5.36016	-2.80889	-193.028
16	-6.80871	-3.31328	-12.3919	1.69727	-3.02788	2.3034	-7.88664	-6.53695	-18.9289	7.9135	0.396251	-205.572
MEAN of sum of reciprocal squares	0.0687402	85.160836	0.024466	0.2399975	0.3313218	0.109738	0.0225801	91.510402	0.0359787	4.9068391	3.9029157	2.562 E-05
S/N Ratio	11.627893	-19.3024	16.114379	6.1979335	4.7975005	9.5964305	16.462741	-19.6147	14.439546	-6.908018	-5.913892	45.914797



Appendix D.19: Outputs of Taguchi's Experiments: 289 to 304

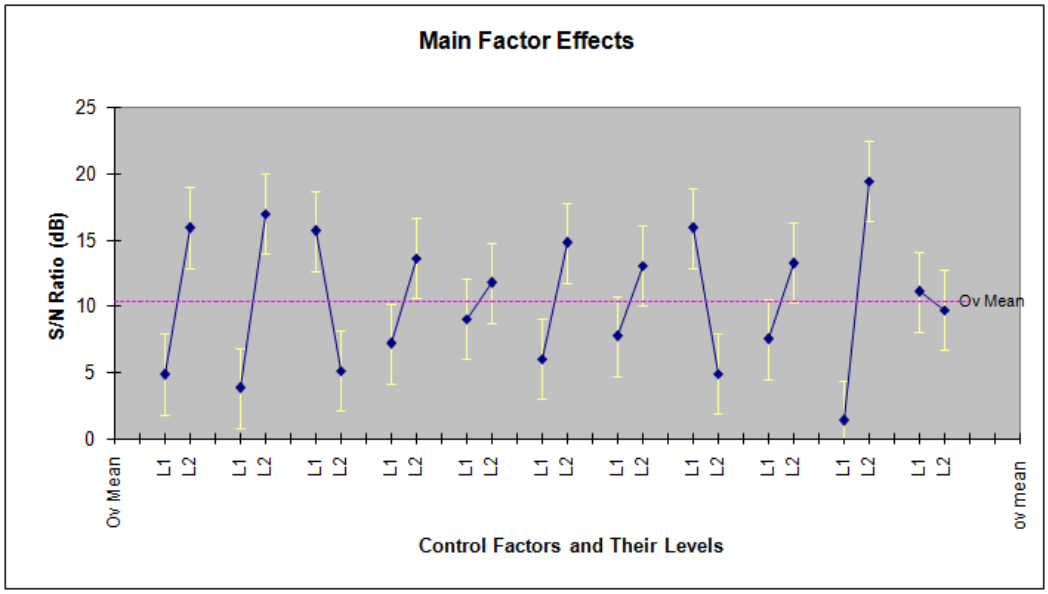
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-7.41701	-4.95746	-14.1418	2.52397	-3.30071	3.87322	-10.598	-5.91061	-20.0524	6.12242	-2.64961	-212.191
2	-2.91788	-0.295896	-5.21284	4.18368	-1.32388	2.83387	-5.12883	2.31525	-2.89759	2.80409	3.33373	-222.268
3	-3.93094	0.927539	-5.96155	3.24143	-1.6462	3.72445	-5.75506	2.39055	-3.571	2.05035	3.6161	-209.542
4	-6.88799	-3.33901	-11.3697	3.24793	-3.71507	4.07077	-8.55248	-4.20804	-15.5777	7.35159	-1.79364	-196.602
5	-6.90667	-4.32882	-11.5007	1.58649	-2.66131	2.99527	-7.58929	-5.3844	-16.8851	6.57111	0.158805	-195.915
6	-3.6668	0.575345	-8.79719	2.11608	-1.34029	2.84243	-7.97282	-3.47853	-12.2757	2.99132	2.75493	-199.343
7	-4.00128	0.607996	-4.63906	4.14293	-2.54136	4.28452	-4.92231	3.65617	-0.982896	3.8167	1.801	-200.755
8	-6.68663	-2.51171	-13.4595	2.12202	-3.61417	3.40419	-10.177	-8.03859	-21.498	4.76824	-0.583446	-182.109
9	-4.67454	-2.1531	-6.49162	4.93787	-0.680049	4.13228	-5.94936	2.39771	-4.0939	6.94242	1.19942	-193.858

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-1.9153	0.904879	-4.32736	2.13157	-0.08556	4.46853	-6.88058	1.33722	-2.99013	2.17493	6.14071	-176.904
11	-2.54088	0.70288	-5.80992	2.48356	-1.23455	3.05377	-6.3228	0.529192	-5.28072	3.30206	4.38768	-163.784
12	-3.37876	-1.98609	-4.70608	1.5553	-1.70677	2.67276	-4.00008	-0.56406	-5.27014	3.72263	-0.61043	-153.371
13	-3.80873	-2.29057	-10.1535	3.93101	-3.74554	1.64947	-7.99427	-1.8886	-12.0421	6.82344	2.26564	-147.95
14	-3.98252	-1.67228	-10.9309	2.07877	-2.99881	1.44745	-8.39581	-3.91154	-14.8424	3.08291	0.296589	-143.713
15	-7.69879	-5.57254	-12.2373	4.58447	-3.18	4.96953	-9.50802	-5.92378	-18.1611	9.40046	0.126308	-152.416
16	-7.69294	-4.08691	-14.0212	4.51685	-4.79195	1.92172	-8.24999	-7.67867	-21.6999	6.12083	-0.732493	-149.982
MEAN of sum of reciprocal squares	0.064886 8	1.398865 8	0.020150 6	0.158151 4	9.431919 8	0.140291	0.022817 7	0.328092 2	0.098376 7	0.075119 4	8.210893 3	3.2E-05
S/N Ratio	11.87843 7	-1.45776	16.95711 4	8.009268 3	-9.746001	8.529702 6	16.41728 2	4.840041 2	10.07107 6	11.24248	-9.143904	44.94884 2



Appendix D.20: Outputs of Taguchi's Experiments: 305 to 320

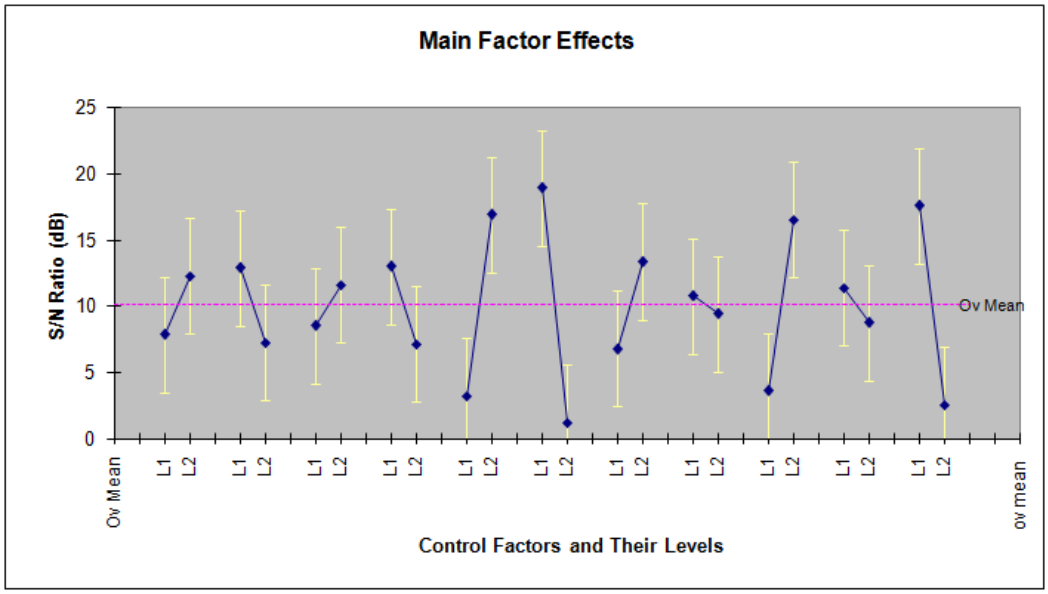
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	1.13793	-2.3164	2.79179	-0.4503	4.30634	-3.376	2.64316	0.326675	3.56974	4.05973	-157.995	-157.995
2	1.57012	-7.3838	1.72324	-1.0494	1.75899	-6.9598	-1.8378	-9.2216	2.3748	3.95854	-138.459	-138.459
3	-2.1705	-9.1370	4.78932	-1.7371	2.91377	-6.6805	-2.7179	-11.855	4.25295	-0.48976	-139.053	-139.053
4	-2.3079	-9.9543	4.0866	-2.3504	3.80223	-7.6779	-4.4598	-14.414	5.73383	-0.68594	-136.72	-136.72
5	0.566221	-10.300	2.90526	-3.6343	2.43609	-8.5125	-3.3118	-13.612	1.84114	2.01803	-137.082	-137.082
6	0.0868001	-5.6491	4.26758	-3.2430	3.49103	-5.3227	2.93158	-2.7175	4.58776	4.01524	-140.667	-140.667
7	-3.1294	-12.662	1.68759	-2.3184	1.48026	-9.2844	-6.9754	-19.637	4.64794	-0.736913	-121.937	-121.937
8	-1.3871	-7.8962	3.94599	-2.0038	3.37155	-7.2217	-3.2902	-11.186	5.45289	2.62697	-136.513	-136.513
9	-6.1510	-10.948	4.40698	-4.3035	4.93046	-8.6279	-6.9483	-17.896	9.57273	-0.289683	-131.487	-131.487
10	-1.0782	-13.291	3.53558	-4.7503	1.06567	-8.3950	-4.2235	-17.514	4.59932	-0.191811	-127.404	-127.404
11	0.177235	-1.2018	3.37349	-0.7219	3.46998	-2.5739	5.73969	4.53779	3.69036	3.15521	-133.94	-133.94
12	-2.9084	-16.442	4.18331	-3.3158	2.49957	-11.251	-8.6784	-25.121	6.19827	-1.660569	-110.063	-110.063
13	0.917811	-7.0219	1.11264	-2.5625	3.65416	-7.3500	0.973189	-6.0487	2.9798	2.02622	-126.475	-126.475
14	0.0689917	-7.9867	3.26169	-1.4916	3.01056	-6.0748	-0.749235	-8.7360	3.5575	0.225213	-119.666	-119.666
15	-5.5301	-12.557	1.50708	-4.4766	3.78305	-8.7919	-4.0155	-16.572	8.02846	-0.977734	116.399	-116.399
16	0.94939	-6.4933	2.05031	-0.7960	2.51817	-5.7372	1.54486	-4.9484	1.38559	0.437007	-116.374	-116.374
MEAN of sum of reciprocal squares	23.431365	0.0249015	0.1950551	0.6250674	0.1902351	0.0234717	0.2902423	0.6425716	0.1050777	4.9612115	6.027E-05	6.027E-05
S/N Ratio	-13.69798	16.037746	7.098427	2.040731	7.207093	16.294545	5.372393	1.920784	9.784893	-6.955877	42.198742	42.198742



Appendix D.21: Outputs of Taguchi's Experiments: 321 to 336

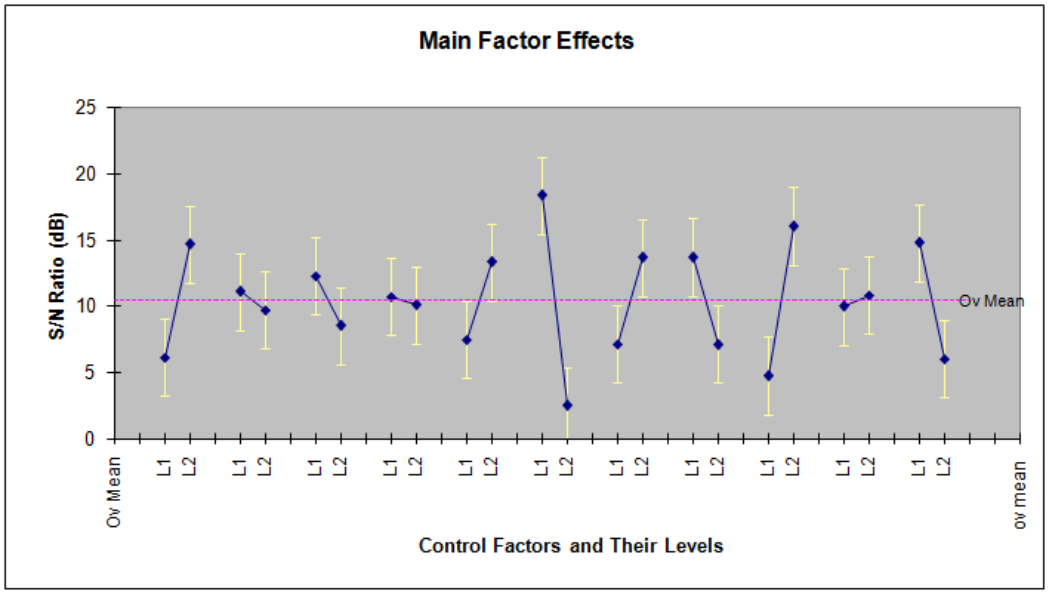
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-6.71159	-2.99128	-16.2935	4.10302	-3.87777	2.01325	-11.5952	-10.846	-27.1395	7.46469	1.69711	-112.662
2	-5.27802	-0.697703	-10.3878	3.70538	-1.32364	1.2794	-6.3892	-6.17606	-16.5639	3.31518	1.45858	-126.75
3	-4.90461	-1.20543	-10.8261	4.67619	-3.27093	1.59348	-7.51499	-3.12923	-13.9553	3.39628	0.0093026	-134.405
4	-7.81675	-3.35699	-13.1836	4.73544	-3.51009	3.07478	-8.4416	-5.87061	-19.0542	6.71461	-2.93823	-137.678
5	-7.61472	-5.16901	-14.9097	2.81838	-4.96073	2.41275	-9.70772	-9.66224	-24.5719	9.93079	-1.52773	-144.389
6	-3.42206	0.182056	-7.39105	1.93333	-1.08425	1.83955	-5.80854	-1.09793	-8.48898	1.60499	1.61262	-154.606
7	-3.20327	-1.35304	-5.28074	3.8348	-0.957517	4.27126	-6.34873	1.97373	-3.30701	5.63214	5.29106	-154.878
8	-7.32319	-4.3876	-10.5153	1.30937	-2.63031	4.61508	-7.80719	-4.56828	-15.0836	8.66724	-1.62362	-135.725
9	-6.87823	-3.15967	-12.3771	3.08196	-2.8261	1.62407	-7.12297	-5.28985	-17.667	5.83775	-1.40921	-134.79

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-6.98893	-5.40225	-12.8384	1.71389	-3.97994	4.10969	-9.95912	-6.83789	-19.6762	7.47332	-1.79859	-142.444
11	-6.73315	-4.03146	-13.1216	2.10992	-2.10033	4.661	-11.0495	-4.71459	-17.8362	5.80376	-0.652153	-149.26
12	-3.16157	1.16886	-9.34188	1.10157	-0.515801	1.72421	-7.90452	-3.48492	-12.8268	2.67808	2.34481	-154.906
13	-9.03964	-7.58585	-16.4174	4.74152	-4.04444	4.49734	-11.8751	-8.1708	-24.5882	11.3624	-1.04063	-161.495
14	-4.44736	-2.03654	-9.91893	1.0895	-2.14704	2.89795	-8.36952	-3.6512	-13.5701	6.82248	3.92019	-166.56
15	-5.0841	-3.47598	-11.1227	4.23541	-3.14775	3.81969	-9.85832	-3.64416	-14.7669	7.90429	2.35824	-166.146
16	-4.04746	-2.71051	-7.92988	2.77104	-2.81633	3.25007	-7.13249	-1.52732	-9.4572	6.00152	0.265637	-161.979
MEAN of sum of reciprocal squares	0.0425973	2.3395557	0.0104627	0.2406659	0.4926998	0.2021827	0.0161501	0.1362796	0.0105983	0.0613775	771.60095	4.864E-05
S/N Ratio	13.706184	-3.691334	19.803544	6.1858553	3.0741758	6.942559	17.918253	8.6556929	19.747639	12.11991	-28.87393	43.12979



