MULTI-OBJECTIVE OPTIMIZATION MODELS FOR PROCESS TARGETING

BY

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This thesis, written by **ASHRAF AHMED A. EL-GA'ALY** under the direction of his thesis advisor and approved by his committee, has been presented to and accepted by Dean of Graduate Studies, in partial fulfillment of the requirement for the degree of **MASTER OF SCIENCE IN SYSTEMS ENGINEERING**.

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Dedicated to

My Family Members

Father, Mother, Tariq, Dalia, Doa'a, Dania & Marianne

Also in Memoriam of My Grandfather & My Grandmother

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All praises are for ALLAH, the most compassionate, the merciful. May peace and blessing be upon his prophet Mohammed (PBUH), his family and his companions. I thank ALLAH (SWT) for giving me the knowledge and patience to complete this thesis.

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THESIS ABSTRACT

Name: ASHRAF AHMED A. EL-GA'ALY

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One of the most important decision problems in production planning and quality control is the determination of the optimal process parameters (mean and variance). Traditionally process targeting problems are formulated as a single objective optimization model. In this thesis the concept of multi-objective optimization is introduced to the process targeting problem. The multi-objective models that have been developed have three objectives: profit maximization, income maximization and product uniformity maximization measured by Taguchi quadratic loss function. Four multi-objective optimization models are developed under four different inspection policies. The first multi-objective optimization model is developed under 100% error-free inspection system. In the second multi-objective optimization model the inspection error free assumption is relaxed using cut-off point for inspection instead of the original specification limits. The third multi-objective optimization model is developed under sampling plan with error-free inspection system. The fourth multi-objective optimization model is developed where the sampling plan inspection system is subject to errors. A suitable and reliable multi-objective optimization technique is employed to generate the set of non-inferior solutions (Pareto optimal set). The utility of the models has been demonstrated using numerical examples. Sensitivity analysis is conducted to study the effect of the model's parameters and inspection errors on the sets of non-inferior solutions.

Keywords: process targeting, quality control, 100% inspection, sampling plan, inspection error, multi-objective optimization, non-inferior solution

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خلاصة الاطروحة

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ازداد في الاونة الاخيرة الاهتمام باقتصاديات ضبط الجودة لما لها من اهمية قصوى في زيادة الارباح للمسؤسسات الصناعية. من اهم مجالات اقتصاديا ضبط الجودة "التصميم الاقتصادي لبلرميترات العمليات الصناعية". منذ خمسينيات القرن الماضي تم اجراء العديد من الدراسات في ه ذا المجال، كل هذه الدراسات اقترحت نماذج امثلية ذات دالة هدف واحدة "غاليا زيادة الربح او خفض التكلفة" للوصول الى القيم المثلى لهذه البرميترات. في هذه الاطروحة تم استنباط مجموعة من النماذج لتحديد القيم المثلى لبلوميترات العمليات الصناعية باستخدام مفهوم الامثلية متعددة الاهداف. هذه الاهداف هي: زيادة صافي الارباح، زيادة صافي الدخل و زيادة انتظام المنتجات باستخدام دالة الخسارة التربيعية.

في هذه الاطروحة تم بناء اربعة نماذج ذات اهداف متعددة تحت فرضيات فحص مختلفة للمنتج . تم بناء النموذج الاول تحت فرضية ان كل عناصر المنتج تفحص بلا اخطاء في عملية الفحص. طوُرالنموذج الثاني حيث يفحص كل عناصر المنتج و لكن بفرض وجود اخطاء في نظام الفحص. النموذج الثالث يتم فيه فحص المنتج بالاعتماد على عينة عشوائية من المنتج مع خلو الفحص من الاخطاء . اخيرا طوُر النموذج الرابع بادخال فرضية وجود اخطاء في الفحص السابق ذو العينات العشوائية.

تم حل امثلة للنماذج الاربعة السابقة لاختبار هذه النماذج باستخدام خوارزمية مناسبة لانشاء مجموعة الحلول المثلى تحت مبدأ باريتو. كذلك درست و اختبرت حساسية هذه النماذج للتغيير في البارمترات المختلفة و للاخطاء في الفحص. تم ايضا مقارنة هذه النماذج و نتائجها عند خلو نظام الفحص من الاخطاء مع اذا كان هناك اخطاء في الفحص. ختمت الاطروحة بتقديم توصيات و مقترحات للبحوث المستقبلية في هذا المجال.

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CHAPTER 1

INTRODUCTION

1.1. PREFACE

The objective of this chapter is to provide an overview of quality control and quality assurance approaches. The overview includes the basic definitions of quality, quality models and thesis organization.

1.2. DEFINITIONS OF QUALITY

In any production process, the product passes through a number of operations before it takes its final form. During these operations, a certain amount of variability will exist due to the presence of variation of raw material, environment etc. From this sense, quality control considered as an essential method to minimize this variability and improve the final product quality.

Quality itself is difficult to define, it is an abstract term. The definition has evolved over time. The following are the classical definitions of quality. **Montgomery (2005)**

- Definition 1: Quality is fitness for use.
- Definition 2: Meeting specifications.

- Definition 3: inversely proportional to variability.

Quality control (QC) can be defined as a procedure or set of procedures intended to ensure that a manufactured product or performed service adheres to a defined set of quality criteria or meets the requirements of the client or customer. In the next subsection established areas of quality will be presented.

1.2.1 STATISTICAL PROCESS CONTROL

Statistical process control (SPC) is the application of statistical methods to monitor and control a process to ensure that it operates at its full potential to produce conforming products. Under SPC, a process behaves predictably to produce as much conforming product as possible with the least possible waste. While SPC has been applied most frequently to control manufacturing lines, it applies equally well to any process with a measurable output. Key tool in SPC are control charts, a focus on continuous improvement and designed experiments. **Montgomery (2005)**

1.2.2 QUALITY ASSURANCE

It is a planned and systemic set of activities to ensure that variances in processes are clearly identified, assessed and improving defined processes for fulfilling the requirements of customers and product or service makers. This is usually done through standards such as ISO and quality auditing.

1.2.3 QUALITY ENGINEERING

The quality engineering philosophy **Taguchi, et al. (1989)** is not only to consider the quality of final product, but it considers the quality concept and quality cost through all phases of a product's life cycle. The life cycle begins with product planning and continues through the phases of product design, production process design, on-line production process control, market development and packaging, as well as maintenance and product services. From this standpoint, product quality is determined by the economic losses imposed upon society from the time a product is released for shipment. These losses caused by deviation in a product's functional characteristics from their specified nominal values.

Two types of uncontrollable factors can cause deviation from target values, external and internal factors. Operating environment variables (e.g. temperature) are examples of external factors. There are two categories of internal factors, deterioration (e.g. wearing out of parts) and manufacturing process imperfection (e.g. variation in machine setting).

Quality control activities at the product planning, design and production engineering phase are referred to as off-line quality engineering, whereas the quality control activities during actual production phase are referred to as on-line quality engineering. In the off-line quality engineering three steps must be followed which namely system design, parameter design and tolerance design. On-line quality engineering includes activities such as production inspection, employment of adjustment processes, production process improvement and use of automatic control system.

1.2.4 QUALITY LOSS FUNCTION

Earlier, the concept of defective was widely used as a measurement of quality level. So, the loss incurs only if the shipped product is defective and any item falls within the specification limits is classified as a conforming item and no loss is incurred. Otherwise it is classified as nonconforming and economic loss is incurred. The step loss function was used to evaluate the quality loss of out of specifications (see Figure 1-1), but the loss is always incurred when a product's quality characteristic deviates from its target value, regardless of how small the deviation is. Taguchi proposed a quadratic penalty function for this deviation known as Taguchi quadratic loss function (see Figure 1-2).**Taguchi, et al. (1989).**

Taguchi function minimizes the loss of deviating from the target mean. Assume the loss due to a defective item is A, denote the loss function by $L(y)$ and expand it in a Taylor series about the target mean:

$$L(y) = L(T) + L^{'}(T)(y - T) + \frac{L^{''}(T)}{2}(y - T)^2 + \cdots (1.1)$$

$L(y) = 0$ When $y = T$ and the minimum value attained at this point, its fist derivative with respect to T is zero. When we neglect terms with power higher than 2, equation (1.1) reduces to

$$L(y) = \frac{L^{''}(T)}{2}(y - T)^2 (1.2)$$

$$L(y) = k(y - T)^2 (1.3)$$

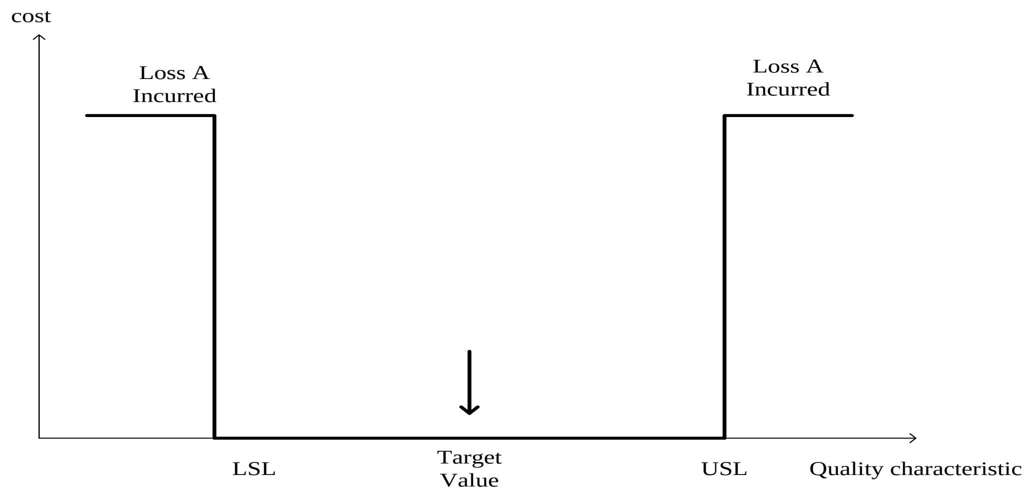

Figure1-1 Step loss function

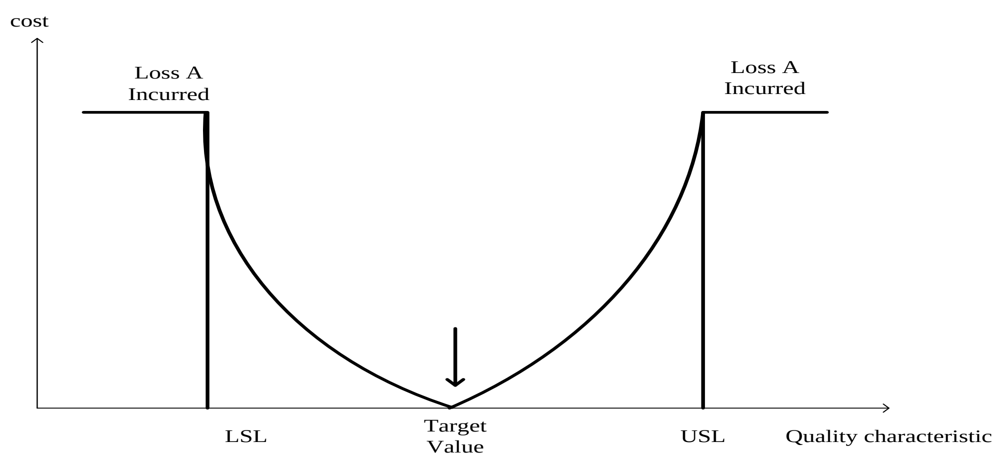

Figure1-2 Taguchi symmetric quadratic loss function

1.2.5 TOTAL QUALITY MANAGEMENT

Total Quality Management (TQM) is an approach that seeks to improve quality and performance which will meet or exceed customer expectations. This can be achieved by integrating all quality-related functions and processes throughout the company. TQM looks at the overall quality measures used by a company including managing quality design and development, quality control and maintenance, quality improvement, and quality assurance. TQM takes into account all quality measures taken at all levels and involving all company employees. **Besterfield, et al. (2003)**

Another essential topic in quality control area is known as process targeting. This topic is discussed in detail in the next separate section.

1.3. PROCESS TARGETING

An important aspect in quality control area is the determination the optimum process parameter values from economic perspective, which is known as process targeting problem. This problem relates the product quality and conformity to the production cost by finding the optimum parameters and settings.

Due to the inherent variability discussed earlier, a product may or may not be able to meet the desirable specifications. To increase the acceptance level of a product, the process parameters could be set higher than their intended level, resulting in a cost of over doing (give away cost). Therefore, the process targeting problem objective is to find the optimum parameter settings which achieve the both issues, product quality and conformity and minimize the total cost resulting from quality cost, manufacturing cost, material cost, etc.

The initial process targeting model has been proposed by **Springer (1951)** which is defined as follows:

A can filling process is considered. The quality characteristic is assumed to be the net weight of the filled can. The value of this variable is a random variable y, which assumed to be normally distributed with known variance. This quality characteristic has a lower and upper specification limit, LSL and USL, respectively. A product is accepted if y falls within the specifications ($LSL \leq y \leq USL$) and rejected otherwise. The inspection assumed to be 100%, automatic and error free. Finally, the objective is to minimize the expected total production cost.

The model formulated by **Springer (1951)** has been extended and modified several times in the literature. These extended models, proposed and relaxed different type of assumption. The assumptions include reprocessing the rejected items, measurement error, deal with the profit instead of the cost, use Taguchi quadratic loss function, etc.

This thesis focuses on this area of quality control.

1.4. INSPECTION

Inspection is the process of examining a product or a process to asses if specifications are met or not. It is usually the classification of a product under quality control aspect is done by inspection. The inspection can be done manually or automatic and sometime requires a specific type of measurement systems and tools. The most common inspection policies are no inspection, 100% inspection and acceptance sampling.

In the no inspection policy as the name states, there is no inspection done at all. It is obvious that, this policy involves a great amount of risk of accepting defective products.

In the 100% inspection policy all the produced items are inspected, removing the defective ones (which may be reprocessed, scrapped, replaced with good items, etc.). The incurred cost by this policy is higher than any other policy, but the outgoing quality is better.

The previous two policies are two extremes since the former incurs low cost but low outgoing quality also, where the later has a perfect outgoing quality but incurs high cost. In the middle of these two extremes the acceptance sampling policy takes place. In this policy a sample should be picked at random from the lot, and on the basis of information that was yielded by the sample, a decision should be made regarding the disposition of the lot. In general, the decision is either to accept or reject the lot. There are several types and dimensions of acceptance sampling plans; one should determine which plan to use according to the process nature and the precision. Some of these dimensions are single, double or multiple (sequential) sample plans, rectifying or non-rectifying plan etc.

Finally, an essential issue with any inspection policy is that of the inspection perfection **Hong and Elsayed (1999) and Duffuaa and Siddiqui (2003)**.The inspection system is not perfect. The terms accuracy and precision are often used in this connection. Accurate measurement system is the one that contains no systemic negative or positive error about the true value, which is known as unbiased measurement. On the other hand, high precision means that the measurement system has a little or no random variability in the measured value.

1.5. THESIS ORGANIZATION

The problem of process targeting is the focus of this thesis. The problem of process targeting has been formulated as a multi-objective optimization problem under different conditions

The rest of the thesis is organized as follows: chapter 2 presents the literature review. Chapter 3 contains the first multi-objective optimization model with 100% error-free inspection is used as means of quality control. Chapter 4 contains the second multi-objective optimization model under 100% error-prone inspection system. Chapter 5 contains the third multi-objective optimization model with sampling plan error-free inspection system. Chapter 6 contains the fourth multi-objective optimization model under sampling plan error-prone inspection system. Finally, chapter 7 contains summary of the results of the four above developed models and future research suggestions.

CHAPTER 2

LITERTURE REVIEW AND OBJECTIVES

2.1 PREFACE

The purpose of this chapter is to present the literature review on the process targeting area. Next, the concept of the multi-objective optimization and some of the algorithms for solving the multi-objective optimization models are explained. The basic models which are used in this thesis are presented at the end of the chapter.

2.2 LITERTURE REVIEW

Springer (1951) is the first who initiated the targeting problem. He has developed the first model to determine the optimum process target mean for a canning process. The model assumed to be normally distributed with upper and lower specification limits and known mean. He has considered the cost of under filling and over filling as fixed but different. The model aims to find the optimum process target mean that minimizes the expected total cost.

Bettes (1962) addressed the same model as **Springer (1951).** This model based on trial and error to find the optimum process target mean.

Hunter and Kartha (1977) proposed a model to determine the optimum process target mean of a filling process that maximizes the expected total income. The quality characteristic assumed to be normally distributed with lower specification limit. Cans with quality characteristic value above the specification limit are sold at a fixed price and cans with quality characteristic value below the specification limit are rejected and sold in secondary markets at a reduced price. They have provided a monograph that aids to find the optimum process target mean for any set of cost variables.

Nelson (1979) provided a monograph for the model presented in **Springer (1951)**.

Carlsson (1984) modified the work of **Hunter and Kartha (1977)** to include the fixed cost and the variable cost and applied his model in a steel beam industry. He derived a more general income function where a premium was added when the product displayed a high quality and a deduction was made when the product exhibited an inferior quality.

Bisgaard, et al. (1984) extended the model of **Hunter and Kartha (1977)**. The assumption that the under filled cans are sold in secondary markets is unrealistic as empty cans are sold at the same reduced prices as well as near full can. In this model cans drop below the lower specification limit are sold in secondary markets at reduces price proportional of the can content. Industrial examples of different distributions of the process are provided such as, normal, lognormal and Poisson distributions.

Golhar (1987) the assumption made in **Bisgaard, et al. (1984)** is unrealistic because it creates infinite number of selling prices for each filling amount below the specification limit. Hence, **Golhar (1987)** modified this assumption and formulated another model. In this model cans drop below the specification limit are empted and refilled at fixed reprocessing cost.

Vidal (1988) provided a graphical method to determine the optimum process target mean for the model in **Bisgaard, et al. (1984)**.

Golhar and Pollock (1988) extended the model in **Golhar (1987)** to include an upper specification limit, and reduce the cost associated with reprocessing cans exceed the upper specification limit. This model turn to the model in **Golhar (1987)** as the upper specification limit tends to infinity.

Rahim and Banerjee (1988) are the first to consider a process with linear drift. They have proposed a search algorithm and graphical method to find the optimum production run length.

Carlsson (1989) proposed a model to find the optimum process target mean under acceptance sampling for the case of two variable quality characteristics.

Schmidt and Pfeifer (1989) investigated the effects of the variance reduction and the associated cost saving in a single level canning process. The relationship between the percentage reduction in the standard deviation and the cost saving, assumed to be simple linear relationship.

Schmidt and Pfeifer (1991) extended the model in **Golhar (1987)** to a two level canning process to determine both process target mean and the upper specification limit. A comparison between a single and two level canning process and the associated cost saving is proposed also.

Boucher and Jafari (1991) extended the model in **Hunter and Kartha (1977)** by introducing a single sampling inspection plan instead of 100% inspection.

Molly (1991) formulated the problem of a uniform filling process under compliance testing. The objective was to minimize the non-compliance and give-away cost.

Golhar and Pollock (1992) studied the effect of variance reduction on the expected total cost for the model in **Golhar and Pollock (1988)**.

Dodson (1993) developed a cost model to determine the optimum process mean that minimizes the total expected cost considering both upper and lower specification limits. He assumed that the variable price for conforming items with a linear relation with the ingredient amount.

Bai and Lee (1993) formulated a model to determine the optimum target mean of a filling process in which inspection based on a correlated variable instead of the quality characteristic itself.

Arcelus and Rahim (1994) proposed an algorithm to determine the optimum target mean for both variable and attribute quality characteristic simultaneously.

Al-Sultan (1994) addressed the problem of two machines in series with inspection sampling plan. He has proposed an algorithm to find the optimum target mean for two machines in series, with single sampling inspection at each machine.

Lee andKim (1994) considered a filling process where a lower specification limit is given and the outgoing cans are inspected with a surrogate variable which is correlated with the quality characteristic of interest. Under and over filled cans are emptied and refilled. A profit model is constructed which involves selling price, filling, rework, inspection, and penalty costs to determine the optimal process mean, cutoff value and upper specification limit.

Das (1995) proposed a non-iterative numerical method to find the optimum process target mean based on **Hunter and Kartha (1977)** model and discussed the importance of process variability.

Ladeny (1995) proposed a model where the over and under filled item are reprocessed at a different cost. The model objective is to determine the optimum process target mean that maximizes the expected total profit.

Mihalko and Golhar (1995) were the first who consider the process variance as a decision variable as well as the process target mean. The proposed model finds a confidence interval for the optimum process target mean for the case of unknown process variance.

Liu, et al. (1995) developed a model to determine the optimum process target mean and upper specification limit for a filling process with limited capacity constraint.

Arcelus (1996) introduced Taguchi quadratic loss function**.** The process target mean in this model is trade-off between the target process mean that maximizes (minimizes) the expected total profit (the expected total cost) for the manufacturer and the target mean of the society.

Aecelus and Rahim (1996) presented four models for different assumptions related to finding a trade-off between conformity and uniformity. Taguchi quadratic loss function has been used to measure products uniformity.

Chen and Chung (1996) considered the quality selection problem in which the process mean shifts to out of control state as a result of an assignable cause at a random point in time that follows exponential distribution. An economic model was proposed for determining the optimum process target mean and production run length, which are determined by the tradeoff among the expected total revenue, the adjustment cost and the inspection cost.

Pulak and Al-Sultan (1996) developed a model to determine the optimum process target mean under rectifying inspection plan that maximizes the expected total profit. They have also considered the effect of variance reduction in the cost saving.

Lee and Jang (1997) introduced the case of three-class screening. In this model the products are sold in two different markets with different price structures. They have developed two models in this paper. The first model, to determine the optimum process target mean when the inspection based on the quality characteristic it’s self. The second model, to determine the optimum process target mean when the inspection based on a correlated variable.

Liu and Taghavachari (1997) studied the economic selection of the process target mean and the upper specification limit of filling process under capacity constraints. The filling amount assumed to follow an arbitrary continuous distribution, and the upper specification limit can be presented by a very simple formulation regardless of the shape of distribution.

Pulak and Al-Sultan (1997) presented a computer program for nine different process targeting problem models.

Al-Sultan and Al-Fawzan (1997a) extended the model in **Rahim and Banerjee (1988),** assumed a process with random linear drift with known standard deviation and both specification limits. The model objective is to determine the optimum process target mean and production cycle length.

Al-Sultan and Al-Fawzan (1997b) investigated the effect of variance reduction in the expected total cost in the model proposed by **Rahim and Banerjee (1988)**. The optimum process target mean and production run length are determined.

Roan, et al. (1997) considered other production parameters i.e. setup cost and raw material procurement policies. They have adopted two discount polices in the model and assumed that the production rate is a function of the process mean.

Cain and Janssen (1997) proposed a model to determine the optimum process target mean where the cost is asymmetrical across the target. The cost assumed to be linear below lower specification limit and quadratic above upper specification limit.

Pollock and Golhar (1998) assumed a filling process with constant demand and capacity constraint. Using a profit function that includes the cost of production and a penalty for under-production, the optimum process target mean can be found.

Al-Sultan and Al-Fawzan (1998) developed a model to determine the optimal initial process mean and production run which minimizes the total cost. They studied a multistage production system where the processing at each stage was performed by a process that deteriorated randomly with time.

Wen and Mergen (1999) proposed a model that helps minimize the quality costs when the process is not capable of meeting specification limits. The proposed method, which is a special case of the one proposed by **Springer (1951)**, is a short-term measure to deal with the loss due to incapability of the process. The process is assumed to be in statistical control but not 100% capable of meeting the specification limits.

Hong and Elsayed (1999) studied the effect of measurement error on the optimal target mean for the case of two-class screening process.

Hong, et al (1999) considered the situation where there are several markets with different cost/price structures. They have provided methods for determining the optimum target mean and specification limits for each market those maximize the expected total cost. They have assumed that all items are inspected prior to shipment, and the inspection is performed on a variable which is highly correlated with the quality characteristic of interest.

Pfeifer (1999) presented a general model for a filling process consisting of a piecewise linear profit function with two break points.

Phillips and Cho (2000) developed a model to determine the optimum process target mean of skewed and symmetric process distribution. Beta distribution is considered in the model which can be shaped and scaled to fit most of skewed and symmetric process distributions. The model uses the quadratic loss function to evaluate the quality cost within the specification and determines the optimum process target mean which minimizes the expected total cost.

Rahim and Al-Sultan (2000) considered the problem of simultaneously determining the optimal target mean and target variance for a process. The model aims to reduce the total expected cost and the product variability.

Rahim and Shaibu (2000) proposed a model similar to the model in **Springer (1951)** but in term of profit instead of cost. A product within the specifications incurs a profit *p*. a product below the lower specification limit or above the upper specification limit incurs cost *Cl* or *Cu*, respectively. The model determines the optimum process target mean which maximizes the expected total profit.

Roan, et al. (2000) incorporated the issues associated with production setup and raw material procurement into the classical process targeting problem. The product is assumed to have a lower specification limit, and the non-conforming items are scrapped with no salvage value. The production cost of an item is a linear function of the amount of the raw material used in producing the item. The proposed model aims to determine the optimum process target mean, production run size and material order quantity which minimize the expected total cost.

Shao, et al. (2000) proposed a model where several grades of consumer specifications may be sold within the same market. In such situations, manufacturers may hold goods that have been rejected by one customer to sell the same goods to another consumer in the same market later. The expected profit function for such firms must consider the holding costs as well as the profits associated with this sales strategy. The model objective is to determine the optimum process target mean that maximizes the expected total profit.

Siddiqui (2001) developed a multi class targeting model under error and error free measurement system. The effect of measurement error eliminate by set optimal cut off points. The product uniformity also considered using Taguchi quadratic loss function.

Hung (2001) presented a trade-off model between the product quality and the adjustment cost to determine both the optimum process target mean and variance, which minimize the expected total cost. The symmetric Taguchi quadratic loss function is adapted to for measuring the loss of profit due to deviate from the process mean within the specification limits.

Lee, et al. (2001) proposed a model to determine the optimum process target mean and specification limits under single and two-stage screening. In single-stage screening case inspection can be used directly on the quality characteristic of interest or on a variable that is correlated with the quality characteristic.

Lee and Elsayed (2002) considered the problem of determining the optimum process target mean and screening limits of a surrogate variable associated with product quality under a two-stage screening procedure. In this procedure, the surrogate variable is inspected first to decide whether an item should be accepted, rejected or the quality characteristic of interest is then observed to classify the undecided items. The model finds the optimum process target mean and screening limits which maximize the expected total profit.

Chen and Chou (2002) modified **Wen and Mergen (1999)** model by including Taguchi quadratic loss function for a one sided specification limit to evaluate the quality cost. The model objective is determining the optimum process target mean.

Chen, et al. (2002a) proposed another modified **Wen and Mergen(1999)** cost model with asymmetric linear and quadratic loss function to measure the quality cost of products within specification limits, for determining the optimum process target mean.

Chen, et al. (2002b) proposed a similar modification in **Wen and Mergen (1999)** model like **Chen et al. (2002)** to determine the optimum process target mean. Here, two specific conditions are considered: 1) the process standard deviation is proportional to the process mean. 2) The auto correlated process.

Duffuaa and Siddiqui (2002) proposed two process targeting models for three-class screening. Product uniformity considered in the models using Taguchi quadratic loss function.

Teeravaraprug and Cho (2002) extended Taguchi univariate loss function to a multivariate quality loss function. The model included the same three cost elements. Their model could also be used for the case where co-variances among the quality characteristics exist.

Chen and Chou (2003) proposed another modification in **Wen and Mergen (1999)** model. They have studied the effect of multiple quality characteristics in the original model. The bivariate quality characteristic and asymmetric quadratic loss function are taking into account in the development of the cost model.

Duffuaa and Siddiqui (2003) proposed a process targeting model for three-class screening. The case of measurement error present in inspection system is considered in this model.

Kim and Cho (2003) proposed a similar model of **Phillips and Cho (2000)** to determine the optimum process target mean. In this model, Weibull distribution is used to fit most of skewed and symmetric process distributions.

Lee, et al. (2004) used a similar concept as **Golhar (1987)**, with upper and lower specification limits. Over and under filled cans are empted and refill again, with the assumption that the reprocessing cost is proportional of the amount of ingredient in a container can that is not changed after reprocessing. The proposed economic model consists of the selling price and the cost of production, inspection, reprocessing and quality, the later cost evaluated using Taguchi quadratic loss function. The objective of the model is to determine the optimum process target mean where the process standard deviation is known.

Rahim and Tuffaha (2004) revisited **Chen and Chung (1996)** problem and used Taguchi’s loss function and an upper limit for the process parameter to determine the optimal process mean and production run. They used a sampling inspection in addition to 100% inspection and provided a comparison between them. They showed that the target mean in the sampling case was always higher than the 100% inspection case, while the production run was almost the same in both scenarios.

Bowling, et al. (2004) are the first who discussed the roles of a Markovian approach and then develops the general form of a Markovian model for optimum process target levels within the framework of a multi-stage serial production system which maximize the expected profit per item.

Chen and Chou (2004) modified the model in **Hung (2001)** to determine the optimum process target mean and variance, by considering both the linear and quadratic asymmetric loss function to evaluate the quality cost.

Kulos (2005) developed a profit model to determine the optimum target mean for a product has two quality characteristics which produced by two machines in series.

Fareedduddain (2005) developed four process targeting models with different inspection policies for two stage production process in series for a product with two quality characteristics.

Teeravaraprug (2005) considered a situation of two market products. In this case, a product was classified into two grades with respect to market specifications. It was reasonably assumed in the model that each grade had its price and the manufacturers could not produce every item to a good grade due to the variation of product performance. An optimization procedure was proposed to identify the optimal initial value of a process target. However, he assumed that the variance was constant which needs to be relaxed in future.

Chen and Chou (2005) further presented a modified **Wen and Mergen (1999)** model with log-normal distribution. The step loss function and the piecewise linear loss function of product are considered in the modified model to determine the optimum process target mean.

Chen (2005) proposed a modified **Pulak and Al-Sultan (1997)** model, by considering both the lot tolerance percentage defective (LTPD) and the average outgoing quality limit (AOQL). In this model the optimum process target mean which maximizes the expected total profit is obtained.

Lee, et al. (2005) considered the problem of determining the optimum process target mean and screening limits under single-screening procedure. Two surrogate variables correlated to the quality characteristic of interest are observed simultaneously in the single-screening procedure.

Li (2005) stated that, using a quadratic loss function when the actual loss function is non quadratic may yield incorrect input parameter levels. In certain situations, a linear loss function is more appropriate in industrial applications. Hence, the optimum process target mean is determined under a truncated asymmetrical linear loss function to describe unbalanced tolerance design, which minimizes the total expected cost.

Hong, et al. (2006) most of the models in the targeting literature assumed the nominal the best quality characteristic. The authors here have developed a cost model assuming that the quality characteristic of interest is the larger the better (L-Type). The objective of the model is to determine the optimum process mean and tolerance limits.

Jordan and Maghsoodloo (2006) proposed a profit model with fixed selling price, a linear cost to produce and fixed reprocessing cost under the uniform distribution. The objective of this model is to find the optimum process target mean and upper specification limit.

Chen (2006a) proposed a modified **Wen and Mergen (1999)** cost model with mixed quality loss function to determine the optimum process target mean. The mixed quality loss function includes a quadratic loss function for products within the specifications and a piecewise linear loss function for products out of specifications.

Chen (2006b) presented a modified economic manufacturer quantity (EMQ) model with imperfect product quality. The quality of products within the specifications is measured using asymmetric quadratic loss function, products drop below the lower specification limit are scrapped and products fall above the upper specification limit are reworked again. Perfect and imperfect rework procedures are considered to determine the optimum process target mean and production quantity.

Mujahid and Duffuaa (2007) proposed a process targeting model for a product with multi-characteristic and these quality characteristics cannot be measured directly but calculated indirectly from multi-input process parameter. The relation between the observed parameters and the required characteristics is addressed using fuzzy techniques. A genetic algorithm is developed to obtain optimal process targets.

Lee, et al. (2007) developed a model for determining the optimum target mean for a production process where multiple products are processed. The quality characteristic of the products assumed to be normally distributed with known variances and common process mean. Product fail to meet the specifications are scrapped. The objective of the model is to find the common process mean which maximizes the expected total profit.

Chen andLai (2007a) proposed a modified **Al-Sultan and Pulak (1997)** model to determine the optimum process target mean under rectifying inspection plan, with Taguchi quadratic loss function for measuring the quality cost within the specifications. Assume that the non-conforming items found in the sample of accepted lot are replaced by conforming ones.

Chen and Lai (2007b) proposed an integrated model with EMQ model and **Chen and Lai (2007a)** model to determine the optimum process target mean, specification limits and production quantity which maximize the expected total profit.

Hong and Cho (2007) proposed a model for jointly determine the optimum process target mean and tolerance limits for several markets with different cost structures. The effect of measurement error has been investigated in the model.

Tahera, et al. (2008) provided a review paper for the work that has been done in the area of economic selection of process parameters including process mean and production run.

Chen and Chen (2008) modified **Bowling, et al. (2004)**by taking into account the quality cost for the work-in-process and the finished product within the specification limits based on the bivariate quality loss function.

Duffuaa, et al. (2009a) developed a profit model to determine the optimum target mean for a product with two quality characteristics produced by two processes in series. The quality of the product is controlled by an error free 100% inspection plan. The proposed model aims to determine the optimum process target mean that maximizes the total expected profit by determined by the setting of the first process, whereas the second quality characteristic depends on the setting of the two processes.

Duffuaa, et al. (2009b) developed a profit model to determine the optimum target mean similar to the model in **Duffuaa, et al. (2009a).** In this model the product also assumed to have two quality characteristics produced by two processes in series, but the inspection plan used in this model is an error free single sample inspection plan. As well as the first model, this model determines the optimum process target mean that maximizes the total expected profit using the same procedure.

Chen and Khoo (2009) proposed an integrated model with production and quality. The model consists of, a modified **Al-Sultan (1994)** model with *k* machines in a serial production system based on a single sampling inspection plan and EMQ model. The symmetric quadratic loss function is used to evaluate the quality cost within the specifications. The model objective is to determine the optimum process target mean and production quantity which maximize the expected total profit.

Chen (2009a) modified the economic manufacturer quantity model (EMQ) with imperfect quality. Hence, it is necessary to include the quality cost in the EMQ model. The objective of this model to determine the optimum process target mean and production run length which minimizes the expected total cost. Taguchi symmetric quadratic loss function is used to evaluate the product quality cost within the specification limits.

Chen (2009b) proposed a model to determine the optimum process target mean and production run length those maximize the expected total profit of the EMQ model with perfect rework process. Taguchi quadratic loss function for the larger the better (L-Type) quality characteristic used to evaluate the quality cost within the specification limits.

Chen (2010) modified the model in **Al-Sultan (1994)** model with *k* machines in a serial production system based on a single sampling inspection plan and EMQ model like the modification made in **Chen and Khoo (2009)**. Here the author used the asymmetric quadratic loss function to evaluate the quality cost within the specifications instead of the symmetrical function used in **Chen and Khoo (2009)**. The model objective is to determine the optimum process target mean and production quantity which maximize the expected total profit.

The literature review revealed that the process targeting problem has not been modeled in a multi-objective optimization framework. Hence, a need for research in this area exists.

2.3 THESIS OBJECTIVES

The following objectives are planned to be accomplished during the course of the thesis:

1. Develop a multi-objective process targeting model using 100% inspection as a mean for product quality control assuming perfect inspection.

2. Develop a multi-objective process targeting model using acceptance sampling as a mean for product quality control assuming perfect inspection.

3. Generalized the two model developed in objectives 1 and 2 to situation where inspection error is present.

2.4 MULTI-OBJECTIVE OPTIMIZATION (MOO)

In many real-world problems, decisions depends on multiple and conflicting criteria. There is usually not a unique solution that simultaneously optimizes all criteria. Multi-objective optimization aims to identify the best trade-off between these criteria. The general multi-objective model is given as:

$$max_{x\epsilon X}\ \boldsymbol{f}(\boldsymbol{x}) = [\ f_1(\boldsymbol{x})\ , f_1(\boldsymbol{x}), \dots\dots, f_n(\boldsymbol{x})]$$

Where X is the feasible region defined with m constraints as:

$$X = \{\boldsymbol{x} | g_i(\boldsymbol{x}) \leq 0\ ;\ i\ = 1,2, \dots.., m\}$$

Multi-objective optimization problems can be found in various fields that include: product and process design, finance, aircraft design, the oil and gas industry, automobile design, or wherever optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives. An example of multi-objective optimization problems is maximizing the profit and minimizing the cost of a product. Another example is minimizing the weight while maximizing the strength of a particular component.

There are no certain optimality conditions for the multi-objectives optimizations problems because a solution which maximizes one objective will not, in general, maximize any of the other objectives. In other word, what is optimal in term of one of the n objectives is usually non-optimal for the other n-1 objectives. Hence, a concept called non inferiority “non-dominance” will serve a similar purpose for multi-objective optimization just like the single objective optimization optimality conditions.

A feasible solution to a multi-objective optimization problem is said to be non-inferior if there exists no other feasible solution that will yield an improvement in one objective without causing degradation in at least one other objective. Mathematically, $\boldsymbol{x}^*$ is said to be a non-inferior solution of a general multi-objective optimization problem like the one defined above if there no $\boldsymbol{x} \epsilon X$ (feasible) such that $f_i(\boldsymbol{x}) \geq f_i(\boldsymbol{x}^*)$ for all $j = 1,2,..,n$ with strict inequality for at least one j. **Miettinen (1999), Cohon (1978)** and **Chankong and Haimes (1983).**

The following techniques are commonly used to generate and characterize the set of non-inferior solutions for the multi-objective optimization problems. These techniques transform the multi-objective problem into single objective or series of single objective problems then, used the classical optimality conditions to determine their solutions. The set of non-inferior solutions is obtained from these solutions. The techniques are:

- The weighting method $P(\boldsymbol{w})$**.**

  The idea is to associate each objective function with a weighting coefficient and minimize/maximize the weighted sum of the objectives. In this way, the multiple objective functions are transformed into a single objective function.

- The K^{th} objective, ε constraint method $P_k(\boldsymbol{\varepsilon})$.

  In this method, one of the objective functions is selected to be optimized and all the other objective functions are converted into constraints by setting an upper bound to each of them.

- The K^{th} objective, lagrangian method $P_k(\boldsymbol{\varepsilon})$.

2.5 PROCESS TARGETING MODEL

The problem formulated in this section will be used in different settings in this thesis. It will be the basis for the research work in all of the coming chapters.

2.5.1 DESCRIBTION OF THE PRODUCTION PROCESS

This industrial production process produces items that have a quality characteristic y with two control limits. Primary market specification limit (LSL) and secondary market specification limit (L). Produces items may fall into three categories or areas. First, an item whose quality characteristic is above the primary market specification limit $(y \geq LSL)$, is sold in a primary market at a regular price $\$a$ but, have give away cost $\$g$ per item of excess quality measure for a good item. Then, an item whose quality characteristic locates between the two limits$(L \leq y < LSL)$, is sold in a secondary market at reduced price $\$r$ where $r < a$. Finally, am item has a quality characteristic below the secondary market specification limit $(y < L)$, is reworked again incurring rework cost $\$R$. The production cost is assumed to be known and constant per item $\$c$. This item processing cost consists of several costs (processing, labor, inspection, etc).The quality characteristic of interest y is normally distributed with unknown mean T and known standard deviationσ.

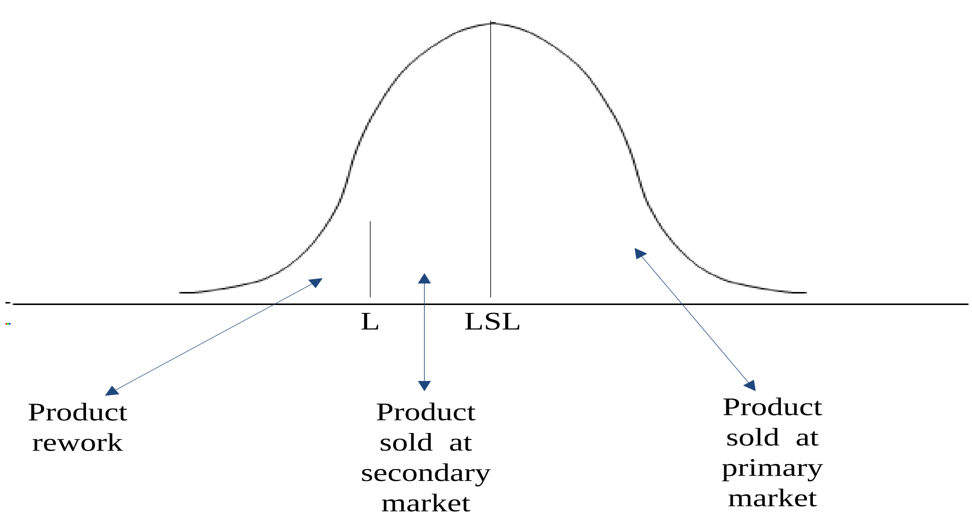

Figure 2-1 the classifications of the production process

A schematic flowchart for the production process described above is given in (Figure 2-2).

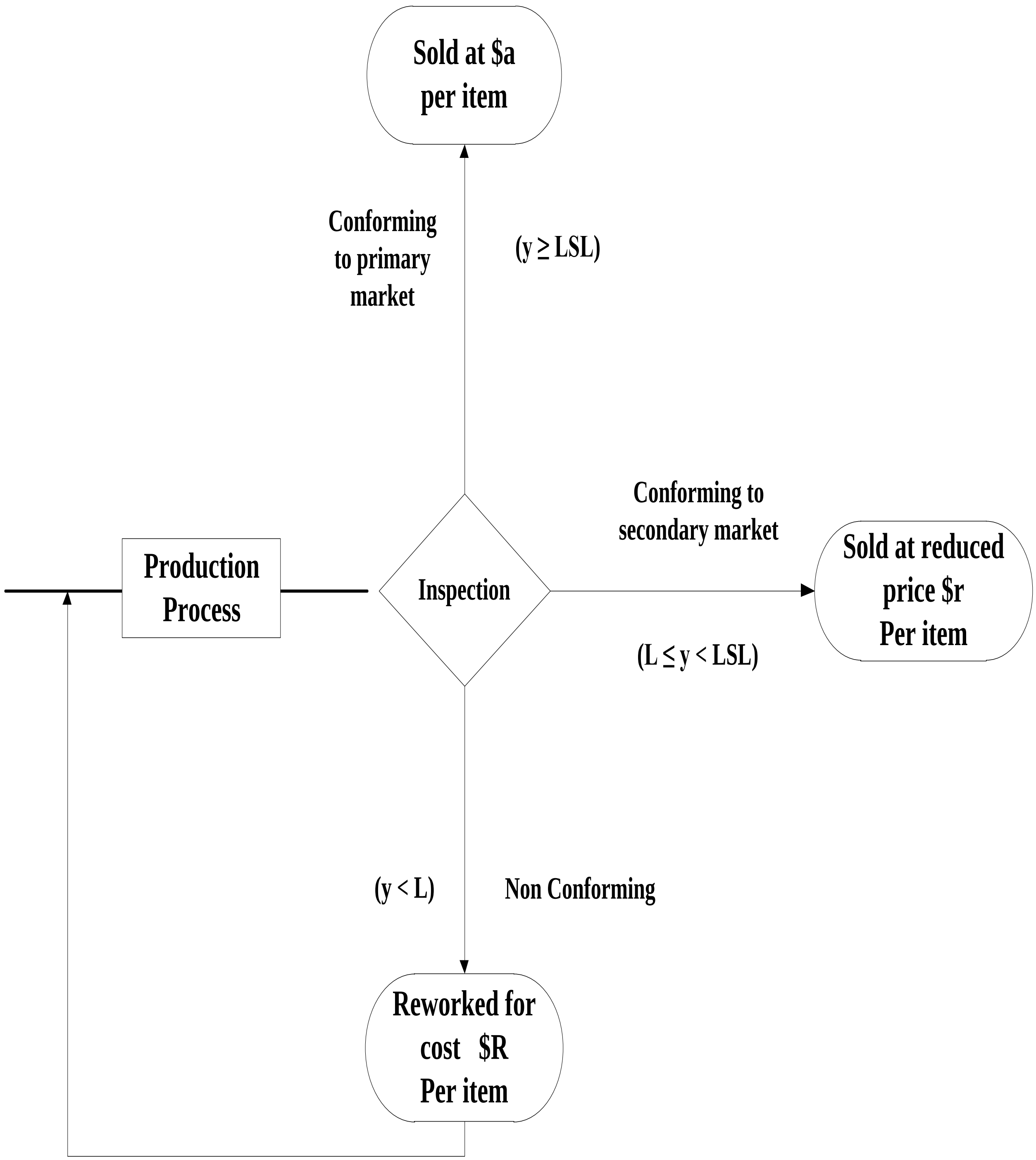

Figure 2-2 The basic production process

2.6 PROBLEM FORMULATION

Consider the production process in figure 2.2. Let y be the measured quality characteristic of the product that has two specification limits (LSL *and* L)and a target value T .(e.g. in the can filling problem the quality characteristic is the net weight of the material in the can and in a painting problem the quality characteristic could be the thickness of the paint). The net selling price of a product that meets primary market specification is $\$a$ and the selling price of a product which meets secondary market specification is $\$r(a > r)$. Let $g$denotes the excess material measured for accepted item ($g > 0$) . The problem under consideration is to find the optimal process target mean that optimizes the following three objectives:

- Maximizing net profit.
- Maximizing net income.
- Maximizing product uniformity measured by the deviation from a specified target as measured by Taguchi quadratic loss function.

It is to be noted that minimizing Taguchi quadratic loss function will ensure product uniformity around a target value.

Here in our model, there are three objectives (n = 3) and one constraint (m = 1). There are three objectives: maximizing the net profit, maximizing the net income and maximizing the product uniformity. Thus, the multi-objective optimization model for our study will be as:

$$max\ \boldsymbol{f}(T) = [\, f_1(T), f_2(T), -f_3(T)] \quad (2.1)$$

$$subject\ to \qquad T \geq LSL \qquad (2.2)$$

Where

$f_1(T)$: The expected profit per item for the production process.

$f_2(T)$: The expected income per item for the production process.

$f_3(T)$: The expected loss resulting from deviation from the target mean per item for the production process.

2.7 CONCLUSION

In this chapter, the literature in the area of process targeting is reviewed, followed by a clear statement of the problem and the modeling framework for the problem. Next, two models are given using 100% error-free and error-prone inspection system and other two models using error-free and error-prone sampling plan.

CHAPTER 3

MULTI-OBJECTIVE PROCESS TARGETING MODEL WITH 100% ERROR-FREE INSPECTION SYSTEM

3.1 PREFACE

The purpose of this chapter is to develop a multi-objective optimization model for the problem stated in chapter 2, and will be described in section 3.2 of this chapter. The model developed in this chapter assumes an error-free 100% inspection policy for product quality control. The model has three objective functions to be maximized with respect to the process target mean. The utility of the model has been demonstrated using an example from the literature. Sensitivity analysis is conducted for the model's parameters to assess the sensitivity of the results in section 3.4.

3.2 STATEMENT OF PROBLEM

Consider the production process that mentioned in chapter two (figure 2-1).The quality characteristic y for items produced is normally distributed with unknown mean T, known standard deviationσ. The primary market and secondary market specification limits LSL and L, respectively. If an item is conforming $(y \geq LSL)$ then, it is sold at a regular price $\$a$ and costs $\$g$ per item of excess quality. If it is conforming to secondary market item $(L \leq y < LSL)$ then, it is sold at reduced price $\$r$ .If it is non-conforming $(y < L)$ then, rework with cost $\$R$. The production cost is assumed to be known and constant $\$c$. After the items are being produced they are 100% inspected using an error-free measurement system. The problem here is to develop a multi-objective optimization model to determine the optimum process target mean.

3.3 MODEL DEVELOPMENT

Three objective functions will be developed under the condition of the above production process. These three objectives will form the multi-objective framework under which the optimum process target mean will be determined.

3.3.1. OBJECTIVE I (PROFIT OBJECTIVE FUNCTION)

The first objective is a profit objective function, which attempts to maximize the total expected profit per item for the production process mentioned above. Let P the profit per item and $E(P)$ its expected value. Hence, P is given by the following equation

$$P = \begin{cases} a - g(y - LSL) - cy & if\ y \geq LSL \\ r - cy & if\ \ L \leq y < LSL \\ E(P) - R - cy & if\ \ y < L \end{cases} \tag{3.1}$$

Now the expected profit can be found as the following

$$E(P)$$

$$= a\int_{LSL}^{\infty} f(y)dy\, g\int_{LSL}^{\infty} yf(y)dy + g.LSL\int_{LSL}^{\infty} f(y)dy - c\int_{LSL}^{\infty} yf(y)dy\ + r\int_{L}^{LSL} f(y)dy$$

$$- c\int_{L}^{LSL} yf(y)dy + E(P)\int_{-\infty}^{L} f(y)dy - R\int_{-\infty}^{L} f(y)dy$$

$$- c\int_{-\infty}^{L} yf(y)dy \tag{3.2}$$

Where:

$f(y) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{1}{2\sigma}(y-T)^2}$is the normal distribution density function with mean T and standard deviation σ. Let $z = \frac{y-T}{\sigma}$then,

$\varphi(z) = \frac{1}{\sqrt{2\pi}} e^{z^2}$is the standard normal distribution density function. Now consider the following:

$\int_{-\infty}^{y} f(y)dy = \int_{-\infty}^{\frac{y-T}{\sigma}} \varphi(z)\, dz = \Phi(z)$the standard normal cumulative distribution function.

Now let’s define the following:

$$\alpha = \frac{LSL - T}{\sigma}\ , \qquad \delta = \frac{L - T}{\sigma}$$

$$\beta = \Phi\left(\frac{LSL - T}{\sigma}\right) = \Phi(\alpha)\ \ , \quad \gamma = \Phi\left(\frac{L - T}{\sigma}\right) = \Phi(\delta)$$

Standardizing the normal distribution function to standard normal using the transformation $z = \frac{y-T}{\sigma}$ and β, γ we get:

$$E(P) = a(1-\beta) - g\int_{LSL}^{\infty} y\, f(y)dy + g.LSL(1-\beta) + r(\beta-\gamma) + \gamma E(P) - \gamma R$$
$$- c\int_{-\infty}^{\infty} y\, f(y)dy \tag{3.3}$$

By simplifying and rearranging the last equation, the total expected profit is the following

$$E(P) = \frac{(a + g.LSL)(1-\beta)}{(1-\gamma)} - \frac{g}{(1-\gamma)}\int_{LSL}^{\infty} y\, f(y)dy + \frac{r(\beta-\gamma)}{(1-\gamma)} - \frac{\gamma.R}{(1-\gamma)}$$
$$- \frac{c.T}{(1-\gamma)} \tag{3.4}$$

3.3.2. OBJECTIVE II (INCOME OBJECTIVE FUNCTION)

Objective 2 is a modified version of **Hunter and Karta (1977)** model. The objective of this function is to maximize the net income per item for the production process described previously in chapter 2. Let I denotes the income per item and $E(I)$ be the expected income per item. Hence, I is given by the following equation

$$I = \begin{cases} a - g(y - LSL) & if\ y \geq LSL \\ r & if\ \ L \leq y < LSLS \\ E(I) - R & if\ \ y < L \end{cases} \tag{3.5}$$

Hence, the expected income per item is the following

$$E(I) = a\int_{LSL}^{\infty} f(y)dy - g\int_{LSL}^{\infty} yf(y)dy + g.LSL\int_{LSL}^{\infty} f(y)dy \; + r\int_{L}^{LSL} f(y)dy$$

$$+ E(I)\int_{-\infty}^{L} f(y)dy - R\int_{-\infty}^{L} f(y)dy \qquad (3.6)$$

Standardizing the normal distribution function to standard normal using the transformation $z = \frac{y-T}{\sigma}$ and β, γ we get:

$$E(I) = a(1-\beta) - g\int_{LSL}^{\infty} y\,f(y)dy + g.LSL(1-\beta) + r(\beta-\gamma) + \gamma E(I) - \gamma R \qquad (3.7)$$

Simplify and rearrange this equation, the expected income per item is the following

$$E(I) = \frac{(a+g.LSL)(1-\beta)}{(1-\gamma)} - \frac{g}{(1-\gamma)}\int_{LSL}^{\infty} y\,f(y)dy + \frac{r(\beta-\gamma)}{(1-\gamma)} - \frac{\gamma R}{(1-\gamma)} \qquad (3.8)$$

Both functions (expected profit and expected income) have not simplified integration. This integration can be simplified as following

From the conditional expectation we have

$$E(y|y \geq LSL) = \frac{\int_{LSL}^{\infty} yf(y)dy}{\int_{LSL}^{\infty} f(y)dy} \qquad (3.9)$$

This expectation is a one sided truncated normal distribution, which has the following formula

$$E(y|y \geq LSL) = T + \sigma\lambda(\alpha)(3.10)$$

Where:

$$\lambda(\alpha) = \frac{\emptyset(\alpha)}{1 - \Phi(\alpha)}\ , \lambda(\alpha) = \frac{\emptyset(\alpha)}{1 - \beta} \tag{3.11}$$

Hence, we can find the expression of the integration

$$\int_{LSL}^{\infty} yf(y)dy = E(y|y \geq LSL). \int_{LSL}^{\infty} f(y)dy \tag{3.12}$$

By substituting (3.10) in (3.12), we get

$$\int_{LSL}^{\infty} yf(y)dy = [T + \sigma\lambda(\alpha)]. [1 - \Phi(\alpha)] \tag{3.13}$$

Now, substitute (3.11) in (3.13)

$$\int_{LSL}^{\infty} yf(y)dy = \left[T + \frac{\sigma\emptyset(\alpha)}{1 - \beta}\right]. (1 - \beta) \tag{3.14}$$

Rearrange the right hand side we end up with

$$\int_{LSL}^{\infty} yf(y)dy = [T(1 - \beta) + \sigma\emptyset(\alpha)] \tag{3.15}$$

Now, using (3.15) the profit function “equation (2.4)” can be written as

$$E(P) = \frac{(a + g.LSL)(1 - \beta)}{(1 - \gamma)} - \frac{g[T(1 - \beta) + \sigma\emptyset(\alpha)]}{(1 - \gamma)} + \frac{r(\beta - \gamma)}{(1 - \gamma)} - \frac{\gamma R}{(1 - \gamma)} - \frac{c.T}{(1 - \gamma)} \tag{3.16}$$

Similarly, the income function “equation (2.8)” is written as

$$E(I) = \frac{(a + g.LSL)(1-\beta)}{(1-\gamma)} - \frac{g[T(1-\beta) + \sigma\emptyset(\alpha)]}{(1-\gamma)} + \frac{r(\beta-\gamma)}{(1-\gamma)} - \frac{\gamma R}{(1-\gamma)} \qquad (3.17)$$

3.3.3. OBJECTIVE III (PRODUCT UNIFORMITY OBJECTIVE FUNCTION)

In this section, the product uniformity function will be developed. The production process under study has no upper specification limit. Hence, the quality level and product uniformity are evaluated by using the loss function approach for the larger the better type of tolerance. In this type there is no predetermined target level and the larger the value of the characteristic, the better. Under this type of tolerance the optimal (ideal) target value is hypothetically ∞, and the loss incurred when the quality characteristic falls below the lower specification limit (i.e. LSL). Particularly in this model, as well the quality characteristic y falls away from LSL as more cost incurs due to the more excess material used. Therefore, this cost prevents the target mean of approaching ∞.

The loss function of the larger the better tolerance type is obtain by the following

$$L(\boldsymbol{y}) = k\sum_{i=1}^{n}\frac{1}{{y_i}^2}$$

In the above formula, n is the sample size and k is the quality loss coefficient$k = R\Delta^2$.$\Delta$is the tolerance limit, which in the larger the better case is the lower specification limit.

In the production process under study the produced item is classified into three areas based on specifications, conforming to primary market, conforming to secondary market and non-conforming. Hence, the quality loss function will be

$$L(y) = \begin{cases} \dfrac{k}{y^2} + g(y - LSL) & if\ y \geq LSL \\ \dfrac{k}{y^2} + (a - r) & if\ L < y < LSL \\ \dfrac{k}{y^2} + a + R & if\ y < L \end{cases} \tag{3.18}$$

Now the expected loss is given by

$$E\big(L(y)\big) = k\int_{LSL}^{\infty} \frac{1}{y^2} f(y)dy + g\int_{LSL}^{\infty} (y - LSL) f(y)dy + k\int_{L}^{LSL} \frac{1}{y^2} f(y)dy$$
$$+ (a - r)\int_{L}^{LSL} f(y)dy + k\int_{-\infty}^{L} \frac{1}{y^2} f(y)dy + (a + R)\int_{-\infty}^{L} f(y)dy \tag{3.19}$$

Standardizing the normal distribution function to standard normal using the transformation $z = \frac{y-T}{\sigma}$ and β, γ we get:

$$E\big(L(y)\big) = k\int_{-\infty}^{\infty} \frac{1}{y^2} f(y)dy + g[T(1-\beta) + \sigma\emptyset(\alpha)] - g.LSL(1-\beta)$$
$$+ (a - r)(\beta - \gamma) + (a + R)\gamma \tag{3.20}$$

3.3.4. THE MULTI-OBJECTIVE OPTIMIZATION MODEL

Now we are ready to formulate the multi-objective optimization framework for the problem defined in section 3.1., using the formulation in section 2.5. The multi-objective model is given by the following

$$max\ \boldsymbol{f}(\boldsymbol{T}) = [f_1(\boldsymbol{T}), f_2(\boldsymbol{T}), f_3(\boldsymbol{T})]$$

Subject to

$$T \geq LSL$$

Where:

$f_1(\boldsymbol{T}) = E(P)$ equation 3.16

$f_2(\boldsymbol{T}) = E(I)$ equation 3.17

$f_3(\boldsymbol{T}) = -E\big(L(y)\big)$ equation 3.20

3.4 RESULTS AND SENSITIVITY ANALYSIS

In this section, an illustrative example for the model developed above is presented using parameters from the literature. This is followed by sensitivity analysis for these model's parameters, to discover their effect on the results.

3.4.1. SOLUTION METHODOLOGY

The proposed solution methodology consists of three main steps:

- Step 1: each objective function is evaluated individually using a uniform line search method with step length λ in the interval $I = [LSL, LSL + b]$, where b is an appropriate positive number.

- Step 2: Generate the set of non-inferior points:

i. Define $T_{min} = Min({T_1}^*, {T_2}^*, {T_3}^*)$and $T_{max} = Max\ ({T_1}^*, {T_2}^*, {T_3}^*)$

ii. Let $T_i = T_{min} + i\lambda\epsilon[T_{min}, T_{max}]$: $i = 1,2,..,n$ and

$$T_j = T_{min} + j\lambda\epsilon[T_{min}, T_{max}] : j = 1,2,..,n$$

iii. The point$T_i$is a non-inferior point if there is no T_j such that:

$$\{f_k(T_j) \geq f_k(T_i) :\ \forall\ k = 1,2,3\}$$

- Step 3: Rank the set of non-inferior points:

  i. Normalize: $\frac{f_k(T_i)}{f_k({T_i}^*)}$, i=1,2,..,n and k=1,2,3

  ii. Define the normalized sum$\boldsymbol{S_i}$as: $\boldsymbol{S_i} = \sum_{k=1}^{3} \frac{f_k(T_i)}{f_k({T_i}^*)}$

  iii. Define the percentage absolute deviation $\boldsymbol{PAD_i}$as:$\boldsymbol{PAD_i} = \frac{|3-S_i|*100}{3}$, i=1,2,3

  iv. Rank the points according to $\boldsymbol{PAD_i}$from the smallest to the largest. The smaller the$\boldsymbol{PAD_i}$, the higher preference of the point.

3.4.2. NUMERICAL EXAMPLE

Consider a production process, which produces products have a normally distributed quality characteristic y. If quality characteristic is above the primary market specification $LSL = 10$, then it sold at a regular price \$80, If the quality characteristic is below the LSL but above the secondary market specification $L = 9$, then it sold at a reduced price \$67.5, and if the quality characteristic falls below L, the item reworked with cost \$4. The processing cost of an item is \$7, and the excess material cost per item of material is \$2. The process standard deviation σ is 0.5. The uniform search is conducted over the interval $T \in [10,20]$. Table 3.1 below summarizes the obtained results

Table 3-1 The optimum values of the three objective functions of model 1

	PROFIT OBJECTIVE $f_1(T)$	INCOM OBJECTIVE $f_2(T)$	UNIFORATY OBJECTIVE $f_3(T)$
T^*	10.4	10.9	11
$f_i(T^*)$	3.1673098	77.658091	-5.675613

Figures 3-1, 3-2, 3-3 and 3-4 show the plot of the profit objective, income objective, uniformity objective and the three objectives together in the interval $[10,20]$, respectively.

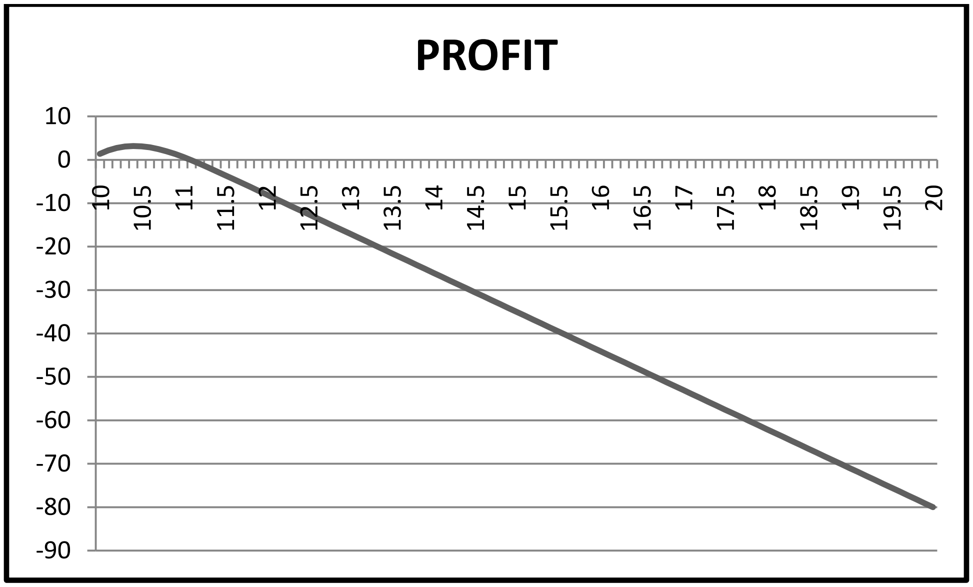

Figure 3-1 plot of the profit objective function of model 1

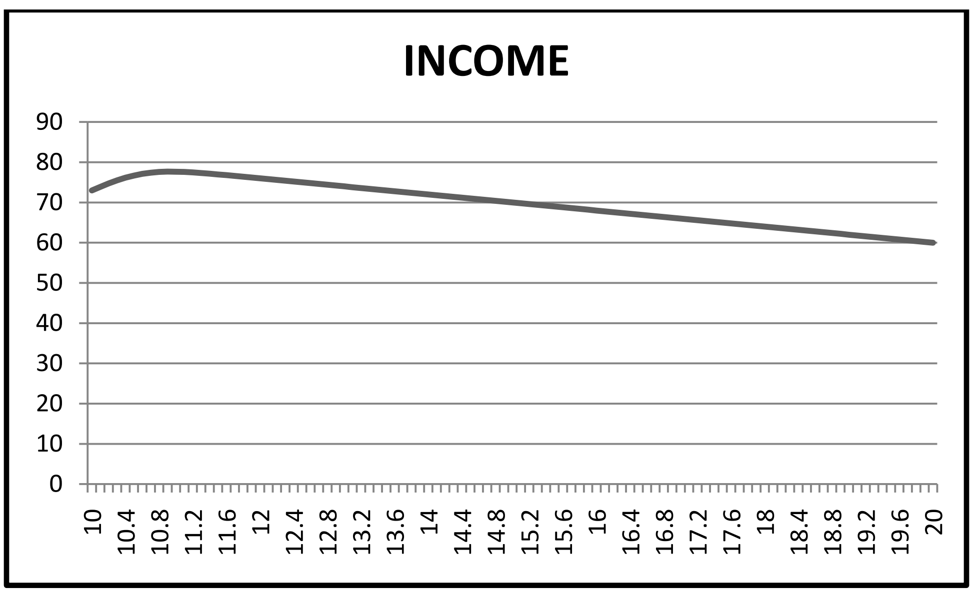

Figure 3-2 plot of the income objective function of model 1

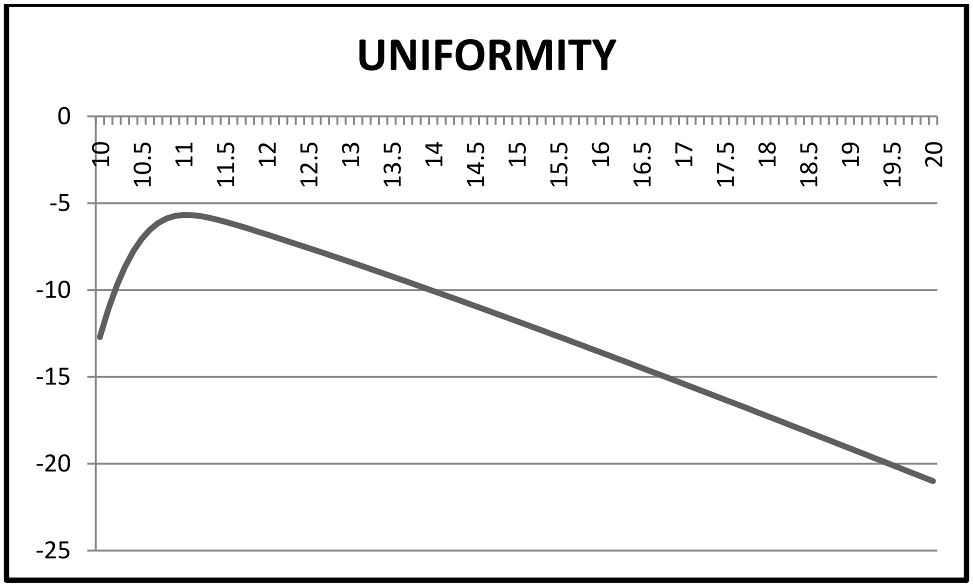

Figure 3-3 plot of the product uniformity objective function of model 1

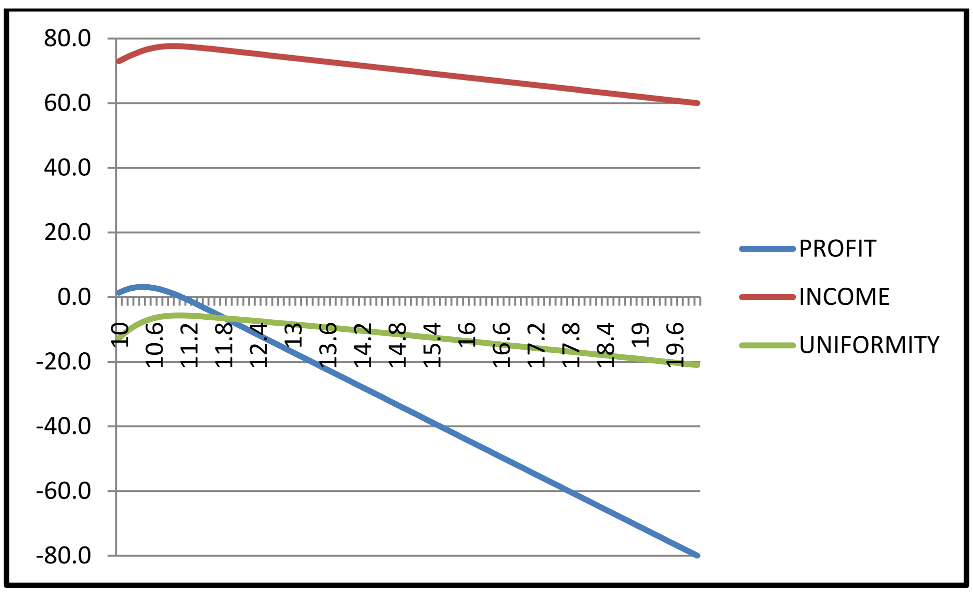

Figure 3-4 plots of the three objective functions of model 1

Now, the set of non-inferior solution is summarized in table 3-2 below,

Table 3-2 The set of non-inferior solution of model 1

T^*	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.4	3.167309802	76.1537998	-7.764953331	5th
10.5	3.099189011	76.69854063	-7.058077932	3rd
10.6	2.86417834	77.11519903	-6.521806878	1st
10.7	2.480891594	77.4061361	-6.136839835	2nd
10.8	1.969783196	77.58181372	-5.882176319	4th
10.9	1.35257024	77.65809079	-5.735727303	6th
11	0.650897802	77.65333657	-5.675613137	7th

3.4.3. SENSITIVITY ANALYSIS FOR THE PARAMETERS

In this section, the effect of the process standard deviation σ and the cost parameters (c, g and R), on the target meant value, on the objective function values and on the set of non-inferior solutions is studied.

First, the effect of the standard deviation on the three objective function values and the process target mean is stated on tables 3-3, 3-4 and 3-5 below

Table 3-3 The sensitivity analysis of the process standard deviation on the profit objective function of model 1.

σ		PROFIT		
		T	OBJECTIVE VALUE	CHANGE PERCENTAGE
0.875	+75%	10.7	-1.12031988	-135.371%
0.75	+50%	10.6	0.458104358	-85.536%
0.625	+25%	10.5	1.913844804	-39.575%

0.5	original	10.4	3.167309802	0%
0.375	-25%	10.4	4.268106251	34.7549%
0.25	-50%	10.3	5.542292242	74.98422%
0.125	-75%	10.2	7.315086901	130.9558%

Table 3-4 The sensitivity analysis of the process standard deviation on the income objective function of model 1.

σ		INCOME		
		T	OBJECTIVE VALUE	CHANGE PERCENTAGE
0.875	+75%	11.3	76.47681202	-1.52113%
0.75	+50%	11.2	76.83362848	-1.06166%
0.625	+25%	11.1	77.22887969	-0.55269%
0.5	original	10.9	77.65809079	0%
0.375	-25%	10.8	78.13873997	0.61893%
0.25	-50%	10.6	78.66257878	1.2935%
0.125	-75%	10.3	79.25766026	2.05976%

Table 3-5 The sensitivity analysis of the process standard deviation on the product uniformity objective function of model 1.

σ		UNIFORMITY		
		T	OBJECTIVE VALUE	CHANGE PERCENTAGE
0.875	+75%	11.6	-6.79449756	-19.713895%
0.75	+50%	11.4	-6.40717641	-12.88959%
0.625	+25%	11.2	-6.03781297	-6.381686%
0.5 (original)	original	11	-5.675613137	0%

0.375	-25%	10.8	-5.303156339	6.5624064%
0.25	-50%	10.6	-4.903364272	13.606439%
0.125	-75%	10.4	-4.512636459	20.490767%

From the tables above, it is clear that the profit objective function is very sensitive to the change in the process standard deviation more than the income objective function. This can be explained as following: in equations 3.16 and 3.17 the profit objective function has the term $\frac{c.T}{(1-\gamma)}$ more than the income objective function. As the standard deviation increases, the value of γ increases, consequently, the whole term value increases more than 70 which is the minimum value of the term $c.T$.

From table 3-4, the process standard deviation has a moderate effect on the product uniformity objective function. This is because; in equation 3.25 the standard deviation affects both the probabilities and the value of the random variable y (i.e. the quality characteristic).

The sets of non-inferior solutions for the above mentioned sensitivity analysis of the process standard deviation can be found on appendix A.

Now, the effect of the three cost parameters (c, g and R) on the three objective functions is stated on tables 3-6, 3-7 and 3-8 below.

Table 3-6 The sensitivity analysis of the cost parameters on the profit objective function of model 1.

SENSITIVITY		PROFIT		
PARAMETER	CHANGE	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
c=10 g=3 R=6	+50%	10.3	-33.731	-1164.97%
c=8.7 g=2.5 R=5	+25%	10.3	-15.34	-584.322%
c=8.4 g=2.4 R=4.8	+20%	10.3	-11.6618	-468.193%
c=8.05 g=2.3 R=4.6	+15%	10.4	-7.9642	-351.449%
c=7.7 g=2.2 R=4.4	+10%	10.4	-4.2537	-234.299%
c=7.35 g=2.1 R=4.2	+5%	10.4	-0.54318	-117.149%
c=7 g=2 R=4	original	10.4	3.16731	0%
c=6.65 g=1.9 R=3.8	-5%	10.4	6.8778	117.1495%
c=6.3 g=1.8 R=3.6	-10%	10.5	10.5924	234.4281%
c=5.95 g=1.7 R=3.4	-15%	10.5	14.339	352.717%
c=5.6 g=1.6 R=3.2	-20%	10.5	18.0856	471.0069%
c=5.25 g=1.5 R=3	-25%	10.5	21.83215	589.2963%

c=3.5 g=1 R=2	-50%	10.7	40.7377	1186.191%

Table 3-7 The sensitivity analysis of the cost parameters on the income objective function of model 1.

SENSITIVITY		INCOME		
PARAMETER	CHANGE	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
c=10 g=3 R=6	+50%	10.8	76.71428	-1.21535%
c=8.7 g=2.5 R=5	+25%	10.9	77.18468	-0.6096%
c=8.4 g=2.4 R=4.8	+20%	10.9	77.27936	-0.48769%
c=8.05 g=2.3 R=4.6	+15%	10.9	77.37404	-0.36577%
c=7.7 g=2.2 R=4.4	+10%	10.9	77.46873	-0.2438%
c=7.35 g=2.1 R=4.2	+5%	10.9	77.56341	-0.1219%
c=7 g=2 R=4	original	10.9	77.6581	0%
c=6.65 g=1.9 R=3.8	-5%	11	77.75647	0.12668%
c=6.3 g=1.8 R=3.6	-10%	11	77.8596	0.25949%
c=5.95 g=1.7 R=3.4	-15%	11	77.96274	0.39229%

c=5.6 g=1.6 R=3.2	-20%	11	78.06587	0.5251%
c=5.25 g=1.5 R=3	-25%	11	78.169005	0.6579%
c=3.5 g=1 R=2	-50%	11.1	78.70615	1.34958%

Table 3-8 The sensitivity analysis of the cost parameters on the product uniformity objective function of model 1.

SENSITIVITY		UNIFORMITY		
PARAMETER	CHANGE	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
c=10 g=3 R=6	+50%	11	-8.370162477	-47.47591626%
c=8.7 g=2.5 R=5	+25%	11	-7.022887807	-23.73795813%
c=8.4 g=2.4 R=4.8	+20%	11	-6.753432873	-18.9903665%
c=8.05 g=2.3 R=4.6	+15%	11	-6.483977939	-14.24277488%
c=7.7 g=2.2 R=4.4	+10%	11	-6.214523005	-9.49518326%
c=7.35 g=2.1 R=4.2	+5%	11	-5.94506807	-4.747591631%
c=7 g=2 R=4	original	11	-5.675613137	0%
c=6.65 g=1.9 R=3.8	-5%	11	-5.406158203	4.74759162%

c=6.3 g=1.8 R=3.6	-10%	11.1	-5.130876966	9.597838297%
c=5.95 g=1.7 R=3.4	-15%	11.1	-4.855533464	14.44918202%
c=5.6 g=1.6 R=3.2	-20%	11.1	-4.580189962	19.30052575%
c=5.25 g=1.5 R=3	-25%	11.1	-4.30484646	24.15186948%
c=3.5 g=1 R=2	-50%	11.2	-2.919419727	48.56203803%

It is clear from tables 3-6 and 3-7, that the profit objective function is more sensitive to the change in the cost parameters than the income objective function. Again, the term $\frac{c.T}{(1-\gamma)}$is the only difference between the two objective functions (equations 3.16 and 3.17). This term contains the production cost c, which has the largest value among the other two cost parameters. Also, the minimum value of the enumerator is 70. Therefore, the value of the profit objective function is affected by any change in the production cost parameters c. Also, this result can be verified using the derivatives of the profit and income objective functions with respect to the cost parameters.

$$\frac{\partial E(P)}{\partial g} = \frac{\partial E(I)}{\partial g} = \frac{LSL(1-\beta) - [T(1-\beta) + \sigma\emptyset(\alpha)]}{(1-\gamma)}$$

$$\frac{\partial E(P)}{\partial R} = \frac{\partial E(I)}{\partial R} = \frac{-\gamma}{(1-\gamma)}$$

$$\frac{\partial E(P)}{\partial c} = \frac{-T}{(1-\gamma)}$$

$$\frac{\partial E(I)}{\partial c} = 0$$

From the four equations above, it is clear that the rate of changes in the profit and the income objective functions with respect to one item changes in the excess material cost “g” and the rework cost “R” are the same. But, the change in the profit objective function due to one item change in the production cost “c” is very large, while, there is no change in the income objective function associated with change in the production cost “c”.

In table 3-8, the product uniformity is sensitive to the change in the cost parameters. This sensitivity comes from the considerable amount of change in the quality loss coefficient k and the associate penalties due to any change in the cost parameter values. This can be shown using the partial derivatives for the product uniformity objective function

$$\frac{\partial - E(L(y))}{\partial g} = -[T(1-\beta) + \sigma\emptyset(\alpha)] + LSL(1-\beta)$$

$$\frac{\partial - E(L(y))}{\partial R} = -LSL^2 \int_{-\infty}^{\infty} \frac{1}{y^2} f(y)dy - \gamma$$

$$\frac{\partial - E(L(y))}{\partial c} = 0$$

The sets of non-inferior solutions for the above mentioned sensitivity analysis of the process standard deviation can be found on appendix A.

3.5 CONCLUSION

In this chapter, a multi-objective optimization model is developed for a process targeting problem. Three objective functions are maximized simultaneously to find the optimum setting of the process target mean. 100% error-free inspection policy is used for product quality control. The set of non-inferior solutions was generated for an example contains some data from the process targeting literature. Sensitivity analysis for the process standard deviation and the cost parameters was conducted, to study their effect on the process target mean setting and the three objective function values. In the model developed in this chapter, inspection is assumed to be error free. This assumption is relaxed in chapter 4.

CHAPTER 4

MULTI-OBJECTIVE PROCESS TARGETING MODEL WITH 100% ERROR-PRONE INSPECTION SYSTEM

4.1 PERFACE

The purpose of this chapter is to extend the multi-objective model developed in charter three to the case where the inspection system (manually or automated) is error prone. This assumption is more realistic assumption as conformed in the literature. The motivation behind this extension is the fact that measurement system can cause considerable loss due to misclassification of the products. This loss can be either a loss in profit due to misclassify a higher quality product as a lower quality product, or vice versa. The loss per item due to this error may seem small, however, the overall loss may be in millions (considering millions of items produced per year). The rest of the assumptions and conditions under which the model has been developed are the same as chapter three for the same production process described in chapter two (section 2.5). This chapter is organized as follows: the problem description is presented in section 4.2, and the model development in section 4.3. An illustrative example is shown in section 4.4, followed by sensitivity analysis for the model's parameters in section 4.5. The conclusion of this chapter is stated in section 4.6.

4.2 STATEMENT OF PROBLEM

Consider the production process described in chapter 2 (figure 2-1). In this process the produced item has a normally distributed quality characteristic y with unknown mean T, known standard deviation σ, primary market and secondary market specification limits LSL and L. Items conforming to primary market $(y \geq L)$ are sold at $\$a$ and incur a cost of $\$g$ per item of excess material. Items conforming to secondary market $(L \leq y < LSL)$ are sold at $\$r$. Non-conforming items $(y < L)$ are reworked with cost $\$R$. The production cost is known and constant $\$c$. Now consider the case where the inspection system is error prone. Thus, it tends to misclassify the produced items according to their quality characteristic level. Hence, the measured quality characteristic has an observed value (i.e. x) which is different from the actual value (i.e. y) due to the presence of inspection error. Both quality characteristics (the observed X and the actual Y) are normally distributed and the relation between them is the following

$$X = Y + \varepsilon \tag{4.1}$$

Where ε is a random variable which represents the inspection error. ε has a normal distribution with mean 0 and known standard deviation $\varepsilon \sim N(0, \sigma_\varepsilon)$.