Appendix D.22: Outputs of Taguchi's Experiments: 337 to 352

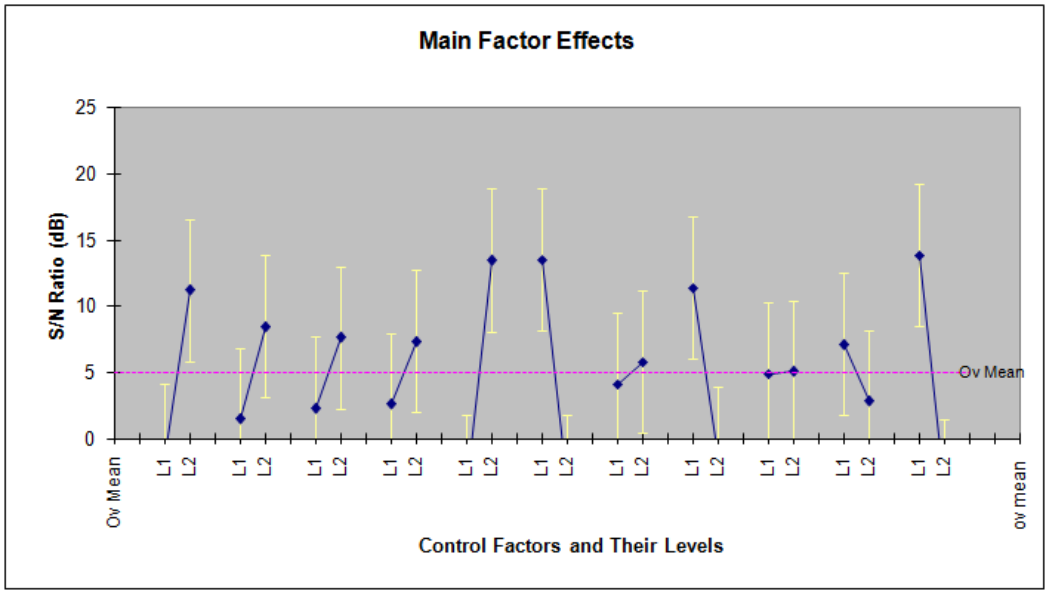
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-4.04746	-2.71051	-7.92988	2.77104	-2.81633	3.25007	-7.13249	-1.52732	-9.4572	6.00152	0.265637	-161.979
2	-4.29203	-0.734361	-7.03205	1.28211	-2.53638	4.43112	-7.17114	1.10156	-5.9305	4.16375	2.28362	-157.854
3	-6.33576	-3.5437	-13.1098	3.5924	-3.40555	2.37332	-9.14732	-5.58536	-18.6951	8.26954	3.12697	-147.729
4	-8.0833	-5.27798	-16.0785	1.86739	-4.12704	3.30846	-11.3037	-9.36504	-25.4435	7.86246	-1.82354	-149.723
5	-3.41833	-1.05564	-7.59443	1.73181	-0.119302	2.4927	-6.66879	-0.734401	-8.32883	6.00397	5.00714	-163.604
6	-4.58958	-0.503647	-9.06856	3.4674	-2.11158	4.24894	-8.72792	-2.81589	-11.8844	3.82565	3.47196	-157.186
7	-3.20905	1.65895	-7.29866	4.07509	-1.19315	1.70653	-5.79614	0.823665	-6.47499	2.45412	4.74498	-151.478
8	-5.64173	-1.51778	-12.0708	2.38728	-2.6715	1.95247	-8.38153	-6.76292	-18.8337	3.74387	-1.51851	-144.173
9	-7.73203	-3.51337	-13.1523	3.78766	-3.92683	2.42153	-7.84183	-5.55462	-18.707	7.28843	0.253499	-156.87
10	-3.91651	0.358497	-9.60378	2.39572	-0.680717	1.88355	-7.57082	-5.06272	-14.6665	4.50162	3.69029	-159.709
11	-5.40511	-3.6282	-11.4609	3.4404	-2.9723	3.38329	-9.43907	-5.39695	-16.8578	6.58167	-1.14169	-163.42
12	-5.03204	-2.39438	-7.41346	2.09039	-2.45285	4.47514	-6.85655	-3.11059	-10.524	4.74636	-0.413524	-166.555
13	-5.5586	-1.21044	-9.85094	2.8795	-3.53253	3.85952	-8.15186	-3.5345	-13.3854	4.24034	0.858535	-162.944
14	-6.34464	-5.09524	-12.34	1.93519	-3.90783	2.10062	-8.096	-7.28223	-19.6222	8.15417	0.316247	-160.374
15	-1.88863	2.89029	-2.70984	2.165	-0.158338	4.0972	-4.91841	4.3233	1.61345	-1.56381	2.8736	-167.242
16	-6.75487	-4.88096	-10.446	4.13032	-4.73349	4.10407	-7.79518	-3.37228	-13.8183	7.50259	-1.76867	-155.104
MEAN of sum of reciprocal squares	0.059867 3	1.110805 3	0.019865 3	0.192499 5	7.614596	0.143437 1	0.018771 6	0.345830 1	0.033751 8	0.070639 4	3.243089 7	4.053 E-05
S/N Ratio	12.22810 2	-0.456379	17.01904 6	7.155703 4	-8.816469	8.433383 9	17.26499 2	4.611371 6	14.71703 3	11.50953 2	-5.109559	43.92219 2



Appendix D.23: Outputs of Taguchi's Experiments: 353 to 368

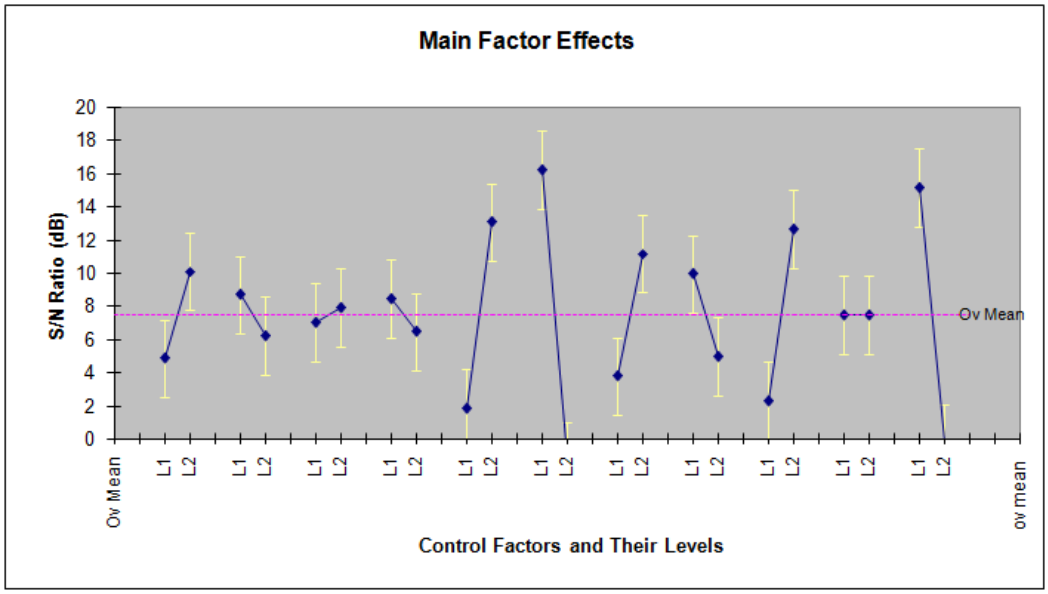
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-2.60531	2.18203	-4.08913	2.66821	-1.26761	2.91131	-4.39513	2.75822	-1.33091	1.01826	2.70023	-139.602
2	-0.61933	4.33766	1.15791	1.42387	-0.437091	3.55904	-1.7818	5.1719	6.3298	-0.772661	7.92726	-127.707
3	-3.2776	1.11946	-4.79383	3.93063	-1.13388	2.18644	-3.70268	1.68324	-3.1106	0.332018	0.157348	-105.178
4	-5.28437	-1.08059	-7.96386	4.01832	-3.42784	2.6779	-5.35739	-4.01895	-11.9828	3.32549	1.22168	-100.028
5	-3.43245	0.0017104	-4.83169	2.89885	-0.705061	3.96851	-5.36774	3.27625	-1.55544	2.17657	0.251331	-97.3507
6	-3.78055	-0.672797	-7.52889	4.71731	-1.81554	1.49421	-5.24255	1.04538	-6.48351	5.50212	3.38627	-85.7723
7	-7.5149	-4.63485	-16.9904	2.94799	-2.88639	2.55495	-12.0305	-12.4371	-29.4275	7.61499	-3.25217	-74.8782
8	-6.45692	-1.734	-10.0086	1.61932	-4.27487	4.5687	-8.1204	-3.07375	-13.0824	5.30503	-0.29811	-98.2329
9	-6.83635	-3.18993	-12.6383	1.21627	-2.57191	3.2272	-9.02915	-4.88037	-17.5187	5.36968	-1.03688	-96.1666

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-7.5201	-4.23747	-17.9896	3.31366	-3.11312	1.67256	-12.142	-12.4956	-30.4851	7.51406	-0.292867	-104.002
11	-5.02386	-1.97209	-10.7859	1.90738	-3.23971	4.13443	-9.89644	-4.54324	-15.3291	4.08637	0.296717	-125.748
12	-6.41188	-4.4659	-10.32	1.25785	-1.5691	4.72189	-8.63001	-4.16543	-14.4854	8.63639	-0.31496	-129.633
13	-6.99328	-2.09183	-14.901	4.24952	-4.19051	3.88597	-11.7937	-9.82904	-24.73	3.10499	-3.72996	-127.21
14	-3.47145	-0.261676	-6.484	1.88968	-2.95953	4.48782	-7.50038	2.07959	-4.40441	4.23764	2.3257	-144.74
15	-7.08507	-3.29018	-15.5064	4.32523	-4.71621	2.0566	-10.4779	-8.64318	-24.1496	5.90373	-2.92609	-131.808
16	-4.98935	-1.3584	-7.73099	4.83003	-2.45506	4.61206	-7.35369	-2.20827	-9.93926	4.49207	-0.660646	-146.196
MEAN of sum of reciprocal squares	0.2204515	22789.454	0.0671186	0.2167706	0.683452	0.1437134	0.0435158	0.1513521	0.0812039	0.8267809	6.2542062	8.669E-05
S/N Ratio	6.566868 7	-43.57734	11.731574	6.639995 5	1.652919 9	8.425026 4	13.613534	8.200116 2	10.904229	0.826095 9	-7.961722	40.620261



Appendix D.24: Outputs of Taguchi's Experiments: 369 to 384

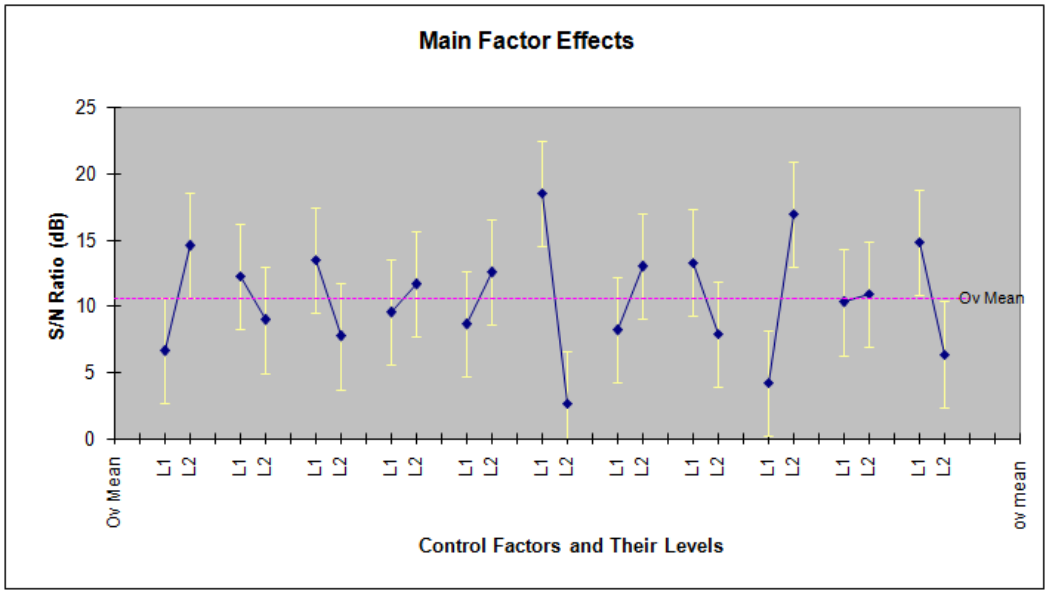
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-4.8648	-1.22275	-9.4625	1.50948	-0.291601	2.43709	-7.0348	-4.78489	-14.2474	6.17589	1.78349	-139.053
2	-6.13165	-3.82117	-11.253	4.46931	-2.94164	2.8376	-7.95895	-3.27014	-14.5231	7.45463	-0.022222	-143.986
3	-5.51069	-3.26399	-10.817	1.5899	-3.89928	3.62058	-8.92688	-6.3216	-17.1386	7.76757	3.40068	-142.612
4	-5.26387	-3.38818	-14.0313	4.47628	-4.18349	1.12973	-9.89712	-7.74919	-21.7804	6.87545	0.784554	-141.518
5	-3.74883	-1.0436	-7.86052	2.57703	-1.80885	3.71049	-7.82218	1.24229	-6.61823	5.9748	5.60719	-150.611
6	-3.84538	-1.5439	-7.65187	1.83635	-1.24934	3.38947	-7.19596	-0.859603	-8.51148	4.44823	3.31159	-137.495
7	-7.60602	-4.18588	-13.4031	3.8691	-2.80629	4.44597	-10.2431	-6.27202	-19.6752	5.35029	-2.76727	-132.859
8	-5.64941	-4.3552	-11.7415	1.05336	-3.66543	2.98702	-9.07907	-7.43176	-19.1732	8.6243	1.21921	-140.513
9	-4.47407	-0.44813	-9.94896	4.55967	-0.436151	3.34318	-8.81806	-2.14446	-12.0934	3.46462	3.50332	-145.988
10	-4.40475	-1.77423	-9.07699	2.47679	-3.27285	3.8898	-8.56204	-3.25335	-12.3303	4.50371	0.241796	-144.995
11	-2.64835	0.0924222	-7.17896	2.11375	-1.14316	1.25895	-5.78956	-0.570082	-7.74905	3.66845	5.25286	-144.79
12	-4.86549	-3.43284	-10.2155	1.11067	-4.30913	2.34558	-7.69558	-5.15992	-15.3754	6.2243	-0.787174	-140.147
13	-1.36808	2.64939	-2.1102	4.38492	-0.469847	3.77091	-4.51303	3.39145	1.28125	-0.452834	2.4101	-143.746
14	-4.25577	-0.578191	-7.29266	1.02084	-2.57591	4.80203	-7.83893	0.644254	-6.64841	5.40826	3.24021	-129.983
15	-8.03547	-4.05569	-13.7825	1.42094	-4.21064	4.75031	-10.4973	-7.32521	-21.1077	6.32351	-4.58716	-118.344
16	-5.25601	-2.90107	-11.2328	2.80421	-2.93978	3.17735	-9.1541	-4.7326	-15.9654	7.11044	1.55136	-129.216
MEAN of sum of reciprocal squares	0.074013 5	0.737418 6	0.024477 4	0.333695	1.560224	0.137939 7	0.016389 1	0.342178 7	0.047514 3	0.354861 5	136.50148	5.251 E-05
S/N Ratio	11.30689 2	1.322859 2	16.11235	4.766502 5	-1.93187	8.603107	17.85445 7	4.657470 2	13.23175 2	4.499410 6	-21.35137	42.79779 5



Appendix D.25: Outputs of Taguchi's Experiments: 385 to 400

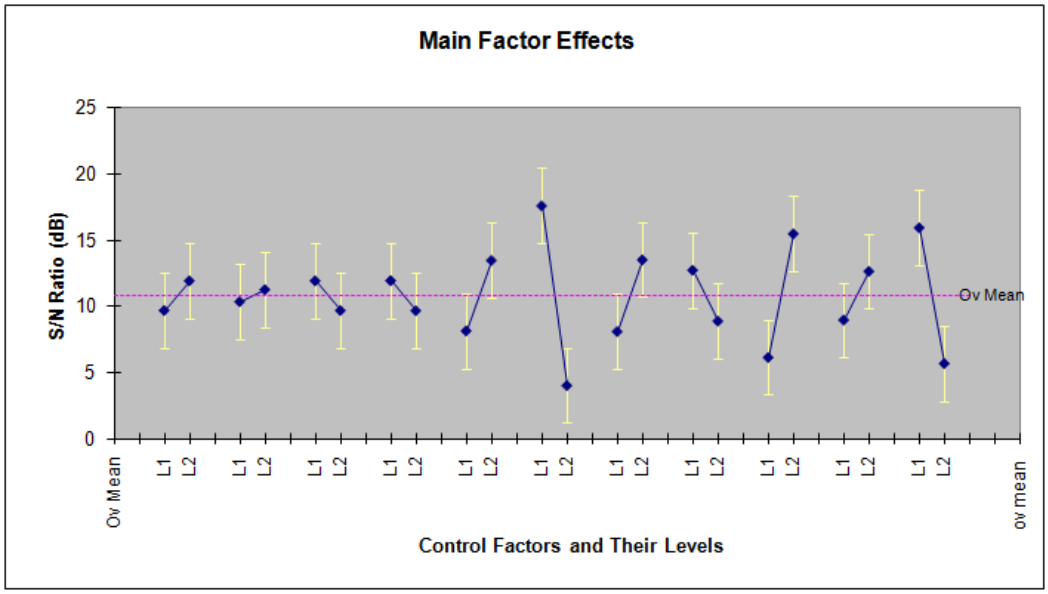
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-3.66093	0.808679	-7.32735	2.73054	-3.44529	3.90161	-7.56804	-1.85154	-9.17889	2.07253	2.95282	-130.575
2	-5.18265	-2.67516	-7.44736	4.93714	-3.39087	4.5035	-6.76821	0.79416	-6.6532	4.36386	-0.257906	-124.557
3	-5.92425	-2.03027	-7.78308	3.33153	-2.04491	4.84453	-6.70336	1.65082	-6.13226	6.87714	2.78885	-111.83
4	-4.58187	-0.910714	-8.98775	3.85412	-1.84651	4.81646	-9.22233	-0.415917	-9.40366	5.03353	2.46513	-95.0117
5	-8.24055	-4.11986	-16.3194	2.28113	-3.35272	3.52833	-11.6072	-9.18481	-25.5043	6.98214	-1.37564	-86.9181
6	-2.74011	1.29106	-4.98553	1.60676	-0.064558	4.59214	-6.83757	-0.430503	-5.41604	3.60809	3.3826	-101.991
7	-7.62444	-3.00012	-14.2951	2.42159	-4.33578	4.70043	-11.3711	-8.08584	-22.3809	6.1388	-0.339932	-93.5335
8	-5.61508	-1.85196	-11.475	1.4134	-4.50912	2.2676	-8.12755	-4.95644	-16.4315	4.73384	1.46233	-100.825
9	-8.09687	-3.52725	-13.0997	4.49671	-3.68798	3.57359	-8.57637	-7.20102	-20.3007	8.14254	-1.28367	-104.442

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-6.7329	-2.30019	-12.7346	3.32265	-2.71571	1.61826	-7.62001	-5.76926	-18.5039	6.24592	-0.457252	-107.592
11	-4.05152	0.779033	-5.94764	1.41502	-2.6923	3.96333	-5.85946	1.36256	-4.58508	1.9203	3.57173	-114.07
12	-8.31438	-7.09289	-16.4309	3.62127	-3.72213	3.23493	-11.3514	-10.9759	-27.4068	10.6676	-2.86943	-102.839
13	-6.98732	-2.73756	-12.6737	4.72388	-2.40816	4.98666	-10.6731	-4.50339	-17.1771	4.61642	-0.926641	-117.351
14	-3.58756	-0.650067	-9.88091	3.82789	-3.42667	1.10907	-7.40242	-2.85835	-12.7393	5.23355	3.01199	-121.146
15	-6.10932	-3.31817	-11.349	3.03452	-2.90871	3.24911	-8.48881	-4.10027	-15.4493	8.06891	1.94314	-119.57
16	-6.05846	-1.38999	-12.8663	2.00994	-2.07133	4.17116	-10.979	-6.14474	-19.011	2.39214	-3.25026	-116.804
MEAN of sum of reciprocal squares	0.039253 1	0.505077 6	0.011199 3	0.151245	16.115007	0.141954 8	0.014184 3	0.920256 2	0.009125	0.055831 4	2.154992 3	8.744 E-05
S/N Ratio	14.061256	2.966419 1	19.508101	8.203190 9	-12.0723	8.478497 8	18.481906	0.360912 4	20.397651	12.531217	-3.334457	40.582799



Appendix D.26: Outputs of Taguchi's Experiments: 401 to 416

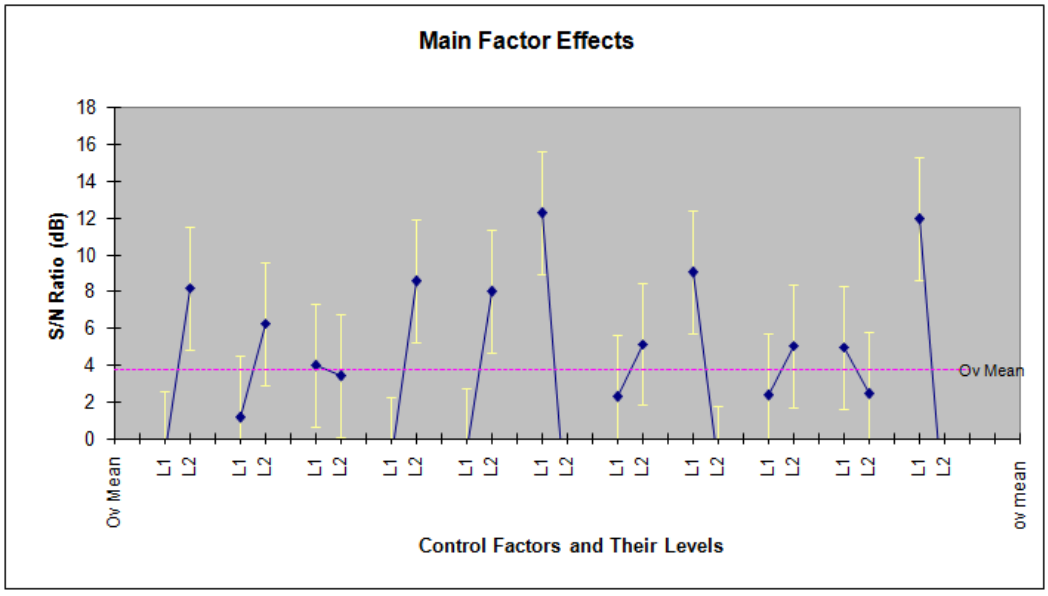
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-4.9048	-1.6262 8	-7.6137 4	4.0582 1	-1.6584 8	4.6893 4	-7.3982 7	-0.9164 7	-8.5302 1	5.0307 9	1.5633 5	-130.3 26
2	-6.5779 2	-3.1896 4	-11.437 9	3.5769 4	-3.5484 2	3.2719 7	-8.1319 3	-4.8305 6	-16.268 4	5.3969 8	-2.1367 4	-120.9 38
3	-6.5157 3	-2.8085 5	-11.362 5	4.0052 9	-3.5608 1	4.6631 7	-9.5099 6	-4.5616	-15.924 1	4.2803 5	-3.1787	-123.5 48
4	-3.5100 5	1.1020 4	-6.5506 4	2.2501 3	-2.9491 3	4.0388 1	-7.0794	2.2728 2	-4.2778 2	1.0695 8	0.9120 57	-128.3 12
5	-2.9770 8	-1.9599 6	-6.4312 1	4.4707 4	-0.5929 55	2.1465 4	-5.6006 7	-0.4712 83	-6.9025	6.2217 4	4.0863 3	-119.9 09
6	-6.4519	-2.0732 1	-13.300 6	2.3778 3	-2.5902 2	2.4865 9	-9.3353 4	-7.7950 6	-21.095 7	3.9579 4	-3.0975 4	-109.5 58
7	-4.9457	-2.9114 8	-9.7187	2.4227 7	-1.0913 7	2.7629 7	-7.5359 6	-2.2083 2	-11.927	6.2030 8	-0.1826 43	-125.4 41
8	-3.2525 3	1.5740 5	-4.2207 1	1.5730 3	-1.2573	4.4940 8	-5.4622 6	2.3896 1	-1.8311	2.1485 9	3.5422 3	-126.2 87
9	-4.2102 6	-1.8055	-4.5415	4.2560 6	-2.9691	4.2999 3	-4.6311 7	2.1188 2	-2.4226 8	4.3796 7	-0.2139 35	-111.3 51
10	-6.7285 3	-3.4129 2	-11.908 2	2.8169 4	-3.4295 2	4.4578 7	-9.6375 1	-3.3832 9	-15.291 5	6.9788	-1.0855	-95.60 16
11	-5.4183 1	-0.9317 39	-10.448 8	2.6092 8	-2.1833 6	3.8349 8	-8.8655	-5.3369 8	-15.785 8	3.3058 4	-1.9256 2	-95.26 49
12	-4.8077 4	-1.0129 4	-4.9238 3	2.0068 7	-2.0635 9	4.7224 1	-4.8385 1	-3.7788 6	-1.1449 8	2.8454 8	-0.9388 97	-103.1 46
13	-7.1192 6	-2.7539	-10.457 5	3.3938 8	-2.1566 8	4.5337 4	-7.8720 1	-3.7472 3	-14.204 8	5.6506 2	-0.7829 06	-89.20 81
14	-5.7362 5	-2.9831 9	-7.5050 4	4.7503 1	-2.8829 6	3.9804	-5.7492	-0.3680 38	-7.8730 8	4.3167 5	-2.6456 6	-87.18 81
15	-4.7437 1	-2.5302 8	-9.3067	4.513	-2.3696 7	3.6328 7	-8.1958 6	-2.9453 9	-12.252 1	6.0921 1	0.6205 53	-80.08 96
16	-5.133	-1.1748 7	-6.3356 4	2.2352 8	-1.3006 6	4.1369	-5.3395 4	-1.5807	-7.9163 4	5.6659	1.4951	-77.02 89
MEAN of sum of reciprocal squares	0.0463 96	0.3288 821	0.0208 424	0.1340 004	0.4426 673	0.0800 439	0.0236 894	0.9815 725	0.0923 848	0.1116 049	4.0534 223	9.322 E-05
S/N Ratio	13.335 195	4.8295 975	16.810 529	8.7289 405	3.5392 257	10.966 719	16.254 461	0.0807 761	10.343 997	9.5231 661	-6.0782 19	40.30 486



Appendix D.27: Outputs of Taguchi's Experiments: 417 to 432

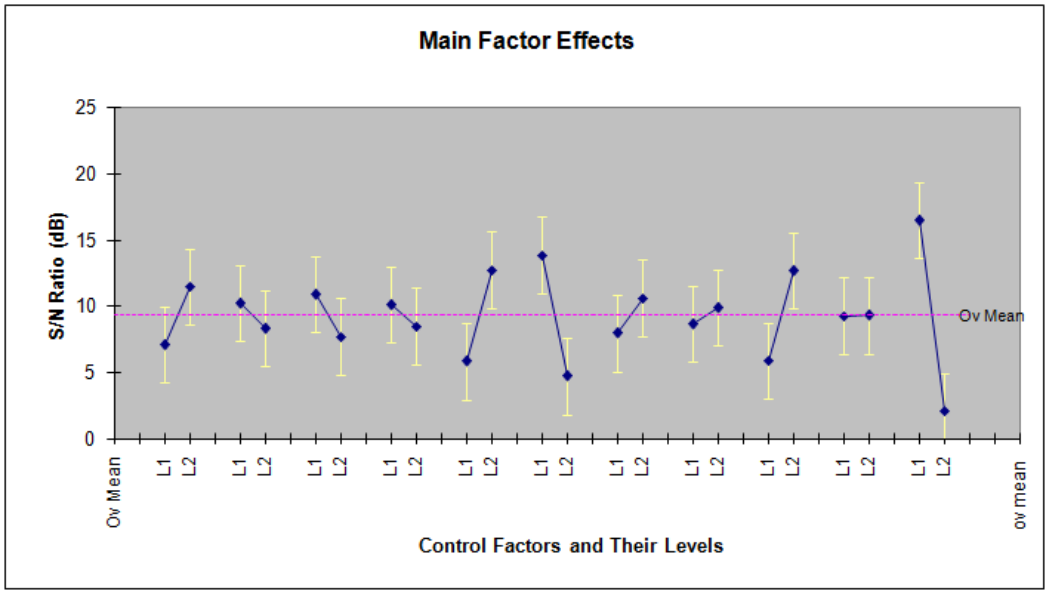
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-6.9688	-3.4382	-14.34	1.7600	-2.4927	3.2161	-10.587	-8.9263	-23.266	6.5175	-1.0641	-68.032
		9		9	9		2	6	3	1	8	7
2	-1.0107	2.4671	-2.1987	2.4795	-0.0993	3.4916	-4.6797	3.2009	1.0022	-0.4656	3.5369	-82.110
	4		6	1	56	8		7	1	67	7	5
3	-5.0297	-2.5455	-7.4119	2.6361	-0.8920	4.7502	-7.1324	-0.2827	-7.6947	6.4457	1.0309	-70.116
	4	3	4	5	83	7	6	98	4	2	1	6
4	-1.8885	1.8729	-1.3910	3.1773	-1.6756	4.1541	-3.6566	3.7862	2.3951	0.2590	1.4732	-61.839
		7	3	8	5	5	8		8	23	9	7
5	-4.5963	-0.7103	-10.607	1.5024	-4.0594	2.3850	-8.3957	-2.7642	-13.371	4.0671	1.9765	-44.880
	6	59		9		9	3	5	2	4	5	8
6	-3.6376	-0.7327	-7.8659	2.9978	-0.8701	3.9264	-8.1547	-0.3066	-8.1725	3.2463	1.6576	-45.932
	8	65		5	72	8		11	1	1	9	7
7	-6.3985	-2.5490	-14.011	2.6867	-3.0544	3.7855	-11.398	-7.1286	-21.140	4.9647	-0.3681	-41.526
	8	6	5	6	4	7	5	9	2	7	21	3
8	-5.3290	-2.7513	-6.9616	4.4972	-0.6478	4.2885	-5.9211	0.9700	-5.9916	4.4449	1.1354	-51.963
	3	6	5	2	9	2	4	31	2	8	6	7
9	-6.0738	-2.7201	-12.838	2.5660	-1.1570	3.5164	-10.280	-6.5388	-19.377	6.4505	-0.2025	-40.138
	4	6	3	4	1	4	9	6	1	4	3	8

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-6.80373	-5.34051	-11.8857	1.67335	-3.59894	3.80153	-8.8835	-8.0831	-19.9688	10.1532	0.857915	-49.5297
11	-5.94384	-3.51032	-8.76098	1.70151	-3.2819	4.76028	-7.57742	-3.4018	-12.1628	5.42372	0.633046	-51.8793
12	-8.69866	-5.19239	-14.9733	3.77226	-3.82361	4.3938	-10.6685	-9.66124	-24.6346	9.48386	-2.81139	-47.571
13	-3.44473	-2.10828	-7.0469	2.89613	-1.93545	3.50825	-7.11042	0.1852	-6.8617	7.1044	3.901377	-56.7838
14	-6.95466	-2.99826	-15.2962	3.50934	-3.58292	2.34713	-10.6887	-8.38133	-23.6776	6.1421	-2.28386	-44.3411
15	-1.33443	1.84528	-1.13547	2.73014	-0.306182	3.92919	-3.73023	5.84013	4.70466	0.346315	2.298889	-59.3172
16	-3.66545	-0.005813	-5.45712	3.61754	-3.00148	4.58713	-6.37881	1.9426	-3.51452	4.17077	4.344331	-42.5899
MEAN of sum of reciprocal squares	0.153652 9	1973.2093	0.109914	0.164059 6	7.930643 3	0.081513 7	0.024691 1	3.603171 5	0.093018 8	1.886465 7	2.500237 9	0.000391 6
S/N Ratio	8.134592 6	-32.95173	9.589470 2	7.849982 8	-8.993084	10.88769 3	16.07459 4	-5.566849	10.31429 4	-2.756489	-3.979813	34.07127



Appendix D.28: Outputs of Taguchi's Experiments: 433 to 448

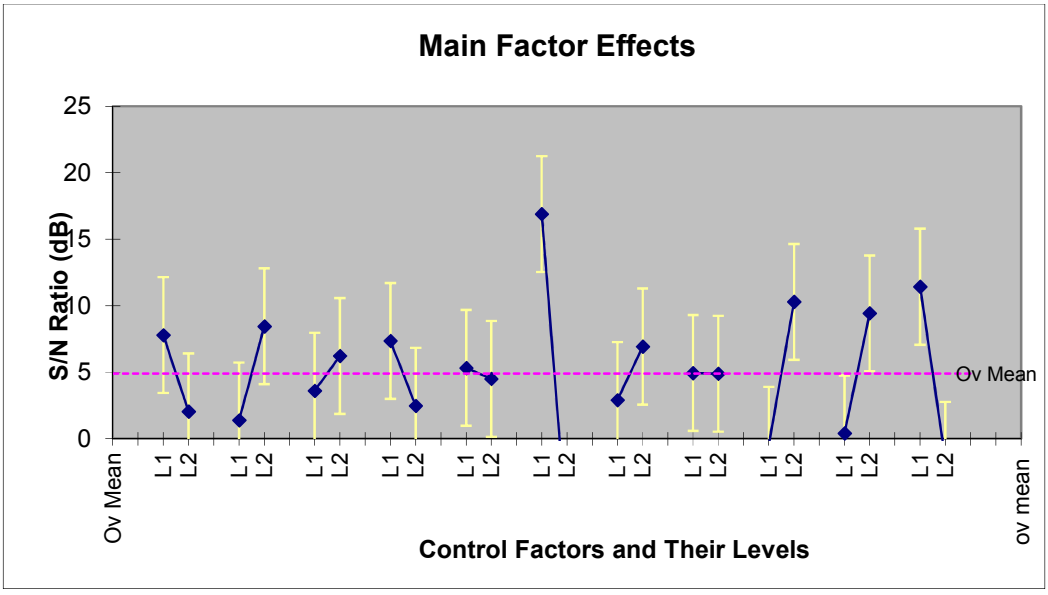
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-7.60509	-4.4594	-14.911	2.34393	-4.99977	4.98985	-12.2958	-6.24478	-21.1558	8.57644	-0.316486	-24.7067
2	-5.37508	-3.60667	-10.5296	2.4562	-2.91633	4.61943	-9.7739	-2.42266	-12.9522	6.97398	0.920614	-27.8546
3	-3.26213	1.40967	-9.94459	4.04308	-1.21102	1.0867	-7.76915	-1.53192	-11.4765	2.34674	3.226 02	-23.0815
4	-6.43262	-1.69007	-16.0803	2.44343	-2.17118	1.17562	-10.8233	-10.9351	-27.0154	6.48387	-0.27863	-24.3546
5	-6.2661	-4.68863	-10.8634	4.5115	-2.47194	2.64733	-7.24459	-3.8743	-14.7377	7.01849	-1.52717	-44.9567
6	-8.80991	-6.08682	-16.7449	2.89977	-4.08731	2.62402	-10.559	-9.18174	-25.9267	10.3526	-0.99881	-45.1267
7	-5.21268	-0.308503	-9.10002	1.00051	-1.73614	4.97114	-8.85848	-3.95914	-13.0592	4.26367	2.94557	-56.7367
8	-5.79577	-4.46696	-10.1929	3.45229	-1.40655	4.89922	-9.29638	-1.40309	-11.596	6.84073	-1.42362	-55.6296
9	-5.93616	-1.16972	-10.0255	1.26648	-3.77161	4.36226	-8.4516	-6.26341	-16.2889	5.95082	1.775 98	-52.0882
10	-8.1649	-5.55438	-18.2725	1.30215	-4.4567	2.01642	-12.124	-12.8187	-31.0911	9.46833	0.541984	-52.8076
11	-6.29809	-1.76986	-13.8192	3.59256	-4.47612	2.99148	-10.5126	-5.27903	-19.0982	3.98462	0.593019	-73.2516
12	-6.70222	-5.36555	-14.3375	4.81555	-4.39373	2.02776	-9.66307	-5.57247	-19.91	6.82214	-3.41083	-80.1897
13	-7.21461	-3.22389	-16.2646	1.67718	-4.37136	3.00758	-12.0575	-8.89544	-25.16	6.46694	-0.100225	-88.9156
14	-3.61192	1.0359	-5.3079	2.7457	-3.00146	2.09762	-3.7936	-0.284137	-5.59203	1.97793	1.203 65	-102.828
15	-8.96389	-4.15305	-17.1595	3.59979	-4.83868	3.05707	-11.2527	-10.7255	-27.885	6.70924	-5.10741	-95.9852
16	-1.96386	2.4023	-0.636427	4.08573	-1.5669	4.32641	-2.99898	7.49502	6.8586	-0.581239	4.761 24	-115.124
MEAN of sum of reciprocal squares	0.0472135	0.9111679	0.1727075	0.247263	0.1932076	0.2044911	0.0214323	0.9180021	0.0066653	0.2445427	8.687456	0.0006265
S/N Ratio	13.259339	0.4040161	7.6268883	6.068409	7.1397589	6.8932556	16.689318	0.3715632	21.761833	6.1164523	-9.388926	32.03084