The correlation coefficient between the actual and observed quality characteristics ρ is given by the formula

$$\rho = 1 - \frac{{\sigma_\varepsilon}^2}{{\sigma_x}^2} = \frac{{\sigma_y}^2}{{\sigma_x}^2} \tag{4.2}$$

Since, the actual and observed quality characteristics are both normally distributed; then, their joint distribution is bivariate normal distribution which is given by

$$f(y,x) = \frac{1}{2\pi\sigma_y\sigma_x\sqrt{1-\rho^2}} e^{\frac{1}{2(1-\rho^2)}[\frac{(y-\mu)^2}{{\sigma_y}^2}+\frac{(x-\mu)^2}{{\sigma_x}^2}-\frac{2\rho(y-\mu)(x-\mu)}{\sigma_y\sigma_x}]} \tag{4.3}$$

To reduce the effect of the inspection error, instead of using the original limits (LSL and L) for inspection, we based the inspection on new limits (cut off points) and use these new limits as the classification criteria (figure 4-1).

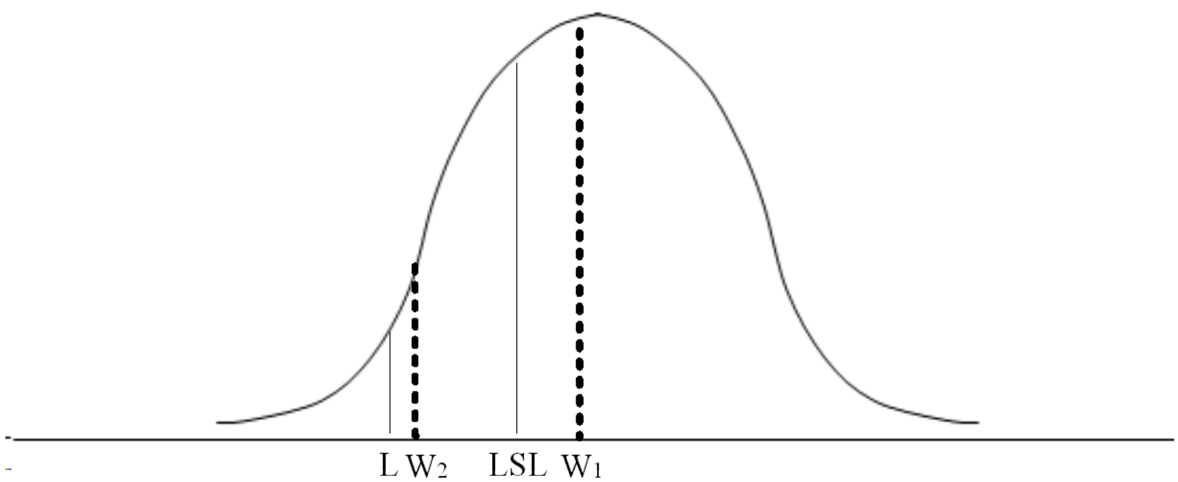

Figure 4-1 Cut off points for the inspection error

The location of these cut off points depends on many factors, such as: the loss in profit due to misclassifying a higher quality product into a lower quality, the penalty associated with misclassifying a lower quality product with a higher quality, the value of the mean, the value of the standard deviation…etc.

Prior to model development, the types of losses and penalties associated with misclassification of the items will be described. First, there are three type of loss in profit due to misclassify a higher quality product as a lower quality product (table 4-1).

Table 4-1 Loss in profit due to product misclassification

Loss in profit	Due to
a-r	Classify a primary market item as a secondary market item
a	Classify a primary market item as a non-conforming item
r	Classify a secondary market item as a non-conforming item

Also, there are three types of penalties associated with misclassify a lower quality product as a higher quality product. These penalties reflect on replacement and warranty costs and loss of good will and customer dissatisfaction (table 4-2).

Table 4-2 Penalties due to product misclassification

Penalty	Due to
b_1	Classify secondary market item as a primary market item
b_2	Classify a non-conforming item as a primary market item
b_3	Classify a non-conforming item as a secondary market item

The problem we are trying to solve here is to develop a multi-objective optimization model that provides the optimum process target mean and cut off points.

4.3 MODEL DEVELOPMENT

The multi-objective optimization framework will be developed below with three objective functions as stated on the thesis objectives. The multi-objective will be solved to find the optimum value of the process target mean and the value of the two cut off points too.

4.3.1. OBJECTIVE I (PROFIT OBJECTIVE FUNCTION)

As the previous chapter, the first objective function in the multi-objective optimization model is the profit objective. Here, a profit objective function will be developed for the production process under study. The goal is to find the values of the process target mean and the cut off points those maximize the profit function.

Now let P the profit per item, and $E(P)$be its expected value. Hence, P is given by the following equation

$$P = \begin{cases} a - g(y - LSL) - cy & if \quad x \geq w_1 \;\; , \;\; y \geq LSL \\ a - cy - b_1 & if \quad x \geq w_1 \;\; , \;\; L \leq y < LSL \\ a - cy - b_2 & if \quad x \geq w_1 \;\; , \;\; y < L \\ r - (a - r) - cy & if \quad w_2 \leq x < w_1 \;\; , \;\; y \geq LSL \\ r - cy & if \quad w_2 \leq x < w_1 \;\; , \;\; L \leq y < LSL \\ r - cy - b_3 & if \quad x < w_2 \;\; , \;\; y < L \\ E(P) - R - a - cy & if \quad x < w_2 \;\; , \;\; y \geq LSL \\ E(P) - R - r - cy & if \quad x < w_2 \;\; , \;\; L \leq y < LSL \\ E(P) - R - cy & if \quad x < w_2 \;\; , \;\; y < L \end{cases} \quad (4.4)$$

Now the derivation of the expected profit per item can be express as the following

$$E(P) = a\int_{w_1}^{\infty}\int_{LSL}^{\infty} f(x,y)dy\,dx - g\int_{w_1}^{\infty}\int_{LSL}^{\infty} y.f(x,y)dy\,dx$$

$$+\,g.LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty} f(x,y)dy\,dx - c\int_{w_1}^{\infty}\int_{LSL}^{\infty} y.f(x,y)dy\,dx$$

$$+a\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx - c\int_{w_1}^{\infty}\int_{L}^{LSL} y.f(x,y)dy\,dx - b_1\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx$$

$$+a\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx - c\int_{w_1}^{\infty}\int_{-\infty}^{L} y.f(x,y)dy\,dx - b_2\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx$$

$$+r\int_{w_2}^{w_1}\int_{LSL}^{\infty} f(x,y)dy\,dx - (a-r)\int_{w_2}^{w_1}\int_{LSL}^{\infty} f(x,y)dy\,dx - c\int_{w_2}^{w_1}\int_{LSL}^{\infty} y.f(x,y)dy\,dx$$

$$+r\int_{w_2}^{w_1}\int_{L}^{LSL} f(x,y)dy\,dx - c\int_{w_2}^{w_1}\int_{L}^{LSL} y.f(x,y)dy\,dx$$

$$+r\int_{w_2}^{w_1}\int_{-\infty}^{L} f(x,y)dy\,dx - c\int_{w_2}^{w_1}\int_{-\infty}^{L} y.f(x,y)dy\,dx - b_3\int_{w_2}^{w_1}\int_{-\infty}^{L} f(x,y)dy\,dx$$

$$+E(P)\int_{-\infty}^{w_2}\int_{LSL}^{\infty} f(x,y)dy\,dx - R\int_{-\infty}^{w_2}\int_{LSL}^{\infty} f(x,y)dy\,dx - a\int_{-\infty}^{w_2}\int_{LSL}^{\infty} f(x,y)dy\,dx$$

$$-\,c\int_{-\infty}^{w_2}\int_{LSL}^{\infty} y.f(x,y)dy\,dx$$

$$+E(P)\int_{-\infty}^{w_2}\int_{L}^{LSL} f(x,y)dy\,dx - R\int_{-\infty}^{w_2}\int_{L}^{LSL} f(x,y)dy\,dx - r\int_{-\infty}^{w_2}\int_{L}^{LSL} f(x,y)dy\,dx$$

$$-\,c\int_{-\infty}^{w_2}\int_{L}^{LSL} y.f(x,y)dy\,dx$$

$$+E(P)\int_{-\infty}^{w_2}\int_{-\infty}^{L} f(x,y)dydx$$

$$-R\int_{-\infty}^{w_2}\int_{-\infty}^{L} f(x,y)dydx - c\int_{-\infty}^{w_2}\int_{-\infty}^{L} y.f(x,y)dydx \qquad (4.5)$$

By arranging and add the similar terms we get the following

$$E(P) = a\int_{w_1}^{\infty}\int_{-\infty}^{\infty} f(x,y)dy\,dx$$

$$-g\int_{w_1}^{\infty}\int_{LSL}^{\infty} y\,.f(x,y)dy\,dx$$

$$+g.LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty} f(x,y)dy\,dx$$

$$-b_1\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx$$

$$-b_2\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx$$

$$+r\int_{w_2}^{w_1}\int_{-\infty}^{\infty} f(x,y)dy\,dx - (a-r)\int_{w_2}^{w_1}\int_{LSL}^{\infty} f(x,y)dy\,dx$$

$$-b_3\int_{w_2}^{w_1}\int_{-\infty}^{\infty} f(x,y)dy\,dx$$

$$+E(P)\int_{-\infty}^{w_2}\int_{-\infty}^{\infty} f(x,y)dy\,dx - R\int_{-\infty}^{w_2}\int_{-\infty}^{\infty} f(x,y)dy\,dx$$

$$-a\int_{-\infty}^{w_2}\int_{LSL}^{\infty} f(x,y)dy\,dx - r\int_{-\infty}^{w_2}\int_{L}^{LSL} f(x,y)dy\,dx$$

$$-c\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} y.f(x,y)dy\,dx \qquad (4.6)$$

Arrange and add more we get

$$
\begin{aligned}
&E(P) \\
&= a\int_{w_1}^{\infty}\int_{-\infty}^{\infty} f(x,y)dy\,dx \\
&- g\int_{w_1}^{\infty}\int_{LSL}^{\infty} y\,.\,f(x,y)dy\,dx \\
&+ g.\,LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty} f(x,y)dy\,dx \\
&- b_1\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx - b_2\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx \\
&+ r\int_{w_2}^{w_1}\int_{-\infty}^{\infty} f(x,y)dy\,dx + r\int_{w_2}^{w_1}\int_{LSL}^{\infty} f(x,y)dy\,dx - b_3\int_{w_2}^{w_1}\int_{-\infty}^{\infty} f(x,y)dy\,dx \\
&+ E(P)\int_{-\infty}^{w_2}\int_{-\infty}^{\infty} f(x,y)dy\,dx \\
&- R\int_{-\infty}^{w_2}\int_{-\infty}^{\infty} f(x,y)dy\,dx - a\int_{-\infty}^{w_1}\int_{LSL}^{\infty} f(x,y)dy\,dx - r\int_{-\infty}^{w_2}\int_{L}^{LSL} f(x,y)dy\,dx \\
&- c\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} y.\,f(x,y)dy\,dx \qquad (4.7)
\end{aligned}
$$

Finally, we can reduce the expected profit function to the following

$$E(P) = a\int_{w_1}^{\infty} f(x)dx - g\int_{w_1}^{\infty}\int_{LSL}^{\infty} y.f(x,y)dy\,dx + g.LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty} f(x,y)dy\,dx + r\int_{w_2}^{w_1} f(x)dx$$

$$+E(P)\int_{-\infty}^{w_2} f(x)dx - R\int_{-\infty}^{w_2} f(x)dx - cT - b_1\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx$$

$$- b_2\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx - b_3\int_{w_2}^{w_1}\int_{-\infty}^{L} f(x,y)dy\,dx$$

$$- a\int_{-\infty}^{w_1}\int_{LSL}^{\infty} f(x,y)dy\,dx + r\int_{w_2}^{w_1}\int_{LSL}^{\infty} f(x,y)dy\,dx$$

$$- r\int_{-\infty}^{w_2}\int_{L}^{LSL} f(x,y)dy\,dx \qquad (4.8)$$

4.3.2. OBJECTIVE II (INCOME OBJECTIVE FUNCTION)

Here, we are going to develop an income objective function, which by maximize we can obtain the optimum values of the process target mean and the cut off points.

Define I as the income per item and $E(I)$ its expected value. Hence, I is given by the following equation

$$I = \begin{cases} a - g(y - LSL) & if \quad x \geq w_1 \ , \ y \geq LSL \\ a - b_1 & if \quad x \geq w_1 \ , \ L \leq y < LSL \\ a - b_2 & if \quad x \geq w_1 \ , \ y < L \\ r & if \quad w_2 \leq x < w_1 \ , \ y \geq LSL \\ r & if \quad w_2 \leq x < w_1 \ , \ L \leq y < LSL \\ r - b_3 & if \ w_2 \leq x < w_1 \ , \ y < L \\ E(I) - R & if \quad x < w_2 \ , \ y \geq LSL \\ E(I) - R & if \quad x < w_2 \ , \ L \leq y < LSL \\ E(I) - R & if \ x < w_2 \ , \ y < L \end{cases} \tag{4.9}$$

Now the derivation of the expected income per item can be express as the following

$$E(I) = a\int_{w_1}^{\infty}\int_{LSL}^{\infty} f(x,y)dy\,dx - g\int_{w_1}^{\infty}\int_{LSL}^{\infty} y.f(x,y)dy\,dx$$

$$+ g.LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty} f(x,y)dy\,dx$$

$$+a\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx - b_1\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx$$

$$+a\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx - b_2\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx$$

$$+r\int_{w_2}^{w_1}\int_{LSL}^{\infty} f(x,y)dy\,dx$$

$$+r\int_{w_2}^{w_1}\int_{L}^{LSL} f(x,y)dy\,dx$$

$$+r\int_{w_2}^{w_1}\int_{-\infty}^{L} f(x,y)dy\,dx - b_3\int_{w_2}^{w_1}\int_{-\infty}^{L} f(x,y)dy\,dx$$

$$+E(I)\int_{-\infty}^{w_2}\int_{LSL}^{\infty} f(x,y)dy\,dx - R\int_{-\infty}^{w_2}\int_{LSL}^{\infty} f(x,y)dy\,dx$$

$$+E(I)\int_{-\infty}^{w_2}\int_{L}^{LSL} f(x,y)dy\,dx - R\int_{-\infty}^{w_2}\int_{L}^{LSL} f(x,y)dy\,dx$$

$$+E(I)\int_{-\infty}^{w_2}\int_{-\infty}^{L} f(x,y)dy\,dx - R\int_{-\infty}^{w_2}\int_{-\infty}^{L} f(x,y)dy\,dx \tag{4.10}$$

Now, add the similar term together

$$E(I) = a\int_{w_1}^{\infty}\int_{-\infty}^{\infty} f(x,y)dy\,dx - g\int_{w_1}^{\infty}\int_{LSL}^{\infty} y.f(x,y)dy\,dx$$

$$+ g.LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty} f(x,y)dy\,dx + r\int_{w_2}^{w_1}\int_{-\infty}^{\infty} f(x,y)dy\,dx$$

$$+ E(I)\int_{-\infty}^{w_2}\int_{-\infty}^{\infty} f(x,y)dy\,dx - R\int_{-\infty}^{w_2}\int_{-\infty}^{\infty} f(x,y)dy\,dx$$

$$- b_1\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx - b_2\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx$$

$$- b_3\int_{w_2}^{w_1}\int_{-\infty}^{L} f(x,y)dy\,dx \tag{4.11}$$

Then, the expected income per item is given by the following

$$E(I) = a\int_{w_1}^{\infty} f(x)\,dx - g\int_{w_1}^{\infty}\int_{-\infty}^{\infty} y.f(x,y)dy\,dx + g.LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty} f(x,y)dy\,dx$$

$$+ r\int_{w_2}^{w_1} f(x)\,dx + E(I)\int_{-\infty}^{w_2} f(x)\,dx - R\int_{-\infty}^{w_2} f(x)\,dx$$

$$- b_1\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx - b_2\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx$$

$$- b_3\int_{w_2}^{w_1}\int_{-\infty}^{L} f(x,y)dy\,dx \qquad (4.12)$$

Now consider the following notations:

Let $f(y) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{1}{2\sigma}(y-T)^2}$ is the normal distribution density function. Let $z = \frac{y-T}{\sigma}$then,

$\varphi(z) = \frac{1}{\sqrt{2\pi}} e^{z^2}$ is the standard normal distribution density function. Now consider the following:

$\int_{-\infty}^{y} f(y)dy = \int_{-\infty}^{\frac{y-T}{\sigma}} \varphi(z)\,dz = \Phi(z)$the standard normal distribution cumulative probability function.

Now let’s define the following:

$$\alpha = \frac{LSL - T}{\sigma}\ ,\quad \delta = \frac{L - T}{\sigma}$$

$$\beta = \Phi\left(\frac{LSL - T}{\sigma}\right) = \Phi(\alpha) \quad , \quad \gamma = \Phi\left(\frac{L - T}{\sigma}\right) = \Phi(\delta)$$

$$\omega = \frac{w_1 - T}{\sigma} \quad , \quad \eta = \frac{w_2 - T}{\sigma}$$

$$\Omega = \Phi\left(\frac{w_1 - T}{\sigma}\right) = \Phi(\omega) \quad , \quad \xi = \Phi\left(\frac{w_2 - T}{\sigma}\right) = \Phi(\,\eta)$$

Accordingly equation (4.6) can be written as

$$\begin{aligned} E(P) = a(1-\Omega) - g\int_{w_1}^{\infty}\int_{-\infty}^{\infty} y.f(x,y)dy\,dx + g.LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty} f(x,y)dy\,dx \\ + r(\Omega-\xi) + E(P)\xi - R\xi - cT - b_1\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx \\ - b_2\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx - b_3\int_{w_2}^{w_1}\int_{-\infty}^{L} f(x,y)dy\,dx \end{aligned} \tag{4.13}$$

By arranging the E (p) in the left hand side the function is written as

$$E(P) = \frac{a(1-\Omega)}{(1-\xi)} + \frac{r(\Omega-\xi)}{(1-\xi)} - \frac{R\xi}{(1-\xi)} - \frac{cT}{(1-\xi)}$$

$$- \frac{g}{(1-\xi)} \int_{w_1}^{\infty} \int_{-\infty}^{\infty} y.f(x,y)dy\,dx + \frac{g.LSL}{(1-\xi)} \int_{w_1}^{\infty} \int_{-\infty}^{\infty} f(x,y)dy\,dx +$$

$$- \frac{b_1}{(1-\xi)} \int_{w_1}^{\infty} \int_{L}^{LSL} f(x,y)dy\,dx$$

$$- \frac{b_2}{(1-\xi)} \int_{w_1}^{\infty} \int_{-\infty}^{L} f(x,y)dy\,dx - \frac{b_3}{(1-\xi)} \int_{w_2}^{w_1} \int_{-\infty}^{L} f(x,y)dy\,dx$$

$$- \frac{a}{(1-\xi)} \int_{-\infty}^{w_1} \int_{LSL}^{\infty} f(x,y)dy\,dx + \frac{r}{(1-\xi)} \int_{w_2}^{w_1} \int_{LSL}^{\infty} f(x,y)dy\,dx$$

$$- \frac{r}{(1-\xi)} \int_{-\infty}^{w_2} \int_{L}^{LSL} f(x,y)dy\,dx \qquad (4.14)$$

Similarly, equation (4.10) can be written as

$$E(I)$$

$$= a(1-\Omega) - g \int_{w_1}^{\infty} \int_{-\infty}^{\infty} y.f(x,y)dy\,dx + g.LSL \int_{w_1}^{\infty} \int_{LSL}^{\infty} f(x,y)dy\,dx + r(\Omega-\xi)$$

$$+ E(I) - R\xi - b_1 \int_{w_1}^{\infty} \int_{L}^{LSL} f(x,y)dy\,dx - b_2 \int_{w_1}^{\infty} \int_{-\infty}^{L} f(x,y)dy\,dx$$

$$- b_3 \int_{w_2}^{w_1} \int_{-\infty}^{L} f(x,y)dy\,dx \qquad (4.15)$$

Rearranging E (I) on the left hand side we get

$$E(I) = \frac{(a+g.LSL)(1-\Omega)}{(1-\xi)} + \frac{r(\Omega-\xi)}{(1-\xi)} - \frac{R\xi}{(1-\xi)}$$

$$- \frac{g}{(1-\xi)}\int_{w_1}^{\infty}\int_{-\infty}^{\infty} y.f(x,y)dy\,dx + \frac{g.LSL}{(1-\xi)}\int_{w_1}^{\infty}\int_{-\infty}^{\infty} f(x,y)dy\,dx +$$

$$- \frac{b_1}{(1-\xi)}\int_{w_1}^{\infty}\int_{L}^{LSL} f(x,y)dy\,dx$$

$$- \frac{b_2}{(1-\xi)}\int_{w_1}^{\infty}\int_{-\infty}^{L} f(x,y)dy\,dx - \frac{b_3}{(1-\xi)}\int_{w_2}^{w_1}\int_{-\infty}^{L} f(x,y)dy\,dx \quad (4.16)$$

4.3.3. OBJECTIVE III (PRODUCT UNIFORMITY OBJECTIVE FUNCTION)

In this section, we will develop a loss function for the production process under study (figure 2-1) based on Taguchi quadratic loss function. By minimizing the developed loss function with respect to the process target mean and cut off points we will maximize the product uniformity around the process mean.

Consider the production process under study (figure 2-1), the product quality characteristic y is the larger the better type. Hence hypothetically, the optimum value of the process mean is ∞, but, the higher mean the more material used and more cost incurs. So, the value of the process mean will never approach ∞.

$$L(\boldsymbol{y}) = k\sum_{i=1}^{n}\frac{1}{{y_i}^2}$$

In the above formula, n is the sample size and k is the quality loss coefficient$k = R\Delta^2$.

Δis the tolerance limit, which in the larger the better case is the lower specification limit. In the production process under study a produced item is classified into three areas based on specifications, conforming to primary market, conforming to secondary market and non-conforming. Also due to the error presence, the observed quality characteristic x differs from the actual quality characteristic y. Hence, the quality loss function will be

$$L(y) = \begin{cases} \dfrac{k}{y^2} + g(y - LSL) & if \quad x \geq w_1 \ , \quad y \geq LSL \\ \dfrac{k}{y^2} + b_1 & if \quad x \geq w_1 \ , \ L \leq y < LSL \\ \dfrac{k}{y^2} + b_2 & if \quad x \geq w_1 \ , \quad y < L \\ \dfrac{k}{y^2} + (a - r) & if \quad w_2 \leq x < w_1 \ , \quad y \geq LSL \\ \dfrac{k}{y^2} + (a - r) & if \quad w_2 \leq x < w_1 \ , \ L \leq y < LSL \\ \dfrac{k}{y^2} + (a - r) + b_3 & if \ w_2 \leq x < w_1 \ , \quad y < L \\ \dfrac{k}{y^2} + a + R & if \quad x < w_2 \ , \quad y \geq LSL \\ \dfrac{k}{y^2} + a + R & if \quad x < w_2 \ , \ L \leq y < LSL \\ \dfrac{k}{y^2} + a + R & if \ x < w_2 \ , \quad y < L \end{cases} \qquad (4.17)$$

Now, let E (L(y)) be the expectation of the loss function above. Hence, E (L(y)) is given by the following

$$
\begin{aligned}
&E(L(y)) \\
&= k\int_{w_1}^{\infty}\int_{LSL}^{\infty}\frac{1}{y^2}f(x,y)dy\,dx + g\int_{w_1}^{\infty}\int_{LSL}^{\infty}y\,f(x,y)dy\,dx - g\,LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty}f(x,y)dy\,dx \\
&+\ k\int_{w_1}^{\infty}\int_{L}^{LSL}\frac{1}{y^2}f(x,y)dy\,dx + b_1\int_{w_1}^{\infty}\int_{L}^{LSL}f(x,y)dy\,dx + k\int_{w_1}^{\infty}\int_{-\infty}^{L}\frac{1}{y^2}f(x,y)dy\,dx \\
&+ b_2\int_{w_1}^{\infty}\int_{-\infty}^{L}\frac{1}{y^2}f(x,y)dy\,dx + k\int_{w_2}^{w_1}\int_{LSL}^{\infty}\frac{1}{y^2}f(x,y)dy\,dx \\
&+ (a-r)\int_{w_2}^{w_1}\int_{LSL}^{\infty}f(x,y)dy\,dx + k\int_{w_2}^{w_1}\int_{L}^{LSL}\frac{1}{y^2}f(x,y)dy\,dx \\
&+ (a-r)\int_{w_2}^{w_1}\int_{L}^{LSL}f(x,y)dy\,dx + k\int_{w_2}^{w_1}\int_{-\infty}^{L}\frac{1}{y^2}f(x,y)dy\,dx \\
&+ (a-r)\int_{w_2}^{w_1}\int_{-\infty}^{L}f(x,y)dy\,dx + b_3\int_{w_2}^{w_1}\int_{-\infty}^{L}f(x,y)dy\,dx \\
&+ k\int_{-\infty}^{w_2}\int_{LSL}^{\infty}\frac{1}{y^2}f(x,y)dy\,dx + a\int_{-\infty}^{w_2}\int_{LSL}^{\infty}f(x,y)dy\,dx + R\int_{-\infty}^{w_2}\int_{LSL}^{\infty}f(x,y)dy\,dx \\
&+ k\int_{-\infty}^{w_2}\int_{L}^{LSL}\frac{1}{y^2}f(x,y)dy\,dx + a\int_{-\infty}^{w_2}\int_{L}^{LSL}f(x,y)dy\,dx + R\int_{-\infty}^{w_2}\int_{L}^{LSL}f(x,y)dy\,dx \\
&+ k\int_{-\infty}^{w_2}\int_{-\infty}^{L}\frac{1}{y^2}f(x,y)dy\,dx + a\int_{-\infty}^{w_2}\int_{-\infty}^{L}f(x,y)dy\,dx \\
&+ R\int_{-\infty}^{w_2}\int_{-\infty}^{L}f(x,y)dy\,dx \qquad (4.18)
\end{aligned}
$$

By rearranging the above formula we find the following

$$E(L(y))$$

$$= k\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{1}{y^2}f(x,y)dy\,dx + g\int_{w_1}^{\infty}\int_{LSL}^{\infty}y\,f(x,y)dy\,dx - g\,LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty}f(x,y)dy\,dx$$

$$+ (a-r)\int_{w_2}^{w_1}\int_{-\infty}^{\infty}f(x,y)dy\,dx + a\int_{-\infty}^{w_2}\int_{-\infty}^{\infty}f(x,y)dy\,dx + R\int_{-\infty}^{w_2}\int_{-\infty}^{\infty}f(x,y)dy\,dx$$

$$+ b_1\int_{w_1}^{\infty}\int_{L}^{LSL}f(x,y)dy\,dx + b_2\int_{w_1}^{\infty}\int_{-\infty}^{L}f(x,y)dy\,dx$$

$$+ b_3\int_{w_2}^{w_1}\int_{-\infty}^{L}f(x,y)dy\,dx \qquad (4.19)$$

Now, adding the similar terms together we get the following

$$E(L(y))$$

$$= k\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{1}{y^2}f(x,y)dy\,dx + g\int_{w_1}^{\infty}\int_{LSL}^{\infty}y\,f(x,y)dy\,dx - g\,LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty}f(x,y)dy\,dx$$

$$+ (a-r)\int_{w_2}^{w_1}f(x)dx + a\int_{-\infty}^{w_2}f(x)dx + R\int_{-\infty}^{w_2}f(x)dx$$

$$+ b_1\int_{w_1}^{\infty}\int_{L}^{LSL}f(x,y)dy\,dx + b_2\int_{w_1}^{\infty}\int_{-\infty}^{L}f(x,y)dy\,dx$$

$$+ b_3\int_{w_2}^{w_1}\int_{-\infty}^{L}f(x,y)dy\,dx \qquad (4.20)$$

Using the standard normal distribution and the notations defined in the previous section the expected loss can be written as

$$E(L(y)) = k\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{1}{y^2}f(x,y)dy\,dx + g\int_{w_1}^{\infty}\int_{LSL}^{\infty}y\,f(x,y)dy\,dx$$
$$- g\,LSL\int_{w_1}^{\infty}\int_{LSL}^{\infty}f(x,y)dy\,dx + a\Omega - r(\Omega - \xi) + R\xi$$
$$+ b_1\int_{w_1}^{\infty}\int_{L}^{LSL}f(x,y)dy\,dx + b_2\int_{w_1}^{\infty}\int_{-\infty}^{L}f(x,y)dy\,dx$$
$$+ b_3\int_{w_2}^{w_1}\int_{-\infty}^{L}f(x,y)dy\,dx \qquad (4.21)$$

4.3.4. THE MULTI-OBJECTIVE OPTIMIZATION FRAMEWORK

In this section, the multi-objective optimization model will be formulated in the same fashion described in section 2.5. The model goal is to find the optimum values of the process target mean and the two cut off points which maximize the three objectives simultaneously. The objectives are total expected profit per item, the total expected income per item and the product uniformity. The multi-objective optimization model is given by

$$max\,\boldsymbol{f}(\boldsymbol{T}) = [f_1(\boldsymbol{T}), f_2(\boldsymbol{T}), f_3(\boldsymbol{T})]$$

Subject to

$$T \geq LSL$$

Where

$f_1(\boldsymbol{T}) = E(P)$ equation 4.14

$f_2(\boldsymbol{T}) = E(I)$ equation 4.16

$f_3(\boldsymbol{T}) = -E\big(L(y)\big)$ equation 4.21

4.4 RESULTS AND SENSITIVITY ANALYSIS

In this section, an illustrative example for the model developed above is presented using parameters from the literature. This is followed by sensitivity analysis for these model's parameters, to discover their effect on the results.

4.4.1. SOLUTION METHODOLOGY

The proposed solution methodology consists of three main steps:

- Step 1: each objective function is evaluated individually using a uniform line search method with step length λ in the interval$I_1 = [LSL, LSL + b]$. Then, for each $T \in I_1$, conduct a cyclic search and evaluate the three objective values for $w_1$and $w_2$in the intervals $I_2 = [LSL - d, LSL + d]$and$I_3 = [L - d, L + d]$repectively. Where b and dare appropriate positive numbers.

- Step 2: Generate the set of non-inferior points as following:

i. Define $T_{min} = Min(T_1{}^*, T_2{}^*, T_3{}^*)$and $T_{max} = Max\ (T_1{}^*, T_2{}^*, T_3{}^*)$

ii. Let $T_i = T_{min} + i\lambda\epsilon[T_{min}, T_{max}]$: $i = 1,2,..,n$ and

$$T_j = T_{min} + j\lambda\epsilon[T_{min}, T_{max}] : j = 1,2,..,n$$

iii. The point(T_i, w_1, w_2) is a non-inferior point if there is no (T_j, w_1, w_2) such that:

$$\{f_k(T_j, w_1, w_2) \geq f_k(T_i, w_1, w_2) : \forall\, k = 1,2,3\}$$

- Step 3: Rank the set of non-inferior points as following:

  i. Normalize: $\frac{\boldsymbol{f_k(T_i)}}{\boldsymbol{f_k(T_i{}^*)}}$, i=1,2,..,n and k=1,2,3

  ii. Define the normalized sum$\boldsymbol{S_i}$as: $\boldsymbol{S_i = \sum_{k=1}^{3} \frac{f_k(T_i)}{f_k(T_i{}^*)}}$

  iii. Define the percentage absolute deviation $\boldsymbol{PAD_i}$as:$\boldsymbol{PAD_i = \frac{|3-S_i|*100}{3}}$, i=1,2,3

  iv. Rank the points according to $\boldsymbol{PAD_i}$from the smallest to the largest. The smaller the$\boldsymbol{PAD_i}$, the higher preference of the point.

4.4.2. NUMERICAL EXAMPLE

Consider a production process, which produces products that have a normally distributed quality characteristic y. If the value of the quality characteristic is above the primary market specification $LSL = 10$, then it sold at a regular price of $80, If the quality characteristic is below the LSL but above the secondary market specification $L = 9$, then it sold at a reduced price $67.5, and if the quality characteristic falls below L, the item reworked with cost $4. The inspection system tends to make some classification error, if a secondary market product is classified as a primary market product, then the producer compensates the customer with penalty$b_1 = a - r$, if a non-conforming product is classified as a primary market product, then the producer compensates the customer with penalty$b_2 = a$, finally, if a secondary market product is classified as a non-conforming product, then the producer compensates the customer with penalty $b_3 = r$. The processing cost of an item is $7, and the excess material cost per item of material is $2. The process standard deviation is 0.5 and the correlation coefficient between the actual quality characteristic y and the observed one x is$\rho = 0.85$, i.e.$\sigma_\varepsilon = 0.210042$ and $\sigma_x = 0.542326$.The uniform search is conducted over the interval$T \in [10,20]$, and the cyclic search over $w_1 \in [9.5,10.5]$and $w_2 \in [8.5,9.5]$. Table 4.1 below summarizes the obtained results

Table 4-3 The optimum values of the three objective factions of model 2

	PROFIT OBJECTIVE $f_1(T)$	INCOM OBJECTIVE $f_2(T)$	UNIFORATY OBJECTIVE $f_3(T)$
T^*	10.6	11.1	11
${w_1}^*$	9.8	9.5	9.5
${w_2}^*$	8.5	9.7	8.5
$f_i(T^*)$	1.403287191	77.40167523	-5.626598613

The above result can be interpret as the following, the primary market cut-off point $w_1$is lower than the primary market specification limit (LSL) which means, more lower quality items will be classify as a higher quality specially, more secondary market items classify as primary market items. The reason behind that; the penalty cost which the producer is going to pay for this misclassification is $(a-r) which is in our example $12.5, but in the other way around, if $w_1$is larger than the primary market specification limit (LSL) then, more primary market items are classified as secondary market item and the loss in the profit is also $(a-r) plus excess material cost of the primary market items fall actually above LSL. Therefore, it's more profitable to set the primary market cut-off point w_1 below the primary market specification limit LSL. For the secondary market cut-off pointw_2 of the income objective function, it is located above the secondary market specification limit L. this because there is no production cost in the income objective function and the rework cost is smaller than the penalty cost of classifying a conforming item as defective one. Therefore, if a defective item is classified as a primary market or a secondary market item then, the loss in profit are $a and $r, respectively. While in the other way around, if a defective item is classified as a primary market or a secondary market item will be reworked at $4.