Appendix D.29: Outputs of Taguchi's Experiments: 449 to 464

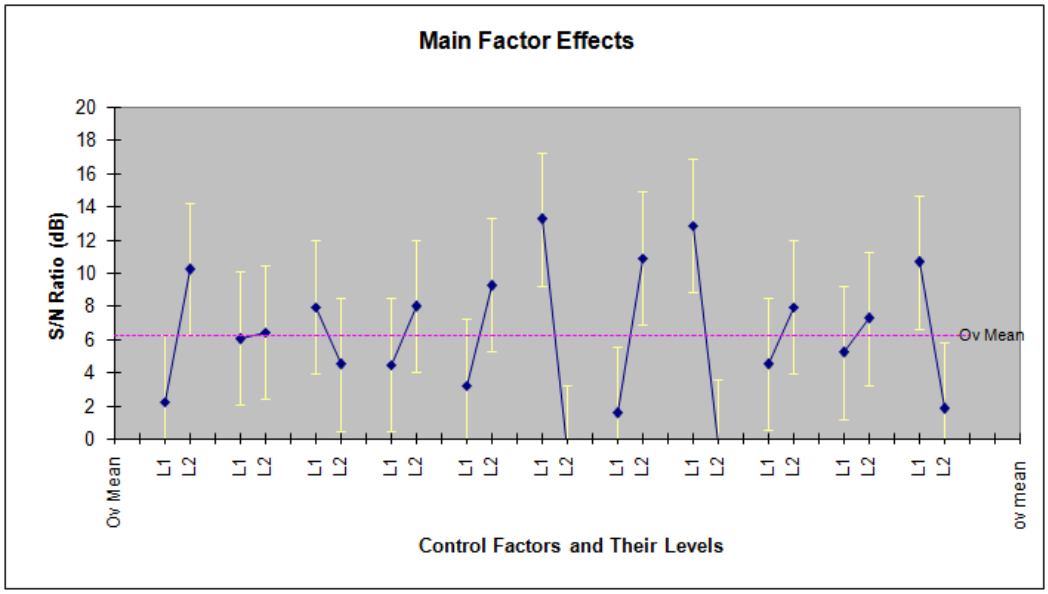
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-4.65436	-0.374273	-6.77196	4.98214	-3.30687	4.9881	-7.1057	0.525012	-6.24694	5.07535	3.20299	-89.0424
2	-4.86826	-3.81839	-7.75152	3.55314	-2.86048	4.11895	-7.00222	-2.26893	-10.0205	8.49593	1.67327	-71.6694
3	-5.56621	-2.23218	-6.53891	1.32194	-1.93942	4.6769	-5.64961	2.21108	-4.32783	5.37184	0.0278378	-60.6989
4	-4.107	0.82876	-6.92534	2.3377	-1.88322	3.45596	-6.2743	-1.77529	-8.70063	3.97916	2.6864	-48.7952
5	-5.09764	-2.16576	-11.9513	2.08447	-2.06502	1.10951	-7.96321	-4.00259	-15.9539	4.99343	2.32859	-43.9178
6	-7.45038	-5.12665	-11.3493	1.02038	-3.9782	4.99202	-8.89094	-6.76537	-18.1147	7.99222	-2.02698	-50.0161
7	-5.98883	-3.79225	-10.8212	2.02669	-3.36518	3.62184	-8.45422	-3.90929	-14.7305	4.79823	-3.70109	-52.6761
8	-8.49243	-4.87939	-18.6001	4.12777	-4.82614	2.7184	-12.826	-13.6036	-32.2036	8.00207	-1.43296	-58.0837
9	-4.24652	-3.00849	-8.84317	2.80903	-2.4634	2.83678	-7.43343	-2.30967	-11.1528	6.57071	0.659575	-78.7179

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-7.49242	-4.10158	-16.3622	3.18324	-4.02749	1.81985	-10.6897	-8.90411	-25.2663	7.40077	-0.91551	-74.8503
11	-6.90304	-4.49352	-13.2927	1.73271	-3.76238	2.9817	-9.37138	-8.31947	-21.6122	8.72758	-1.41016	-89.6831
12	-8.06521	-3.82756	-16.813	1.422	-4.89583	4.1055	-12.8533	-9.75293	-26.566	5.04108	-5.16384	-99.4464
13	-6.84043	-2.75722	-16.5209	1.04493	-3.13266	1.53491	-11.2154	-11.8457	-28.3666	6.65089	-1.27063	-121.661
14	-1.53035	0.642569	-2.11772	1.13075	-0.75682	3.72488	-4.31225	2.05703	-0.06096	3.29017	4.65195	-145.556
15	-4.27953	0.377015	-6.15406	3.80818	-2.80742	3.89927	-5.7738	-0.01487	-6.16894	2.7578	0.894813	-129.623
16	-6.40667	-2.15832	-11.9819	2.22733	-1.9229	4.68332	-10.2585	-6.18202	-18.1639	5.91482	-1.19321	-119.098
MEAN of sum of reciprocal squares	0.059608 7	1.284559	0.025930 3	0.337061 3	0.246341 9	0.159069	0.018636 7	301.5115	18.106432	0.041408	86.543044	0.000218 2
S/N Ratio	12.246902	-1.087541	15.861926	4.722910 5	6.084616 8	7.984144 4	17.296306	-24.79304	-12.57833	13.829155	-19.37232	36.611457



Appendix D.30: Outputs of Taguchi's Experiments: 465 to 480

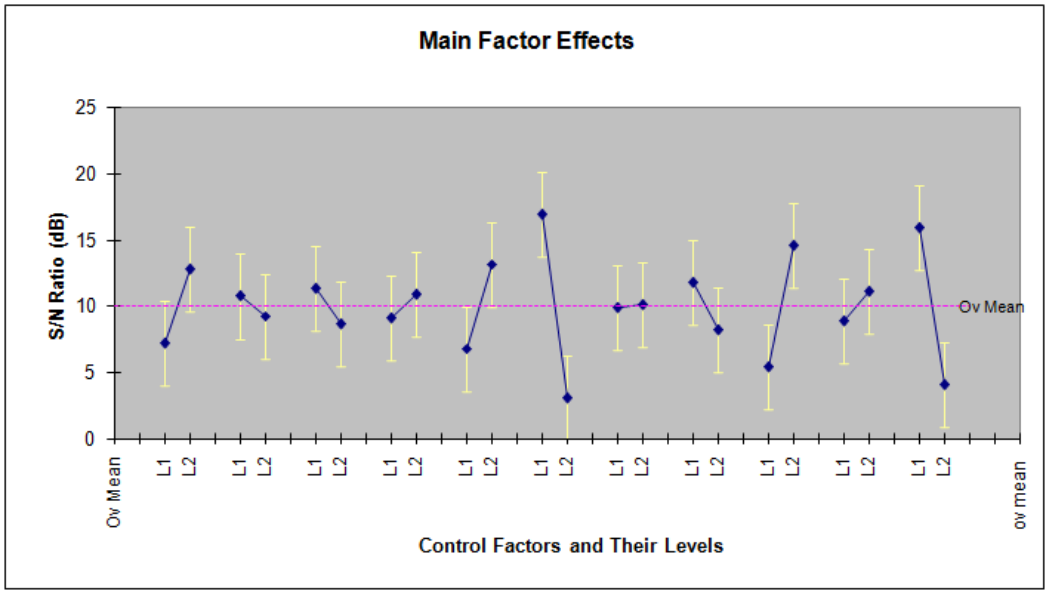
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-3.995	-1.3169	-8.6931	2.6383	-2.2407	3.4123	-8.1105	-2.4805	-11.173	5.9058	3.9268	-125.269
2	-6.0947	-4.9292	-11.024	3.8530	-3.1886	4.4616	-9.3910	-6.4227	-17.446	8.5205	-1.1311	-118.89
3	-7.3128	-3.7633	-13.819	1.6603	-4.9893	4.3405	-10.847	-8.3134	-22.133	7.2227	-0.6144	-119.481
4	-1.0136	1.1345	-1.2306	2.1160	-0.0589	3.1407	-3.3577	5.9655	4.7349	2.6492	4.7967	-127.974
5	-3.4448	0.0976	-8.1188	1.7189	-1.9545	1.2417	-5.9157	-1.3481	-9.4670	3.4434	3.4334	-105.875
6	-3.6467	0.7709	-4.3789	2.4518	-0.7763	4.2276	-4.9598	3.9687	-0.4102	1.5044	1.0203	-103.948
7	-3.8068	-0.2692	-7.5639	4.5130	-1.2940	2.2446	-6.0016	-3.7114	-11.275	5.0514	1.9883	-91.263
8	-3.8781	-0.7057	-5.8823	1.7624	-2.5563	3.4947	-5.4989	-2.0394	-7.9218	3.0835	2.4343	-89.520
9	-6.9974	-5.9010	-10.585	3.5485	-3.2591	3.8396	-7.4275	-3.9563	-14.541	9.5795	-0.6399	-83.725
10	-6.3051	-2.1795	-10.890	4.5689	-4.0755	2.6287	-7.2145	-1.3493	-12.240	5.0168	-1.3334	-77.972
11	-7.9427	-4.1113	-14.432	1.8496	-3.4543	3.4589	-9.9490	-8.6103	-23.043	7.6411	-3.0881	-75.074
12	-3.0402	-1.0107	-8.3521	4.5612	-0.5436	2.5068	-7.8188	-1.0867	-9.4389	2.2797	2.7937	-86.733
13	-4.7306	0.0944	-5.0100	4.0665	-1.6685	4.6824	-4.9619	4.1399	-0.8701	3.4718	0.4982	-84.288
14	-5.6696	-2.0168	-10.993	3.8446	-2.3122	4.3644	-9.6879	-3.2395	-14.232	3.3507	-1.8857	-66.248
15	-7.0568	-4.4176	-12.173	3.5514	-4.0003	2.4573	-7.5742	-5.1497	-17.323	8.4122	-1.0489	-69.628
16	-3.2105	1.7592	-6.0699	1.0205	-2.6351	2.8747	-5.7341	-1.2954	-7.3653	0.1585	2.3043	-69.958
MEAN of sum of reciprocal squares	0.1148 746	15.851 073	0.0609 583	0.2010 528	19.653 975	0.1354 529	0.0271 069	0.2268 755	0.4936 878	2.7385 045	0.9029 83	0.0001 274
S/N Ratio	9.3977 599	-12.000 59	12.149 67	6.9668 988	-12.934 5	8.6821 168	15.669 207	6.4421 236	3.0654 757	-4.3751 35	0.4432 044	38.947 297



Appendix D.31: Outputs of Taguchi's Experiments: 481 to 496

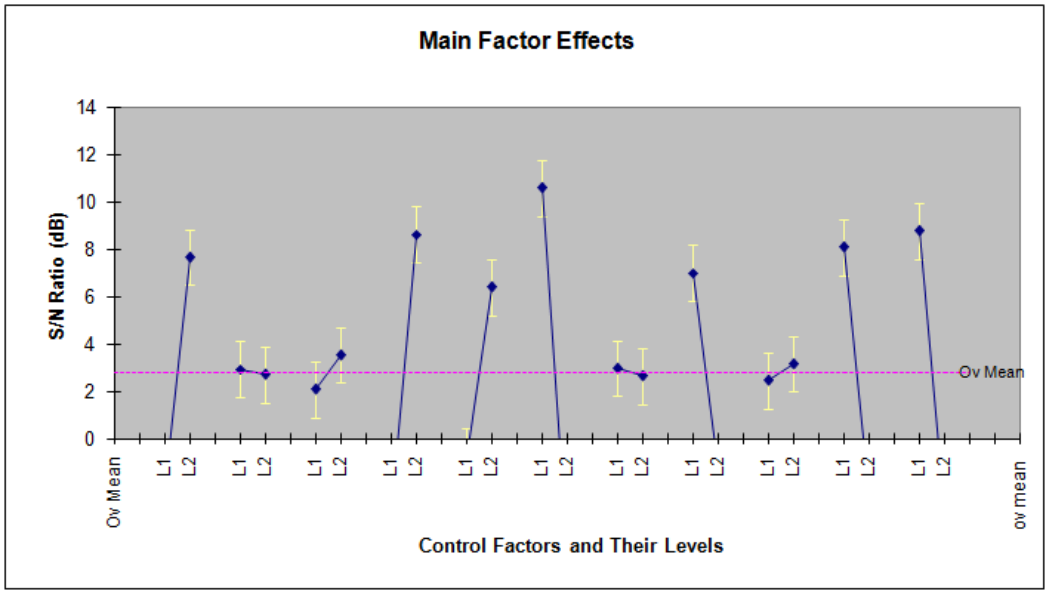
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-6.3068	-2.6040 5	-11.432 4	2.2143 3	-4.7836 8	4.5995 3	-9.7251 1	-3.6497 9	-15.082 2	4.8293 9	0.7717 84	-68.305 1
2	-4.2573 2	0.5504 14	-8.8842	2.8206	-2.7084 4	3.1611 1	-7.7879 8	-2.8323 6	-11.716 6	1.1596 3	1.4709 6	-66.651 8
3	-3.6886 1	0.4933 65	-7.5978	4.6697 8	-2.4064	3.4780 7	-7.3872 6	-1.2206 5	-8.8184 5	3.2808 1	2.1670 7	-67.97
4	-4.0610 3	0.7886 17	-10.795 5	1.9391 8	-2.6351	2.0447 6	-8.7792 6	-5.8712 3	-16.666 8	1.2946 1	1.4494 7	-61.871 7
5	-4.6779	-0.2383 94	-9.5809 5	3.4302 7	-4.5900 4	1.8688 3	-6.7718 8	-4.4747 4	-14.055 7	3.5776 2	2.2632 7	-72.82
6	-4.0708 6	-2.6565 5	-4.7381 5	3.4014 2	-2.5005 6	4.8966 2	-5.5639 2	1.0302 1	-3.7079 4	5.0170 5	3.156	-72.780 1
7	-4.7969 5	-2.6067 1	-11.243 5	3.7969 6	-2.8731 9	3.1045 3	-9.5511 2	-4.6347 7	-15.878 3	6.7135 8	2.6828 2	-53.709 8
8	-5.5096 1	-0.9042 99	-12.094 9	4.0297 7	-0.7532 87	1.0385 1	-7.6237 5	-5.2859 2	-17.380 8	2.7283 2	-0.9051 92	-55.003
9	-6.4685	-4.6884	-12.238 7	1.9087	-4.0265 2	4.6811 4	-10.451 3	-5.1958 6	-17.434 6	8.9051 7	-0.6781 84	-67.558 8

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-5.18754	-3.23047	-6.84215	1.18866	-2.66464	3.58438	-5.23899	1.05173	-5.79042	5.85175	-0.667926	-67.5203
11	-7.11905	-5.92854	-13.88	1.7044	-4.41749	4.46998	-11.2309	-5.24042	-19.1204	7.5535	-1.86671	-57.8258
12	-4.72099	-0.516159	-10.318	1.12708	-0.328625	1.77977	-7.37674	-5.16087	-15.4788	4.83382	2.1421	-62.9816
13	-6.91829	-3.98232	-10.6336	3.62746	-4.32581	4.12345	-7.83875	-5.26508	-15.8987	8.42889	0.195333	-70.254
14	-4.59925	-0.509715	-10.5209	2.26517	-2.0647	1.39994	-7.32164	-3.11892	-13.6399	4.77755	4.23509	-65.5623
15	-5.80887	-3.53877	-8.03516	1.59698	-2.20874	4.87116	-7.09745	-0.203998	-8.23916	8.31397	3.16983	-67.1164
16	-6.87194	-5.45082	-13.3967	1.14618	-4.22576	2.97854	-9.50329	-7.23233	-20.629	9.87136	1.22326	-53.2885
MEAN of sum of reciprocal squares	0.0414531	2.4128263	0.0128518	0.2758287	0.8399203	0.1994181	0.0180303	1.8093794	0.0117941	0.1278456	2.4100707	0.0002448
S/N Ratio	13.824434	-3.825261	18.910376	5.5936059	0.7576194	7.0023533	17.439968	-2.575297	19.283334	8.9331424	-3.820298	36.112331



Appendix D.32: Outputs of Taguchi's Experiments: 497 to 512

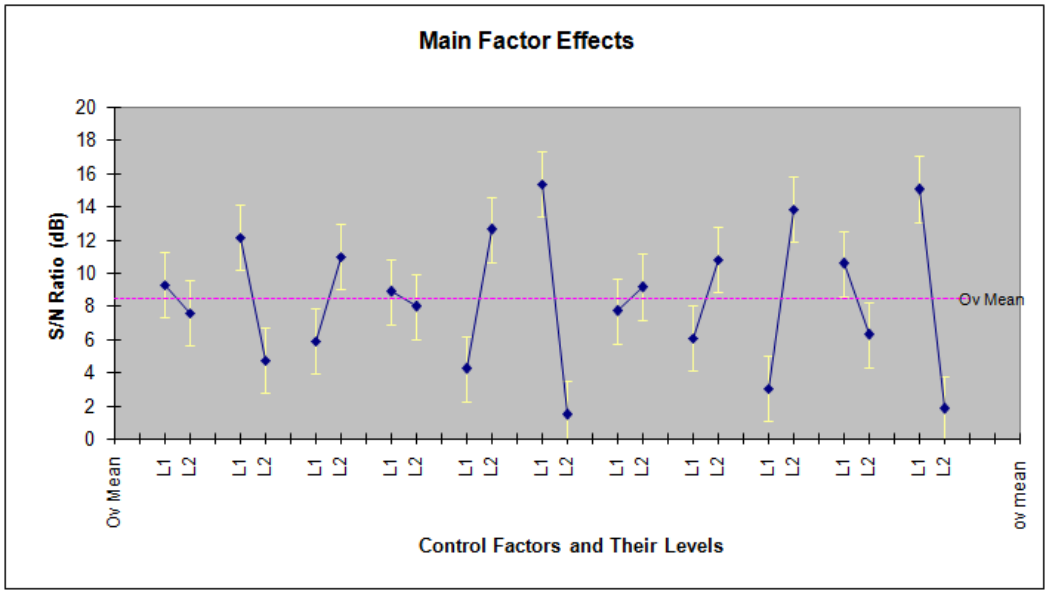
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-6.21591	-1.81576	-15.576	4.7523	-2.45682	1.53041	-10.8905	-9.25444	-24.8304	6.74547	0.154022	-57.6089
2	-1.80712	1.21632	-1.84699	4.8574	-0.064287	3.11844	-3.15831	4.98298	3.13599	1.46459	3.28197	-71.7168
3	-3.74197	-0.84872	-4.94937	2.30536	-2.75563	3.46025	-4.66765	1.48052	-3.46886	3.72793	2.49327	-51.3973
4	-3.25824	-2.00471	-5.9141	4.05697	-1.82556	3.09523	-5.7511	0.892212	-5.02189	5.85759	2.83059	-38.5439
5	-5.05717	-0.667601	-9.08758	2.09778	-3.75913	2.54352	-6.57394	-3.79972	-12.8873	3.85464	2.30674	-25.0569
6	-6.31169	-4.30133	-14.6179	1.57211	-3.11837	1.68111	-9.98732	-10.1298	-24.7477	7.90767	0.845585	-23.3673
7	-6.81344	-3.60493	-9.8504	3.91203	-4.32292	4.00111	-7.03808	-5.29416	-15.1446	6.88144	1.05151	-38.4672
8	-5.20305	-0.571145	-8.86252	1.93289	-2.94571	4.6812	-8.34067	-3.31074	-12.1733	5.19985	1.06582	-33.0867
9	-3.70832	-0.656257	-7.3516	4.99295	-0.925962	3.91262	-7.5559	2.05859	-5.29301	3.53795	0.252982	-29.7086
10	-3.29787	-0.004433	-5.99351	4.4829	-2.11612	1.56255	-4.2582	-0.433883	-6.4274	4.41073	2.77711	-20.1985
11	-4.09023	-1.2989	-7.54193	3.97467	-2.75875	4.48148	7.93318	-2.35858	-9.90052	5.61623	1.85804	-10.6974
12	-2.05193	2.70018	-0.873504	4.69413	-1.83602	3.57608	-2.39765	6.52349	5.64999	0.347179	2.82592	-1.9426
13	-6.11388	-2.13437	-9.43565	2.10514	-1.61624	3.82993	-7.1517	-1.43137	-10.867	4.59756	-2.3313	21.9508
14	-2.67922	0.559073	-6.5464	2.41856	-0.060353	3.46551	-7.33269	-0.569115	-7.11551	2.92436	3.56773	22.2377
15	-7.22068	-2.77762	-15.2053	4.47424	-2.53709	4.16153	-12.1461	-6.72158	-21.9269	6.59146	-2.12871	27.4814
16	-6.11365	-2.61777	-11.7245	2.8413	-2.6265	4.25076	-9.86162	-5.3827	-17.1072	6.89453	2.64634	17.4182
MEAN of sum of reciprocal squares	0.082304	3392.7991	0.1206404	0.1337408	34.65418	0.1434544	0.0369581	0.7449276	0.0246511	0.6244483	4.1606183	0.0189237
S/N Ratio	10.84579	-35.30558	9.1850734	8.7373598	-15.39756	8.432861	14.322901	1.2788594	16.081637	2.0450354	-6.191579	17.229948



Appendix D.33: Outputs of Taguchi's Experiments: 513 to 528

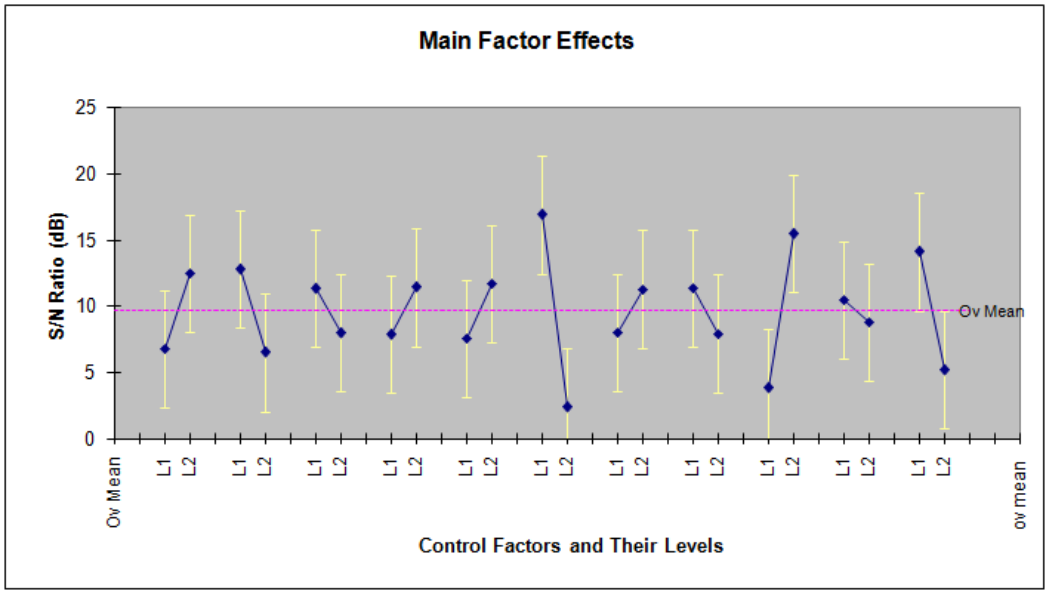
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-3.75256	0.911688	-9.00268	2.42674	-1.71053	3.19746	-8.44758	-2.35584	-11.3585	3.34766	1.92547	17.9214
2	-5.7002	-0.946528	-11.2172	1.40415	-3.99854	1.64445	-7.16144	-6.27187	-17.4891	5.84643	2.51991	15.5878
3	-4.45899	-1.78226	-7.19955	1.78967	-2.76187	4.42175	-7.16231	-0.407817	-7.60736	6.66774	3.27217	11.8128
4	-6.03951	-2.09533	-10.9003	3.18558	-3.81017	4.96859	-9.82943	-6.09057	-16.9909	5.0032	-0.010539	25.1677
5	-5.69856	-2.56177	-11.9214	2.6529	-4.0704	3.01409	-9.23698	-2.57717	-14.4986	7.41083	2.20813	22.5656
6	-5.70736	-1.63537	-9.59055	3.6074	-2.83399	4.8751	-8.75828	-3.2742	-12.8647	3.75079	-0.693808	26.1178
7	-4.75881	-3.46649	-7.3423	2.191	-1.15902	3.81645	-6.39994	0.734824	-6.60748	5.25027	-0.327677	27.4564
8	-8.81716	-6.05286	-18.2432	2.44626	-4.34767	1.93872	-11.3648	-9.63437	-27.8776	11.0372	-1.87523	33.6851
9	-3.15235	-0.406422	-7.6875	4.23109	-1.65429	3.1096	-7.64475	-0.380826	-8.06832	2.83069	3.7079	18.7242

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-6.83578	-2.03179	-15.2642	4.77312	-3.24902	2.42561	-10.854	-6.44525	-21.7095	6.40618	-1.15544	25.333
11	-6.68257	-3.59635	-15.5502	1.18251	-2.96513	2.81065	-11.6783	-9.35043	-24.9006	7.36724	-1.77387	14.9583
12	-5.70693	-3.90531	-11.3445	4.98684	-1.85136	3.20166	-8.83924	-4.93035	-16.2749	5.51459	-1.92639	-3.76048
13	-7.7272	-3.98516	-14.8452	3.01079	-3.29743	4.73099	-11.849	-6.18523	-21.0304	6.5349	-1.05628	-9.06749
14	-3.30171	-0.890949	-7.21174	2.15363	-2.90201	2.45025	-6.36027	-1.28153	-8.49327	2.42485	0.947391	-16.8209
15	-4.3844	-0.390301	-8.36087	2.45756	-1.91932	2.44596	-6.42242	-3.98192	-12.3428	2.18733	-1.02734	-15.9881
16	-6.09953	-1.86264	-9.91926	2.13449	-1.29223	4.32798	-8.14771	-4.23314	-14.1524	4.09422	-0.149002	-21.8479
MEAN of sum of reciprocal squares	0.042542	1.2023995	0.0109783	0.1688703	0.2279605	0.1232554	0.0153212	1.0710772	0.0077129	0.0639274	604.30733	0.0078961
S/N Ratio	13.711817	-0.800488	19.594651	7.7244661	6.4214031	9.0919411	18.147086	-0.298208	21.127797	11.943129	-27.81258	21.025873



Appendix D.34: Outputs of Taguchi's Experiments: 529 to 544

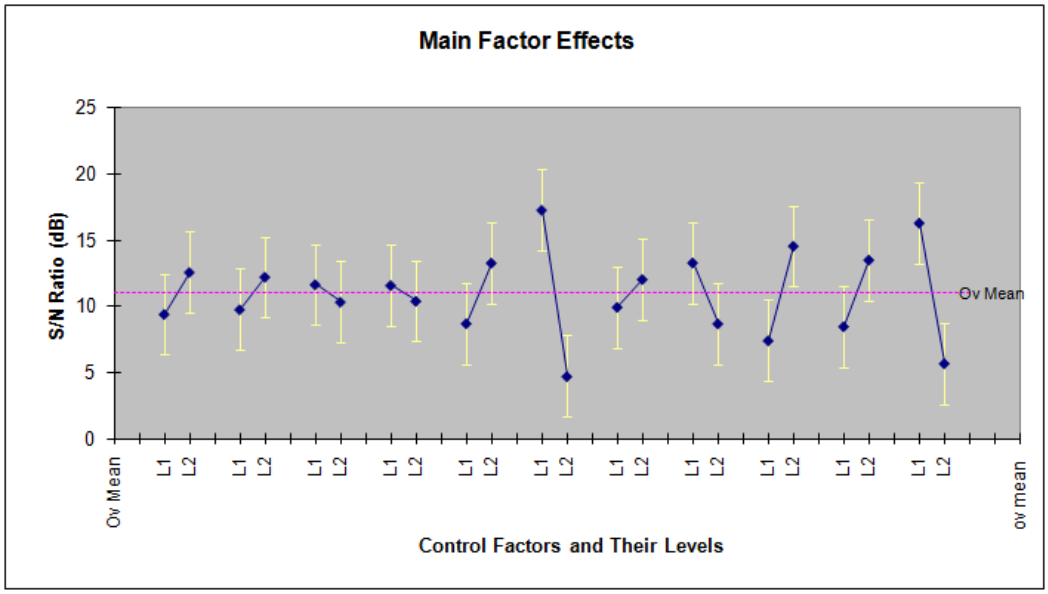
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-6.42027	-2.87815	-11.4483	1.0493	-3.54655	4.09532	-9.12335	-3.9109	-15.3592	7.86414	2.41768	-23.4793
2	-6.40214	-1.4914	-9.64211	2.94965	-2.90657	4.52471	-7.76468	-3.45739	-13.0995	5.79281	-1.02215	-21.3037
3	-8.89815	-4.58992	-19.2584	2.45288	-4.04894	2.63694	-12.9971	-14.4661	-33.7245	6.71653	-4.39496	-18.3886
4	-3.47158	-0.495574	-6.8041	1.42549	-1.70299	4.07128	-7.4038	-0.812951	-7.61705	3.00178	0.467508	-48.1826
5	-6.77263	-2.5591	-14.3412	2.24289	-4.84716	1.48872	-9.05731	-8.49468	-22.8359	6.94042	1.296	-43.8078
6	-4.10558	0.565397	-5.70694	3.96608	-1.86371	4.84308	-6.44443	-0.459655	-6.16659	4.30595	1.9341	-53.3777
7	-9.08595	-4.10968	-14.3687	2.41888	-4.5677	4.40937	-9.69215	-8.37568	-22.7444	8.15329	-2.36597	-40.3775
8	-7.28965	-6.01545	-14.3611	4.69414	-4.36247	4.95568	-12.0271	-6.63626	-20.9973	9.29191	-1.17312	-46.9547
9	-6.41933	-2.66126	-14.1975	3.42324	-1.94622	3.62468	-11.4029	-6.10298	-20.3005	6.51036	-0.951062	-49.4722
10	-3.4922	1.254551	-8.02773	3.38617	-0.07734	2.43445	-6.96998	-0.447619	-8.47535	0.941281	2.76068	-59.717
11	-5.49861	-1.88915	-8.31117	3.69405	-1.51342	2.95354	-5.7661	-2.57159	-10.8828	5.69293	2.58407	-59.0275
12	-7.03121	-4.5823	-14.4255	1.47857	-3.31495	2.3624	-9.75666	-6.62823	-21.0537	6.76923	-1.78755	-51.8301
13	-4.60983	-2.15644	-8.65904	3.19572	-2.04714	4.61861	-8.66782	-1.5674	-10.2264	5.79849	1.383133	-63.9321
14	-4.22391	-0.582002	-9.83647	2.61607	-0.285063	3.09562	-8.70818	-1.16565	-11.0021	3.95244	0.36005	-56.342
15	-6.59651	-3.41667	-14.0262	4.73414	-4.38257	3.27183	-10.7015	-8.19771	-22.2239	7.68595	1.842711	-57.8155
16	-7.24238	-2.56128	-14.3727	2.52882	-2.69248	1.59599	-8.72628	-8.84767	-23.2203	5.68865	-0.116865	-61.4928
MEAN of sum of reciprocal squares	0.0351979	0.8191248	0.0097881	0.2156769	12.087112	0.130658	0.0129154	0.8441316	0.006727	0.1064062	6.0549579	0.0007686
S/N Ratio	14.534836	0.8664995	20.093036	6.6619637	-10.82323	8.838641	18.888908	0.7358984	21.721814	9.7303317	-7.821111	31.143005



Appendix D.35: Outputs of Taguchi's Experiments: 545 to 560

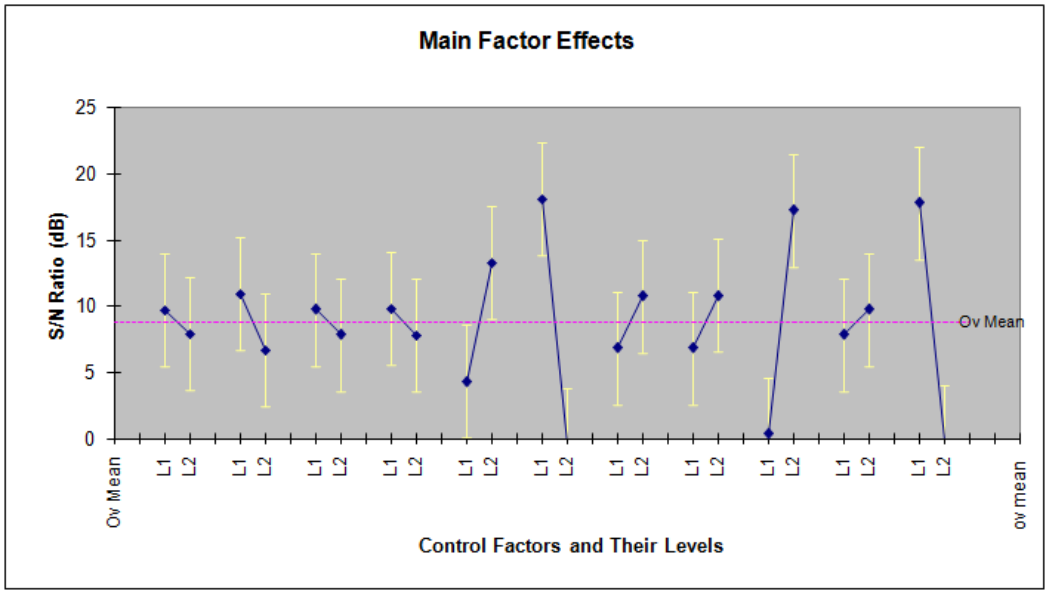
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-5.2025 1	-3.3300 7	-8.7897 3	1.3752 2	-3.2216 1	4.5233 5	-8.1105 7	-3.2886 1	-12.078 3	7.8286 5	1.7129	-75.011 6
2	-5.2542 7	-2.8599	-11.703 6	2.3503 5	-2.9530 6	3.7301 5	-10.179 5	-5.5076 7	-17.211 3	7.5065 1	3.6181 3	-69.706 6
3	-5.5379 9	-2.2714 1	-10.910 8	2.0439	-1.1695	4.1220 6	-9.4948 6	-4.9122 4	-15.823	5.0703 9	0.8171 3	-68.725 1
4	-7.5299 2	-3.1476 7	-13.065 4	3.5421 4	-2.5330 4	3.9143 2	-9.4498 5	-7.9718 2	-21.037 3	6.5781 5	-1.9725 6	-72.565 8
5	-3.9427 8	-0.4181 74	-6.6580 4	4.8709 8	-2.2582	2.9908	-5.7060 6	-0.2853 07	-6.9433 4	2.2751 7	0.4630 61	-81.608
6	-7.8485 2	-2.8784 4	-14.042 9	2.8306 1	-3.0450 3	3.7795 7	-9.9739 6	-8.4712	-22.514 1	4.3627 7	-5.2673 7	-74.420 7
7	-7.2536 3	-2.7522 3	-16.071 2	3.8577 9	-2.5815 8	2.2283 1	-11.045 9	-11.224 8	-27.296	4.9849	-0.9833 35	-90.547 3
8	-5.8098 5	-2.6980 7	-12.011 6	4.7676 4	-3.2607 9	3.2973 3	-9.4990 6	-6.8231 7	-18.834 8	4.7869 9	-1.4994	-111.10 5
9	-4.2194	-1.5140 2	-6.2142 3	1.4507 8	-2.6909 2	3.1857	-5.1805 3	-0.4684 12	-6.6826 5	4.9736 5	1.9209 3	-118.27 7

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-5.56328	-3.38281	-10.3191	2.29929	-3.91559	3.60663	-8.36241	-4.03611	-14.3552	7.89978	1.86557	-108.591
11	-3.87956	-1.39093	-7.12759	2.00298	-1.59318	2.00477	-5.25281	1.74281	-5.38478	4.62702	1.60807	-104.227
12	-3.50621	1.19574	-3.20318	2.16227	-2.3623	4.84385	-4.54082	2.32494	-0.878236	1.88676	0.786963	-96.9965
13	-6.27203	-3.08583	-11.6231	1.93508	-4.57201	4.63524	-9.98633	-6.46437	-18.0875	7.89811	2.7814	-81.316
14	-4.43441	0.44182	-5.97512	1.4634	-1.87185	3.81727	-5.35799	0.915507	-5.05962	4.21677	3.73741	-79.8257
15	-6.1803	-3.4728	-11.343	2.70657	-4.4278	3.78194	-8.94467	-5.28489	-16.6279	7.4008	0.696619	-67.9697
16	-3.84481	1.04322	-7.30659	2.36439	-3.69798	4.27322	-7.73499	-2.83786	-10.1445	1.2225	0.694693	-66.8647
MEAN of sum of reciprocal squares	0.039502	0.9378986	0.0178399	0.2156365	0.1657303	0.0785276	0.0187547	1.2461356	0.0948383	0.1015119	0.9904814	0.0001553
S/N Ratio	14.033807	0.2784412	17.486072	6.6627763	7.8059812	11.049776	17.268901	-0.955653	10.230163	9.9348316	0.0415368	38.087898