The set of non-inferior solution is given below in table 4-2

Table 4-4 The set of non-inferior solutions of model 2

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.6	8.5	9.8	1.4023514	75.8249	-6.5366195	38th
10.6	8.6	9.8	1.397201	75.827165	-6.538841	37th

10.7	8.5	9.5	1.2550251	76.173132	-6.0013327	19th
10.7	8.6	9.5	1.2523356	76.174189	-6.0024873	20th
10.7	8.7	9.5	1.2459373	76.175885	-6.0052983	22nd
10.7	8.8	9.5	1.231711	76.178418	-6.0116453	24th
10.7	8.5	9.6	1.3239929	76.264166	-6.0218072	1st
10.7	8.6	9.6	1.3213065	76.265226	-6.0229618	2nd
10.7	8.7	9.6	1.3149146	76.266927	-6.0257728	4th
10.7	8.8	9.6	1.3007011	76.269471	-6.0321198	7th
10.7	8.9	9.6	1.2710886	76.273049	-6.0454743	13th
10.7	8.5	9.7	1.3847704	76.370876	-6.0669894	18th
10.7	8.6	9.7	1.3820879	76.371939	-6.068144	17th
10.7	8.7	9.7	1.3757038	76.373647	-6.070955	16th
10.7	8.8	9.7	1.3615057	76.376203	-6.077302	14th
10.7	8.9	9.7	1.3319224	76.379804	-6.0906565	10th
10.7	9	9.7	1.2739064	76.384679	-6.1170001	8th
10.7	8.5	9.8	1.3904112	76.463277	-6.1512987	26th
10.7	8.6	9.8	1.3877328	76.464343	-6.1524533	25th
10.7	8.7	9.8	1.3813585	76.466056	-6.1552642	23rd
10.7	8.8	9.8	1.3671777	76.468623	-6.1616113	21st
10.7	8.9	9.8	1.3376216	76.472245	-6.1749658	15th
10.7	9	9.8	1.2796682	76.477157	-6.2013094	3rd
10.7	8.5	9.9	1.2862996	76.508581	-6.2954959	12th
10.7	8.6	9.9	1.2836251	76.509648	-6.2966505	11th
10.7	8.7	9.9	1.277252	76.511364	-6.2994615	9th
10.7	8.8	9.9	1.2630869	76.513936	-6.3058085	6th
10.7	8.9	9.9	1.2335674	76.517568	-6.319163	5th
10.8	8.5	9.5	1.1271668	76.739529	-5.7817284	50th
10.8	8.6	9.5	1.1258212	76.740007	-5.7823064	51st

10.8	8.7	9.5	1.1225443	76.740796	-5.783745	52nd
10.8	8.8	9.5	1.1150808	76.742013	-5.7870692	54th
10.8	8.9	9.5	1.0991336	76.743789	-5.7942384	58th
10.8	8.5	9.6	1.1612563	76.789973	-5.7955729	39th
10.8	8.6	9.6	1.1599117	76.790453	-5.7961509	40th
10.8	8.7	9.6	1.156637	76.791243	-5.7975896	42nd
10.8	8.8	9.6	1.1491778	76.792463	-5.8009137	44th
10.8	8.9	9.6	1.1332386	76.794245	-5.8080829	48th
10.8	9	9.6	1.1011338	76.796771	-5.8226053	55th
10.8	8.5	9.7	1.1957843	76.859088	-5.8301669	30th
10.8	8.6	9.7	1.1944409	76.859568	-5.830745	31st
10.8	8.7	9.7	1.1911681	76.860361	-5.8321835	32nd
10.8	8.8	9.7	1.1837138	76.861584	-5.8355077	34th
10.8	8.9	9.7	1.1677846	76.863375	-5.8426769	36th
10.8	9	9.7	1.1356989	76.865916	-5.8571993	43rd
10.8	9.1	9.7	1.0744326	76.869517	-5.8850141	57th
10.8	8.5	9.8	1.1851012	76.914856	-5.8949957	27th
10.8	8.6	9.8	1.1837591	76.915337	-5.8955737	28th
10.8	8.7	9.8	1.1804903	76.916131	-5.8970123	29th
10.8	8.8	9.8	1.1730396	76.917358	-5.9003364	33rd
10.8	8.9	9.8	1.1571186	76.919155	-5.9075056	35th
10.8	9	9.8	1.1250548	76.921709	-5.9220281	41st
10.8	9.1	9.8	1.0638261	76.925333	-5.9498428	56th
10.8	9.2	9.8	0.9523607	76.930598	-6.0005302	61st
10.8	8.5	9.9	1.0865845	76.932917	-6.0075076	45th
10.8	8.6	9.9	1.0852436	76.933399	-6.0080856	46th
10.8	8.7	9.9	1.0819773	76.934194	-6.0095242	47th
10.8	8.8	9.9	1.0745317	76.935421	-6.0128484	49th

10.8	8.9	9.9	1.0586208	76.93722	-6.0200176	53rd
10.8	9	9.9	1.0265764	76.939778	-6.03454	59th
10.8	9.1	9.9	0.9653832	76.943409	-6.0623548	60th
10.8	9.2	9.9	0.8539811	76.948688	-6.1130421	62nd
10.9	8.5	9.5	0.7945182	77.102799	-5.6641578	79th
10.9	8.6	9.5	0.7938692	77.103007	-5.6644366	80th
10.9	8.7	9.5	0.7922509	77.103359	-5.665146	81st
10.9	8.8	9.5	0.7884738	77.103919	-5.6668244	83rd
10.9	8.9	9.5	0.7801921	77.104769	-5.6705364	84th
10.9	8.5	9.6	0.8011632	77.121101	-5.6714697	74th
10.9	8.6	9.6	0.8005146	77.12131	-5.6717485	75th
10.9	8.7	9.6	0.7988968	77.121662	-5.6724579	76th
10.9	8.8	9.6	0.7951206	77.122223	-5.6741363	78th
10.9	8.9	9.6	0.7868417	77.123074	-5.6778483	82nd
10.9	9	9.6	0.769703	77.124338	-5.6855738	85th
10.9	8.5	9.7	0.8223379	77.167329	-5.697633	63rd
10.9	8.6	9.7	0.8216896	77.167537	-5.6979118	64th
10.9	8.7	9.7	0.8200725	77.16789	-5.6986213	65th
10.9	8.8	9.7	0.8162979	77.168452	-5.7002996	69th
10.9	8.9	9.7	0.8080221	77.169306	-5.7040116	71st
10.9	9	9.7	0.7908897	77.170576	-5.7117372	73rd
10.9	9.1	9.7	0.7572151	77.172478	-5.7269673	86th
10.9	8.5	9.8	0.8064574	77.200429	-5.7459983	66th
10.9	8.6	9.8	0.8058094	77.200637	-5.7462771	67th
10.9	8.7	9.8	0.8041931	77.200991	-5.7469865	68th
10.9	8.8	9.8	0.8004209	77.201554	-5.7486648	70th
10.9	8.9	9.8	0.7921478	77.202409	-5.7523768	72nd
10.9	9	9.8	0.7750222	77.203683	-5.7601024	77th

10.9	9.1	9.8	0.7413605	77.205592	-5.7753325	87th
10.9	9.2	9.8	0.6782012	77.208533	-5.8039454	90th
10.9	9.3	9.8	0.5645413	77.213205	-5.855431	93rd
10.9	9.4	9.8	0.5130571	77.220761	-5.9444938	94th
10.9	8.9	9.9	0.7078054	77.205636	-5.8371174	88th
10.9	9	9.9	0.6906832	77.20691	-5.8448429	89th
10.9	9.1	9.9	0.6570354	77.208819	-5.860073	91st
10.9	9.2	9.9	0.5938994	77.211762	-5.888686	92nd
10.9	9.3	9.9	0.4802765	77.216436	-5.9401715	95th
10.9	9.4	9.9	0.4288601	77.223997	-6.0292343	96th
11	8.5	9.5	0.2947733	77.300181	-5.6265986	104th
11	8.6	9.5	0.2944716	77.300268	-5.6267282	105th
11	8.7	9.5	0.293701	77.300418	-5.6270653	106th
11	8.8	9.5	0.2918571	77.300666	-5.6278823	109th
11	8.9	9.5	0.2877063	77.301056	-5.6297363	111th
11	9	9.5	0.2788702	77.301663	-5.6337028	114th
11	9.1	9.5	0.2609828	77.302621	-5.6417551	117th
11	8.5	9.7	0.2935329	77.32439	-5.6470831	97th
11	8.6	9.7	0.2932313	77.324477	-5.6472127	98th
11	8.7	9.7	0.2924608	77.324628	-5.6475498	99th
11	8.8	9.7	0.2906182	77.324876	-5.6483668	100th
11	8.9	9.7	0.2864688	77.325267	-5.6502208	108th
11	9	9.7	0.2776363	77.325875	-5.6541873	112th
11	9.1	9.7	0.2597554	77.326837	-5.6622397	115th
11	9.2	9.7	0.2251564	77.328401	-5.677842	118th
11	8.5	9.8	0.2810179	77.346623	-5.6825449	101st
11	8.6	9.8	0.2807164	77.34671	-5.6826745	102nd
11	8.7	9.8	0.2799461	77.346861	-5.6830117	103rd

11	8.8	9.8	0.2781033	77.347109	-5.6838286	107th
11	8.9	9.8	0.2739556	77.347501	-5.6856826	110th
11	9	9.8	0.2651245	77.348111	-5.6896491	113th
11	9.1	9.8	0.2472483	77.349074	-5.6977015	116th
11	9.2	9.8	0.2126571	77.350643	-5.7133038	119th
11	9.3	9.8	0.1484049	77.353267	-5.7422927	120th
11	9.4	9.8	0.1149032	77.357708	-5.7941148	121st
11	9.5	9.8	-0.165024	77.365177	-5.8834448	122nd
11.1	8.5	9.5	-0.335427	77.367999	-5.6488571	129th
11.1	8.6	9.5	-0.335563	77.368034	-5.6489151	130th
11.1	8.7	9.5	-0.335917	77.368096	-5.6490696	131st
11.1	8.8	9.5	-0.336785	77.368201	-5.6494531	132nd
11.1	8.9	9.5	-0.338793	77.368373	-5.6503464	133rd
11.1	9	9.5	-0.34319	77.368653	-5.6523122	135th
11.1	9.1	9.5	-0.352364	77.369119	-5.6564236	136th
11.1	9.2	9.5	-0.37068	77.369919	-5.6646426	138th
11.1	8.5	9.6	-0.384925	77.32377	-5.6407851	140th
11.1	8.6	9.6	-0.38506	77.323805	-5.6408431	141st
11.1	8.7	9.6	-0.385414	77.323867	-5.6409976	142nd
11.1	8.8	9.6	-0.386282	77.323972	-5.641381	143rd
11.1	8.9	9.6	-0.38829	77.324143	-5.6422744	144th
11.1	9	9.6	-0.392687	77.324422	-5.6442401	145th
11.1	9.1	9.6	-0.40186	77.324886	-5.6483516	147th
11.1	8.5	9.7	-0.328898	77.391504	-5.6657618	123rd
11.1	8.6	9.7	-0.329033	77.391539	-5.6658198	124th
11.1	8.7	9.7	-0.329387	77.391601	-5.6659742	125th
11.1	8.8	9.7	-0.330255	77.391706	-5.6663577	126th
11.1	8.9	9.7	-0.332262	77.391878	-5.6672511	127th

11.1	9	9.7	-0.336659	77.392159	-5.6692168	128th
11.1	9.1	9.7	-0.345831	77.392627	-5.6733282	134th
11.1	9.2	9.7	-0.364143	77.393429	-5.6815473	137th
11.1	9.3	9.7	-0.399267	77.394838	-5.6973196	139th
11.1	9.4	9.7	-0.420155	77.397326	-5.7264621	146th
11.1	9.5	9.7	-0.580005	77.401675	-5.7784074	148th

4.4.3. SENSITIVITY ANALYSIS FOR THE PARAMETERS

In this section, the sensitivity analysis for the correlation coefficient ρ and the penalty costs is conducted, to study their effect on the model and the results

First, the effect of the correlation coefficient between actual quality characteristic y and the observed quality characteristic x is studied. Four cases are tested in tables 4-3, 4-4 and 4-5 below show the effect of the correlation coefficient on the three objective functions.

Table 4-5 The sensitivity analysis of the correlation coefficient on the profit objective function of model 2.

ρ	PROFIT				
	T	w_2	w_1	OBJECTIVE VALUE	CHANGE PERCENTAGE
0.95	10.6	8.5	9.9	1.89158168	34.88642%
0.90	10.6	8.5	9.8	1.624591083	15.84764%
0.85 (original)	10.6	8.5	9.8	1.403287191	0%
0.8	10.7	8.5	9.7	1.271954429	-9.298453%
0.75	10.7	8.5	9.6	1.10925804	-20.90014%

Table 4-6 The sensitivity analysis of the correlation coefficient on the income objective function of model 2.

ρ	INCOME				
	T	w_2	w_1	OBJECTIVE VALUE	CHANGE PERCENTAGE
0.95	11	9.5	10	77.60560789	0.263473%
0.90	11.1	9.5	9.9	77.41250907	0.013997%
0.85 (original)	11.1	9.5	9.7	77.40167523	0%
0.8	11.1	9.5	9.7	77.38962532	-0.015568%
0.75	11.1	9.5	9.5	77.35064151	-0.06593%

Table 4-7 The sensitivity analysis of the correlation coefficient on the product uniformity objective function of model 2.

ρ	UNIFORMITY				
	T	w_2	w_1	OBJECTIVE VALUE	CHANGE PERCENTAGE
0.95	12.4	8.5	9.8	-3.820241898	32.10388%
0.90	11.2	8.5	9.6	-5.619766639	0.121423%
0.85 (original)	11	8.5	9.5	-5.626598613	0%
0.8	11	8.5	9.5	-5.633498691	-0.12263%
0.75	11	8.5	9.5	-5.644154922	-0.31202%

It is clear that as the correlation coefficient ρ increases the error standard deviation decreases as well. Therefore, as the correlation coefficient value increased the deviation between the actual and observed quality characteristics is decreased and approaches zero.

Hence, the model tends to be closer to the model in chapter three with no inspection error.

The higher the value of the correlation coefficient, the higher value for the three objective function values (profit, income and product uniformity) because, if the correlation coefficient value is high then, more produced items are classified correctly according to their quality characteristic values therefore, no more penalty cost is going to be paid. While the small value of the correlation coefficient means more produced items are misclassified due to the high deviation between the actual and observed quality characteristics. Hence, more penalties are going to be paid which resulting in more loss which reduce the net profit and income per item and more variability between the produced items.

The sets of non-inferior solutions of the sensitivity analysis on the correlation coefficient can be found in appendix B.

Now, we come to the sensitivity analysis of the penalty cost parameters (table 4-2). These penalties associated with classifying and selling a lower quality product as a higher quality one. In the original model the producer compensates the customer by what the customer has paid for the higher quality. Ten cases are tested; tables 4-8, 4-9 and 4-10 summarize the results of the conducted sensitivity analysis on the penalty cost parameters.

Table 4-8 The sensitivity analysis of the penalty costs on the profit objective function of model 2

PROFIT

penalties	T	$w_2{}^*$	$w_1{}^*$	OBJECTIVE VALUE	CHANGE PERCENTAGE
+50%	10.7	8.5	9.8	1.093482413	-22.02508%
+25%	10.7	8.5	9.8	1.242172255	-11.42218%
+20%	10.7	8.5	9.8	1.271910224	-9.301605%
+15%	10.7	8.5	9.8	1.301648192	-7.1810264%
+10%	10.7	8.5	9.8	1.331386161	-5.0604475%
Original	10.6	8.5	9.8	1.403287191	10.6
-10%	1.6	8.5	9.8	1.485551432	5.9328933%
-15%	10.6	8.5	9.8	1.526683553	8.865976%
-20%	10.6	8.5	9.8	1.567815673	11.79906%
-25%	10.6	8.5	9.7	1.612108094	14.957497%
-50%	10.6	8.5	9.7	1.857968755	32.48953%

Table 4-9 The sensitivity analysis of the penalty costs on the income objective function of model 2

INCOME					
penalties	T	$w_2{}^*$	$w_1{}^*$	OBJECTIVE VALUE	CHANGE PERCENTAGE
+50%	11.1	9.5	9.9	77.3420366	-0.077051%
+25%	11.1	9.5	9.7	77.36845583	-0.042918%
+20%	11.1	9.5	9.7	77.37509971	-0.0343346%
+15%	11.1	9.5	9.7	77.38174359	-0.0257509%
+10%	11.1	9.5	9.7	77.38838747	-0.0171673%

Original	11.1	9.5	9.7	77.40167523	0%
-10%	11.1	9.5	9.7	77.41496299	0.0171673%
-15%	11.1	9.5	9.7	77.42160687	0.025751%
-20%	11.1	9.5	9.7	77.42825075	0.034335%
-25%	11.1	9.5	9.7	77.43489463	0.042918%
-50%	11.1	9.5	9.8	77.46811403	0.085836%

Table 4-10 The sensitivity analysis of the penalty costs on the product uniformity objective function of model 2.

PRODUCT UNIFORMITY					
penalties	T	$w_2{}^*$	$w_1{}^*$	OBJECTIVE VALUE	CHANGE PERCENTAGE
+50%	11.1	8.5	9.6	-5.714670912	1.56528%
+25%	11.1	8.5	9.6	-5.67772801	-0.908709%
+20%	11.1	8.5	9.6	-5.67033943	-0.777394%
+15%	11	8.5	9.6	-5.6625449	-0.638864%
+10%	11	8.5	9.6	-5.65064017	-0.427284%
Original	11	8.5	9.5	-5.62659861	0%
-10%	11	8.5	9.5	-5.60098779	0.45517%
-15%	11	8.5	9.5	-5.58818238	0.68276%
-20%	11	8.5	9.5	-5.57537697	0.91035%
-25%	11	8.5	9.5	-5.56257156	1.13794%

-50%	10.9	8.8	9.5	-5.464147477	2.8872%

It is clear that, as well the penalty cost values increases the net the three objective values decrease, since the producer pays more if the items' quality is misclassified. For the larger increase in the penalty cost, the cut-off points are wider than the original case to reduce the probability to the misclassification.

The sets of non-inferior solutions of the sensitivity analysis on the penalty costs can be found in appendix B.

4.5 CONCLUSION

In this chapter, a multi-objective optimization model has been developed for process targeting problem. Three objective functions are maximized simultaneously to find the optimum setting of the process target mean. The assumption of the inspection error is relaxed in this chapter and the concept of cut-off points is used to reduce the impact of the error. The set of non-inferior solutions was generated for an example contains some data from the process targeting literature. Sensitivity analysis for the correlation coefficient between the actual and observed quality characteristics and the penalty cost parameters was conducted, to study their effect on the optimal process target mean and the three objective function values.

CHAPTER 5

MULTI-OBJECTIVE PROCESS TARGETING MODEL WITH SAMPLING PLAN AND ERROR-FREE INSPECTION SYSTEM

5.1 PREFACE

In this chapter a multi-objective optimization model has been developed for a process targeting problem. The production process used in the development of this chapter and the next one is described in section 5.2. In this production process sampling plan is used as the mean for product quality control. The sampling plan inspection is considered to be error-free which the assumption that will be relaxed is in the next chapter. After defining the production process, the process targeting problem statement and a multi-objective optimization model for this production process are stated in sections 5.3 and 5.4, respectively. The utility of the developed model has been shown using a numerical example from the literature and sensitivity analysis is conducted on the parameters in section 5.5. The chapter is concluded in section 5.6.

5.2 DESCRIBTION OF THE PRODUCTION PROCESS

Consider a production process described in figure 5.1 that produces items have quality characteristic y with unknown mean value T and known standard deviation value σ. The quality characteristic has a lower specification limit LSL. Also assume that, no inspection takes place before producing a lot of size N. Then a sample of size n is drawn from the lot. Now there are three cases: first case, the number of non-conforming items in the sample is less than or equal to a pre-determined first rejection criteria d_1 (accepting number of non-conforming item in the sample), then, the lot is sold in a primary market for $\$a$ per item. Second case, the number of non-conforming items in the sample falls between the first rejection criteria d_1 and the second rejection criteria d_2 ($d_1 < d_2$), then, the lot is sold in a secondary market for $\$r$ (r < a) per item. The third and last case, the number of non-conforming items in the sample exceeds d_2, then, the entire lot is reworked for a cost $\$R$ per item.

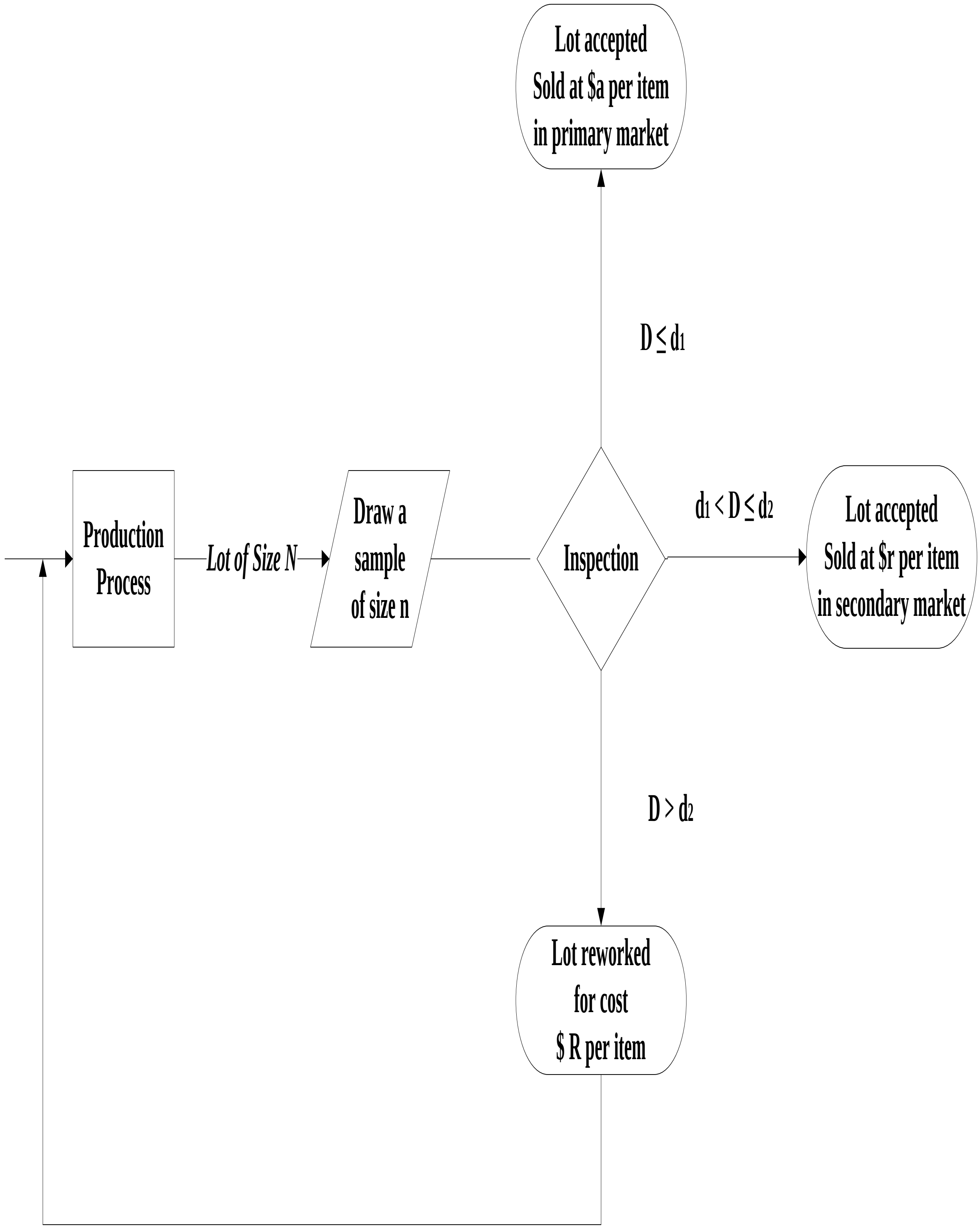

Figure 5-1 The description of the production process under sampling plan

5.3 STATEMENT OF THE PROBLEM

Consider the production process described in figure (5-1).A produced item is classified as defect if its quality characteristic does not meet the specification (falls below the lower specification limit LSL). After producing a lot of size N, a sample of size n is drawn from the lot and all the items in the sample are inspected. The number of the defective in the sample D is compared with the values of the two critical values$d_1$and d_2: $d_1 < d_2$(allowed number of defects). If the number of observed defectives in the sample D is less than d_1, the lot is accepted and sold in a primary market at a regular price, the cost of excess quality is considered in this situation. Then, If D falls between $d_1$and d_2, then, the lot is sold at secondary market at a reduced price. If D is greater thand_2, the whole lot is reworked again. The production and inspection cost per item c and I, respectively, are fixed and known.

A multi-objective optimization model will be developed next. By applying an appropriate optimization technique, the optimum process target mean id obtained.

5.4 MODEL DEVELOPMENT

In this section, a multi-objective optimization model has been developed. This model consists of three objective functions, expected profit per item, expected income per item and product uniformity. The development of these objectives is based on the production process in figure 5-1.

Now, let's determine the probabilities of classifying the lot to be sold in a primary market, secondary market or to be reworked.

First, the probability that an item falls below LSL is given by the following

$$p(y < LSL) = \Phi\left(\frac{LSL - T}{\sigma}\right) = \beta \tag{5.1}$$

The distribution of number of defectives in an incoming lot follows the binomial probability distribution with parameterβ.

The lot is said to be primary market conforming if the number of defects in the sample is less that $d_1$with probability

$$p(D \leq d_1) = \sum_{i=0}^{d_1} \binom{n}{i} \beta^i (1-\beta)^{n-i} \tag{5.2}$$

The probability of classifying the lot as a secondary market conforming is

$$p(d_1 < D \leq d_2) = \sum_{i=0}^{d_2} \binom{n}{i} \beta^i (1-\beta)^{n-i} - \sum_{i=0}^{d_1} \binom{n}{i} \beta^i (1-\beta)^{n-i} \tag{5.3}$$

$$p(d_1 < D \leq d_2) = \sum_{i=d_1+1}^{d_2} \binom{n}{i} \beta^i (1-\beta)^{n-i} \tag{5.4}$$

Finally, the probability of reworking the whole entire lot is

$$p(D > d_2) = \sum_{i=d_{2+1}}^{n} \binom{n}{i} \beta^i (1-\beta)^{n-i} = 1 - \sum_{i=0}^{d_2} \binom{n}{i} \beta^i (1-\beta)^{n-i} \tag{5.5}$$

Also, define $y^{'}$ as the expected value of the quality characteristic y where y is above the lower specification limit

$$y^{'} = E(y|y \geq LSL) = \frac{\int_{LSL}^{\infty} y f(y) dy}{\int_{LSL}^{\infty} f(y) dy} \quad (5.6)$$

5.4.1. OBJECTIVE I (PROFIT OBJECTIVE FUNCTION)

Let's define Pro and E (Pro) to be the profit per lot and its expectation, respectively. Also, define P and E (P) as the profit per item and its expected value, respectively. Starting by defining the profit per lot formula, we will end up with an equation for the expected profit per item as the following

$$Pro = \begin{cases} aN - g(y - LSL)N - In - cyN & if \quad D \leq d_1 \\ rN - In - cyN & if \quad d_1 < D \leq d_2 \\ E(Pro) - RN - In - cyN & if \quad D > d_2 \end{cases} \quad (5.7)$$

Now the expected profit per lot is given by

$$\begin{aligned} E(Pro) = {} & a\, N \,.\, p(D \leq d_1) - g(y - LSL)N \,.\, p(D \leq d_1) - I\, n \,.\, p(D \leq d_1) \\ & - c\, y\, N \,.\, p(D \leq d_1) \; + r\, N \,.\, p(d_1 < D \leq d_2) - I\, n \,.\, p(d_1 < D \leq d_2) \\ & - c\, y\, N \,.\, p(d_1 < D \leq d_2) + E(Pro) \,.\, p(D > d_2) - R\, N \,.\, p(D > d_2) \\ & - I\, n \,.\, p(D > d_2) - cyN.\, p(D > d_2) \end{aligned} \quad (5.8)$$

Rearranging the above equation we get

$$E(Pro) = \frac{1}{1 - p(D > d_2)} [a\, N\, .p(D \leq d_1) - g(y - LSL)N\, .p(D \leq d_1)$$
$$+ r\, N\, .p(d_1 < D \leq d_2) - R\, N\, .p(D > d_2) - I\, n\; - c\, T\, N] \qquad (5.9)$$

Divide all the terms by N we get the expected profit per item as the following

$$E(P) = \frac{1}{1 - p(D > d_2)} \Big[a\, .p(D \leq d_1) - g(y - LSL)\, .p(D \leq d_1) + r\, .p(d_1 < D \leq d_2)$$
$$- R\, .p(D > d_2) - I\, \frac{n}{N} - c\, T\Big] \qquad (5.10)$$

The term $1 - p(D > d_2)$ is equivalent to$p(D \leq d_2)$. So, the expected profit per item can be written as

$$E(P) = \frac{1}{p(D \leq d_2)} \Big[a\, .p(D \leq d_1) - g(y - LSL)\, .p(D \leq d_1) + r\, .p(d_1 < D \leq d_2)$$
$$- R\, .p(D > d_2) - I\, \frac{n}{N} - c\, T\Big] \qquad (5.11)$$

Now, y is replaced by $y' = E(y|y \geq LSL) =$, where f(y) is the normal distribution density function.

$$E(P) = \frac{1}{p(D \leq d_2)} \Big[a\, .p(D \leq d_1) - g(y' - LSL)\, .p(D \leq d_1) + r\, .p(d_1 < D \leq d_2)$$
$$- R\, .p(D > d_2) - I\, \frac{n}{N} - c\, T\Big] \qquad (5.12)$$

5.4.2. OBJECTIVE II (INCOME OBJECTIVE FUNCTION)

Let Inc, E (Inc), I and E (I) be the total income per lot, expected income per lot, income per item and expected income per item, respectively.

Now, the total income per lot is given by

$$Inc = \begin{cases} aN - g(y - LSL)N & if \quad D \le d_1 \\ rN & if \quad d_1 < D \le d_2 \\ E(Inc) - RN & if \quad D > d_2 \end{cases} \tag{5.13}$$

Now the expected income per lot is given by

$$\begin{aligned} E(Inc) = {} & a\,N\,.p(D \le d_1) - g(y - LSL)N\,.p(D \le d_1) \ + r\,N\,.p(d_1 < D \le d_2) \\ & + E(Inc)\,.p(D > d_2) - R\,N\,.p(D > d_2) \end{aligned} \tag{5.14}$$

Rearranging the above equation we get

$$\begin{aligned} E(Inc) = {} & \frac{1}{1 - p(D > d_2)}[a\,N\,.p(D \le d_1) - g(y - LSL)N\,.p(D \le d_1) \\ & + r\,N\,.p(d_1 < D \le d_2) - R\,N\,.p(D > d_2)] \end{aligned} \tag{5.15}$$

Divide all the terms by N we get the expected profit per item as the following

$$\begin{aligned} E(I) = {} & \frac{1}{1 - p(D > d_2)}[a\,.p(D \le d_1) - g(y - LSL)\,.p(D \le d_1) + r\,.p(d_1 < D \le d_2) \\ & - R\,.p(D > d_2)] \end{aligned} \tag{5.16}$$

While$1 - p(D > d_2) = p(D \le d_2)$, so, equation 5.19 can be written as

$$E(I) = \frac{1}{p(D \leq d_2),} [a\,.\,p(D \leq d_1) - g(y - LSL)\,.\,p(D \leq d_1) + r\,.\,p(d_1 < D \leq d_2)$$
$$- R\,.\,p(D > d_2)] \tag{5.17}$$

Again, replace y with $y' = E(y|y \geq LSL)$

$$E(I) = \frac{1}{p(D \leq d_2),} [a\,.\,p(D \leq d_1) - g(y' - LSL)\,.\,p(D \leq d_1) + r\,.\,p(d_1 < D \leq d_2)$$
$$- R\,.\,p(D > d_2)] \tag{5.18}$$

5.4.3. OBJECTIVE III (PRODUCT UNIFOMITY OBJECTIVE FUNCTION)

In this section, a loss function for the production process under study (figure 5-1) has been developed based on Taguchi quadratic loss function. By minimizing the developed loss function with respect to the process target mean we will ensure the product uniformity around the process target mean will be ensured.

The product quality characteristic y has the larger the better quality type. Hence theoretically, the optimum value of the process mean is∞, but, the higher mean the more material used and more cost incurs. So, the value of the process mean will never approach ∞. The loss function of the larger the better quality type is given by

$$L(\boldsymbol{y}) = k \sum_{i=1}^{N} \frac{1}{{y_i}^2}$$

k is the quality loss coefficient $k = R\Delta^2$ and Δ is the tolerance limit, which in the larger the better case is the lower specification limit. By defining Loss and E (Loss) as the loss and the expected loss per lot, respectively, the expected loss per item is given by

$$Loss = \begin{cases} (N-n)L_{01} + n\,L_{11} & if \quad D \leq d_1 \\ (N-n)L_{02} + n\,L_{12} & if \quad d_1 < D \leq d_2 \\ (N-n)L_{03} + n\,L_{13} & if \quad D > d_2 \end{cases} \tag{5.19}$$

Where

L_{01}, L_{02} and L_{03} are the expected quality loss per uninspected item and L_{11}, L_{12} and L_{13} are the expected quality loss per inspected item. These terms are given by

$$L_{01} = k\int_{-\infty}^{\infty} \frac{1}{y^2} f(y)dy + g(y' - LSL) \tag{5.20}$$

$$L_{02} = k\int_{-\infty}^{\infty} \frac{1}{y^2} f(y)dy + (a - r) \tag{5.21}$$

$$L_{03} = k\int_{-\infty}^{\infty} \frac{1}{y^2} f(y)dy + a + R \tag{5.22}$$

$$L_{11} = \frac{k\int_{LSL}^{\infty} \frac{1}{y^2} f(y)dy}{\int_{LSL}^{\infty} f(y)dy} + g(y' - LSL) \tag{5.23}$$

$$L_{12} = \frac{k\int_{-\infty}^{LSL} \frac{1}{y^2} f(y)dy}{\int_{-\infty}^{LSL} f(y)dy} + (a - r) \tag{5.24}$$

$$L_{13} = \frac{k \int_{-\infty}^{LSL} \frac{1}{y^2} f(y) dy}{\int_{-\infty}^{LSL} f(y) dy} + a + R \tag{5.25}$$

Hence, the expected loss can be expressed as

$$E(LOSS) = [(N-n)L_{01} + n\, L_{11}]\, p(D \le d_1) + [(N-n)L_{02} + n\, L_{12}] p(d_1 < D \le d_2)$$
$$+ [(N-n)L_{03} + n\, L_{13}] p(D > d_2) \tag{5.26}$$

Dividing by N, the expected loss per item is given by

$$E(L) = \left[\left(1 - \frac{n}{N}\right) L_{01} + \frac{n}{N} L_{11}\right] p(D \le d_1) + \left[\left(1 - \frac{n}{N}\right) L_{02} + \frac{n}{N} L_{12}\right] p(d_1 < D \le d_2)$$
$$+ \left[\left(1 - \frac{n}{N}\right) L_{03} + \frac{n}{N} L_{13}\right] p(D > d_2) \tag{5.27}$$

5.4.4. MULTI-OBJECTIVE OPTIMIZATION MODEL

Now we can use the three objective functions developed above to build up a multi-objective maximization framework to obtain the optimum process target mean which maximizes the three objectives simultaneously. The multi-objective optimization model is given by

$$max\, \boldsymbol{f}(\boldsymbol{T}) = [f_1(\boldsymbol{T}), f_2(\boldsymbol{T}), f_3(\boldsymbol{T})]$$

Subject to

$$T \geq LSL$$

Where

$f_1(\boldsymbol{T}) = E(P)$ equation 5.12

$f_2(\boldsymbol{T}) = E(I)$ equation 5.18

$f_3(\boldsymbol{T}) = -E(L)$ equation 5.27

5.5 RESULTS AND SENSITINITY ANALYSIS

In this section, an illustrative example for the developed model is presented. Followed by, sensitivity analysis for the model's parameters (i.e. the process standard deviation, the costs parameters and the sample parameters), to assess changes in these parameters on the model optimal values.

5.5.1. SOLUTION METHODOLOGY

The proposed solution methodology consists of three main steps:

- Step 1: each objective function is evaluated individually using a uniform line search method with step length λ in the interval $I = [LSL, LSL + b]$, where b is an appropriate positive number.

- Step 2: Generate the set of non-inferior points as following:

i. Define $T_{min} = Min({T_1}^*, {T_2}^*, {T_3}^*)$and $T_{max} = Max\ ({T_1}^*, {T_2}^*, {T_3}^*)$

ii. Let $T_i = T_{min} + i\lambda\epsilon[T_{min}, T_{max}]: i = 1,2, . . , n$ and

$$T_j = T_{min} + j\lambda\epsilon[T_{min}, T_{max}] : j = 1,2, . . , n$$

iii. The point T_i is a non-inferior point if there is no T_j such that:

$$\{f_k(T_j) \geq f_k(T_i) : \forall\ k = 1,2,3\}$$

- Step 3: Rank the set of non-inferior points as following:

  i. Normalize: $\frac{f_k(T_i)}{f_k({T_i}^*)}$, i=1,2,..,n and k=1,2,3

  ii. Define the normalized sum$\boldsymbol{S_i}$as: $\boldsymbol{S_i} = \sum_{k=1}^{3} \frac{f_k(T_i)}{f_k({T_i}^*)}$

  iii. Define the percentage absolute deviation $\boldsymbol{PAD_i}$as:$\boldsymbol{PAD_i} = \frac{|3-S_i|*100}{3}$,

  i=1,2,3

  iv. Rank the points according to $\boldsymbol{PAD_i}$from the smallest to the largest.

  The smaller the$\boldsymbol{PAD_i}$, the higher preference of the point.

5.5.2. NUMERICAL EXAMPLE

Consider a production process, that produces items with a quality characteristic that is normally distributed with unknown mean T and known standard deviation σ = 0.5. The items have a lower specification limit LSL = 10. A sampling inspection is used to control the product quality. The sampling plan used after a lot is produced, a sample of size n=10, $d_1 = 1$ and $d_2 = 2$. The processing cost c = \$6, the inspection cost I = \$1 and the excess material cost g = \$2. If the number of non-conforming items in the sample is $d_1 = 1$ then, the lot is sold in a primary market at \$80 per item. Is the number of non-conforming items in the lot is more than $d_1 = 1$ and less than $d_2 = 2$ the, the lot is sold in a secondary market at \$67.5 per item. Finally, if the number of non-conforming items in the sample is more than $d_2 = 2$ then, the lot is reworked again for \$4 per item. To solve this problem, an exhausted uniform search in the interval [10, 20], is done for each objective of the multi-objective model in section 5.4.4, the step size for the search is 0.1. Table 5-1 gives the optimum target value for each objective function individually.

Table 5-1 The optimum objective values of the model 3.

	PROFIT OBJECTIVE $f_1(T)$	INCOME OBJECTIVE $f_2(T)$	UNIFORATY OBJECTIVE $f_3(T)$
T^*	10.9	11	11.1
$f_i(T^*)$	11.83637	77.6829438	-5.64234248

The three graphs below show the plot of each of the three objective functions.

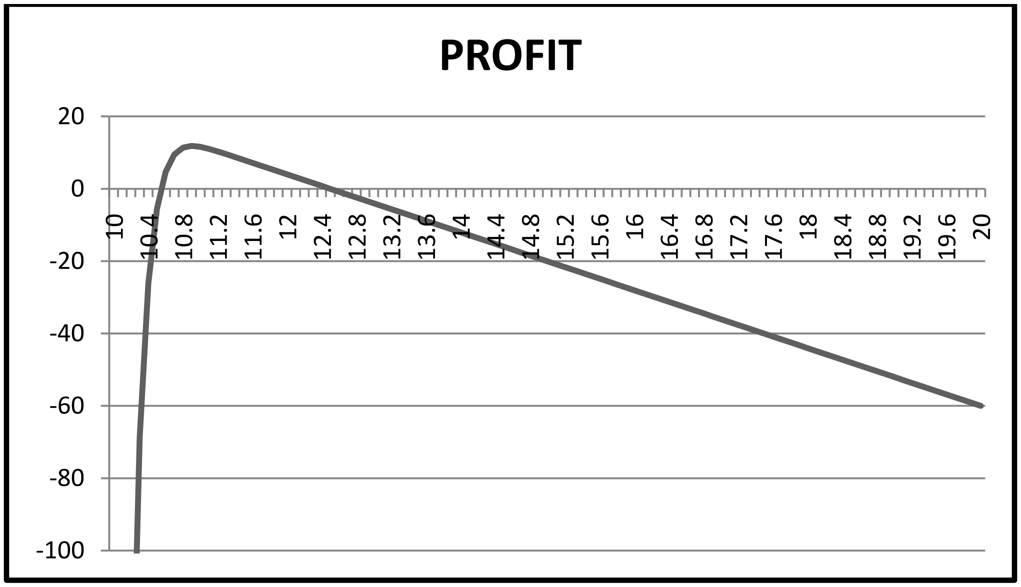

Figure 5-2 the plot of the profit objective function of model 3

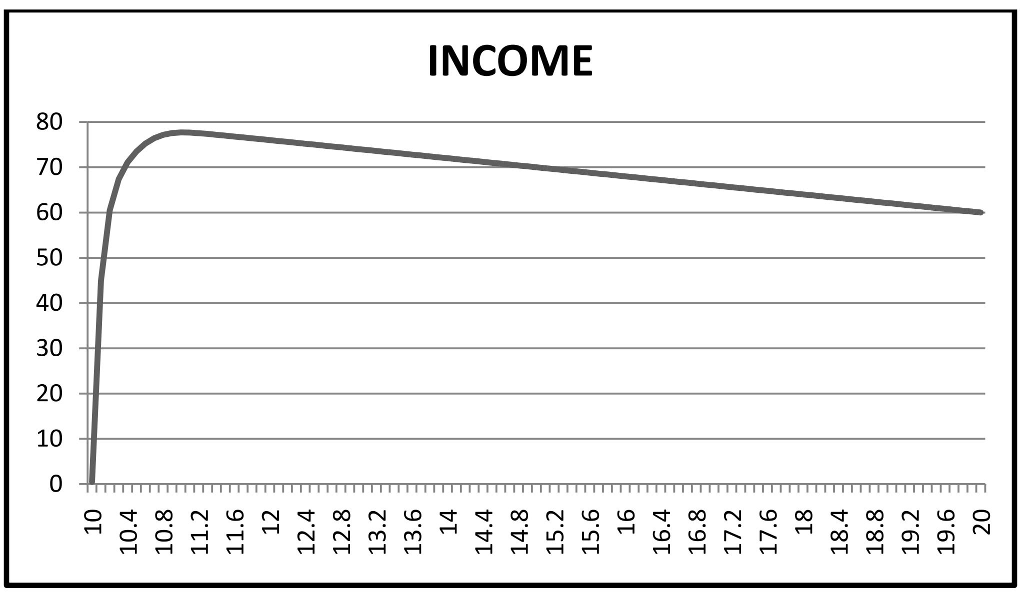

Figure 5-3 the plot of the income objective function of model 3

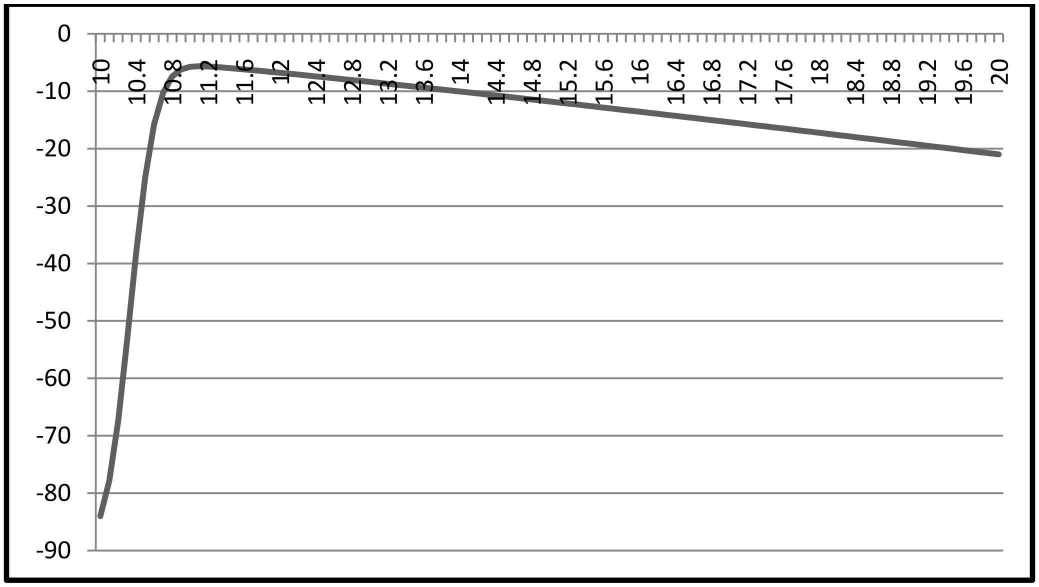

Figure 5-4 the plot of the product uniformity objective function of model 3

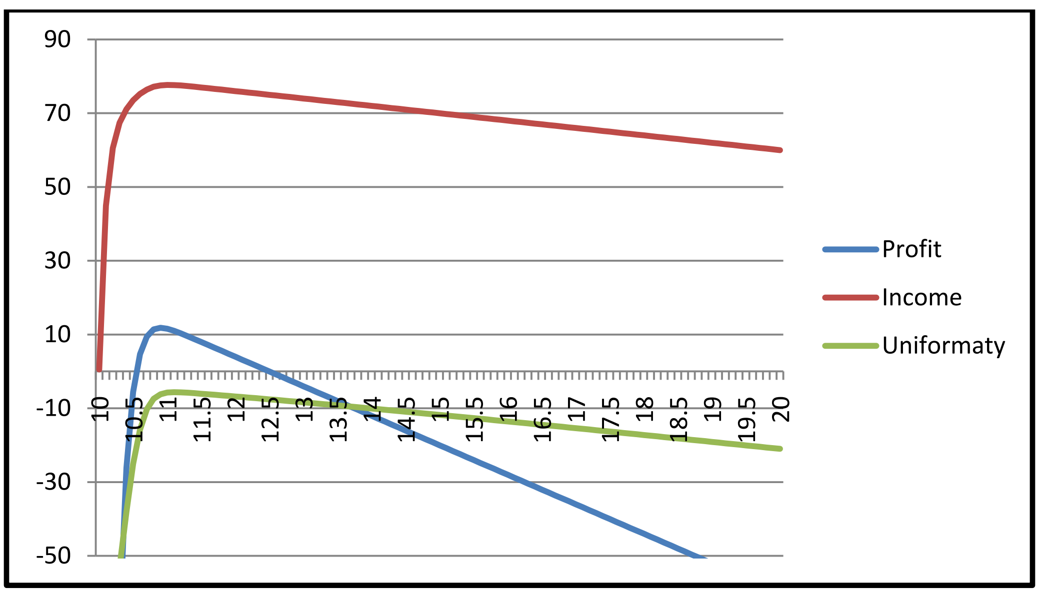

Figure 5-5 the plot of the three objective functions of model 3

Now, the next table 5-2 gives the set of non-inferior solutions of model 3.

Table 5-2 The set of non-inferior solutions of model 3.

T^*	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.83636534	77.55884946	-6.18650541	3rd
11	11.58010795	77.68294383	-5.740859358	1st
11.1	11.00730867	77.64728356	-5.64234248	2nd

5.5.3. SENSITIVITY ANALYSIS

In this section, the effects of the process standard deviation, the cost parameters and the sampling plan parameters are studied. First, the model is evaluated for several values of the standard deviation ($\sigma \pm 25\%, \sigma \pm 50\%$ and$\sigma \pm 75\%$). Tables 5-3, 5-4 and 5-5 below show the change in the objective values for the individual objectives.

Table 5-3 The sensitivity analysis of the process standard deviation on the profit objective function of model 3

SENSITIVITY		PROFIT		
σ	CHANGE	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
0.875	+75%	11.5	6.666397	-43.6787%
0.75	+50%	11.3	8.355732	-29.4063%
0.625	+25%	11.1	10.07473	-14.8833%
0.5	original	10.9	11.83637	0%
0.375	-25%	10.7	13.65979	15.4053%
0.25	-50%	10.5	15.56447	31.49707%
0.125	-75%	10.3	17.49711	47.825%

Table 5-4 The sensitivity analysis of the process standard deviation on the income objective function of model 3

SENSITIVITY		INCOME		
σ	CHANGE	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
0.875	+75%	11.6	76.27216	-1.8161%
0.75	+50%	11.4	76.72193	-1.2371%
0.625	+25%	11.2	77.19075	-0.6336%
0.5	original	11	77.68294	0%
0.375	-25%	10.8	78.19931	0.66471%
0.25	-50%	10.6	78.72272	1.3385%
0.125	-75%	10.3	79.32102	2.1087%

Table 5-5 The sensitivity analysis of the process standard deviation on the product uniformity objective function of model 3

SENSITIVITY		UNIFORMITY		
σ	CHANGE	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
0.875	+75%	11.8	-6.819991542	-20.87163%
0.75	+50%	11.6	-6.431747957	-13.9907%
0.625	+25%	11.3	-6.047053157	-7.172742%
0.5	original	11.1	-5.64234248	0%
0.375	-25%	10.9	-5.259194178	6.790589%
0.25	-50%	10.6	-4.848154617	14.075499%
0.125	-75%	10.3	-4.456025046	21.02526%

In the tables above, it is clear that the profit objective function is more sensitive to the change in the process standard deviation than the income objective function. This can be explained as following: in equations 5.12 and 5.18 the profit objective function have the term $c.T$ more than the income objective function where, the other terms are the same in both objectives.

From table 5-5, the process standard deviation has a moderate effect on the product uniformity objective function. This is because; as well as the standard deviation value increases the product variability increases. Hence, the loss due to this variability increases.

The sets of non-inferior solutions for the above mentioned sensitivity analysis of the process standard deviation can be found on appendix C.

Next, the sensitivity analysis conducted on the cost parameters (c, g, R and I) are shown in tables 5-6, 5-7 and 5-8

Table 5-6 The sensitivity analysis of the cost parameters on the profit objective function of model 3.

COST PARAMETERS	CHANGE	PROFIT		
		T	OBJECTIVE VALUE	CHANGE PERCENTAGE
c=9 g=3 R=6 I=1.5	+50%	10.9	-21.97325	-285.642%
c=7.5 g=2.5 R=5 I=1.25	+25%	10.9	-5.068444	-142.821%

c=7.2 g=2.4 R=4.8 I=1.2	+20%	10.9	-1.687482	-114.257%
c=6.9 g=2.3 R=4.6 I=1.15	+15%	10.9	1.69348	-85.6926%
c=6.6 g=2.2 R=4.4 I=1.1	+10%	10.9	5.07444	-57.1284%
c=6.3 g=2.1 R=4.2 I=1.05	+5%	10.9	8.455403	-28.564%
c=6 g=2 R=4 I=1	original	10.9	11.8364	0%
c=5.7 g=1.9 R=3.8 I=0.95	-5%	10.9	15.21733	28.5642%
c=5.4 g=1.8 R=3.6 I=0.9	-10%	10.9	18.59829	57.1284%
c=5.1 g=1.7 R=3.4 I=0.85	-15%	10.9	21.97925	85.6926%
c=4.8 g=1.6 R=3.2 I=0.8	-20%	10.9	25.3602	114.2568%
c=4.5 g=1.5 R=3 I=0.75	-25%	10.9	28.74117	142.821%

c=3 g=1 R=2 I=0.5	-50%	11	45.6688	285.8348%

Table 5-7 The sensitivity analysis of the cost parameters on the income objective function of model 3.

COST PARAMETERS	CHANGE	INCOME		
		T	OBJECTIVE VALUE	CHANGE PERCENTAGE
c=9 g=3 R=6 I=1.5	+50%	11	76.64566	-1.3353%
c=7.5 g=2.5 R=5 I=1.25	+25%	11	77.1643	-0.6676%
c=7.2 g=2.4 R=4.8 I=1.2	+20%	11	77.26803	-0.5341%
c=6.9 g=2.3 R=4.6 I=1.15	+15%	11	77.37176	-0.4006%
c=6.6 g=2.2 R=4.4 I=1.1	+10%	11	77.47549	-0.2671%
c=6.3 g=2.1 R=4.2 I=1.05	+5%	11	77.57922	-0.13353%
c=6 g=2 R=4 I=1	original	11	77.68294	0%
c=5.7 g=1.9 R=3.8 I=0.95	-5%	11	77.78667	0.13353%

c=5.4 g=1.8 R=3.6 I=0.9	-10%	11	77.8904	0.26706%
c=5.1 g=1.7 R=3.4 I=0.85	-15%	11	77.99413	0.40059%
c=4.8 g=1.6 R=3.2 I=0.8	-20%	11.1	78.09838	0.5348%
c=4.5 g=1.5 R=3 I=0.75	-25%	11.1	78.21115	0.67995%
c=3 g=1 R=2 I=0.5	-50%	11.1	78.77502	1.4058%

Table 5-8 The sensitivity analysis of the cost parameters on the product uniformity objective function of model 3.

COST PARAMETERS	CHANGE	UNIFORMITY		
		T	OBJECTIVE VALUE	CHANGE PERCENTAGE
c=9 g=3 R=6 I=1.5	+50%	11.1	-8.402917629	-48.92605%
c=7.5 g=2.5 R=5 I=1.25	+25%	11.1	-7.022630055	-24.46302%
c=7.2 g=2.4 R=4.8 I=1.2	+20%	11.1	-3.918456834	-19.57042%
c=6.9 g=2.3	+15%	11.1	-6.470515025	-14.67781%

R=4.6 I=1.15				
c=6.6 g=2.2 R=4.4 I=1.1	+10%	11.1	-6.19445751	-9.785209%
c=6.3 g=2.1 R=4.2 I=1.05	+5%	11.1	-5.918399995	-4.892605%
c=6 g=2 R=4 I=1	original	11.1	-5.702071834	0%
c=5.7 g=1.9 R=3.8 I=0.95	-5%	11.1	-5.366284965	4.892605%
c=5.4 g=1.8 R=3.6 I=0.9	-10%	11.1	-5.09022745	9.7852095%
c=5.1 g=1.7 R=3.4 I=0.85	-15%	11.1	-4.814169935	14.67781%
c=4.8 g=1.6 R=3.2 I=0.8	-20%	11.1	-4.53811242	19.57042%
c=4.5 g=1.5 R=3 I=0.75	-25%	11.1	-4.262054905	24.463024%
c=3 g=1 R=2 I=0.5	-50%	11.2	-2.863589664	49.24821%

Tables 5-6, 5-7 and 5-8 show that, the profit objective function is more sensitive to the change in the cost parameters than the income objective function. Again, in equations

5.12 and 5.18 the profit objective function has the term $c.T$ more than the income objective function while, the other terms are the same in both objectives. From the partial derivatives we found that

$$\frac{\partial E(P)}{\partial c} = \frac{-T}{(1-\gamma)}$$

$$\frac{\partial E(I)}{\partial c} = 0$$

Since, the production cost c has the larger value among the other cost parameters; the objective function is more sensitive to the change in the cost parameters.

The product uniformity objective function is also sensitive to the change in the cost parameters. These parameters are found in the loss function penalty coefficients. Hence, any change in the coefficient values is affects the whole terms of the objective function.

The sets of non-inferior solutions for the above mentioned sensitivity analyses of the process standard deviation are provided in appendix C.

Finally, the sensitivity analysis is conducted on the sampling plan parameters (n, d_1 and d_2. Tables 5-9, 5-10 and 5-11 below summarize the sensitivity analysis results

Table 5-9 The sensitivity analysis of the sampling plan on the profit objective function of model 3.

PROFIT				
n	(d_1, d_2)	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
	(0,1)	11.2	9.360474119	-20.9177%

10	(0,2)	11.1	9.753242295	-17.599%
	(0,3)	11.1	9.77129749	-17.4468%
	(1,2) original	10.9	11.83636534	0%
	(1,3)	10.8	12.18375682	2.93495%
	(1,4)	10.8	12.26386554	3.6118%
	(2,3)	10.7	13.26242657	12.048%
	(2,4)	10.7	13.57646639	14.701%
	(3,4)	10.6	14.33949263	21.1478%
15	(0,1)	11.2	8.744479718	-26.12%
	(0,2)	11.2	9.142436937	-22.76%
	(0,3)	11.1	9.157758964	-22.63%
	(1,2)	11	11.13211418	-5.95%
	(1,3)	11.9	11.45855927	-3.192%
	(1,4)	11.9	11.54990293	-2.42%
	(2,3)	11.8	12.40218186	4.78%
	(2,4)	11.8	12.79389989	8.09%
	(3,4)	11.7	13.44030909	13.551%

20	(0,1)	11.3	8.405659994	-28.984%
	(0,2)	11.2	8.753126819	-26.049%
	(0,3)	11.2	8.787386522	-25.76%
	(1,2)	11.1	10.61357049	-10.33%
	(1,3)	11	11.01133371	-6.97%
	(1,4)	11	11.06566177	-6.511%
	(2,3)	10.9	11.94056178	0.88%
	(2,4)	10.9	12.20852788	3.144%
	(3,4)	10.8	12.87093703	8.74%

Table 5-10 The sensitivity analysis of the sampling plan on the income objective function of model 3.

INCOME				
n	(d_1, d_2)	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
10	(0,1)	11.4	76.94108915	-0.955%
	(0,2)	11.4	76.93952299	-0.957%
	(0,3)	11.4	76.9395123	-0.957%
	(1,2) original	11	77.68294383	0%
	(1,3)	11	77.67550697	-0.0096%

	(1,4)	11	77.67520438	-0.0099%
	(2,3)	11.8	78.01733228	0.43%
	(2,4)	11.8	78.00853039	0.419%
	(3,4)	11.7	78.21368967	0.683%
15	(0,1)	11.4	76.8231002	-1.107%
	(0,2)	11.4	76.81957049	-1.1114%
	(0,3)	11.4	76.81953134	-1.1115%
	(1,2)	11.1	77.55049018	-0.171%
	(1,3)	11.1	77.54423525	-0.179%
	(1,4)	11.1	77.54397096	-0.1789%
	(2,3)	10.9	77.88600613	0.261%
	(2,4)	10.9	77.87629082	0.2489%
	(3,4)	10.8	78.09086967	0.525%
	(0,1)	11.5	76.73992795	-1.214%
	(0,2)	11.5	76.73815734	-1.216%
	(0,3)	11.5	76.73814298	-1.2162%
	(1,2)	11.2	77.44181378	-0.3104%

20	(1,3)	11.2	77.43856956	-0.3146%
	(1,4)	11.2	77.43845566	-0.315%
	(2,3)	11	77.79122507	0.1394%
	(2,4)	11	77.78557459	0.1321%
	(3,4)	10.9	77.98644881	0.3907%

Table 5-11 The sensitivity analysis of the sampling plan on the product uniformity objective function of model 3.

UNIFORMITY				
n	(d_1, d_2)	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
10	(0,1)	11.4	-6.177481789	-7.605524%
	(0,2)	11.4	-6.156901291	-7.247032%
	(0,3)	11.4	-6.156760703	-7.244583%
	(1,2) original	11.1	-5.740859358	0%
	(1,3)	11.1	-5.62143552	2.080243%
	(1,4)	11.1	-5.62091966	2.089229%
	(2,3)	10.9	-5.420989624	5.571809%
	(2,4)	10.9	-5.400897762	5.921789%
	(3,4)	10.8	-5.308036399	7.539341%

15	(0,1)	11.5	-6.255269059	-8.9605%
	(0,2)	11.5	-6.241826845	-8.72635%
	(0,3)	11.5	-6.241748107	-8.72498%
	(1,2)	11.2	-5.735878891	0.086755%
	(1,3)	11.2	-5.719643243	0.369563%
	(1,4)	11.2	-5.719240666	0.37658%
	(2,3)	11	-5.503233813	4.139198%
	(2,4)	11	-5.48293661	4.492755%
	(3,4)	10.9	-5.378079369	6.319263%
20	(0,1)	11.6	-6.328003508	-10.22746%
	(0,2)	11.5	-6.305036827	-9.827404%
	(0,3)	11.5	-6.304840879	-9.823991%
	(1,2)	11.2	-5.810152878	-1.207023%
	(1,3)	11.2	-5.771114749	-0.527019%
	(1,4)	11.2	-5.769743438	-0.503132%
	(2,3)	11.1	-5.575079744	2.887714%
	(2,4)	11	-5.546006889	3.394134%

	(3,4)	10.9	-5.446779763	5.122571%

In above tables, the current sample plan is not the optimum. Other sample size and critical values could be better for the three objective function values. The optimum sample plan when the sample size is 10 and ($d_1 = 3, d_2 = 4$), the smallest possible value for the sample size and the greatest possible value of the rejection criteria. The reason for that is, in that case the probability of accepting the lot is the maximum possible since, for a small sample size a if there is a large number of defective items (i.e. 3 and 4) the lot still accepted.

The sets of non-inferior solutions for the above mentioned sensitivity analysis of the process standard deviation can be found on appendix C.

5.6 CONCLUSION

In this chapter, a multi-objective optimization model is developed for a process targeting problem. The model consists of three objective functions that are maximized simultaneously to find the optimum setting of the process target mean. Sampling plan is used as the mean of quality control of the product. An illustrative example contains some data from the process targeting literature has been used to generate the set of non-inferior solutions, followed by sensitivity analysis for the model's parameters to assess their effect on the process target mean setting and the three objective function values. The inspection system used in this model is assumed to be error-free. The inspection error assumption will be relaxed in the next chapter.

CHAPTER 6

MULTI-OBJECTIVE PROCESS TARGETING MODEL WITH SAMPLING PLAN AND ERROR-PRONE INSPECTION SYSTEM

6.1 PREFACE

In this chapter the model of the previous chapter has been modified to the case where the sampling plan inspection system is error prone. Classically, sampling plans have assumed that the inspection process is perfect. But in reality, an inspector (human or automated) is subjected to commit two types of errors:

- Type I error: Classifying a non-defective item as defective, it means inspectors reject a conforming item.
- Type II error: classifying a defective item as non-defective, it means inspectors accept a nonconforming item.

The inspection error can cause a considerable amount of loss due to misclassification of the product quality characteristics. This loss can be interpreted as replacement cost, warranty cost, loss of goodwill and customer dissatisfaction, loss of profit by selling a higher quality item as a lower quality one,…etc. The development of this chapter is based on the production process described in section 5.2 of chapter five. The rest of the assumptions are the same as in chapter 5.In section 6.2 of this chapter the targeting problem is stated. Next a multi-objective optimization model is developed in section 6.3. An illustrative example of the model followed by sensitivity analysis for the model's parameters is presented in section 6.4. Finally, section 6.5 concludes the chapter.

6.2 STATEMENT OF PROBLEM

Consider the production process described in chapter 5 (figure 5-1). The product has a normally distributed quality characteristic y with unknown mean T and known standard deviation σ. The product is said to be non-conforming if its quality characteristic falls below the lower specification limit $y < LSL$. A sampling plan is used for product quality control as follows: after producing N items a sample of size n is drawn. Then, the lot is sold in a primary market if the number of non-conforming items in the sample $D \leq d_1$.The lot is sold in a secondary market if $d_1 < D \leq d_2$ and the lot send for rework again if $D > d_2$. The production and inspection cost per item are c and I, respectively, are fixed and known.

Next the effect of inspection error on the sampling plan decision is addressed. Under the inspection error the observed numbers of conforming and non-conforming items $n - D_e$ and D_e in the sample are different from the actual numbers $n - D$ and D. Also, the probability of conformity and non-conformity are affected by the presence of the inspection error. This deviation is resulted when the numbers of conforming and non-conforming items are subject to type I and type II errors(e_1, e_2), respectively. Consequently, the comparison is made between the observed number of non-conforming items D_e and the rejection criteria $d_1$and d_2.

6.3 MODEL DEVELOPMENT

In this section, the model is developed. Next the objectives functions of the multi-objective optimization model are formulated.

Let's start our argument by defining type I and type II errors probabilities. Type I error (also known as the producer's risk because it denotes the probability that a good lot will be rejected) is the probability of rejecting a lot when it is acceptable. Acceptable means that the true proportion of defective items in the lot is less than or equal to a desired target level of proportion of defectives in the lot (the poorest level for the supplier's process that the consumer would consider to be acceptable as a process average) referred to it as acceptable quality level (AQL).

Hence, the probability of type I error is given by

$$e_1 = p(D > d_1 | q = q_1) = \sum_{i=d_1+1}^{n} \binom{n}{i} {q_1}^i (1 - q_1)^{n-i}$$

$$= 1 - \sum_{i=0}^{d_1} \binom{n}{i} {q_1}^i (1 - q_1)^{n-i} \qquad (6.1)$$

Where $q_1$is the AQL.

Type II error (also known as the consumer's risk because it denotes the probability of accepting a lot of poor quality) is the probability of accepting a lot when it is defective. The lot is considered unacceptable if the true proportion of defective items in the lot exceeds a target level of proportion of defectives in the lot (the poorest level of quality that the consumer is willing to accept in an individual lot) referred to it as lot tolerance percent of defective (LTPD).

Hence, the probability of type II error is given by

$$e_2 = p(D \leq d_1 | q = q_2) = \sum_{i=0}^{d_1} \binom{n}{i} {q_2}^i (1 - q_2)^{n-i} \tag{6.2}$$

Where $q_2$is the LTPD.

Note that, the AQL and LTPD are not characteristics of the sampling plan, but the former is a characteristic of the supplier's process, while the later specified by the consumer.

Both, the probability of non-conformity and the observed number of non-conforming items are affected by the two types of error like **Maghsoodloo (1987)**, **Hassen and Manaspiti (1982)** and **Duffuaa et al. (2009b)**. Accordingly, the probability of non-conformity β_e is given by

$$\beta_e = \beta(1 - e_2) + (1 - \beta)e_1 \tag{6.3}$$

Where

$$\beta = p(y < LSL) = \Phi\left(\frac{LSL - T}{\sigma}\right) \tag{6.4}$$

The observed number of non-conforming items D_e is given by

$$D_e = D(1 - e_2) + (n - D)e_1 \tag{6.5}$$

The observed number of non-conforming items in a sample of size n follows binomial distribution with parameter β_e.

The lot is classified as accepted and sold in a primary market if the observed number of defects in the sample is less that d_1. The probability of that is

$$p(D_e \leq d_1) = \sum_{i=0}^{d_1} \binom{n}{i} {\beta_e}^i (1 - \beta_e)^{n-i} \tag{6.6}$$

The probability of classifying the lot as secondary market conforming and sold in a secondary market is

$$p(d_1 < D_e \leq d_2) = \sum_{i=0}^{d_2} \binom{n}{i} {\beta_e}^i (1 - \beta_e)^{n-i} - \sum_{i=0}^{d_1} \binom{n}{i} {\beta_e}^i (1 - \beta_e)^{n-i} \tag{6.7}$$

$$p(d_1 < D_e \leq d_2) = \sum_{i=d_1+1}^{d_2} \binom{n}{i} {\beta_e}^i (1 - \beta_e)^{n-i} \tag{6.8}$$

Finally, the probability of rejecting and reworking the whole entire lot is

$$p(D_e > d_2) = \sum_{i=d_{2+1}}^{n} \binom{n}{i} {\beta_e}^i (1 - \beta_e)^{n-i} = 1 - \sum_{i=0}^{d_2} \binom{n}{i} {\beta_e}^i (1 - \beta_e)^{n-i} \tag{6.9}$$

Let y' be the expected value of the quality characteristic y when y is above the lower specification limit

$$y' = E(y|y \geq LSL) = \frac{\int_{LSL}^{\infty} yf(y)dy}{\int_{LSL}^{\infty} f(y)dy} \tag{6.10}$$

In the next subsections, the objective functions of the multi-objective optimization model will be developed. The three objective functions will be developed in the same basis of the three objective functions in the previous chapter (5.3)

6.3.1. OBJECTIVE I (PROFIT OBJECTIVE FUNCTION)

Like we did in section (5.3.1), define pro and E (pro) to be the profit per lot and its expectation, respectively. Also, define p and E (p) as the profit per item and its expected value, respectively. Starting by building the profit per lot formula, we will reach the final equation of the expected profit per item.

$$Pro = \begin{cases} aN - g(y - LSL)N - In - cyN & if \quad D_e \leq d_1 \\ rN - In - cyN & if \quad d_1 < D_e \leq d_2 \\ E(Pro) - RN - In - cyN & if \quad D_e > d_2 \end{cases} \tag{6.11}$$

Now the expected profit per lot is given by

$$\begin{aligned} E(Pro) = a\, N\, .p(D_e \leq d_1) - g(y - LSL)N\, .p(D_e \leq d_1) - I\, n\, .p(D_e \leq d_1) \\ - c\, y\, N\, .p(D_e \leq d_1) + r\, N\, .p(d_1 < D_e \leq d_2) - I\, n\, .p(d_1 < D_e \leq d_2) \\ - c\, y\, N\, .p(d_1 < D_e \leq d_2) + E(Pro)\, .p(D_e > d_2) - R\, N\, .p(D_e > d_2) \\ - I\, n\, .p(D_e > d_2) - cyN.p(D_e > d_2) \end{aligned} \tag{6.12}$$

Rearranging the above equation we get

$$E(Pro) = \frac{1}{1 - p(D_e > d_2)} [a\,N\,.\,p(D_e \leq d_1) - g(y - LSL)N\,.\,p(D_e \leq d_1)$$

$$+ r\,N\,.\,p(d_1 < D_e \leq d_2) - R\,N\,.\,p(D_e > d_2) - I\,n\, - c\,T\,N] \qquad (6.13)$$

Divide all the terms by N we get the expected profit per item as the following

$$E(P) = \frac{1}{1 - p(D_e > d_2)} \Big[a\,.\,p(D_e \leq d_1) - g(y - LSL)\,.\,p(D_e \leq d_1)$$

$$+ r\,.\,p(d_1 < D_e \leq d_2) - R\,.\,p(D_e > d_2) - I\,\frac{n}{N} - c\,T\Big] \qquad (6.14)$$

The term $1 - p(D_e > d_2)$ is equivalent to$p(D_e \leq d_2)$. So, the expected profit per item can be written as

$$E(P) = \frac{1}{p(D_e \leq d_2)} \Big[a\,.\,p(D_e \leq d_1) - g(y - LSL)\,.\,p(D_e \leq d_1) + r\,.\,p(d_1 < D_e \leq d_2)$$

$$- R\,.\,p(D_e > d_2) - I\,\frac{n}{N} - c\,T\Big] \qquad (6.15)$$

Now, replace y by its conditional expectation y'

$$E(P) = \frac{1}{p(D_e \leq d_2)} \Big[a\,.\,p(D_e \leq d_1) - g(y' - LSL)\,.\,p(D_e \leq d_1) + r\,.\,p(d_1 < D_e \leq d_2)$$

$$- R\,.\,p(D_e > d_2) - I\,\frac{n}{N} - c\,T\Big] \qquad (6.16)$$

6.3.2. OBJECTIVE II (INCOME OBJECTIVE FUNCTION)

Again here, let’s define Inc, E (Inc), I and E (I) as the total income per lot, expected income per lot, income per item and expected income per item, respectively.

Now, the total income per lot is given by

$$Inc = \begin{cases} aN - g(y - LSL)N & if \quad D_e \leq d_1 \\ rN & if \quad d_1 < D_e \leq d_2 \\ E(Inc) - RN & if \quad D_e > d_2 \end{cases} \tag{6.17}$$

Now the expected income per lot is given by

$$E(Inc) = a\,N\,.\,p(D_e \leq d_1) - g(y - LSL)N\,.\,p(D_e \leq d_1) + r\,N\,.\,p(d_1 < D_e \leq d_2)$$
$$+ E(Inc)\,.\,p(D_e > d_2) - R\,N\,.\,p(D_e > d_2) \tag{6.18}$$

Rearranging the above equation we get

$$E(Inc) = \frac{1}{1 - p(D_e > d_2)}[a\,N\,.\,p(D_e \leq d_1) - g(y - LSL)N\,.\,p(D_e \leq d_1)$$
$$+ r\,N\,.\,p(d_1 < D_e \leq d_2) - R\,N\,.\,p(D_e > d_2)] \tag{6.19}$$

Divide all the terms by N we get the expected profit per item as the following

$$E(I) = \frac{1}{1 - p(D_e > d_2)}[a\,.\,p(D_e \leq d_1) - g(y - LSL)\,.\,p(D_e \leq d_1)$$
$$+ r\,.\,p(d_1 < D_e \leq d_2) - R\,.\,p(D_e > d_2)] \tag{6.20}$$

While$1 - p(D_e > d_2) = p(D_e \leq d_2)$, so, the expected income per item can be written as

$$E(I) = \frac{1}{p(D_e \leq d_2),} [a \,.\, p(D_e \leq d_1) - g(y - LSL) \,.\, p(D_e \leq d_1) + r \,.\, p(d_1 < D_e \leq d_2) - R \,.\, p(D_e > d_2)] \quad (6.21)$$

Now, replace y by its conditional expectation $y^{'}$

$$E(I) = \frac{1}{p(D_e \leq d_2),} [a \,.\, p(D_e \leq d_1) - g(y^{'} - LSL) \,.\, p(D_e \leq d_1) + r \,.\, p(d_1 < D_e \leq d_2) - R \,.\, p(D_e > d_2)] \quad (6.21)$$

6.3.3. OBJECTIVE III (PRODUCT UNIFRMITY OBJECTIVE FUNCTION)

Here, we will develop a loss function for the production process in (figure 5-1) based on Taguchi quadratic loss function in the same fashion in section 5.2.3. Minimizing the developed loss function is equivalent to maximizing the product uniformity around the process target mean. .

The product quality characteristic y has the larger the better quality type with a theoretical process mean∞. The process mean will never approach ∞ since as larger as the process mean approaches more excess material cost carries out. The loss function of the larger the better quality type has the following formula

$$L(\boldsymbol{y}) = k \sum_{i=1}^{N} \frac{1}{{y_i}^2}$$

$k = R\Delta^2$is the quality loss coefficient and Δ is the tolerance limit, which in the larger the better case is the lower specification limit. By Defining Loss and E (Loss) as the loss and the expected loss per lot, respectively, the expected loss per item is given by

$$Loss = \begin{cases} (N-n)L_{01} + n\,L_{11} & if \quad D_e \leq d_1 \\ (N-n)L_{02} + n\,L_{12} & if \quad d_1 < D_e \leq d_2 \\ (N-n)L_{03} + n\,L_{13} & if \quad D_e > d_2 \end{cases} \tag{6.22}$$

L_{01}, $L_{02}$and L_{03} are the expected quality loss per uninspected item and L_{11}, $L_{12}$and $L_{13}$are the expected quality loss per inspected item. These terms are given by

$$L_{01} = k\int_{-\infty}^{\infty}\frac{1}{y^2}f(y)dy + g(y' - LSL) \tag{5.23}$$

$$L_{02} = k\int_{-\infty}^{\infty}\frac{1}{y^2}f(y)dy + (a - r) \tag{5.24}$$

$$L_{03} = k\int_{-\infty}^{\infty}\frac{1}{y^2}f(y)dy + a + R \tag{5.25}$$

$$L_{11} = \frac{k\int_{LSL}^{\infty}\frac{1}{y^2}f(y)dy}{\int_{LSL}^{\infty}f(y)dy} + g(y' - LSL) \tag{5.26}$$

$$L_{12} = \frac{k\int_{-\infty}^{LSL}\frac{1}{y^2}f(y)dy}{\int_{-\infty}^{LSL}f(y)dy} + (a - r) \tag{5.27}$$

$$L_{13} = \frac{k\int_{-\infty}^{LSL}\frac{1}{y^2}f(y)dy}{\int_{-\infty}^{LSL}f(y)dy} + a + R \tag{5.28}$$

Hence, the expected loss can be expressed as

$$E(LOSS) = [(N-n)L_{01} + n\, L_{11}]\, p(D_e \le d_1) + [(N-n)L_{02} + n\, L_{12}] p(d_1 < D_e \le d_2) + [(N-n)L_{03} + n\, L_{13}] p(D_e > d_2) \qquad (5.29)$$

Dividing by N, the expected loss per item is given by

$$E(L) = \left[\left(1-\frac{n}{N}\right) L_{01} + \frac{n}{N} L_{11}\right] p(D_e \le d_1) + \left[\left(1-\frac{n}{N}\right) L_{02} + \frac{n}{N} L_{12}\right] p(d_1 < D_e \le d_2) + \left[\left(1-\frac{n}{N}\right) L_{03} + \frac{n}{N} L_{13}\right] p(D_e > d_2) \qquad (5.30)$$

6.3.4. THE MULTI-OBJECTIVE OPTIMIZATION MODEL

Now we can use the three objective functions developed above to build up a multi-objective maximization framework to obtain the optimum process target mean which maximizes the three objectives simultaneously. The multi-objective optimization model is given by

$$max\, \boldsymbol{f}(\boldsymbol{T}) = [f_1(\boldsymbol{T}), f_2(\boldsymbol{T}), f_3(\boldsymbol{T})]$$

Subject to

$$T \ge LSL$$

Where

$f_1(\boldsymbol{T}) = E(P)$ equation 6.16

$f_2(\boldsymbol{T}) = E(I)$ equation 6.21

$f_3(\boldsymbol{T}) = -E(L)$ equation 6.30

6.4 RESULTS AND SENSITIVITY ANALYSIS

In this section, the above developed model is illustrated through an example. Followed by, sensitivity analysis for the two types of inspection error.

6.4.1. SOLUTION METHODOLOGY

The same method used to generate the set of the non-inferior solution previously is used here with the following three steps:

- Step 1: each objective function is evaluated individually using a uniform line search method with step length λ in the interval $I = [LSL, LSL + b]$, where b is an appropriate positive number.

- Step 2: Generate the set of non-inferior points as following:

  i. Define $T_{min} = Min(T_1{}^*, T_2{}^*, T_3{}^*)$and $T_{max} = Max\ (T_1{}^*, T_2{}^*, T_3{}^*)$

  ii. Let $T_i = T_{min} + i\lambda\epsilon[T_{min}, T_{max}]: i = 1,2,..,n$ and

  $$T_j = T_{min} + j\lambda\epsilon[T_{min}, T_{max}] : j = 1,2,..,n$$

iii. The point T_i is a non-inferior point if there is no T_j such that:

$$\{f_k(T_j) \geq f_k(T_i) : \forall\ k = 1,2,3\}$$

- Step 3: Rank the set of non-inferior points as following:

i. Normalize: $\frac{f_k(T_i)}{f_k(T_i^*)}$, i=1,2,..,n and k=1,2,3

ii. Define the normalized sum S_i as: $S_i = \sum_{k=1}^{3} \frac{f_k(T_i)}{f_k(T_i^*)}$

iii. Define the percentage absolute deviation PAD_i as: $PAD_i = \frac{|3 - S_i| * 100}{3}$,

i=1,2,3

iv. Rank the points according to PAD_i from the smallest to the largest.

The smaller the PAD_i, the higher preference of the point.

6.4.2. NUMERICAL EXAMPLE

The example parameters are the same as those used in chapter five. Consider a production process, which produced items have a normally distributed quality characteristic with unknown mean T and known standard deviation σ = 0.5. The items have a lower specification limit LSL = 10. A sampling inspection is conducted after the items being processed. The sampling plan used after process 1 is: n=10, $d_1 = 1$ and $d_2 = 2$. The processing cost c = \$6, the inspection cost I = \$1 and the excess material cost g = \$2. If the number of non-conforming items in the sample is $d_1 = 1$ then, the lot is sold in a primary market at \$80 per item. Is the number of non-conforming items in the lot is more than $d_1 = 1$ and less than $d_2 = 2$ the, the lot is sold in a secondary market at \$67.5 per item. Finally, if the number of non-conforming items in the sample is more than $d_2 = 2$ then, the lot is reworked again for \$4 per item. The inspection system is subject to make some classification error, some conforming items are rejected (type I error) with probability $e_1 = 0.01$ whereas, some of the defective items are classified as conforming items (type II error) with probability $e_2 = 0.05$. In order to solve this problem, an exhausted uniform search in the interval [10, 20], is done for each objective of the multi-objective model in section 6.3.4, the step size for the search is 0.1. Table 6-1 gives the optimum target value for each objective function individually.

Table 6-1 The optimum objective values of the model 4.

	PROFIT OBJECTIVE $f_1(T)$	INCOME OBJECTIVE $f_2(T)$	UNIFORATY OBJECTIVE $f_3(T)$
T^*	10.9	11.1	11.2
$f_i(T^*)$	11.41625671	77.5186716	-5.825714523

Now, the set of non-inferior solutions of the model is the following

Table 6-2 The set of non-inferior solutions of model 4.

T^*	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.41625671	77.36259089	-6.642330423	4th
11	11.28985493	77.5179858	-6.051419421	1st
11.1	10.81165882	77.5186716	-5.848369095	2nd
11.2	10.16814236	77.42895097	-5.825714523	3rd

6.4.3. SENSITIVITY ANALYSIS FOR THE PARAMETERS

In this section, the effect of the type I and type II errors on the model is studied. Eighty-four combinations of the two error types are tested. The results are summarized in tables 6-3, 6-4 and 6-5 below

Table 6-3 below gives the effect of the two types of error on the profit objective function

Table 6-3 The sensitivity analysis of the two error types on the profit objective function of model 4.