Appendix D.36: Outputs of Taguchi's Experiments: 561 to 576

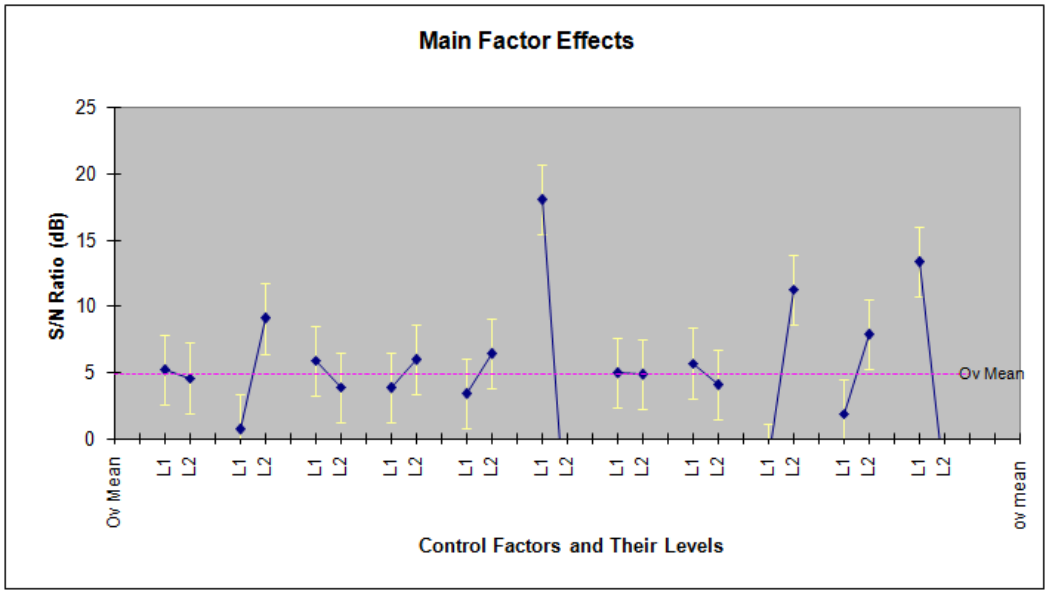
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-7.0746	-3.2075	-11.921	3.7652	-2.3371	4.6780	-9.5250	-4.8983	-16.82	4.7783	-3.8918	-66.196
2	-8.885	-5.1196	-17.138	2.6039	-4.2224	3.6975	-11.950	-11.205	-28.343	8.0893	-1.9010	-73.268
3	-6.0650	-2.0276	-10.542	2.6946	-4.9113	2.3611	-6.8380	-2.3152	-12.857	3.9533	0.3805	-89.602
4	-4.5010	-2.1890	-7.6314	2.7258	-2.7047	3.5553	-6.6857	0.0558	-7.5756	3.7221	-1.8048	-88.257
5	-4.7523	-3.4075	-9.6408	3.3337	-3.4404	1.4788	-6.3673	-1.1486	-10.789	6.0161	1.0539	-84.608
6	-8.1912	-5.9017	-19.782	1.6454	-4.4645	1.3522	-12.943	-13.314	-33.097	7.2795	-4.6736	-80.003
7	-4.5910	-1.3348	-11.080	3.6109	-2.4099	2.8773	-9.3664	-1.5448	-12.625	3.4381	-0.2637	-110.96
8	-3.4123	1.2524	-7.4018	1.0697	-1.3241	3.3665	-7.3560	-1.2132	-8.615	0.8696	0.2215	-113.46
9	-7.6871	-5.9443	-14.108	2.8822	-4.8431	4.3341	-10.755	-7.7434	-21.851	7.7243	-2.6603	-116.77
10	-5.3491	-2.2568	-9.6790	1.1642	-1.5625	4.9000	-9.2299	-2.5711	-12.250	6.4734	0.4580	-123.47
11	-5.7775	-3.0197	-9.8963	2.6053	-4.3433	3.0441	-7.1628	-5.3100	-15.206	4.3160	-1.5838	-121.79
12	-4.5658	-3.0692	-8.8239	4.7101	-1.8490	3.0007	-7.2588	-2.2952	-11.119	4.5169	0.2331	-125.48
13	-5.8077	-2.7467	-11.553	2.7900	-3.1589	3.8530	-9.5988	-5.7452	-17.298	5.3911	-0.0095	-122.38
14	-5.3538	-4.1860	-7.9447	3.4550	-3.5662	4.7830	-7.3739	-0.5323	-8.4770	5.7955	-1.9348	-127.12
15	-4.0160	-0.8974	-10.114	4.2249	-0.5307	2.2007	-8.2991	-3.4898	-13.604	5.2471	2.3685	-118.27
16	-4.4204	-0.6880	-9.7930	3.5483	-3.5046	2.7365	-8.1091	-2.4682	-12.261	5.1586	1.7254	-119.24
MEAN of sum of reciprocal squares	0.0386 168	0.3850 055	0.0098 933	0.2100 739	0.3899 861	0.1498 323	0.0147 084	21.773 462	0.0069 108	0.1250 813	736.17 852	0.0001 063
S/N Ratio	14.132 242	4.1453 305	20.046 597	6.7762 794	4.0895 085	8.2439 459	18.324 335	-13.379 27	21.604 704	9.0280 747	-28.669 83	39.732 965



Appendix D.37: Outputs of Taguchi's experiments: 577 to 592

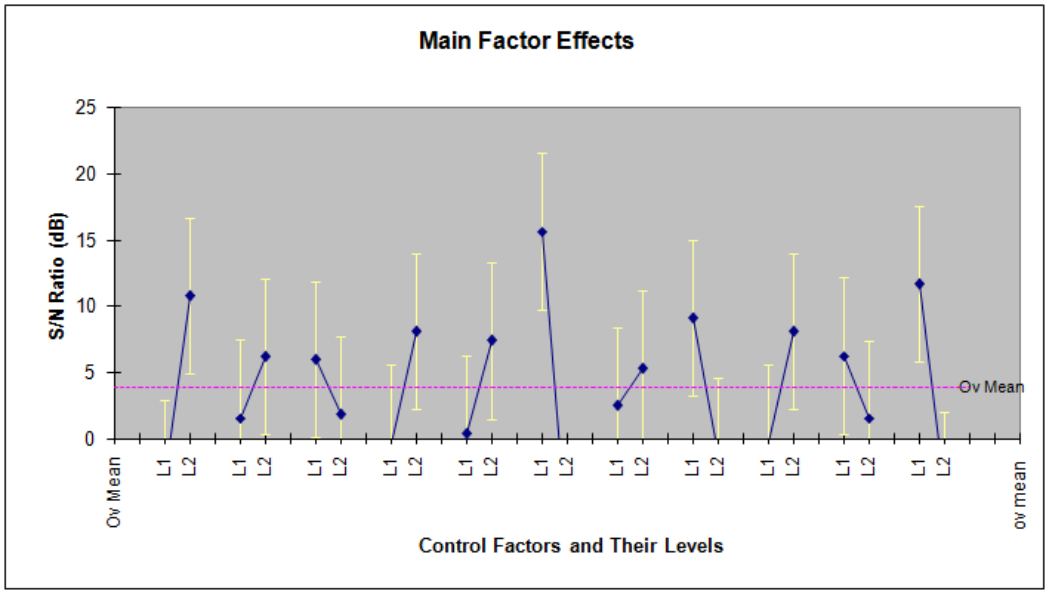
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-8.50084	-3.67428	-16.7913	3.06561	-3.5574	3.05402	-11.3445	-11.9521	-28.7435	7.99319	-0.958133	-116.436
2	-5.82655	-3.47152	-11.9878	1.33543	-3.44247	1.29534	-7.45659	-6.26394	-18.2517	5.03538	-0.763921	-134.035
3	-2.58272	-0.964972	-3.34144	2.35336	-1.78133	1.82701	-2.58572	3.65637	0.314938	3.84158	2.74318	-143.994
4	-2.45203	0.101485	-5.07677	2.34437	-1.53478	3.33027	-5.95501	0.927693	-4.14907	3.73168	3.54	-128.045
5	-3.07196	0.486203	-7.56922	4.42095	-2.12103	2.04494	-6.5422	0.709018	-6.8602	3.23396	3.36137	-117.279
6	-7.20385	-4.51991	-15.469	1.32306	-2.26799	1.37963	-9.64476	-9.36075	-24.8297	7.64446	-1.16849	-108.883
7	-2.72573	1.6684	-4.82729	3.96594	-0.29901	4.31409	-6.41565	0.0076931	-4.8196	2.32366	5.17127	-127.116
8	-5.1614	-1.13528	-10.9012	4.75252	-1.18042	4.28271	-10.0225	-3.49792	-14.3991	6.00972	2.28287	-114.511
9	-4.96847	-0.06512	-11.6931	3.97143	-1.93012	2.02245	-8.74713	-5.42615	-17.1193	2.28483	-0.870931	-113.355

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-5.91707	-3.46101	-9.89859	2.06875	-2.13973	4.48065	-8.46217	-4.14231	-14.0409	7.17968	-0.294029	-123.965
11	-4.50047	-1.80389	-6.62441	2.74525	-0.922298	4.6282	-6.75214	-0.306098	-6.93051	5.66957	2.87159	-123.368
12	-5.61304	-4.06277	-12.1711	1.95324	-2.0672	3.3381	-9.89615	-4.57401	-16.7451	7.52368	0.0467038	-111.117
13	-6.1289	-1.42267	-12.67	2.78349	-1.22198	2.6084	-9.14956	-8.07924	-20.7493	5.02809	-0.668929	-116.178
14	-5.18243	-0.224894	-12.417	3.87191	-2.96965	2.62759	-9.86215	-3.61667	-16.0337	4.35171	2.86666	-130.278
15	-6.75747	-5.03888	-14.3731	2.52262	-3.9067	3.18521	-10.8008	-8.66513	-23.0382	6.58906	-1.68158	-131.911
16	-6.52582	-4.2291	-12.705	3.38675	-4.25526	2.77201	-8.95115	-4.68259	-17.3876	6.6264	-1.1903	-143.561
MEAN of sum of reciprocal squares	0.0577966	24.003916	0.0173234	0.1839474	0.9897958	0.1913511	0.0234941	1126.6921	0.0682717	0.0591382	31.921387	6.645E-05
S/N Ratio	12.380981	-13.80282	17.613663	7.3530638	0.0445439	7.1816901	16.290403	-30.51805	1.6585175	12.281319	-15.04082	41.775118



Appendix D.38: Outputs of Taguchi's Experiments: 593 to 608

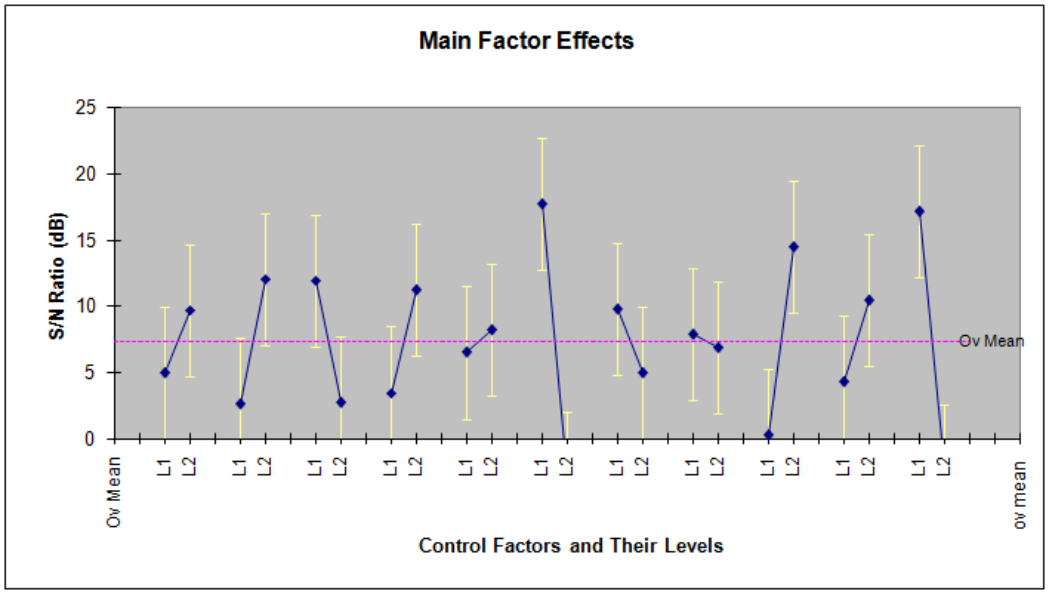
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-5.0998	-0.202378	-10.0931	4.52657	-2.10888	4.14575	-9.13908	-3.8789	-13.972	5.11127	1.64098	-148.244
2	-4.61226	0.254721	-8.32018	1.2167	-2.09193	4.4575	-8.16542	0.239867	-8.08031	2.03043	0.465554	-147.877
3	-4.00293	0.0059757	-8.24944	1.50293	-0.02328	3.05675	-7.30326	-1.72455	-9.97399	2.16052	0.160951	-145.537
4	-4.10492	0.738514	-6.99253	4.44992	-3.72991	4.28902	-7.17663	1.92845	-5.06407	0.925468	-1.17076	-150.154
5	-1.54487	1.15901	-0.849786	2.05861	-1.09742	3.50458	-2.80949	4.5558	3.70601	3.80837	7.16557	-141.64
6	-6.93061	-4.92992	-11.2031	4.15963	-3.43863	4.52806	-8.80051	-6.27736	-17.4804	8.1079	-1.17649	-116.102
7	-5.70177	-3.92895	-7.85231	4.4274	-1.81248	3.89735	-6.04789	-0.339849	-8.19216	7.01176	-1.16855	-115.38
8	-7.33415	-3.99169	-13.8358	3.34953	-2.35847	2.07032	-8.572	-5.33924	-19.1751	6.40505	-3.50587	-105.855
9	-2.14083	2.79508	-5.83413	2.39904	-1.28524	2.47318	-6.16647	2.80505	-3.02908	1.60134	3.33123	-116.724
10	-9.29401	-4.72094	-22.2299	2.88662	-4.54883	1.07072	-14.0067	-18.2196	-40.4496	8.58444	-4.21533	-107.507
11	-4.47101	-0.262747	-12.3893	2.51335	-1.268	1.10364	-9.02192	-6.46098	-18.8503	2.36792	0.226223	-145.61
12	-2.44153	1.02652	-4.45096	4.61214	-1.58359	4.01102	-6.02044	2.54932	-1.90163	1.47961	1.11344	-161.705
13	-2.61667	-0.304272	-5.41023	3.0413	-0.937385	4.66024	-7.4538	0.099532	-5.31098	3.55876	5.61292	-149.67
14	-2.93885	-1.59468	-7.04205	1.40375	-0.924378	1.75209	-5.85529	-1.27456	-8.31661	3.00857	1.40307	-136.814
15	-9.10578	-4.52006	-13.935	4.45296	-4.52811	4.78966	-9.61885	-6.12935	-20.0643	8.98523	-1.21099	-136.408
16	-7.19697	-5.83495	-15.3258	4.6244	-3.35251	3.84451	-11.9734	-8.75928	-24.0851	8.7219	-1.1417	-135.734
MEAN of sum of reciprocal squares	0.092473 8	1870.5956	0.107947 6	0.180333	123.36797	0.152012 3	0.024641 5	8.617900 6	0.040229 2	0.191119 4	3.254294 9	5.836 E-05
S/N Ratio	10.33981 5	-32.7198	9.667868 4	7.439239 6	-20.91202	8.181211 9	16.08333 4	-9.354015	13.95458 2	7.186952 1	-5.124569	42.33865 4



Appendix D.39: Outputs of Taguchi's Experiments: 609 to 624

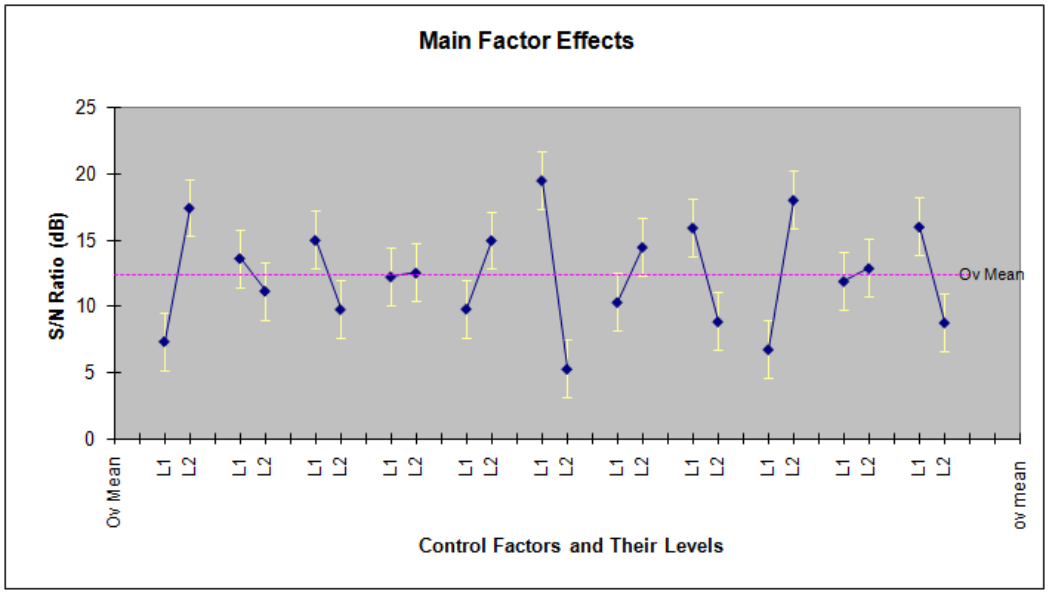
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-8.02947	-3.59997	-13.9753	1.63514	-4.24612	3.56138	-9.5072	-6.2794	-20.2547	6.28732	-4.19804	-144.149
2	-7.50946	-6.08047	-16.4528	1.49553	-2.56543	2.17853	-11.1218	-11.2827	-27.7354	7.71204	-1.04422	-156.01
3	-4.86693	-0.54724	-9.63086	3.88536	-1.70933	3.19812	-7.96205	-2.88179	-12.5126	3.63649	1.639333	-175.654
4	-4.86361	-1.187	-8.32045	3.78553	-3.50175	4.4557	-7.91254	-0.00451	-8.32501	5.80851	1.01248	-175.434
5	-6.54097	-3.14482	-13.7269	2.09309	-3.84007	2.94873	-10.1347	-5.61763	-19.3446	6.32299	-1.1166	-165.295
6	-4.78602	-0.273976	-10.7386	3.2404	-1.48409	3.25954	-9.21217	-6.64289	-17.3815	1.73478	-1.45503	-174.33
7	-3.76866	0.445876	-7.12543	3.48551	-1.81571	4.12024	-7.47701	0.216386	-6.90904	4.3146	5.771133	-187.396
8	-5.50411	-2.15578	-9.44896	3.73627	-1.54802	4.39362	-8.33846	-3.29511	-12.7441	6.55624	0.864313	-173.954
9	-4.26865	-0.884159	-8.70708	2.09164	-0.504224	2.22757	-6.66601	-2.03848	-10.7456	4.51401	0.541741	-170.84