	PROFIT		
(e_1, e_2)	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
(0,0)	10.9	11.83636534	3.6799158%
(0,0.01)	10.9	11.85324691	3.827789%
(0,0.05)	10.9	11.91874836	4.401545%
(0,0.1)	10.9	11.99610828	5.07917%
(0,0.15)	10.9	12.06851167	5.713387%
(0,0.2)	10.8	12.14222604	6.359084%
(0,0.25)	10.8	12.30080469	7.748144%
(0.01,0)	10.9	11.30587488	-0.966883%
(0.01,0.01)	10.9	11.32838134	-0.76974%
(0.01,0.05) "original"	10.9	11.41625671	0%
(0.01,0.1)	10.9	11.52129524	0.92008%
(0.01,0.15)	10.9	11.62104616	1.793841%

(0.01,0.2)	10.9	11.71556677	2.621788%
(0.01,0.25)	10.9	11.80491618	3.40444%
(0.05,0)	11.1	8.427358894	-26.1811%
(0.05,0.01)	11.1	8.440415982	-26.0667%
(0.05,0.05)	11.1	8.49228712	-25.6123%
(0.05,0.1)	11	8.573064435	-24.9048%
(0.05,0.15)	11	8.691676613	-23.8658%
(0.05,0.2)	11	8.80785728	-22.8481%
(0.05,0.25)	11	8.921618937	-21.8516%
(0.1,0)	11.2	1.551619197	-86.40869%
(0.1,0.01)	11.2	1.566840995	-86.2754%
(0.1,0.05)	11.2	1.627572643	-85.7434%
(0.1,0.1)	11.2	1.703137758	-85.0815%
(0.1,0.15)	11.2	1.778315427	-84.42296%
(0.1,0.2)	11.1	1.896180181	-83.3905%
(0.1,0.25)	11.1	2.02795672	-82.2362%
(0.15,0)	11.3	-10.7319061	-194.005%
(0.15,0.01)	11.3	-10.7173106	-193.878%
(0.15,0.05)	11.3	-10.658998	-193.3668%
(0.15,0.1)	11.2	-10.561716	-192.515%
(0.15,0.15)	11.2	-10.431573	-191.3747%

(0.15,0.2)	11.2	-10.301968	-190.2395%
(0.15,0.25)	11.2	-10.172898	-189.1089%
(0.2,0)	11.3	-30.8570258	-370.2902%
(0.2,0.01)	11.3	-30.833276	-370.0822%
(0.2,0.05)	11.3	-30.738385	-369.251%
(0.2,0.1)	11.3	-30.620009	-368.2141%
(0.2,0.15)	11.3	-30.501898	-367.1795%
(0.2,0.2)	11.3	-30.384051	-366.1472%
(0.2,0.25)	11.2	-30.255426	-365.0205%
(0.25,0)	11.4	-63.34724	-654.886%
(0.25,0.01)	11.4	-63.326331	-654.7031%
(0.25,0.05)	11.3	-63.208556	-653.6715%
(0.25,0.1)	11.3	-63.0169846	-651.9934%
(0.25,0.15)	11.3	-62.8258521	-650.3192%
(0.25,0.2)	11.3	-62.6351573	-648.6488%
(0.25,0.25)	11.3	-62.4448993	-646.982%

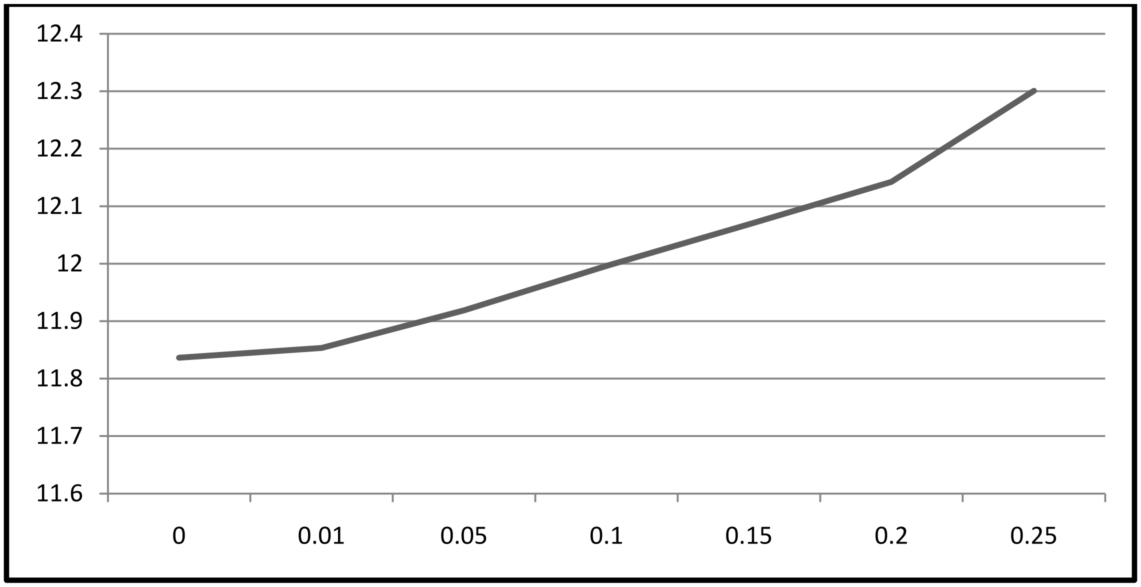

Figure 6-1 The profit objective function versus type II error for type I error equal 0

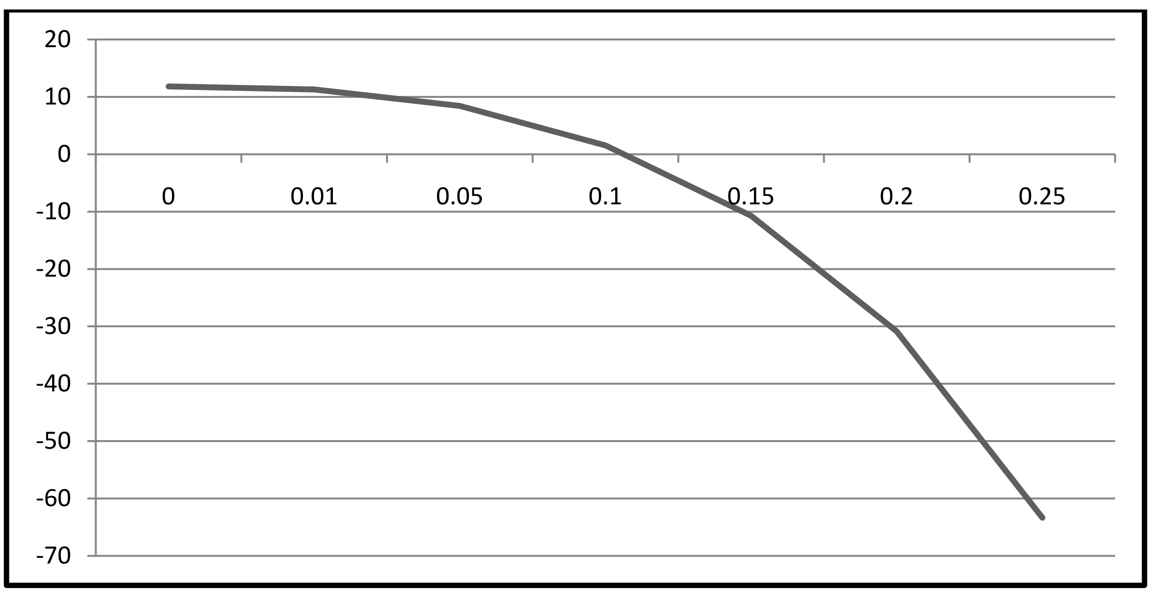

Figure 6-2 The profit objective function versus type I error for type II error equal 0

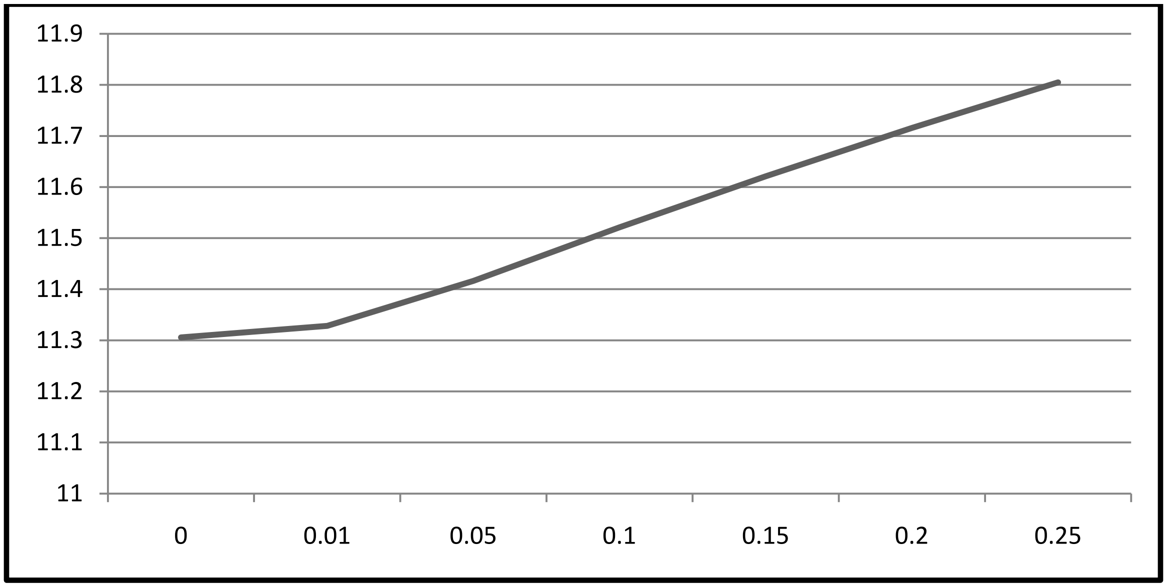

Figure 6-3 The profit objective function versus type II error for type I error equal 0.01

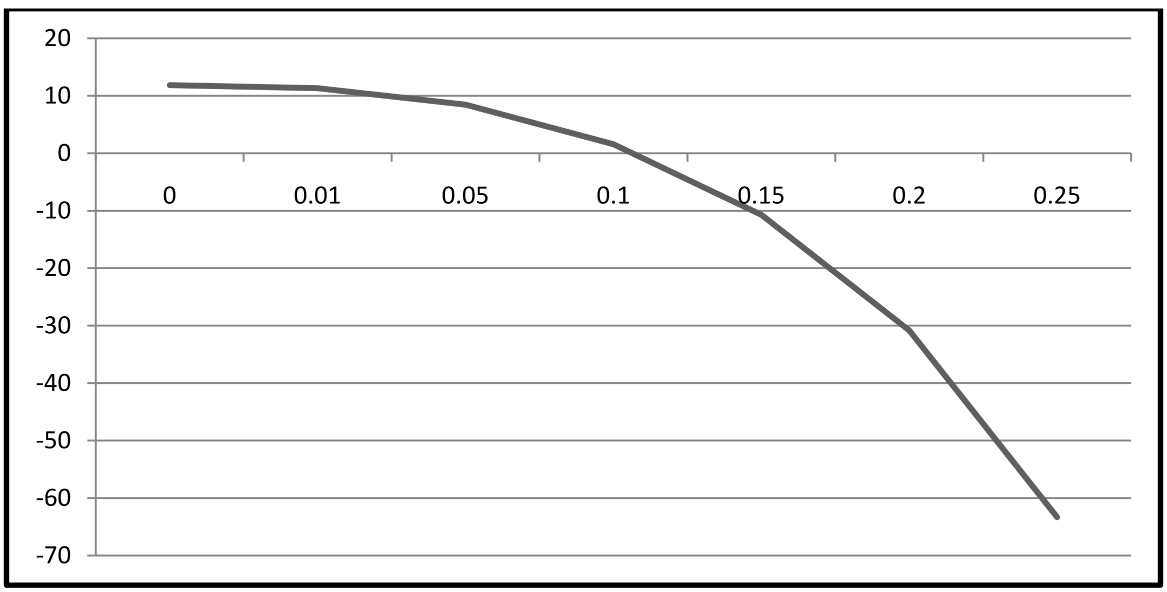

Figure 6-4 The profit objective function versus type I error for type II error equal 0.01

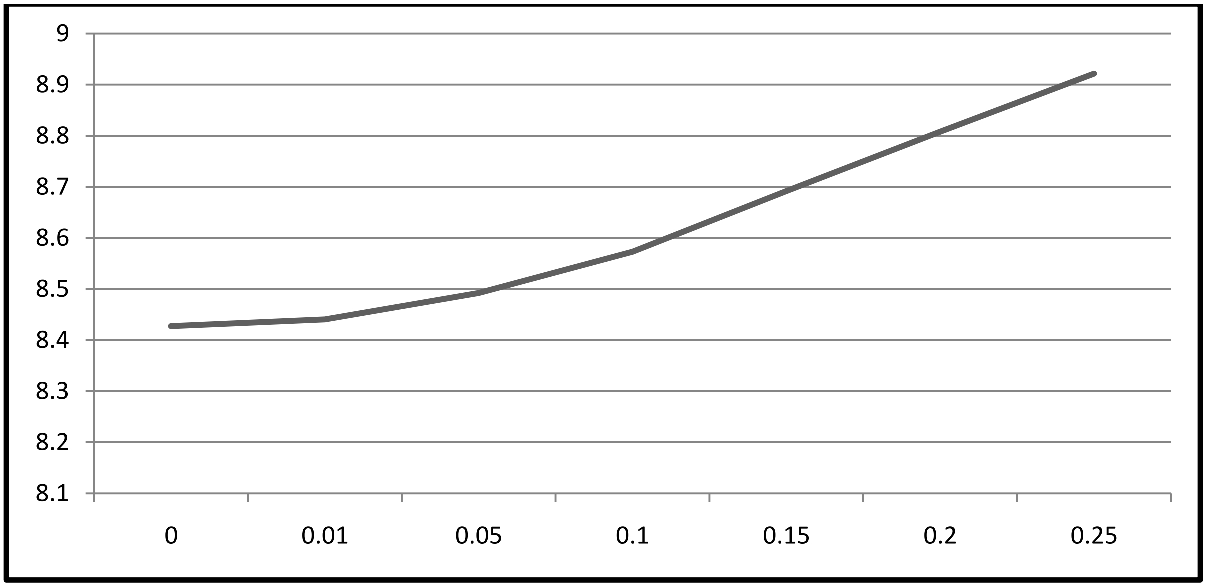

Figure 6-5 The profit objective function versus type II error for type I error equal 0.05

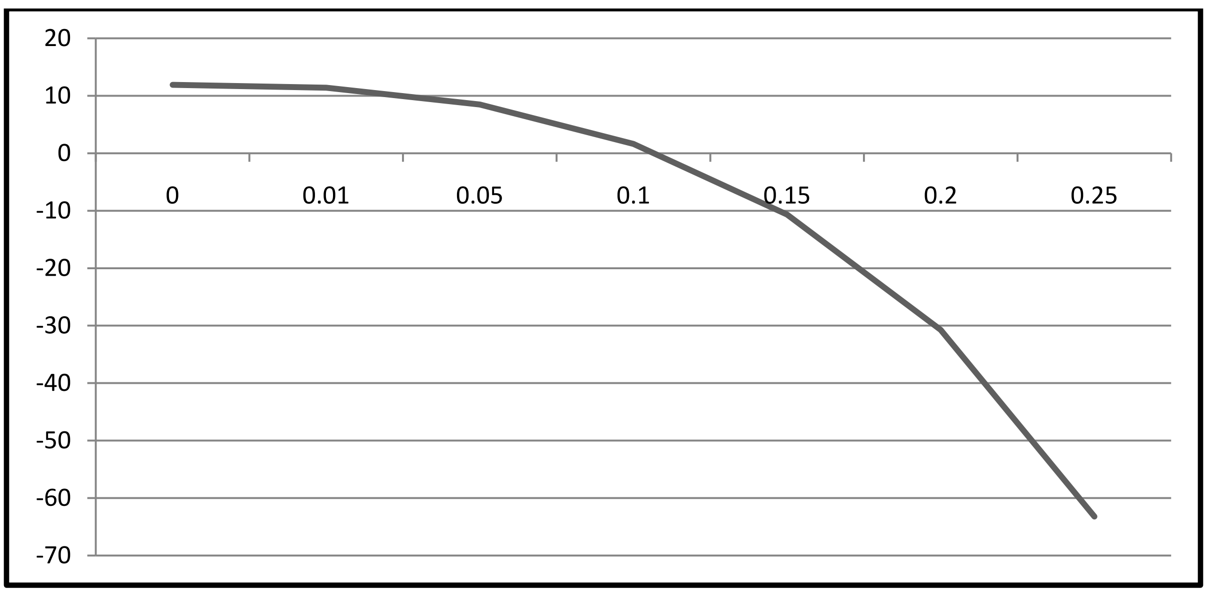

Figure 6-6 The profit objective function versus type I error for type II error equal 0.05

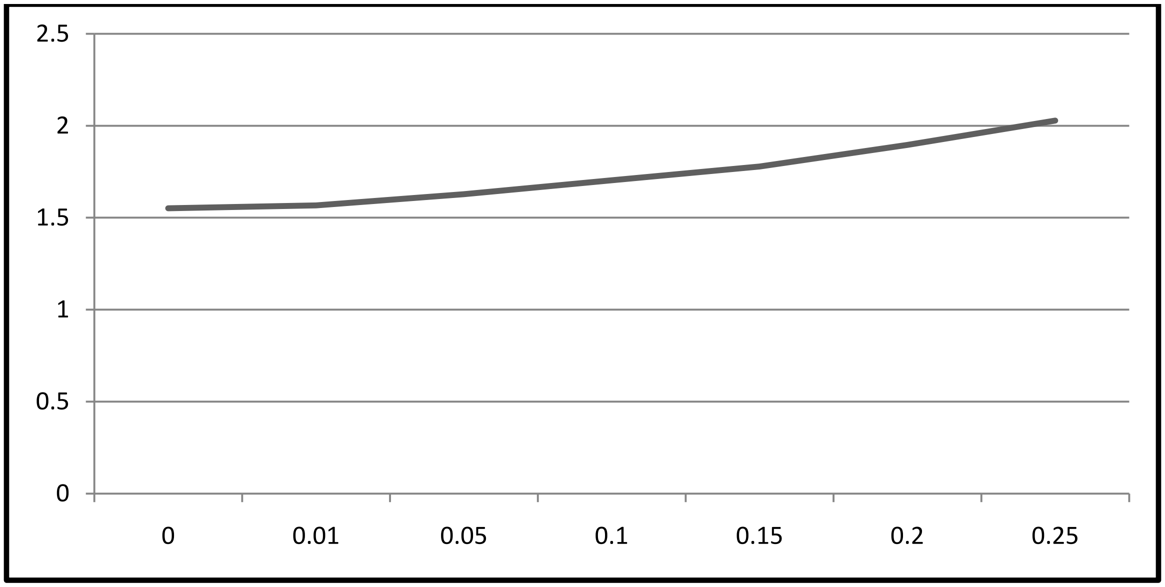

Figure 6-7 The profit objective function versus type II error for type I error equal 0.1

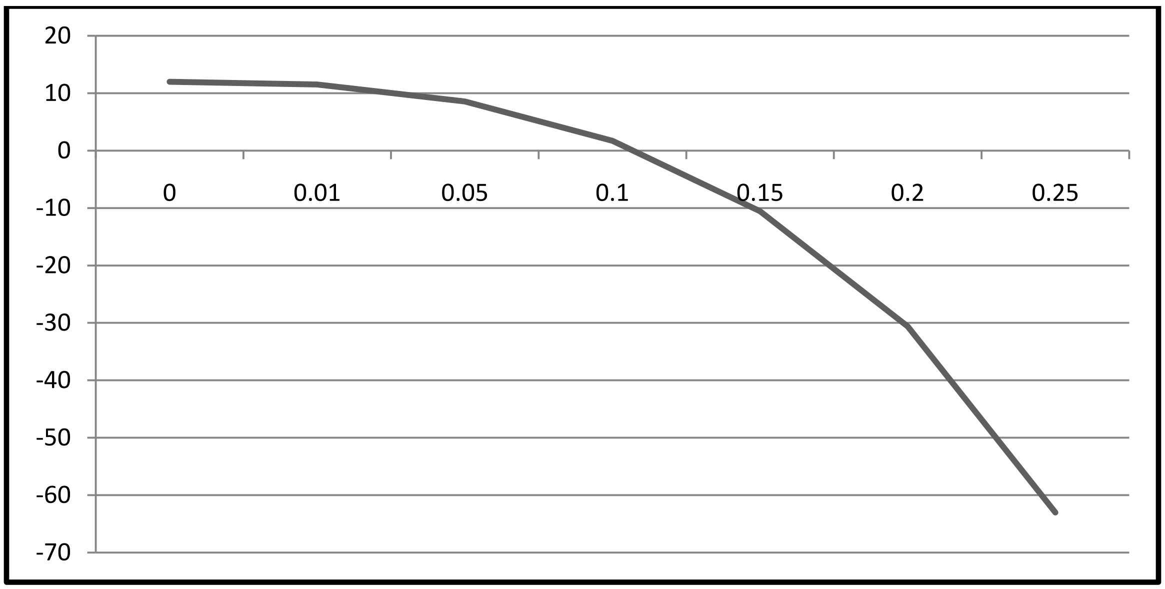

Figure 6-8 The profit objective function versus type I error for type II error equal 0.1

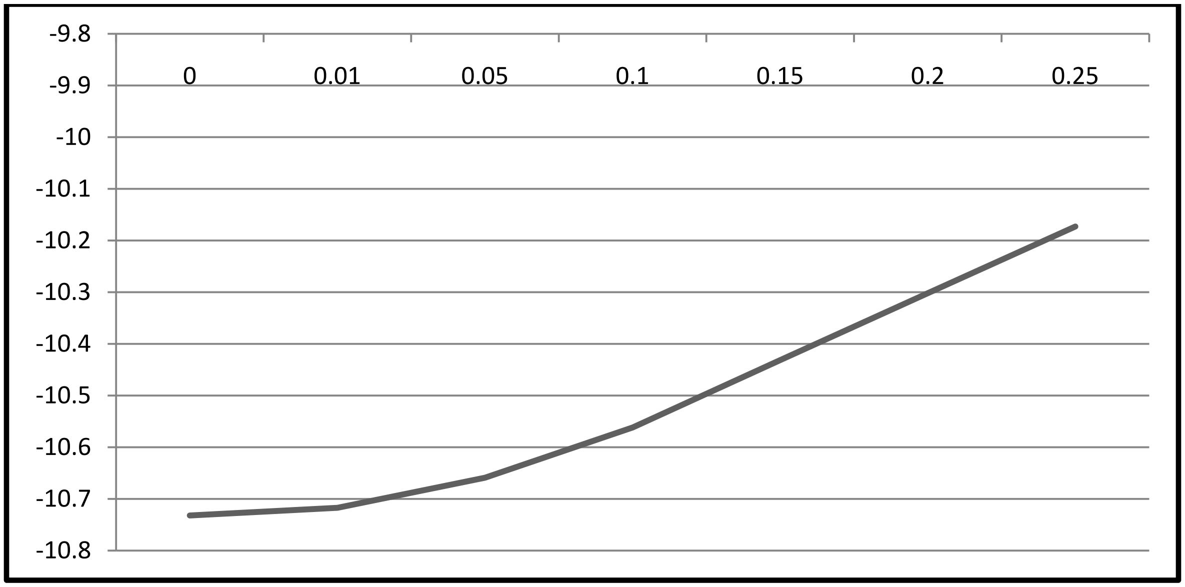

Figure 6-9 The profit objective function versus type II error for type I error equal 0.15

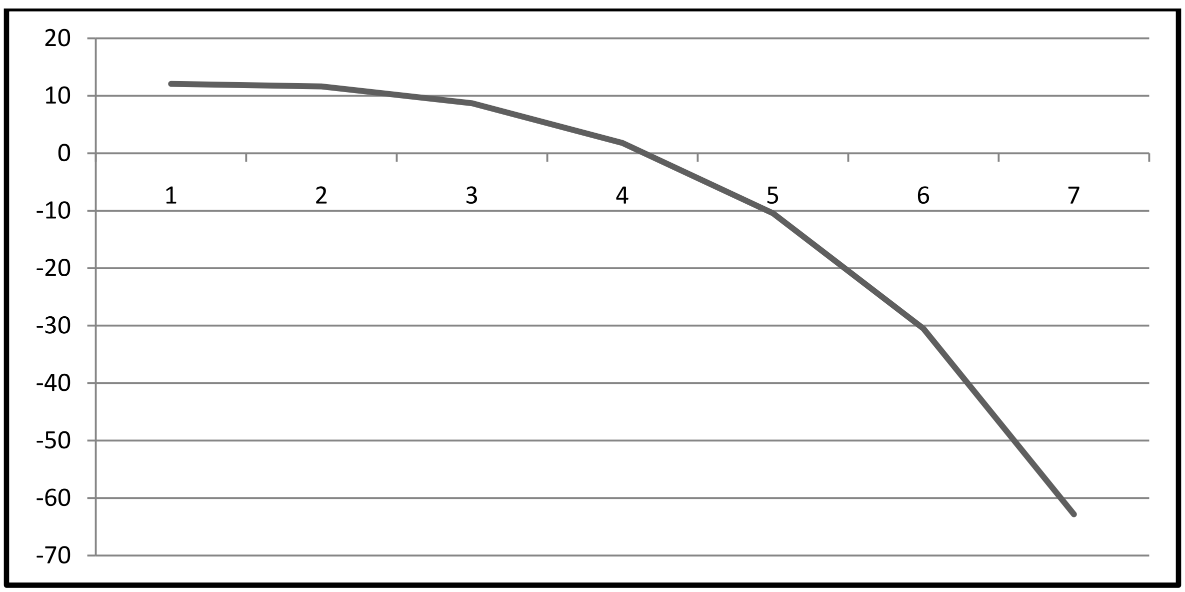

Figure 6-10 The profit objective function versus type I error for type II error equal 0.15

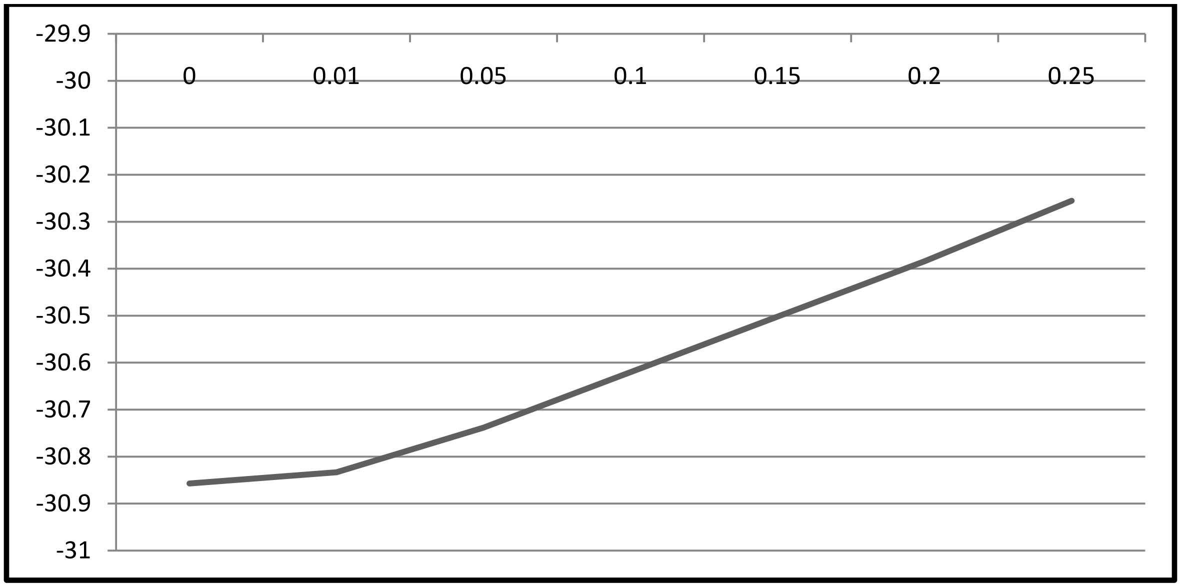

Figure 6-11 The profit objective function versus type II error for type I error equal 0.2

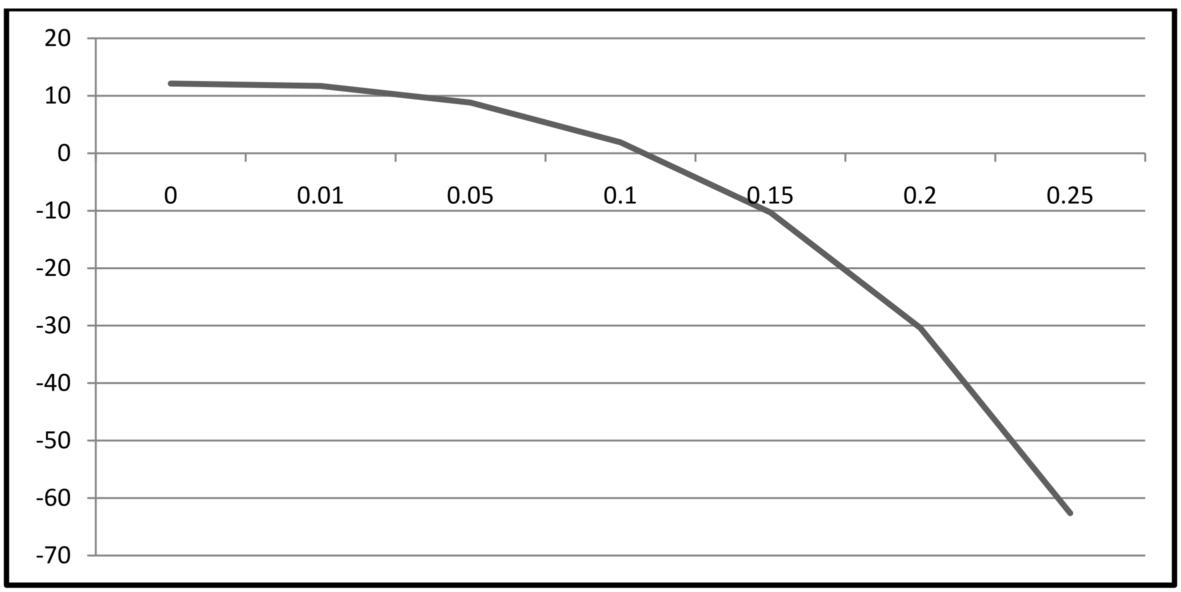

Figure 6-12 The profit objective function versus type I error for type II error equal 0.2

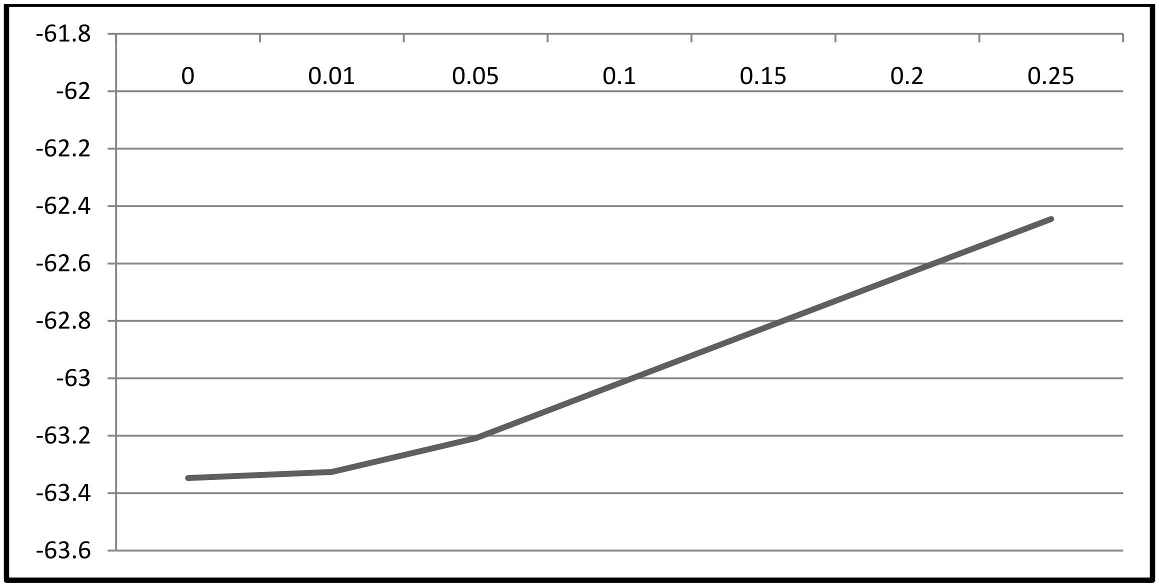

Figure 6-13 The profit objective function versus type II error for type I error equal 0.25

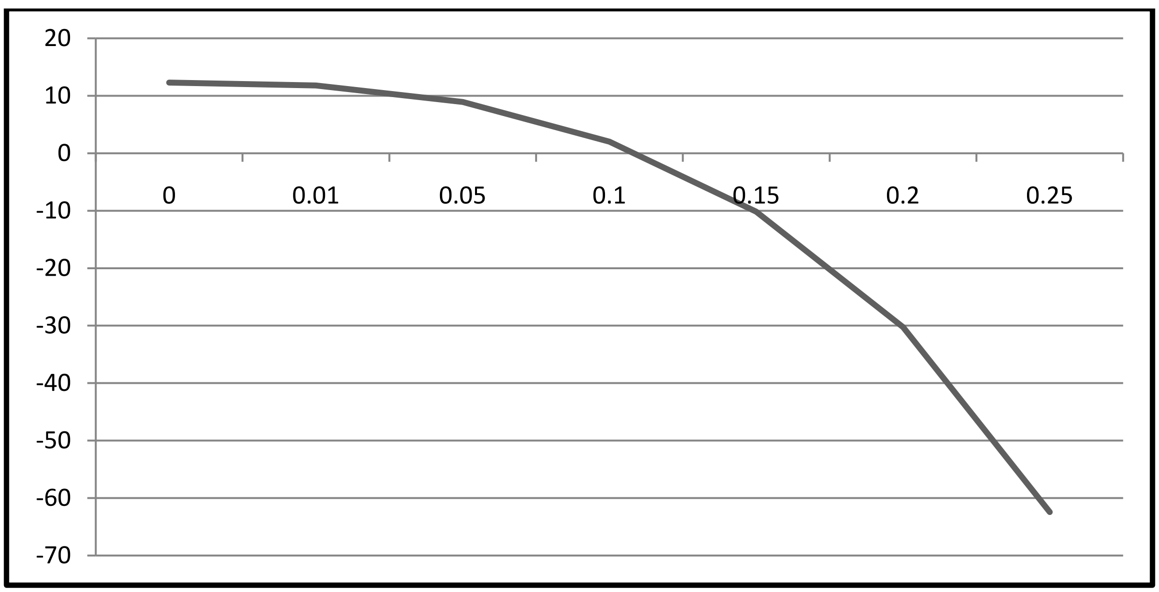

Figure 6-14 The profit objective function versus type I error for type II error equal 0.2

Table 6-4 below gives the effect of the two types of error on the income objective function

Table 6-4 The sensitivity analysis of the two error types on the income objective function of model 4.

	INCOME		
(e_1, e_2)	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
(0,0)	11	77.682944	0.21191%
(0,0.01)	11	77.686762	0.216839%
(0,0.05)	11	77.701742	0.236163%
(0,0.1)	11	77.719796	0.259453%
(0,0.15)	11	77.737085	0.28176%
(0,0.2)	11	77.753589	0.30305%
(0,0.25)	11	77.769286	0.3233%
(0.01,0)	11.1	77.50690767	-0.01518%
(0.01,0.01)	11.1	77.50928142	-0.01211%
(0.01,0.05) “original”	11.1	77.5186716	0%
(0.01,0.1)	11	77.54181293	0.029853%
(0.01,0.15)	11	77.56503665	0.05981%
(0.01,0.2)	11	77.5876398	0.08897%
(0.01,0.25)	11	77.60960485	0.117304%
(0.05,0)	11.2	76.5285911	-1.277216%
(0.05,0.01)	11.2	76.5309699	-1.274147%

(0.05,0.05)	11.1	76.5426265	-1.25911%
(0.05,0.1)	11.1	76.5637928	-1.231805%
(0.05,0.15)	11.1	76.5848587	-1.20463%
(0.05,0.2)	11.1	76.6058226	-1.17759%
(0.05,0.25)	11.1	76.6266826	-1.15068%
(0.1,0)	11.2	74.8926587	-3.38759%
(0.1,0.01)	11.2	74.89559424	-3.3838%
(0.1,0.05)	11.2	74.90733063	-3.368661%
(0.1,0.1)	11.2	74.92198802	-3.34975%
(0.1,0.15)	11.2	74.93663082	-3.33086%
(0.1,0.2)	11.2	74.95125895	-3.31199%
(0.1,0.25)	11.2	74.96587237	-3.29314%
(0.15,0)	11.3	73.01649674	-5.80786%
(0.15,0.01)	11.3	73.0183326	-5.80549%
(0.15,0.05)	11.2	73.02998251	-5.7905%
(0.15,0.1)	11.2	73.04640692	-5.76927%
(0.15,0.15)	11.2	73.06281388	-5.74811%
(0.15,0.2)	11.2	73.07920347	-5.72697%
(0.15,0.25)	11.2	73.09557579	-5.70585%
(0.2,0)	11.3	70.89631056	-8.54292%
(0.2,0.01)	11.3	70.89848406	-8.54012%
(0.2,0.05)	11.3	70.90717369	-8.52891%

(0.2,0.1)	11.3	70.91802591	-8.51491%
(0.2,0.15)	11.3	70.92886725	-8.50093%
(0.2,0.2)	11.3	70.93969776	-8.48695%
(0.2,0.25)	11.2	70.95691837	-8.46474%
(0.25,0)	11.4	68.2689721	-11.9322%
(0.25,0.01)	11.4	68.27050596	-11.9302%
(0.25,0.05)	11.4	68.2766389	-11.9223%
(0.25,0.1)	11.3	68.28678873	-11.9092%
(0.25,0.15)	11.3	68.30094281	-11.89098%
(0.25,0.2)	11.3	68.3150757	-11.8727%
(0.25,0.25)	11.3	68.32918746	-11.85454%

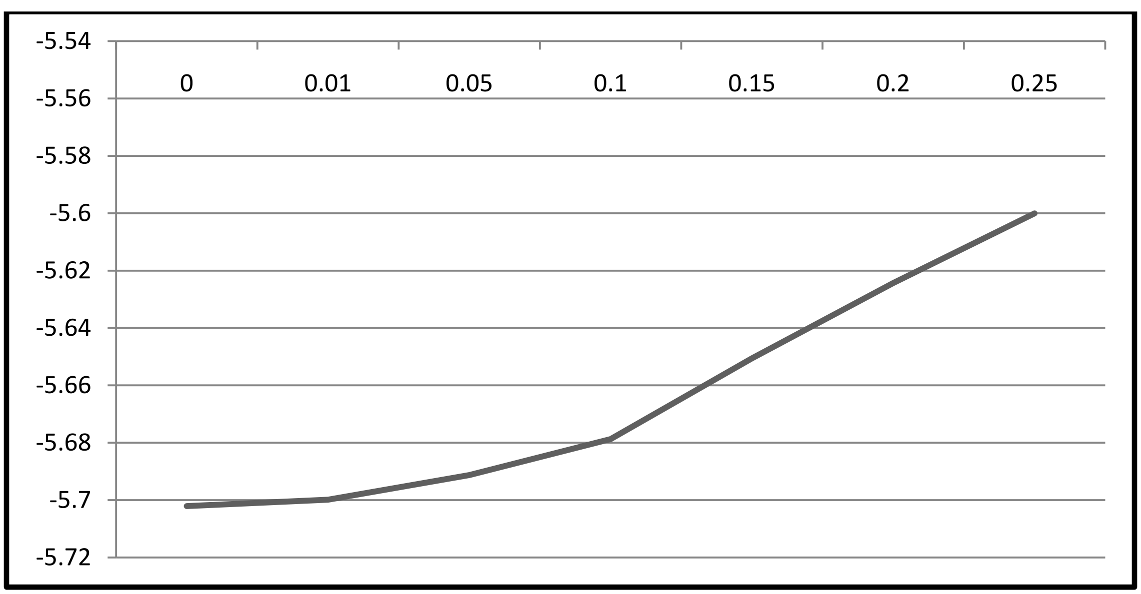

Figure 6-15 The income objective function versus type II error for type I error equal 0

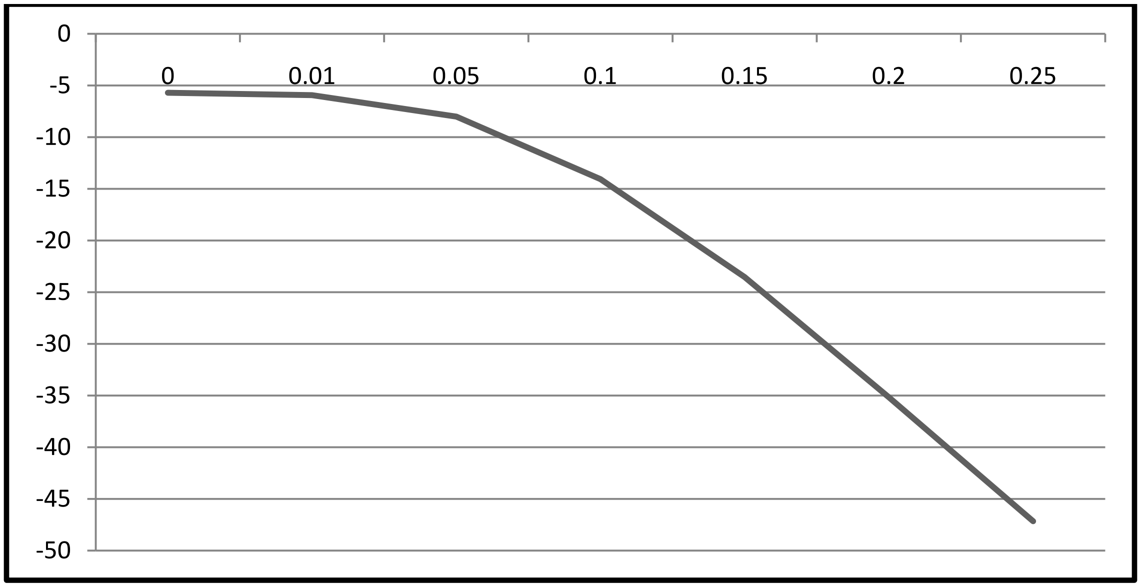

Figure 6-16 The income objective function versus type I error for type II error equal 0

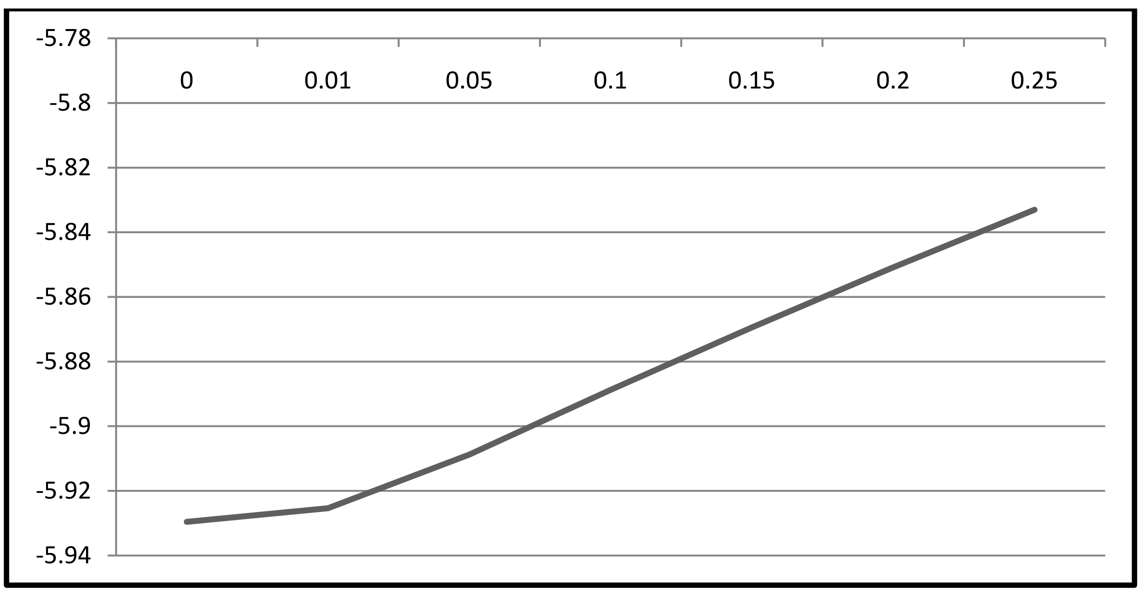

Figure 6-17 The income objective function versus type II error for type I error equal 0.01

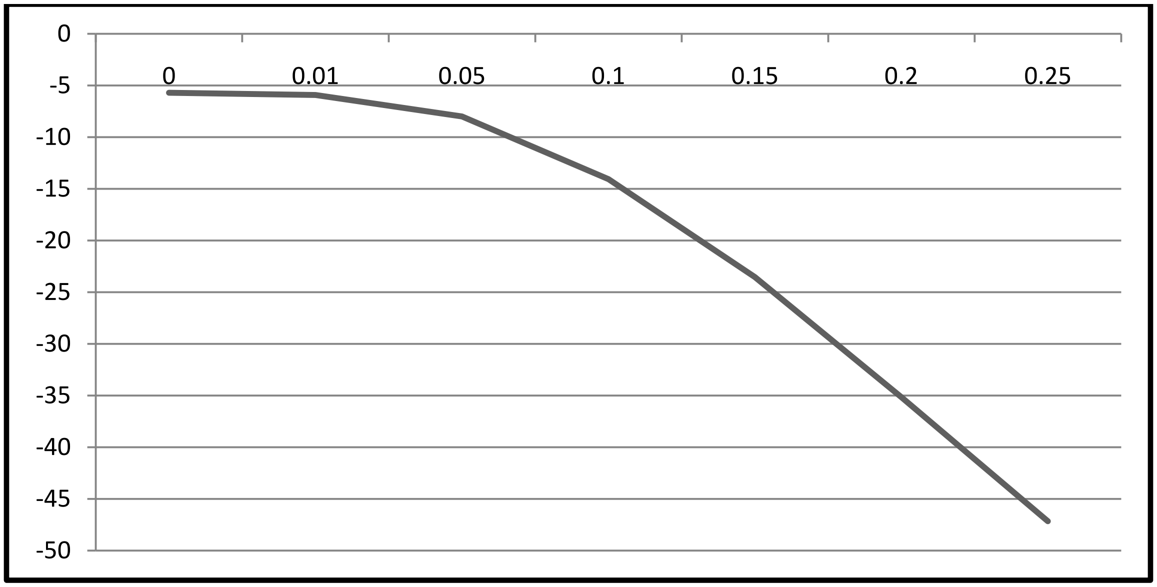

Figure 6-18 The income objective function versus type I error for type II error equal 0.01

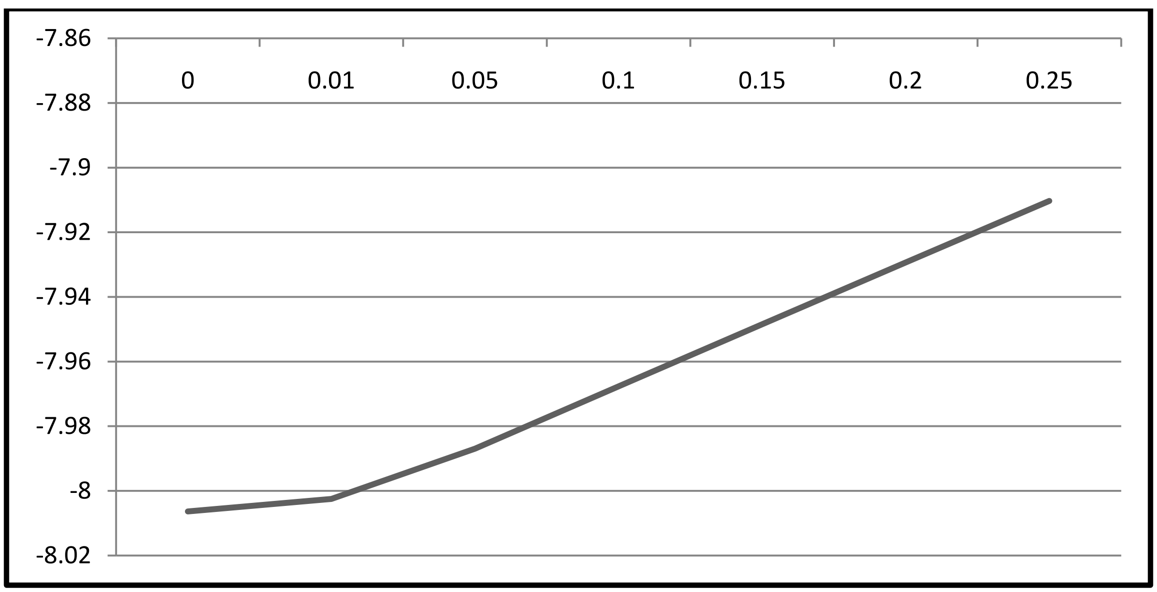

Figure 6-19 The income objective function versus type II error for type I error equal 0.05

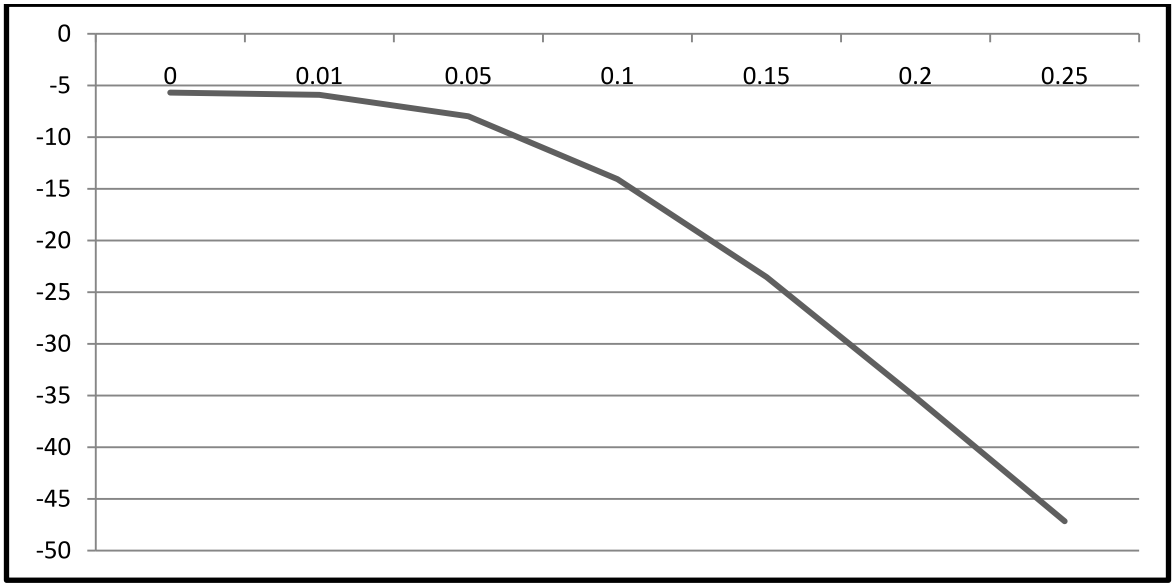

Figure 6-20 The income objective function versus type I error for type II error equal 0.05

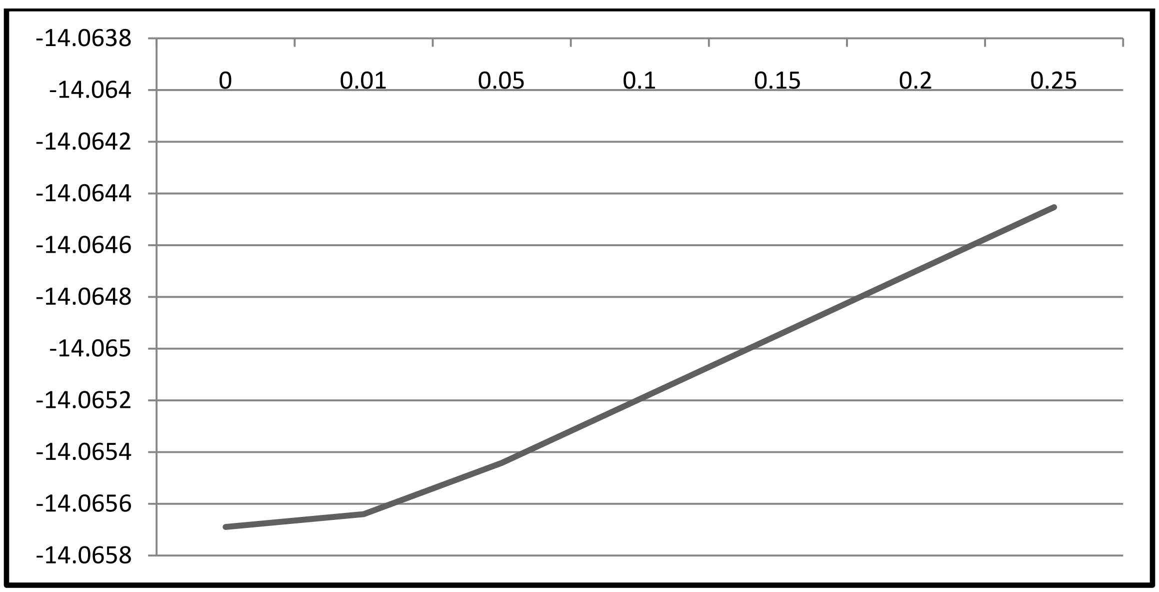

Figure 6-21 The income objective function versus type II error for type I error equal 0.1

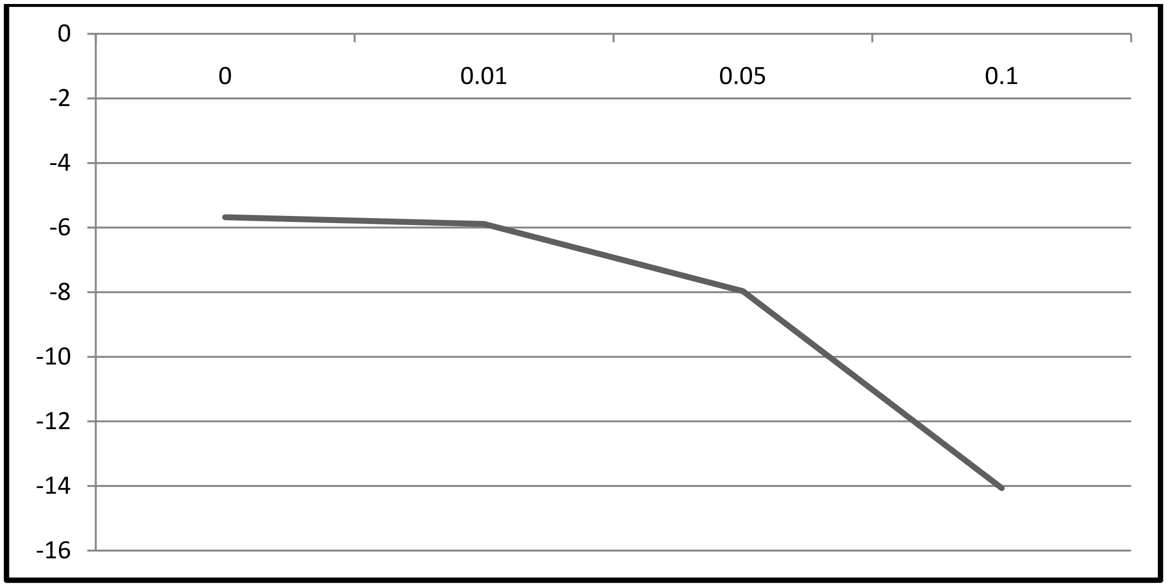

Figure 6-22 The income objective function versus type I error for type II error equal 0.1

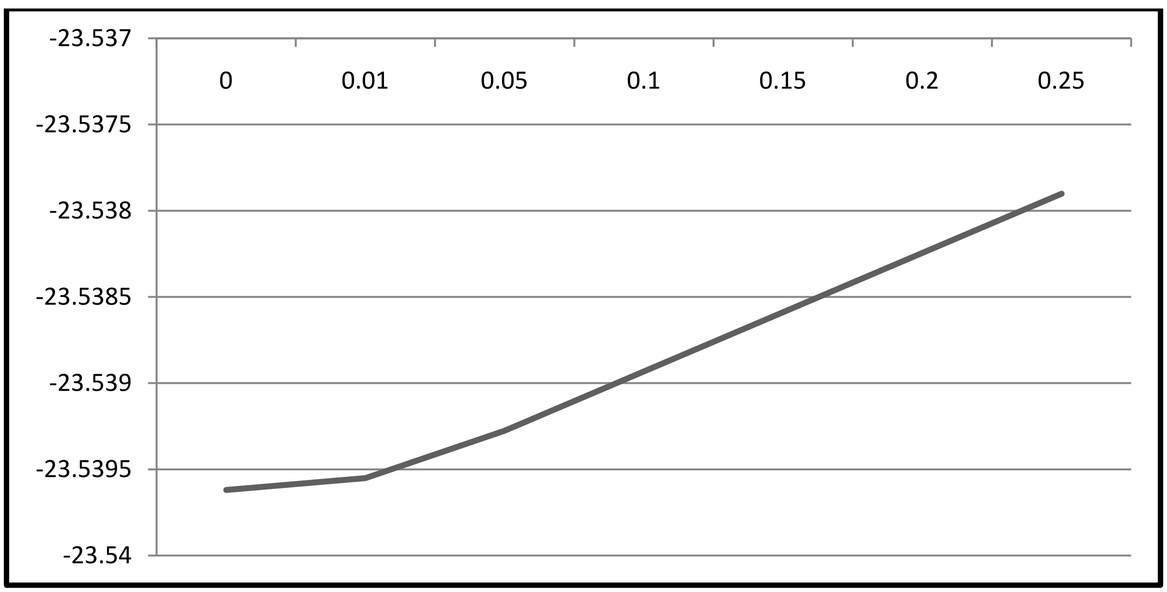

Figure 6-23 The income objective function versus type II error for type I error equal 0.15

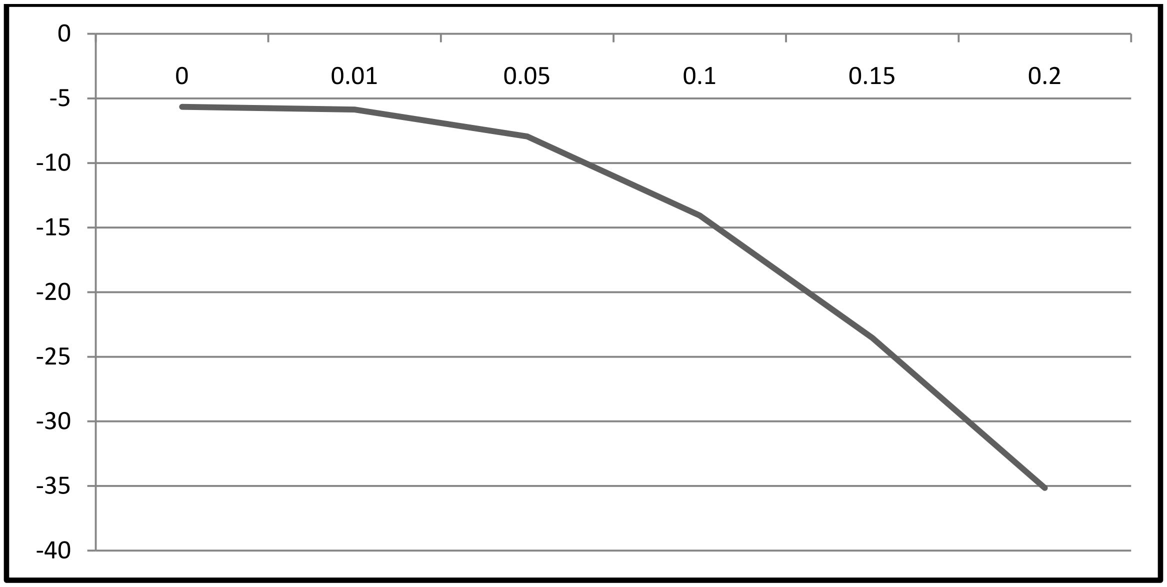

Figure 6-24 The income objective function versus type I error for type II error equal 0.15

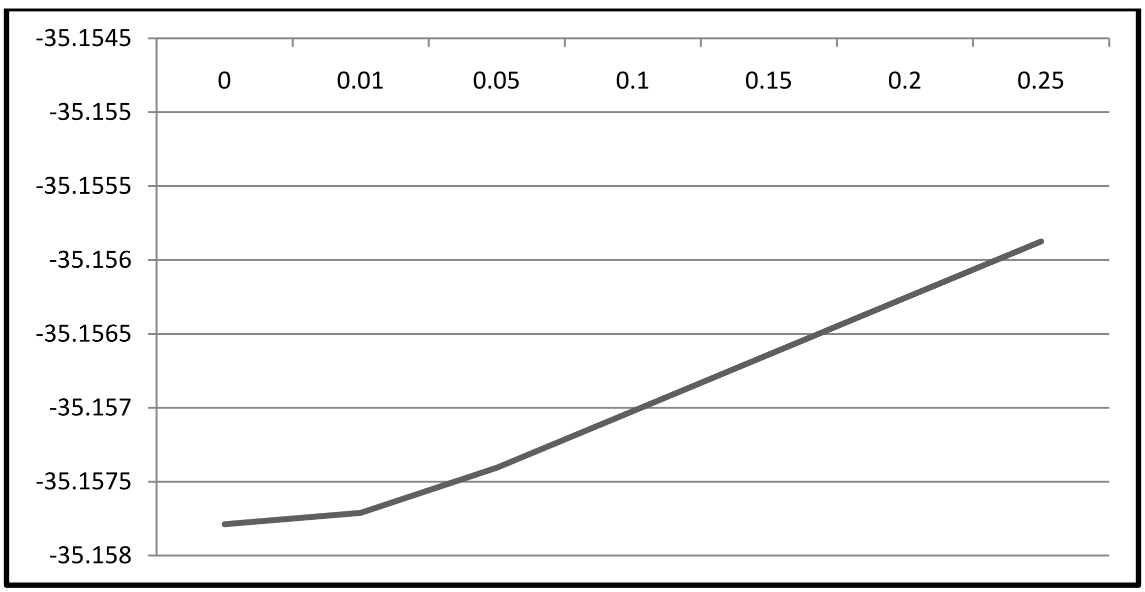

Figure 6-25 The income objective function versus type II error for type I error equal 0.2

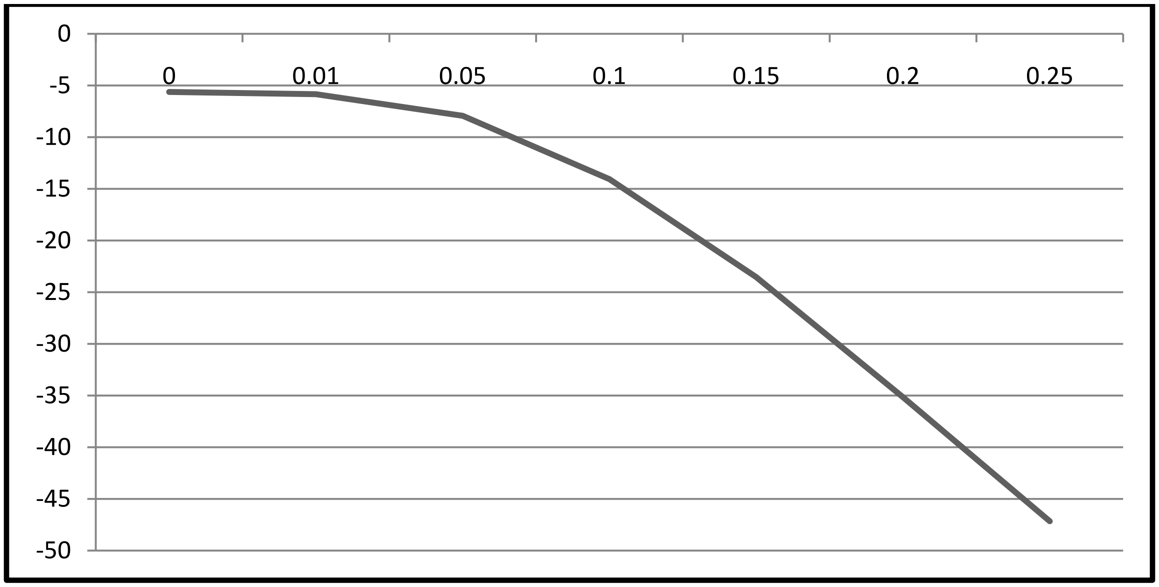

Figure 6-26 The income objective function versus type I error for type II error equal 0.2

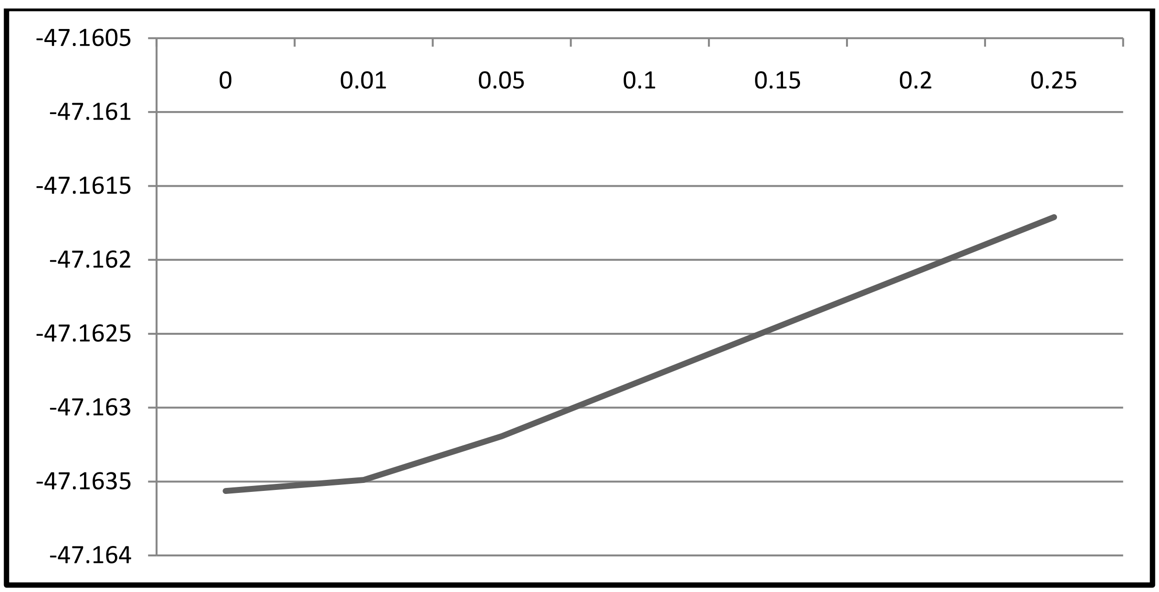

Figure 6-27 The income objective function versus type II error for type I error equal 0.25

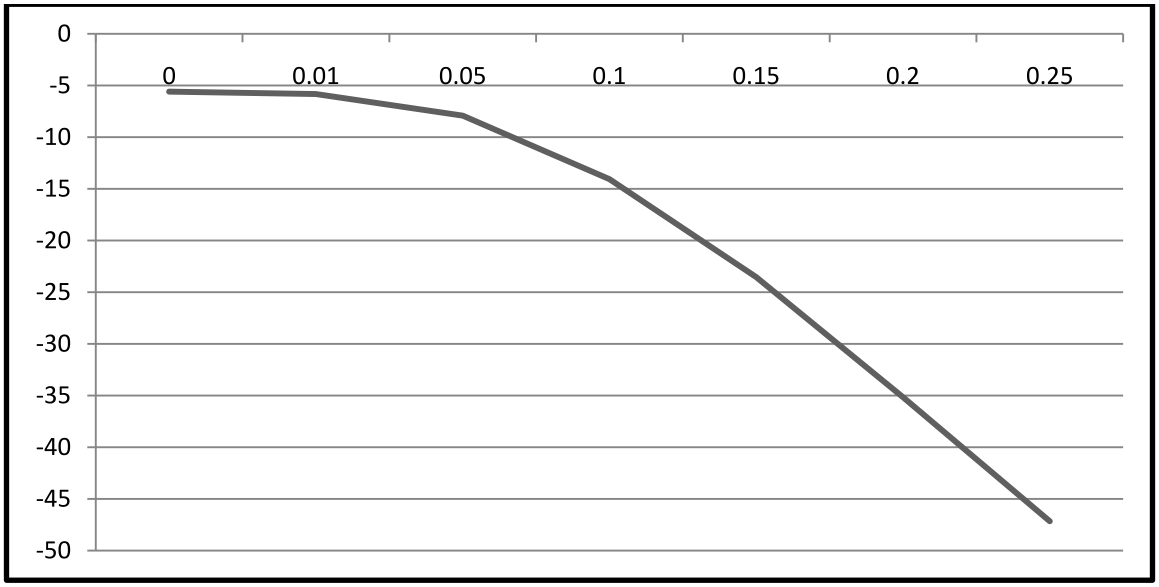

Figure 6-28 The income objective function versus type I error for type II error equal 0.25

Table 6-5 below gives the effect of the two types of error on the product uniformity objective function

Table 6-5 The sensitivity analysis of the two error types on the product uniformity objective function of model 3.

	UNIFORMITY		
(e_1, e_2)	T	OBJECTIVE VALUE	CHANGE PERCENTAGE
(0,0)	11.1	-5.64234248	3.147632%
(0,0.01)	11.1	-5.640134637	3.18553%
(0,0.05)	11.1	-5.631562559	3.332672%
(0,0.1)	11.1	-5.621425757	3.506673%

(0,0.15)	11.1	-5.611923423	3.669783%
(0,0.2)	11.1	-5.603046722	3.822154%
(0,0.25)	11.1	-5.594786633	3.963941%
(0.01,0)	11.2	-5.834456515	-0.150059%
(0.01,0.01)	11.2	-5.832688876	-0.119717%
(0.01,0.05) "original"	11.2	-5.825714523	0%
(0.01,0.1)	11.2	-5.817212125	0.145946%
(0.01,0.15)	11.2	-5.808947774	0.287806%
(0.01,0.2)	11.1	-5.79063127	0.602214%
(0.01,0.25)	11.1	-5.772849716	0.907439%
(0.05,0)	11.4	-7.754803392	-33.113344%
(0.05,0.01)	11.4	-7.752803474	-33.079014%
(0.05,0.05)	11.4	-7.744815613	-32.9419%
(0.05,0.1)	11.4	-7.734857358	-32.770964%
(0.05,0.15)	11.4	-7.724928623	-32.600535%
(0.05,0.2)	11.4	-7.715029402	-32.4306%
(0.05,0.25)	11.4	-7.705159689	-32.261196%
(0.1,0)	11.6	-13.7704828	-136.37414%
(0.1,0.01)	11.6	-13.76938227	-136.3553%
(0.1,0.05)	11.5	-13.7643516	-136.2689%

(0.1,0.1)	11.5	-13.75343889	-136.08158%
(0.1,0.15)	11.5	-13.74253316	-135.8944%
(0.1,0.2)	11.5	-13.73163443	-135.7073%
(0.1,0.25)	11.5	-13.72074268	-135.5203%
(0.15,0)	11.7	-23.41583945	-301.93936%
(0.15,0.01)	11.7	-23.41510003	-301.9267%
(0.15,0.05)	11.7	-23.41214247	-301.8759%
(0.15,0.1)	11.7	-23.40844573	-301.8124%
(0.15,0.15)	11.6	-23.40204915	-301.7026%
(0.15,0.2)	11.6	-23.39447922	-301.573%
(0.15,0.25)	11.6	-23.38691029	-301.4428%
(0.2,0)	11.8	-35.12750418	-502.97332%
(0.2,0.01)	11.8	-35.12711772	-502.9667%
(0.2,0.05)	11.8	-35.12557191	-502.9402%
(0.2,0.1)	11.8	-35.12363966	-502.90698%
(0.2,0.15)	11.8	-35.12170741	-502.8738%
(0.2,0.2)	11.8	-35.11977518	-502.8406%
(0.2,0.25)	11.7	-35.11630989	-502.78117%
(0.25,0)	12.1	-47.16354917	-709.57536%
(0.25,0.01)	12	-47.16348944	-709.5743%

(0.25,0.05)	12	-47.16319308	-709.5692%
(0.25,0.1)	12	-47.16282262	-709.5629%
(0.25,0.15)	12	-47.16245217	-709.5565%
(0.25,0.2)	12	-47.16208171	-709.5501%
(0.25,0.25)	12	-47.16171125	-709.544%

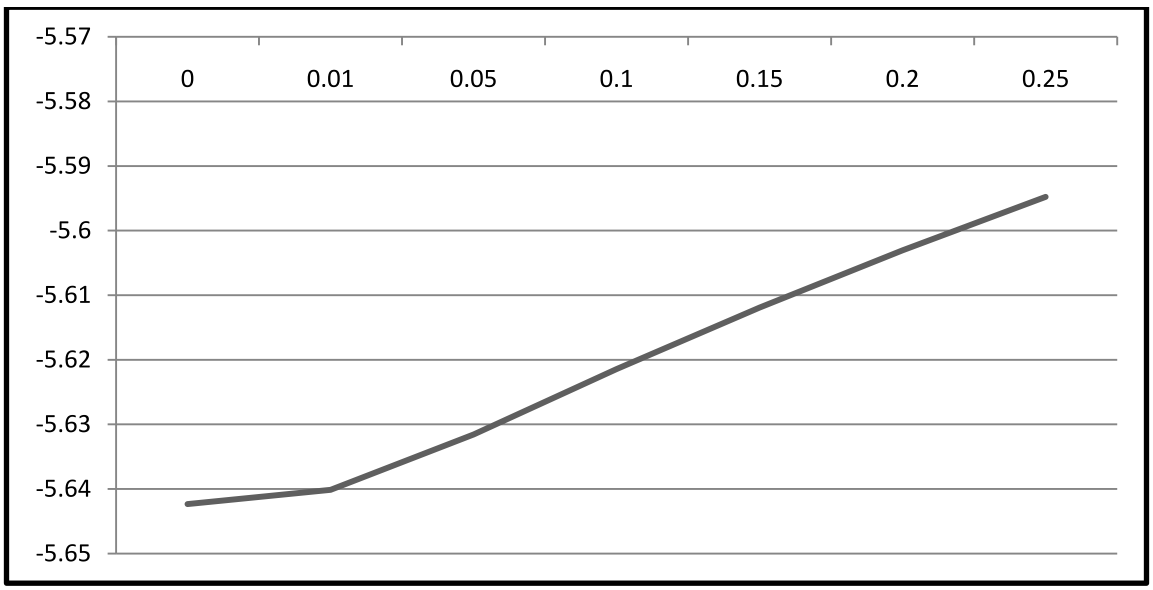

Figure 6-29 The product uniformity objective function versus type II error for type I error equal 0

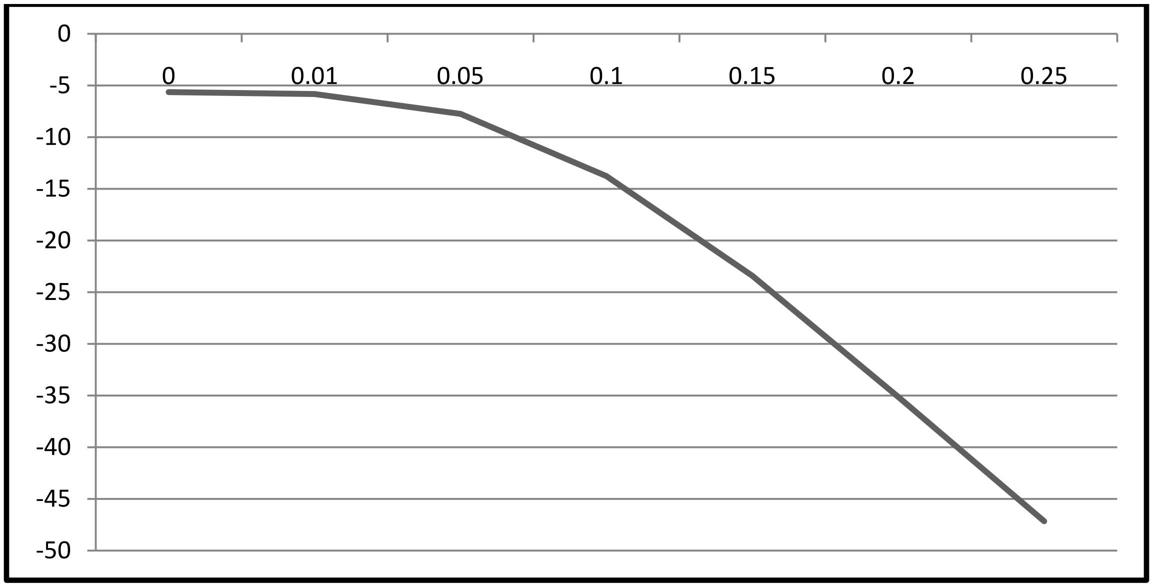

Figure 6-30 The product uniformity objective function versus type I error for type II error equal 0

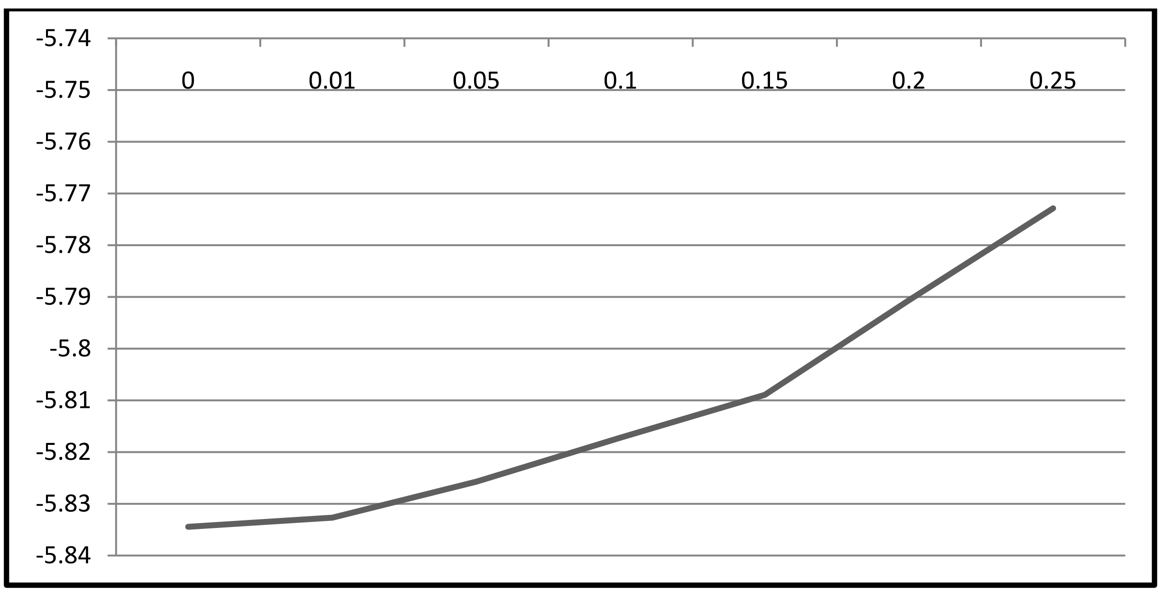

Figure 6-31 The product uniformity objective function versus type II error for type I error equal 0.01

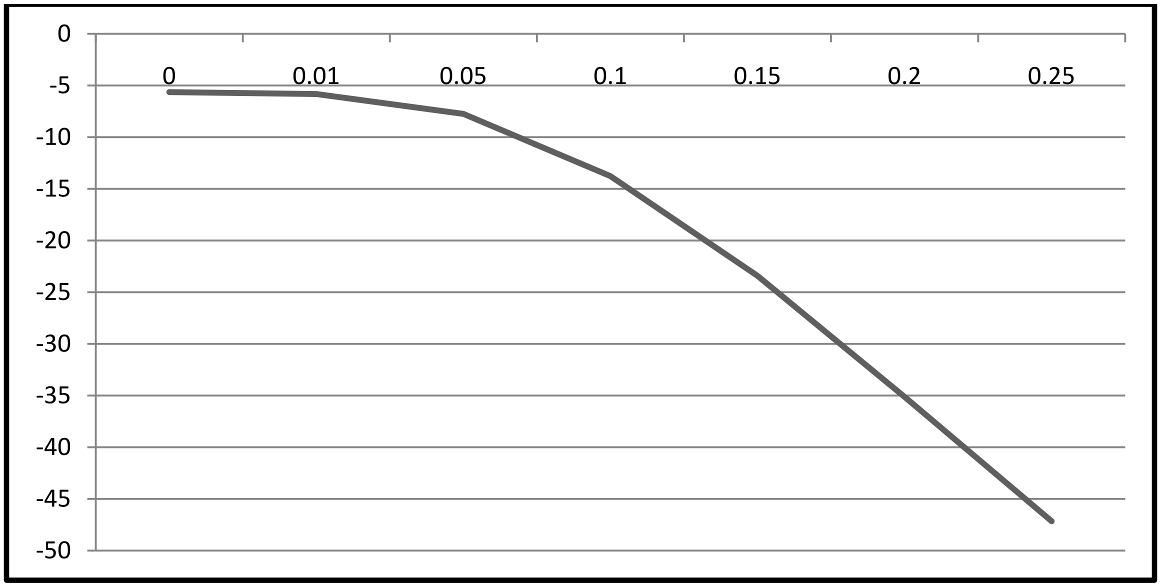

Figure 6-32 The product uniformity objective function versus type I error for type II error equal 0.01

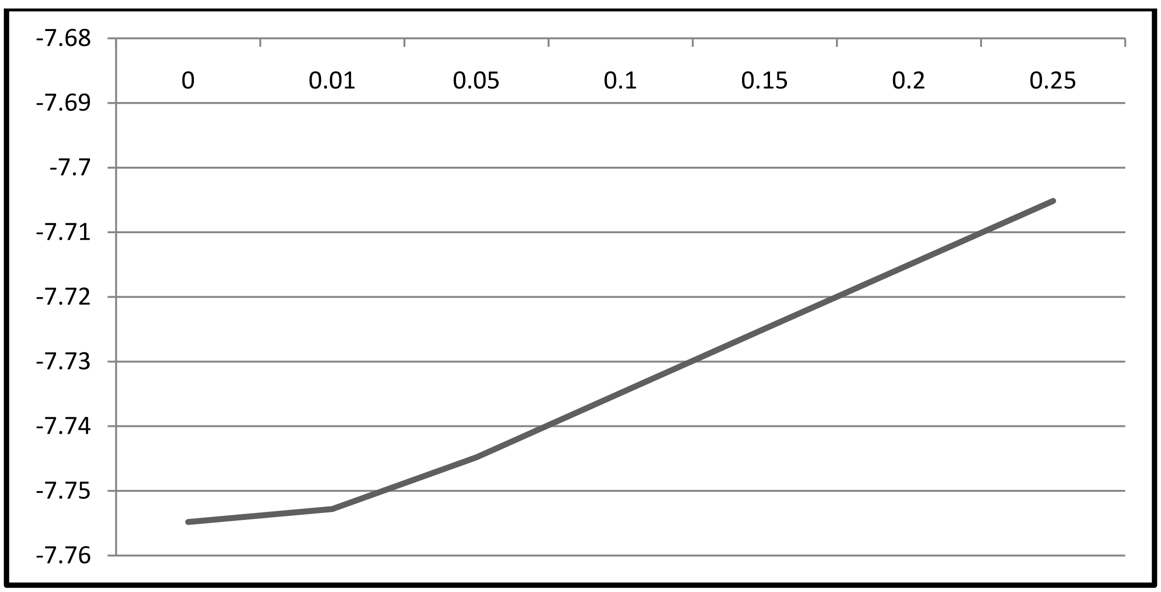

Figure 6-33 The product uniformity objective function versus type II error for type I error equal 0.05