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-5.33286	-1.31474	-10.0294	4.45168	-3.58645	4.38151	-9.07808	-3.80379	-13.8332	2.80817	0.764426	-172.573
11	-2.64944	0.930596	-7.50194	2.08277	-0.294412	2.24178	-7.09428	2.1562	-5.34574	2.70264	4.351	-172.402
12	-5.83339	-2.30693	-10.2875	2.30561	-1.37994	3.82298	-8.27707	-4.85054	-15.138	5.30449	-1.35103	-166.02
13	-2.63187	-0.384464	-1.47301	1.41031	-2.28236	4.24566	-3.0868	6.36203	4.88902	3.78654	2.03038	-170.521
14	-7.35976	-5.03068	-14.5978	1.29917	-3.35382	3.37344	-10.6114	-6.39547	-20.9932	7.14817	-1.11525	-145.963
15	-4.70508	0.0609202	-7.9401	2.71292	-4.26181	2.42039	-5.65541	-4.16414	-12.1042	3.86727	2.95953	-155.594
16	-5.25556	-1.11812	-8.32263	2.11266	-3.56522	2.71206	-5.77914	-1.30292	-9.62555	4.95082	0.802485	-151.98
MEAN of sum of reciprocal squares	0.0434546	20.128099	0.0404912	0.2237934	0.454962	0.1019714	0.0219305	3219.7418	0.0091744	0.0660036	0.8896396	3.701E-05
S/N Ratio	13.619644	-13.03803	13.926392	6.5015271	3.4202487	9.915216	16.589518	-35.07821	20.374219	11.804321	0.5078589	44.31649



Appendix D.40: Outputs of Taguchi's Experiments: 625 to 640

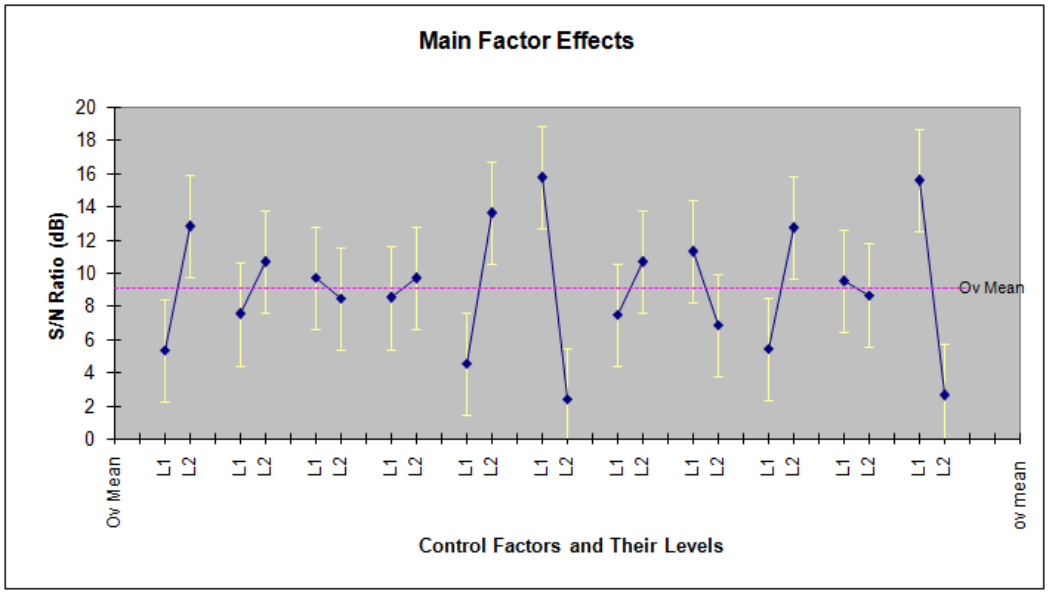
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-4.06715	-0.979636	-7.44342	1.75909	-3.0598	3.54868	-6.92494	1.18101	-6.26241	4.41886	1.54529	-147.654
2	-6.93334	-3.08451	-11.9769	2.1633	-2.82157	4.19336	-9.2369	-4.06714	-16.044	5.14207	-3.63365	-138.866
3	-4.36549	-0.5496	-6.23717	2.22276	-2.94224	4.06456	-5.93624	1.49566	-4.74151	3.90839	1.57555	-145.048
4	-6.60361	-2.03422	-14.8128	3.26645	-3.7411	3.32693	-11.5361	-8.56871	-23.3815	3.96689	-2.14082	-133.737
5	-5.87329	-3.59611	-9.13252	3.17367	-1.30557	3.60985	-6.86908	-2.06358	-11.1961	6.77495	0.680295	-151.638
6	-4.76589	-2.83698	-9.77378	1.98846	-2.41262	1.28119	-6.28908	-4.05695	-13.8307	5.19186	2.36566	-147.518
7	-3.89366	-0.894584	-7.81881	3.61934	-3.12933	4.00791	-7.93305	-1.52202	-9.34083	2.88463	1.63411	-149.916
8	-6.73546	-2.36875	-12.8882	3.55919	-3.67848	4.20441	-10.3571	-3.79549	-16.6837	5.52128	-1.02369	-143.405
9	-5.74346	-1.90072	-13.3531	1.81002	-2.74596	3.09135	-10.701	-6.46052	-19.8137	5.07355	-0.483487	-146.195
10	-7.56266	-3.72087	-14.1149	4.99226	-3.19582	3.84731	-10.3995	-7.58407	-21.699	5.19026	-2.33618	-157.148
11	-5.69724	-3.9168	-10.5619	3.17617	-3.87168	1.29605	-6.16073	-2.56299	-13.1249	7.89154	2.57066	-167.133
12	-8.39572	-4.41173	-13.7229	3.50629	-4.51577	4.72425	-10.0514	-8.23016	-21.9531	7.87024	-2.87826	-162.031
13	-8.0792	-3.40129	-12.4556	2.07748	-4.40537	4.55731	-8.93373	-3.69704	-16.1527	5.43432	-3.54479	-168.072
14	-4.1575	-1.95512	-9.82123	4.06592	-0.097147	3.42862	-9.09235	-3.53889	-13.3601	4.9016	2.83699	-171.46
15	-3.82705	-0.699101	-7.02187	3.32807	-3.82558	1.94028	-5.1351	1.29514	-5.72674	5.54541	4.38346	-171.262
16	-8.23092	-5.48202	-12.0316	1.21168	-3.43217	4.67343	-8.47411	-5.801	-17.8326	9.47583	-1.54547	-156.778
MEAN of sum of reciprocal squares	0.0357251	0.6104352	0.0106706	0.1887158	7.1864766	0.1169047	0.0163004	0.1913161	0.0102513	0.0427443	0.6693408	4.355 E-05
S/N Ratio	14.470266	2.1436041	19.718098	7.2419172	-8.56516	9.3216794	17.878031	7.1824843	19.892204	13.691223	1.743527	43.609822



Appendix D.41: Outputs of Taguchi's Experiments: 641 to 656

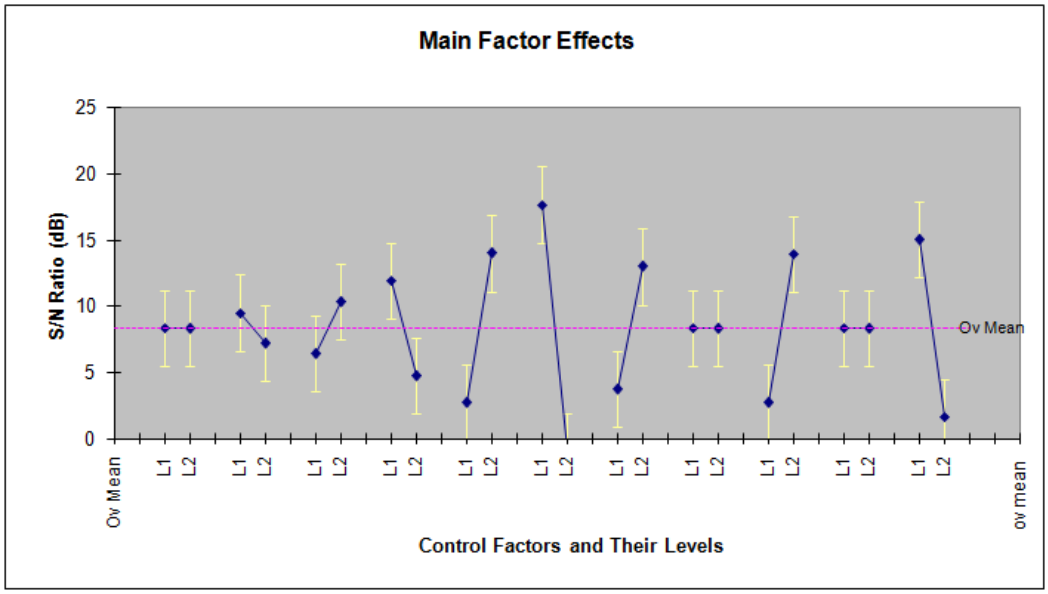
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-3.13136	1.66713	-7.93774	1.99894	-1.30703	2.7101	-7.51648	-1.13085	-9.06859	2.87781	2.8155	-157.759
2	-3.06971	-1.14463	-1.5609	4.91997	-0.776994	4.65509	-3.14627	5.68042	4.11953	5.19842	5.18518	-156.375
3	-6.0433	-4.54139	-8.61696	4.31083	-1.80034	4.76652	-7.34018	-1.66416	-10.2811	7.11824	-0.447428	-126.456
4	-4.07754	-1.03872	-4.1242	2.88201	-3.77474	4.50777	-4.55444	-0.488216	-4.61242	4.20438	0.313105	-119.322
5	-4.72419	0.072988	9.33125	4.34803	-3.57588	3.77528	-8.38234	-2.38713	-11.7184	1.90712	1.35169	-106.092
6	-6.21245	-3.16287	-12.1189	3.56326	-2.88142	4.61094	-10.5174	-6.04126	-18.1602	7.99599	-0.251475	-103.273
7	-6.14485	-4.83024	-8.8635	1.53066	-2.79881	4.16706	-6.88571	-1.63299	-10.4965	8.71817	0.521045	-105.383
8	-1.02741	3.61774	-1.79614	2.66041	-0.962482	2.01329	-2.78201	4.86449	3.06835	-1.12607	3.20795	-96.8034
9	-6.00139	-4.16903	-11.3518	2.37526	-2.92758	4.89656	-10.2469	-5.01852	-16.3703	6.31525	-1.79707	-82.0575

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-7.46858	-5.14795	-11.1006b	3.31665	-4.99309	4.1055	-7.73754	-3.62182	-14.7224	6.56718	-2.02254	-84.0921
11	-4.02923	-1.28426	-7.78957	2.54917	-2.73094	4.57373	-8.33407	-2.44324	-10.2328	4.17819	3.12687	-81.9637
12	-7.07692	-3.74416	-12.8332	3.25453	-4.64083	4.42875	-10.185	-6.59771	-19.4309	5.31435	-3.07503	-75.0481
13	-4.91113	-2.36301	-6.34573	4.06686	-1.88558	4.18201	-5.6166	-1.07662	-7.42235	4.50665	0.827703	-81.2057
14	-3.30917	0.267428	-7.49444	3.55272	-0.45572	2.12395	-6.30922	-0.597351	-8.09179	3.18213	2.7596	-71.0781
15	-5.06355	-0.308575	-12.9228	3.05285	-2.04833	1.74189	-9.60115	-3.76459	-16.6874	1.71228	-2.48862	-68.1274
16	-5.65048	-3.77513	-10.4064	3.55792	-4.01883	3.69143	-8.44733	-3.2948	-13.7012	6.7134	0.226077	-81.9199
MEAN of sum of reciprocal squares	0.1072634	14.328823	0.0612914	0.1236062	0.6417389	0.1020573	0.031774	0.6637607	0.0204329	0.1280898	3.8318276	0.0001183
S/N Ratio	9.6954855	-11.56211	12.126005	9.0795973	1.9264166	9.9115577	14.979286	1.7798849	16.896698	8.9248534	-5.83406	39.269576



Appendix D.42: Outputs of Taguchi's Experiments: 657 to 672

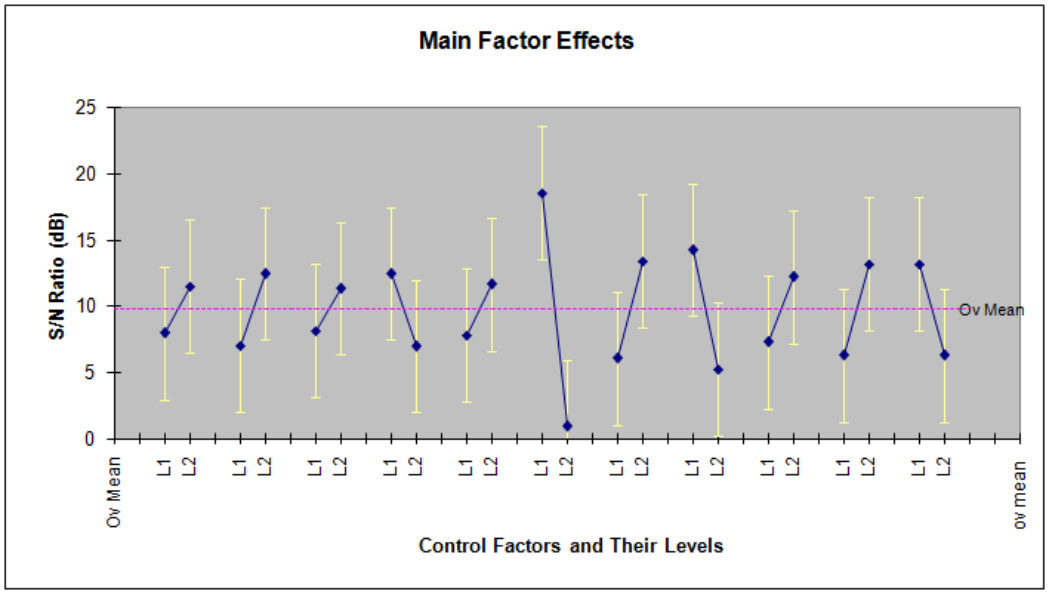
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-6.7907	-4.63104	-12.2302	3.82342	-2.67452	3.73643	-9.17589	-7.4417	-19.6719	8.97019	1.47961	-77.8012
2	-8.33303	-6.66479	-15.1863	3.31819	-4.99336	2.59334	-9.44657	-11.0546	-26.2409	11.3911	-0.507799	-80.0037
3	-3.83959	-0.626952	-7.68715	4.2495	-3.15494	2.48788	-6.33544	-0.403263	-8.09042	3.37099	1.43428	-88.4784
4	-8.46687	-5.52413	-18.3999	3.2109	-4.5636	2.87622	-12.8093	-12.8601	-31.2601	8.299	-4.59915	-81.9735
5	-5.45009	-2.4318	-10.9454	4.98977	-2.62349	3.87363	-9.36899	-4.55398	-15.4994	6.57157	1.75536	-104.981
6	-5.5331	-1.11782	-12.3694	1.7915	-3.92896	1.3667	-8.20299	-5.18846	-17.5578	3.02737	0.0077725	-101.677
7	-6.52377	-4.19934	-13.2134	2.25355	-4.22814	2.58053	-9.27015	-7.47192	-20.6853	6.11477	-3.03449	-111.698
8	-1.46361	3.30598	-3.27442	4.85233	-0.871509	1.91871	-3.72951	4.43873	1.16432	-1.62343	2.82813	-123.432
9	-2.97875	-0.286577	-8.47338	3.35272	-2.83568	1.72442	-7.21906	-3.86643	-12.3398	4.06198	3.95449	-110.77
10	-8.26649	-4.85757	-18.4417	1.98204	-3.462	1.40827	-11.5835	-12.687	-31.1287	8.46027	-3.16282	-109.552
11	-6.65788	-2.49453	-13.3405	4.9188	-3.23822	2.80805	-9.49071	-7.17978	-20.5203	5.03634	-2.27813	-135.682
12	-7.00463	-3.81429	-12.9887	3.14392	-3.12862	4.12312	-10.1072	-7.00417	-19.9929	7.72269	0.256779	-145.525
13	-2.21254	1.56184	-5.05587	4.71553	-0.996801	3.94809	-6.79142	2.31707	-2.73879	1.41661	2.66752	-149.891
14	-6.08391	-2.41774	-12.8568	2.84934	-1.76366	4.15324	-10.9262	-8.77815	-21.635	7.13318	0.704035	-138.847
15	-8.20666	-6.69715	-15.2018	2.08848	-4.21615	4.23015	-11.2253	-8.07629	-23.2781	10.0705	-1.18625	-147.796
16	-3.19643	-2.05582	-3.28678	1.90926	-1.11567	4.10623	-4.19659	2.51372	-0.77306	4.91369	1.62258	-154.079
MEAN of sum of reciprocal squares	0.0777497	1.1260664	0.0206425	0.1346096	0.2939023	0.1775493	0.0196721	0.4534602	0.1725625	0.0881123	1105.1525	8.85E-05
S/N Ratio	11.093012	-0.51564	16.85238	8.7092381	5.3179696	7.5068109	17.061487	3.4346083	7.6305357	10.549636	-30.43422	40.530323



Appendix D.43: Outputs of Taguchi's Experiments: 673 to 688

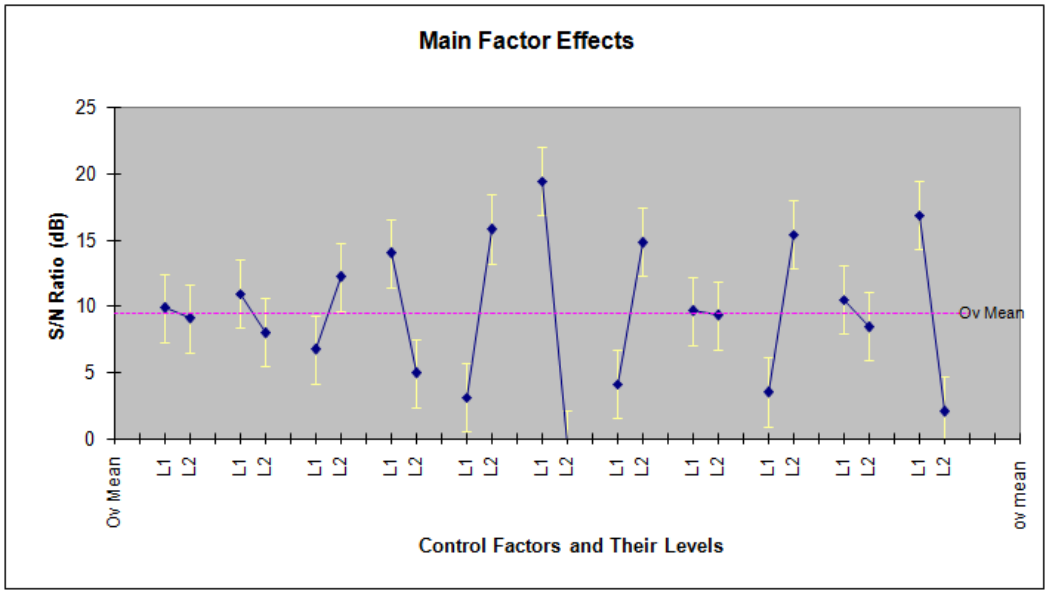
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-7.37847	-5.20126	-15.2195	3.91068	-3.43009	3.842	-11.683	-9.09645	-24.3159	9.59521	-1.14183	-136.574
2	-6.63069	-5.60244	-11.0504	4.03683	-4.1733	4.27935	-8.69904	-1.5978	-12.6482	9.69092	1.42069	-145.477
3	-8.88389	-5.27994	-16.0642	2.92904	-4.64831	3.62704	-10.8074	-8.83886	-24.9031	10.0639	-2.57508	-134.386
4	-4.5957	-2.34155	-9.27007	2.83805	-0.536801	3.95488	-8.62926	-3.41095	-12.681	3.36868	-2.51004	-144.433
5	-7.24543	-5.89136	-15.2113	2.3327	-4.45003	3.47581	-11.4417	-9.42002	-24.6314	8.73709	-1.79989	-150.557
6	-7.00179	-2.63618	-13.5131	1.75933	-2.3078	4.42865	-10.94	-5.85674	-19.3698	7.21899	-0.652022	-161.668
7	-6.07661	-3.31319	-11.591	1.7031	-2.19297	2.64421	-8.15864	-3.72523	-15.3163	5.47572	-1.83622	-168.522
8	-1.30806	0.533537	-3.42895	3.83681	-1.23802	3.97521	-6.09611	3.33071	-0.098243	4.13037	7.85993	-175.332
9	-5.65757	-0.807585	-10.681	1.88361	-2.46441	1.79158	-6.81498	-3.06986	-13.7508	4.2517	0.264022	-153.784

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-8.24714	-6.19959	-17.6988	4.25259	-4.27034	2.56424	-12.0159	-10.4676	-28.1664	9.71781	-0.516624	-158.3
11	-4.82523	-0.243947	-7.54363	3.19554	-2.5977	4.87732	-7.59572	-1.92642	-9.47004	2.66955	0.857609	-171.651
12	-4.23498	-2.42829	-5.11399	3.12572	-2.85982	3.63449	-4.5135	1.91946	-3.19453	6.6787	4.217 21	-165.551
13	-5.06731	-0.480797	-10.7742	1.84967	-3.28839	4.25972	-9.96661	-5.60604	-16.3802	2.0016	0.877076	-144.848
14	-4.17286	-2.82744	-6.68974	3.4881	-2.33031	4.9892	-7.50608	0.545486	-6.14426	6.32251	2.18048	-150.722
15	-3.534	0.576039	-8.41921	1.51569	-2.66685	3.29779	-8.183	-2.35992	-10.7791	4.18997	3.40874	-135.872
16	-5.61212	-4.45033	-13.4767	1.25234	-2.75446	1.50036	-9.3649	-4.96652	-18.4432	5.82528	-0.631796	-132.406
MEAN of sum of reciprocal squares	0.0708	0.8871917	0.0154052	0.2115924	0.3765657	0.1182113	0.015477	0.3136308	6.918604	0.046209	1.786408	4.506 E-05
S/N Ratio	11.499666	0.5198251	18.123325	6.7449987	4.2415924	9.273411	18.103119	5.0358131	-8.400185	13.352732	-2.519807	43.462362



Appendix D.44: Outputs of Taguchi's Experiments: 689 to 704

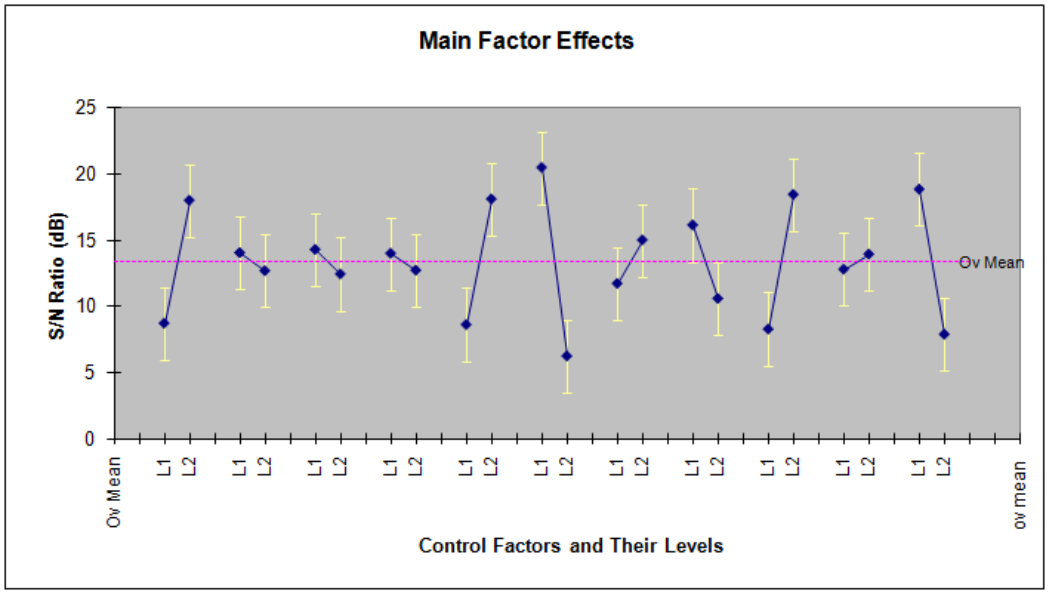
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-6.44306	-3.62932	-11.4257	4.37548	-4.47885	4.88009	-9.86272	-5.87899	-17.3047	8.23782	-0.00424	-143.46
2	-3.35931	0.291494	-3.27719	3.35973	-1.07565	3.91182	-3.8297	2.57761	-0.699584	3.90554	2.66406	-141.154
3	-8.15139	-5.36769	-17.3572	4.97471	-4.64764	3.32662	-12.5325	-9.24955	-26.6068	10.1637	0.215663	-123.187
4	-4.85255	-0.942989	-11.0137	4.69298	-4.24443	3.67055	-9.83167	-6.53133	-17.545	4.82001	3.55166	-131.895
5	-6.61058	-1.78407	-13.1795	4.41301	-2.91969	3.22585	-9.79478	-4.98157	-18.1611	3.79271	-3.37334	-131.164
6	-5.32797	-2.83705	-11.2211	3.39908	-3.76877	3.17645	-9.06959	-3.74019	-14.9613	7.63828	1.28881	-140.667
7	-8.51682	-5.30735	-19.8339	3.35425	-4.32897	1.88907	-13.2062	-13.8392	-33.6731	7.77813	-2.39985	-138.754
8	-4.4612	-1.07251	-9.62613	4.16896	-2.87859	2.88404	-8.04897	-0.837181	-10.4633	3.98787	1.04253	-165.94
9	-6.90982	-2.8787	-14.5035	4.56986	-2.1975	3.89008	-11.4838	-7.68643	-22.19	5.24792	-0.572515	-162.328
10	-3.66129	0.882791	-5.85645	3.6537	-2.31918	4.70968	-6.90483	3.51294	-2.34351	2.37393	0.902152	-173.12
11	-3.33872	-1.51122	-6.88219	1.94784	-1.59047	4.31522	-7.85869	-1.76435	-8.64655	2.65763	0.342379	-159.28
12	-4.37516	-2.55494	-10.6608	3.65724	-4.1502	1.84612	-8.1317	-4.38405	-15.0448	5.40099	1.38988	-157.464
13	-6.10238	-4.87514	-9.06988	3.46723	-1.39472	4.31874	-7.28624	-5.11496	-14.1848	5.94828	-3.09267	-159.426
14	-8.24777	-5.8985	-16.3023	3.91496	-4.30823	3.67882	-11.7334	-10.0069	-26.3092	7.78822	-2.7429	-161.982
15	-4.88838	-0.917584	-8.64753	2.59922	-2.20285	4.8485	-8.60764	-2.06744	-10.715	2.79143	-0.061614	-176.519
16	-6.24172	-3.43917	-9.18915	2.14196	-1.96277	4.24462	-7.19206	-1.52892	-10.7181	5.32222	-3.33531	-173.916
MEAN of sum of reciprocal squares	0.0366144	1.1498406	0.0148806	0.0815279	0.1908241	0.0998472	0.0161023	0.1745541	0.1520747	0.0503674	3727.7184	4.489 E-05
S/N Ratio	14.363482	-0.606376	18.273788	10.886935	7.1936682	10.006642	17.931129	7.5806985	8.1794308	12.978501	-35.71443	43.478574



Appendix D.45: Outputs of Taguchi's Experiments: 705 to 720

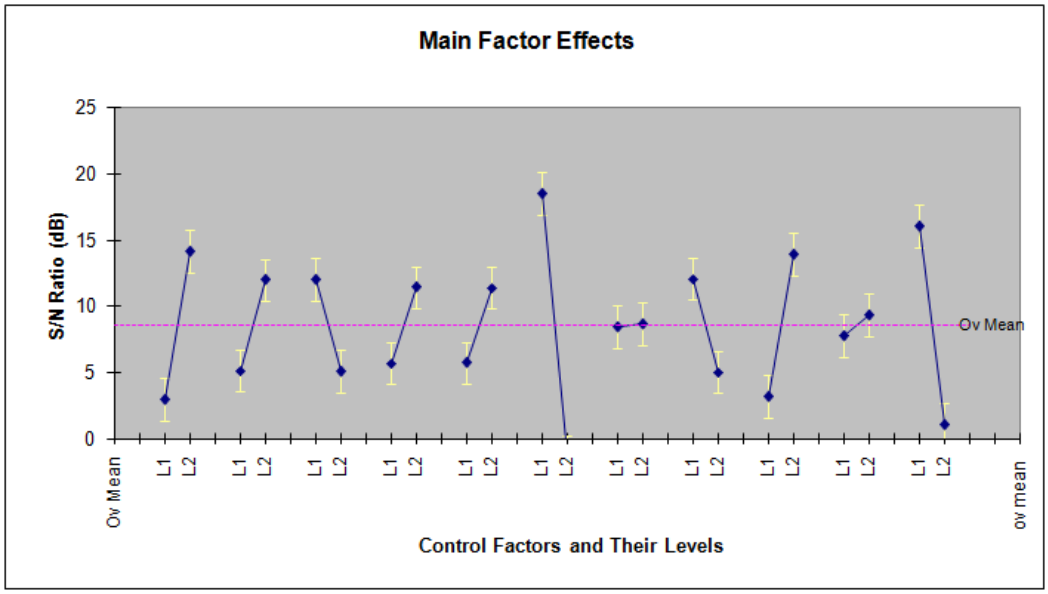
Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-9.09564	-4.87653	-15.4503	1.87844	-4.40825	3.87037	-10.225	-10.6269	-26.0772	6.66642	-4.07564	-173.922
2	-5.10069	-1.10296	-11.3516	4.69405	-2.55815	2.15755	-8.4085	-3.74425	-15.0959	6.0312	2.48453	-190.818
3	-6.67107	-3.44263	-12.9801	3.74989	-4.19763	4.74652	-11.0556	-3.4438	-16.4239	7.45561	2.01415	-189.405
4	-5.81821	-3.40076	-13.1285	4.21145	-4.05822	2.83176	-10.1421	-8.25439	-21.3829	4.5593	-1.4491	-185.03
5	-6.66966	-3.7581	-12.9798	3.01308	-3.48206	3.31259	-9.62275	-3.85449	-16.8343	8.28618	-0.64539	-195.921
6	-2.31678	1.40381	-5.61722	1.60705	-0.37307	3.57368	-6.87413	1.02607	-4.59115	2.62634	3.35095	-197.269
7	-4.40243	-0.220196	-9.68357	4.21453	-0.946365	2.17671	-7.45784	-3.35258	-13.0361	5.13637	3.70773	-188.976
8	-5.89128	-1.91216	-11.5221	2.25351	-1.79716	3.64785	-9.27867	-3.38875	-14.9108	4.31141	-2.31607	-187.31
9	-7.11799	-4.76822	-12.0496	1.80179	-4.88972	3.57693	-8.50853	-5.58997	-17.6396	8.75083	-0.929552	-193.849

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
10	-5.99998	-3.51448	-14.0231	3.64417	-3.80104	2.76538	-10.7885	-7.02253	-21.0456	4.51774	-2.1182	-194.804
11	-4.50716	-2.95775	-11.2963	1.83358	-1.20426	2.11436	-8.90345	-1.84638	-13.1426	6.57173	3.88382	-207.228
12	-8.56848	-4.00942	-19.8384	4.68013	-4.55109	2.13548	-13.4054	-11.1561	-30.9945	7.49978	-2.11298	-207.074
13	-7.48491	-3.36733	-15.9044	3.17291	-3.16408	2.01033	-10.4298	-8.49657	-24.4009	6.22628	-0.211839	-227.94
14	-5.83658	-3.59809	-11.6655	1.64262	-3.58303	4.47262	-10.3016	-3.67208	-15.3376	7.78533	0.549614	-241.59
15	-6.75705	-3.88083	-14.5139	4.91488	-2.4277	3.93712	-11.694	-6.36412	-20.878	6.48446	-0.887426	-240.083
16	-5.62689	-0.880222	-9.44346	2.62062	-4.6435	3.17891	-6.99547	-4.1962	-13.6397	3.08597	-2.05569	-247.76
MEAN of sum of reciprocal squares	0.0369038	1.614713	0.0080858	0.152853	0.6378948	0.1196942	0.0118334	0.1068119	0.0062145	0.0412165	2.1599148	2.481E-05
S/N Ratio	14.329293	-2.080954	20.922754	8.1572614	1.9525093	9.2192698	19.268912	9.7138043	22.065936	13.849285	-3.344366	46.053569



Appendix D.46: Outputs of Taguchi's Experiments: 721 to 730

Expt No.	1	2	3	4	5	6	7	8	9	10	11	12
Repetitions for each expt												
1	-4.39173	-1.57331	-11.5905	1.30968	-3.13336	1.80808	-9.0068	-5.5473	-17.1378	4.78022	1.01037	-250.179
2	-3.61146	0.0767503	-7.4849	2.07086	-2.51634	2.0012	-5.87464	0.2936	-7.1913	2.50792	1.84285	-258.962
3	-3.62853	0.0492 01	-8.0712	2.70864	-3.1633	3.74732	-8.18999	0.5641 53	-7.50704	3.06847	1.01765	-256.229
4	-6.33792	-4.17021	-11.7792	3.68509	-1.59764	3.55644	-8.99774	-5.23471	-17.0139	5.23478	-3.63286	-250.822
5	-7.01365	-3.12629	-14.2887	4.02248	-4.14936	4.17907	-11.4541	-8.01958	-22.3082	6.656	-2.24366	-260.028
6	-4.541	-2.68364	-7.80704	3.0745	-2.76111	2.66081	-5.92685	-1.8857	-9.69274	6.36819	1.92575	-268.276
7	-6.43891	-4.66071	-14.1027	3.02554	-2.51187	3.02412	-10.688	-7.74396	-21.8467	8.27749	0.99623 1	-260.395
8	-1.92864	1.11015	-1.68182	4.35843	-0.124268	4.1618	-3.91498	5.33659	3.65477	2.3483	3.90596	-269.487
9	-6.1314	-1.42125	-12.0338	4.53502	-3.19171	2.01139	-7.91384	-6.95072	-18.9846	3.67375	-2.27891	-247.807
10	-7.33592	-4.44517	-13.3299	3.04662	-3.15845	4.57911	-10.5731	-6.91068	-20.2406	8.35888	-0.679362	-257.495
11	-3.94968	-0.233187	-6.7573	3.62704	-3.67544	2.85786	-5.66548	-0.072099	-6.8294	4.55702	3.09001	-260.838


Main Factor Effects
S/N Ratio (dB)
25
20
15
10
5
0
Ov Mean
Ov Mean
L1
L2
ov mean
Control Factors and Their Levels