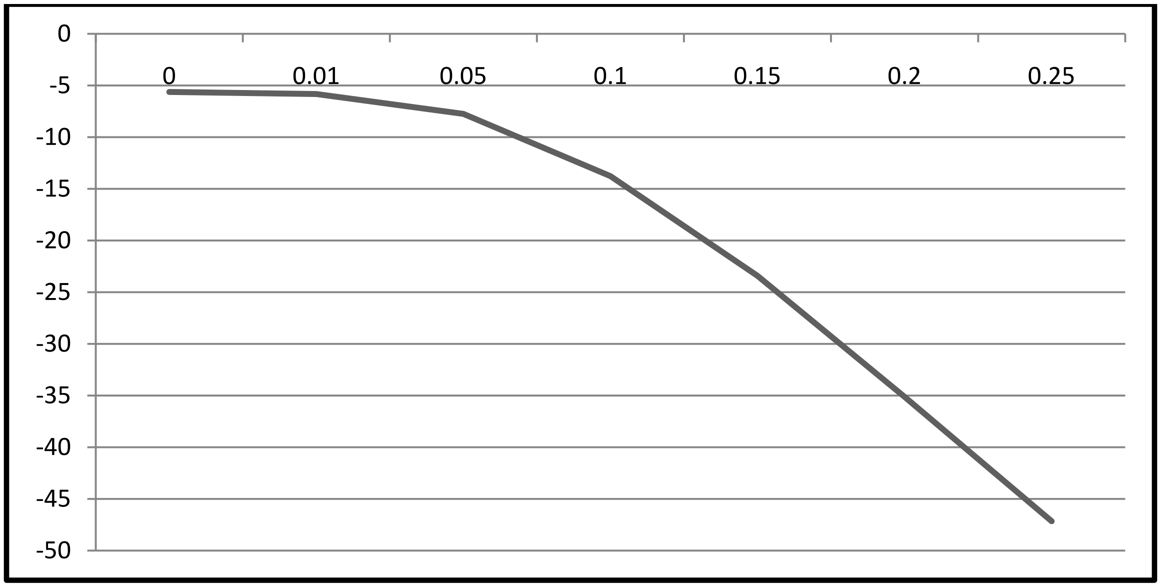

Figure 6-34 The product uniformity objective function versus type I error for type II error equal 0.05

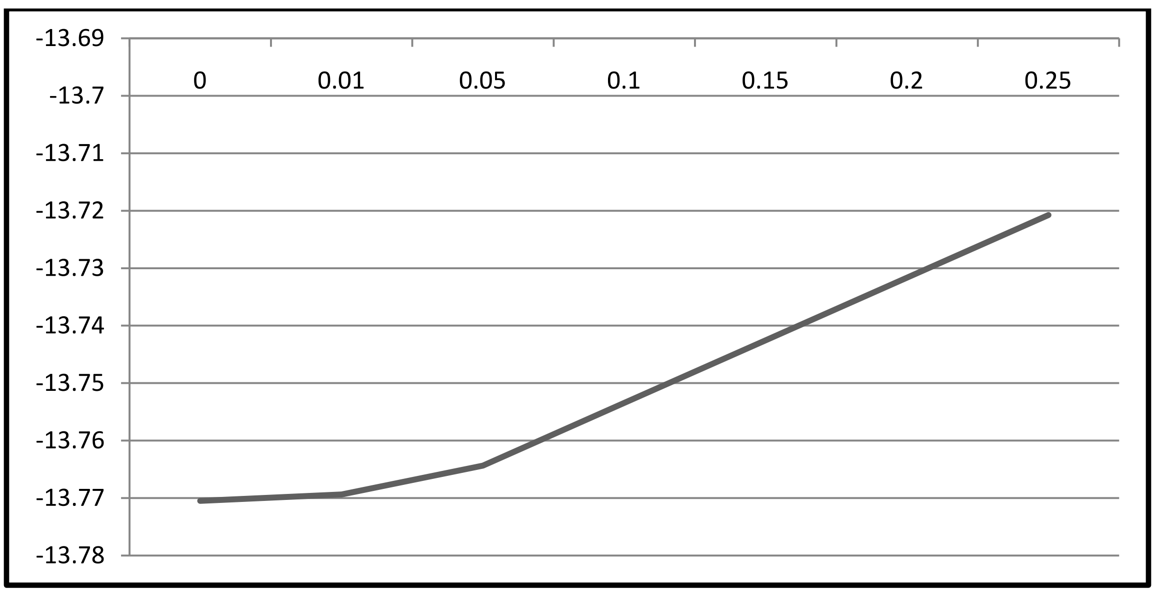

Figure 6-35 The product uniformity objective function versus type II error for type I error equal 0.1

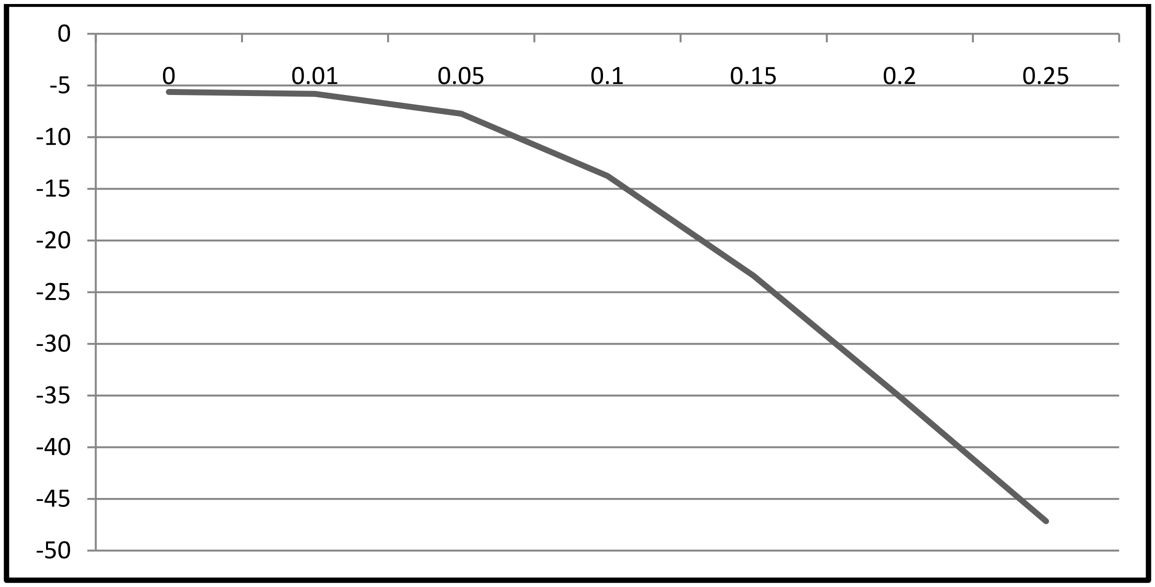

Figure 6-36 The product uniformity objective function versus type I error for type II error equal 0.1

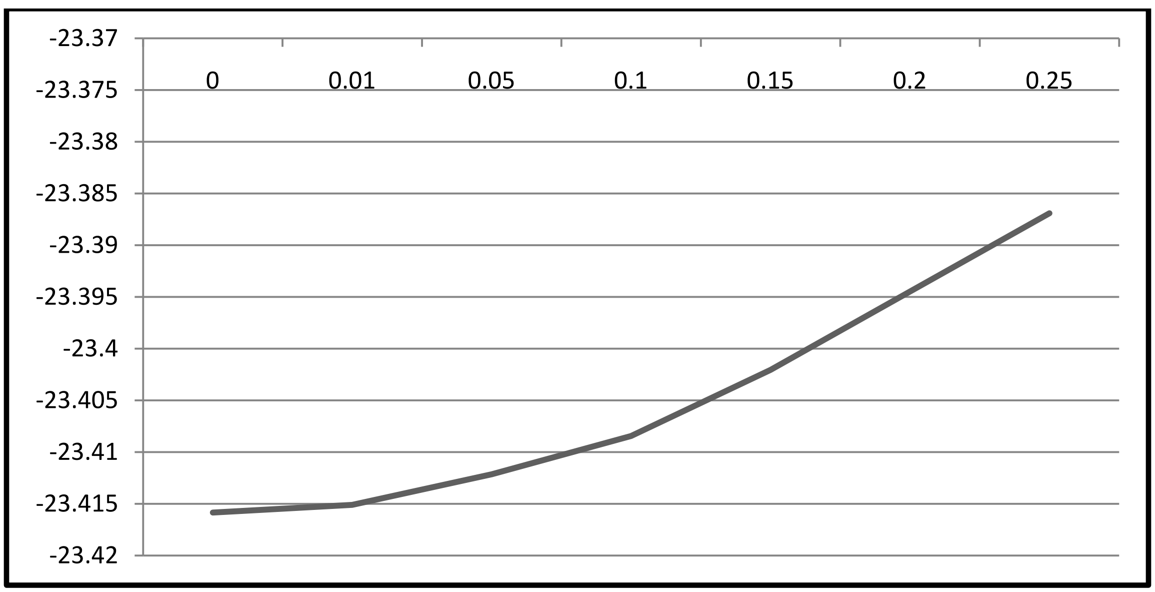

Figure 6-37 The product uniformity objective function versus type II error for type I error equal 0.15

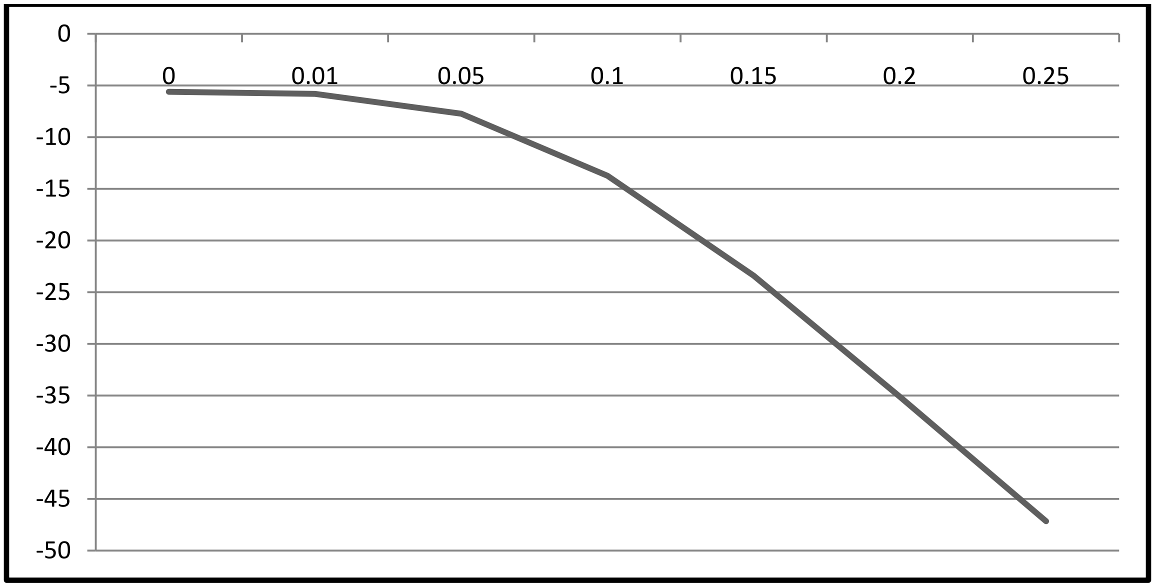

Figure 6-38 The product uniformity objective function versus type I error for type II error equal 0.15

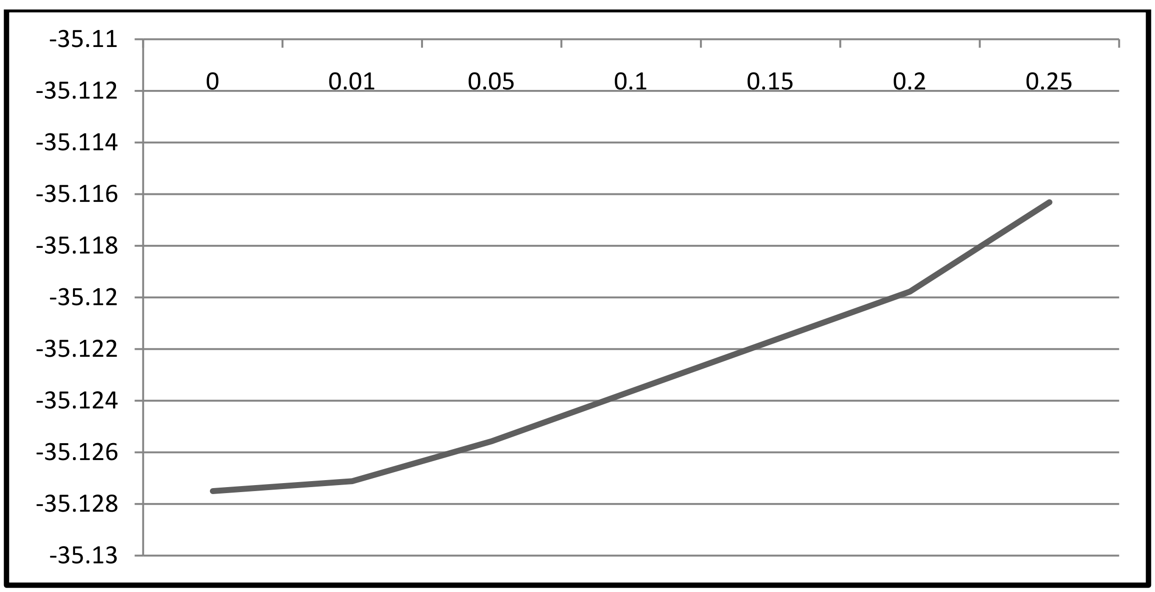

Figure 6-39 The product uniformity objective function versus type II error for type I error equal 0.2

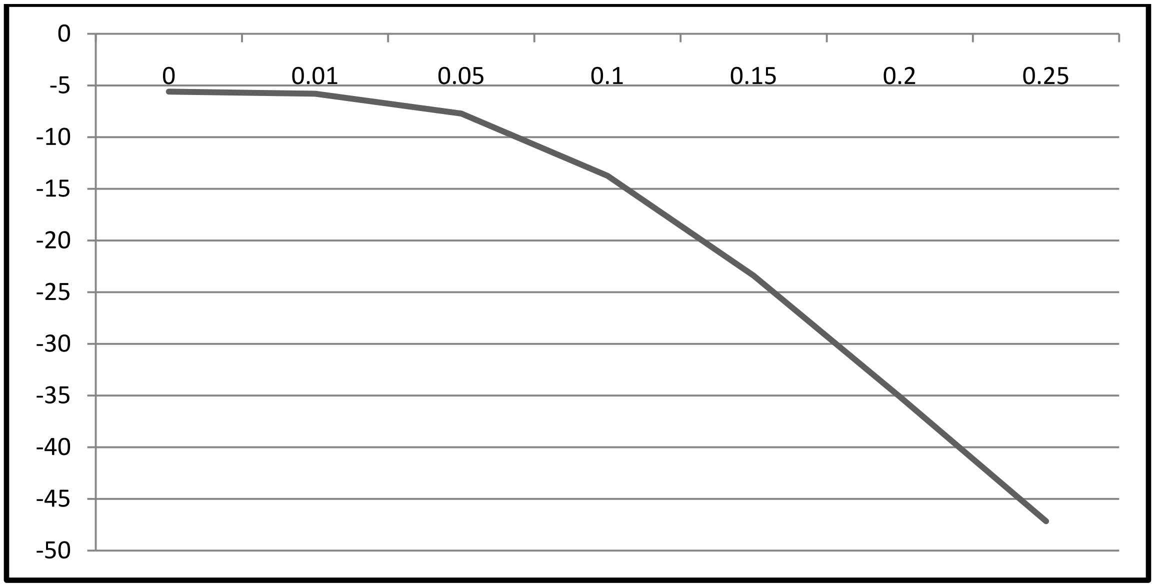

Figure 6-40 The product uniformity objective function versus type I error for type II error equal 0.2

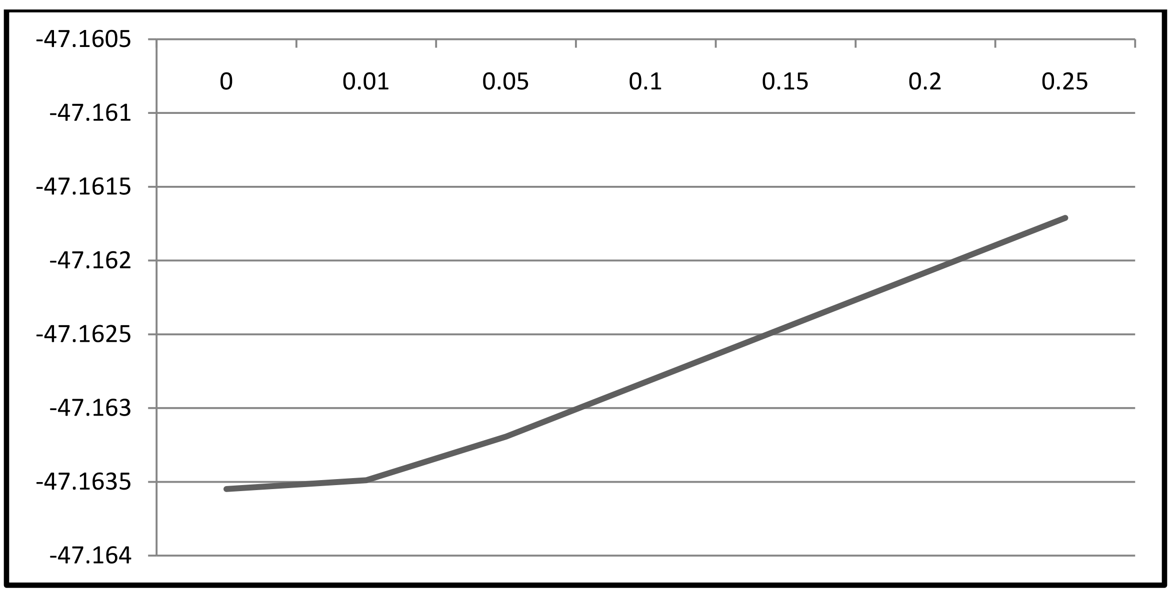

Figure 6-41 The product uniformity objective function versus type II error for type I error equal 0.25

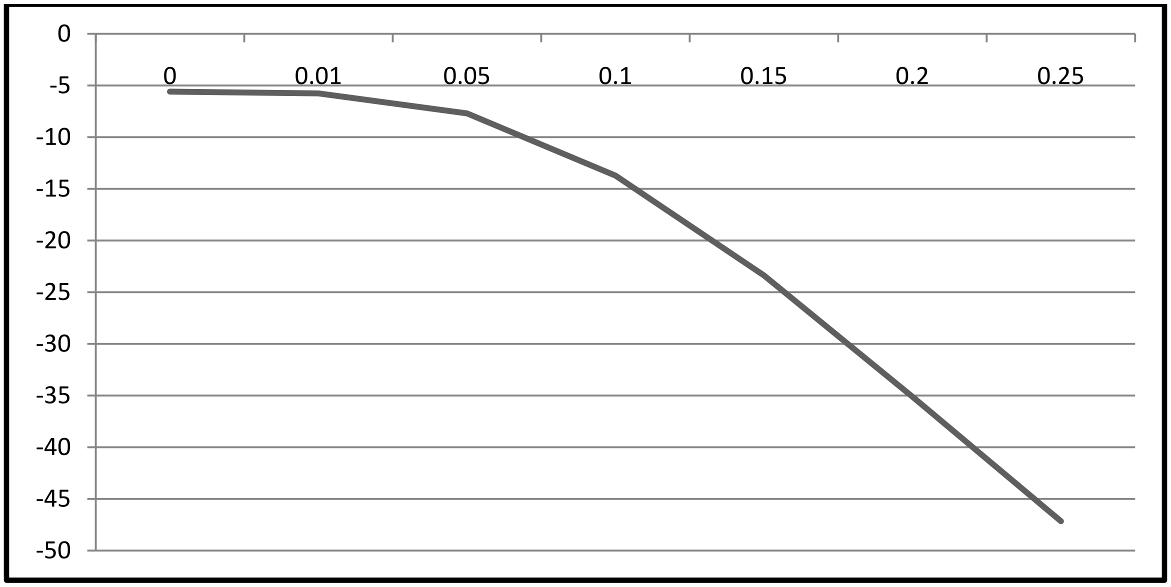

Figure 6-40 The product uniformity objective function versus type I error for type II error equal 0.25

From the three tables and the subsequent graphs above, it’s clear that the type I error has a significant impact on the objective values. On the other hand, type II error has a slight impact on them. This can be explained by the fact that when the inspection system incurs type I error that led to reject more conforming lots and consider them as secondary market lots or defectives, so this makes more loss in the profit. Type II error let to the opposite, more lower quality lots classified as higher quality ones, and while there is no penalties apply to avoid that, more lower quality lot are sold as higher quality and make more profit. Since the probability of classifying an item as conforming is very high (0.96407, 0.986097 and 0.986097 for the profit, income and uniformity objective, respectively) comparing to the probability of rejection (0.03593, 0.013903and 0.013903 for the profit, income and uniformity objective, respectively). Therefore, the occurrence of type I error tends to be higher than type II. In the future research on this model, there must be a penalties in term of loss in profit associated with type I error and in term of customers dissatisfaction and replacement and warranty cost associated with type II error.

6.5 CONCLUSION

In this chapter, a multi-objective optimization model has been developed for a process targeting problem using acceptance sampling. This inspection system is assumed to be error-prone, which means that some conforming items are rejected due to the presence of type I error, and some of the defective items are accepted due to the presence of type II error. The overall result will be in classifying higher quality lots as lower quality ones, or classifying lower quality lots as higher quality ones. The model developed consists of three objective functions maximized simultaneously to find the optimum setting of the process target mean. An illustrative example contains some data from the process targeting literature has been used to generate the set of non-inferior solutions, followed by sensitivity analysis to study the effect of the two types of error on the process target mean setting and the three objective function values.

CHAPTER 7

CONCLUSION

7.1 PREFACE

This chapter concludes the work conducted in this thesis. A brief summary of the models developed in the thesis is provided in section 7.2. Section 7.3, contains comparison between the models developed in the thesis. Finally, section 7.4 suggests directions for further research.

7.2 MODELS COMPARISON

This section provides comparisons between the models developed in the thesis. These comparisons show the effect of the inspection error on the objective function values under the two policies (100% inspection system and sampling plan inspection system). In section 7.3.1 model 1 (multi-objective optimization model for process targeting under 100% error-free inspection) and model 2 (multi-objective optimization model for process targeting under 100% error-prone inspection) are compared. Then, in section 7.3.2 model

3 (multi-objective optimization model for process targeting under sampling plan error-free inspection) and model 4 (multi-objective optimization model for process targeting under sampling plan error-free inspection) are compared.

7.2.1. MODEL 1 VURSES MODEL 2

Table 7-1 Comparison between model 1 and model 2.

	MODEL 1		MODEL 2		CHANGE PERCENTAGE
	T	OBJECTIVE VALUE	T	OBJECTIVE VALUE	
PROFIT	10.4	3.1673098	10.6	1.4032872	55.694666%
INCOME	10.9	77.6580908	11.1	77.4016752	0.3301852%
UNIFORMITY	11	-5.6756131	11	-5.6265986	-0.8635988%

The above table shows that, model 2 has lower objective values for the profit and income objective functions due to the presence of inspection errors. For the uniformity function of model 2 has no more terms than the function of model 1 but the penalties of misclassifying the lower quality items as higher quality ones. These penalties in the numerical example used have the same values of the loss function penalties. Hence, the optimal value of product uniformity function of model 2 is almost the same as the one of model 1.

7.2.2. MODEL 3 VURSES MODEL 4

Table 7-2 Comparison between model 3 and model 4.

	MODEL 3		MODEL 4		CHANGE PERCENTAGE
	T	OBJECTIVE VALUE	T	OBJECTIVE VALUE	
PROFIT	10.9	11.836365	10.9	11.4162567	3.5493044%
INCOME	11	77.6829438	11.1	77.51936716	0.211465%
UNIFORMITY	11.1	-5.64234248	11.2	-5.825714523	3.249928%

The above table shows that, model 3 has higher objective values than model 4 even though no penalty is applied to reduce the impact of inspection errors. The reason for that has been stated in chapter 6 that the impact of type I error in reducing the objective values is higher than type II error since rejecting an accepted lot due to type I error resulted in losing more profit than the gain in the profit of accepting a defective lot due to the presence of type II error.

7.3 SUMMARY

The problem considered in this thesis is the determination of the optimal target mean for a process using the multi-objective optimization under various quality control policies. The multi-objective optimization models consist of three objective functions to be maximized to determine the optimal target mean. These objectives are: the net profit per item, the net income per item and the product uniformity. The major contributions of this thesis are:

- Four different process targeting multi-objective models have developed.
- The first model is developed for the above stated problem where product quality is controlled by 100% error-free inspection system (Model 1)
- The second model is developed for the above stated problem where product quality is controlled by 100% error-prone inspection system (Model 2)
- The third model is developed for the above stated problem where product quality is controlled by sampling plan error-free inspection system (Model 1)
- The fourth model is developed for the above stated problem where product quality is controlled by sampling plan error-prone inspection system (Model 1)
- Examples from the literature are solved using the four process targeting models.
- Sensitivity analysis for all process targeting models has been conducted to study the effect of changing the models' parameters, on the optimal target mean and objective functions optimal values.
- The effect of inspection errors has been studied for models where inspection is error present.

7.4 FUTURE RESEARCH

The work done in this thesis can be extended in several directions. The following points list some of the possible extensions:

- Modify the production process where the product has an upper specification limit (USL).

- Generalize the models to the case that the product has n-class screening classification.

- Extend the models where the production process parameters are unknown (e.g. LSL, L, σ etc.), and determine as decision variables of the optimization models.

- Extend the models where the sampling plan parameters are unknown (e.g. n,d_1, d_2 etc) and determine as decision variables of the optimization models.

- In the model under sampling plan error-prone inspection system, there must be a penalties in term of loss in profit associated with type I error and in term of customers dissatisfaction and replacement and warranty cost associated with type II error.

- Use a penalty method for the occurrence of type I and type II error in the sampling plan. This penalty can be in term of loss of profit for type II error as more conforming item are rejected, and be in term of loss of customer goodwill, warranty and replacement cost for type II error as more defective item are accepted.

- Develop the models with different type of sampling plans (e.g. multiple).

- Develop the model under the assumption that the process deteriorates and shift over time. Different drift functions (e.g. linear, quadratic etc) and distribution functions (e.g. exponential, weibull etc) can be used for that purpose.

- Integrate these quality models with other production and inventory models

- Develop the model under the constraints of certain demand rate and production capacity.

- Extend the models where the production process has multi-stage processes in series.

- Extend the model where the product has multiple quality characteristics either dependent or independent.

- Develop a multi-objective targeting model with other criteria rather than profit, income and product uniformity.

- Develop the models where the product has different cost functions and structures.

Appendix A

Appendix A contains the sets of non-inferior solutions for the two sensitivity analysis cases conducted on chapter three, “multi-objective process targeting model with 100% error-free inspection system”. The two sensitivity analysis cases are conducted on the parameters, the standard deviation σ and the cost parameters (c, g and R).

Tables from 1 to 6 give the set non-inferior solutions for each case of change in the process standard deviation.

Table 1 The set of non-inferior solutions for the case of the process standard deviation “+25%”.

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.5	1.913844804	76.02134369	-8.269226785	4th
10.6	1.827711898	76.4180887	-7.579630407	2nd
10.7	1.587599553	76.73288095	-7.047723238	1st
10.8	1.21558231	76.96620301	-6.651235415	3rd
10.9	0.731578173	77.12193962	-6.369773455	5th
11	0.153741047	77.20668705	-6.184694794	6th
11.1	-0.501412767	77.22887969	-6.079085768	7th
11.2	-1.219036349	77.19788394	-6.03781297	8th

Table 2 The set of non-inferior solutions for the case of the process standard deviation “+50%”.

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.6	0.458104358	75.89900885	-8.963298844	3rd
10.7	0.405567031	76.19267775	-8.244784041	1st

10.8	0.204459596	76.42931559	-7.676481878	2nd
10.9	-0.12423526	76.60924543	-7.238314152	4th
11	-0.561761929	76.73431145	-6.911691119	5th
11.1	-1.09134911	76.8076931	-6.679661091	6th
11.2	-1.698047015	76.83362848	-6.526976701	7th
11.3	-2.368615335	76.81708739	-6.440101917	8th
11.4	-3.091437293	76.76343402	-6.407176405	9th

Table 3 The set of non-inferior solutions for the case of the process standard deviation "+75%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	-1.120319882	75.78038347	-9.75747918	3rd
10.8	-1.131136079	75.99883274	-9.00790943	1st
10.9	-1.282872168	76.17507736	-8.39769818	2nd
11	-1.557554771	76.30953337	-7.910826248	4th
11.1	-1.938874514	76.40333859	-7.531958249	5th
11.2	-2.412056227	76.45830199	-7.246697694	6th
11.3	-2.963767008	76.47681202	-7.041760414	7th
11.4	-3.582046572	76.4617154	-6.905077611	8th
11.5	-4.256247511	76.41617907	-6.825840433	9th
11.6	-4.976976334	76.34354793	-6.794497563	10th

Table 4 The set of non-inferior solutions for the case of the process standard deviation "-25%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.4	4.268106251	77.07498513	-6.645041313	4th
10.5	4.120916845	77.62324475	-6.021304028	2nd
10.6	3.758254285	77.95899041	-5.615219727	1st

10.7	3.21625538	78.11647282	-5.390462478	3rd
10.8	2.538679994	78.13873997	-5.303156339	5th

Table 5 The set of non-inferior solutions for the case of the process standard deviation "-50%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.3	5.542292242	77.64229943	-6.134775309	4th
10.4	5.537005911	78.33700669	-5.36764863	2nd
10.5	5.130391484	78.63039156	-5.003914263	1st
10.6	4.462578778	78.66257878	-4.903364272	3rd

Table 6 The set of non-inferior solutions for the case of the process standard deviation "-75%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.2	7.315086901	78.7150869	-5.131321736	3rd
10.3	7.157660262	79.25766026	-4.514390516	1st
10.4	6.38719231	79.18719231	-4.512636459	2nd

Tables from 7 to 18 give the set non-inferior solutions for each case of change in the cost parameters.

Table 7 The set of non-inferior solutions for the case of the cost parameters "+5%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.4	-0.543176941	76.09263755	-8.012167808	1st
10.5	-0.647402796	76.63191641	-7.307266389	2nd
10.6	-0.921074504	77.04249722	-6.773659588	3rd
10.7	-1.344784555	77.32672218	-6.392071779	4th
10.8	-1.897572095	77.49505995	-6.141498586	5th
10.9	-2.557388395	77.56340819	-5.999813044	6th

11	-3.30235782	77.55020288	-5.945068071	7th

Table 8 The set of non-inferior solutions for the case of the cost parameters "+10%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.4	-4.253663683	76.03147531	-8.259382286	4th
10.5	-4.393994602	76.56529218	-7.556454846	2nd
10.6	-4.706327348	76.96979541	-7.025512297	1st
10.7	-5.170460703	77.24730826	-6.647303722	3rd
10.8	-5.764927386	77.40830619	-6.400820853	5th
10.9	-6.46734703	77.46872558	-6.263898785	6th
11	-7.255613442	77.4470692	-6.214523005	7th

Table 9 The set of non-inferior solutions for the case of the cost parameters "+15%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.4	-7.964150426	75.97031307	-8.506596764	2nd
10.5	-8.140586408	76.49866795	-7.805643303	4th
10.6	-8.491580192	76.89709361	-7.277365007	6th
10.7	-8.996136852	77.16789433	-6.902535666	7th
10.8	-9.632282678	77.32155242	-6.66014312	5th
10.9	-10.37730566	77.37404297	-6.527984526	3rd
11	-11.20886906	77.34393551	-6.483977939	1st

Table 10 The set of non-inferior solutions for the case of the cost parameters "+20%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.3	-11.66180252	75.26337206	-9.644273786	8th
10.4	-11.67463717	75.90915082	-8.753811241	6th
10.5	-11.88717821	76.43204373	-8.05483176	4th
10.6	-12.27683304	76.8243918	-7.529217716	2nd
10.7	-12.821813	77.08848041	-7.157767609	1st

10.8	-13.49963797	77.23479866	-6.919465388	3rd
10.9	-14.2872643	77.27936037	-6.792070268	5th
11	-15.16212469	77.24080183	-6.753432873	7th

Table 11 The set of non-inferior solutions for the case of the cost parameters "+25%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.3	-15.33997428	75.20708258	-9.89016877	8th
10.4	-15.38512391	75.84798858	-9.001025719	7th
10.5	-15.63377002	76.3654195	-8.304020217	4th
10.6	-16.06208588	76.75168999	-7.781070425	2nd
10.7	-16.64748915	77.00906649	-7.412999553	1st
10.8	-17.36699326	77.14804489	-7.178787655	3rd
10.9	-18.19722293	77.18467776	-7.056156009	5th
11	-19.11538031	77.13766814	-7.022887807	6th

Table 12 The set of non-inferior solutions for the case of the cost parameters "+50%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.3	-33.73083305	74.92563518	-11.11964369	8th
10.4	-33.93755762	75.54217737	-10.23709811	7th
10.5	-34.36672905	76.03229838	-9.549962503	5th
10.6	-34.9883501	76.38818094	-9.040333973	3rd
10.7	-35.77586989	76.61199687	-8.68915927	1st
10.8	-36.70376972	76.71427607	-8.475398991	2nd
10.9	-37.74701611	76.71126473	-8.376584714	4th
11	-38.88165842	76.62199972	-8.370162477	6th

Table 13 The set of non-inferior solutions for the case of the cost parameters "-5%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.4	6.877796544	76.21496204	-7.517738853	7th
10.5	6.845780817	76.76516486	-6.808889475	5th
10.6	6.649431183	77.18790084	-6.269954169	3rd

10.7	6.306567742	77.48555002	-5.881607892	1st
10.8	5.837138488	77.66856749	-5.622854052	2nd
10.9	5.262528874	77.7527734	-5.471641562	4th
11	4.604153425	77.75647025	-5.406158203	6th

Table 14 The set of non-inferior solutions for the case of the cost parameters "-10%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.5	10.59237262	76.83178908	-6.559701018	7th
10.6	10.43468403	77.26060265	-6.018101459	4th
10.7	10.13224389	77.56496395	-5.626375948	2nd
10.8	9.704493779	77.75532125	-5.363531785	1st
10.9	9.172487509	77.84745601	-5.207555821	3rd
11	8.557409047	77.85960393	-5.136703269	5th
11.1	7.879037734	77.80997101	-5.130876966	6th

Table 15 The set of non-inferior solutions for the case of the cost parameters "-15%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.5	14.33896443	76.89841331	-6.310512561	7th
10.6	14.21993687	77.33330446	-5.76624875	5th
10.7	13.95792004	77.64437787	-5.371144005	3th
10.8	13.57184907	77.84207502	-5.104209518	1st
10.9	13.08244614	77.94213862	-4.94347008	2nd
11	12.51066467	77.96273762	-4.867248335	4th
11.1	11.87611183	77.92199326	-4.855533464	6th

Table 16 The set of non-inferior solutions for the case of the cost parameters "-20%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.5	18.08555624	76.96503753	-6.061324104	7th
10.6	18.00518971	77.40600627	-5.51439604	6th

10.7	17.78359619	77.72379179	-5.115912061	4th
10.8	17.43920436	77.92882878	-4.84488725	1st
10.9	16.99240478	78.03682122	-4.679384339	2nd
11	16.46392029	78.0658713	-4.597793402	3rd
11.1	15.87318592	78.0340155	-4.580189962	5th

Table 17 The set of non-inferior solutions for the case of the cost parameters "-25%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.5	21.83214804	77.03166176	-5.812135647	7th
10.6	21.79044256	77.47870808	-5.262543331	6th
10.7	21.60927234	77.80320572	-4.860680118	5th
10.8	21.30655965	78.01558255	-4.585564983	2nd
10.9	20.90236341	78.13150383	-4.415298598	1st
11	20.41717591	78.16900499	-4.328338468	3rd
11.1	19.87026001	78.14603775	-4.30484646	4th

Table 18 The set of non-inferior solutions for the case of the cost parameters "-50%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	40.73765308	78.20027533	-3.584520401	6th
10.8	40.64333611	78.44935137	-3.288953648	5th
10.9	40.45215659	78.60491686	-3.094869893	4th
11	40.18345402	78.68467341	-2.981063798	1st
11.1	39.85563048	78.70614897	-2.928128951	2nd
11.2	39.48481086	78.68502303	-2.919419727	3rd

Appendix B

Appendix B contains the sets of non-inferior solutions for the sensitivity analysis on the correlation coefficient between the actual and observed quality characteristics conducted on chapter four, “multi-objective process targeting model with 100% error-prone inspection system”.

Tables from 1 to 4 give the set non-inferior solutions for each case of change in the correlation coefficient.

Table 1 The set of non-inferior solutions for the case of the correlation coefficient “ρ = 0.9”.

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.6	8.5	9.8	1.6245911	75.894422	-6.3071411	26th
10.6	8.6	9.8	1.6218141	75.896608	-6.3079889	25th
10.6	8.7	9.8	1.6142884	75.900011	-6.3104933	22nd
10.6	8.8	9.8	1.5963259	75.904919	-6.3171296	21st
10.6	8.5	9.9	1.5954693	75.991882	-6.4515413	31st
10.6	8.6	9.9	1.5926845	75.994071	-6.4523891	30th
10.6	8.7	9.9	1.5851564	75.997483	-6.4548935	28th
10.7	8.5	9.6	1.4013659	76.299437	-5.9113483	23rd
10.7	8.6	9.6	1.3999264	76.300449	-5.9117756	24th
10.7	8.7	9.6	1.3959611	76.302061	-5.9130683	27th
10.7	8.8	9.6	1.3863049	76.304443	-5.9165721	29th
10.7	8.9	9.6	1.3649539	76.307743	-5.9250759	32nd
10.7	8.5	9.7	1.5065992	76.417184	-5.9358745	13th
10.7	8.6	9.7	1.5051616	76.418198	-5.9363017	14th

10.7	8.7	9.7	1.5012005	76.419814	-5.9375945	15th
10.7	8.8	9.7	1.491553	76.422206	-5.9410983	16th
10.7	8.9	9.7	1.4702191	76.425525	-5.949602	17th
10.7	9	9.7	1.4266421	76.429931	-5.9682407	20th
10.7	8.5	9.8	1.5696872	76.521394	-5.9927633	10th
10.7	8.6	9.8	1.5682508	76.52241	-5.9931905	9th
10.7	8.7	9.8	1.5642936	76.524031	-5.9944833	8th
10.7	8.8	9.8	1.5546519	76.526431	-5.9979871	4th
10.7	8.9	9.8	1.5333235	76.529767	-6.0064909	1st
10.7	9	9.8	1.4897701	76.534205	-6.0251296	11th
10.7	9.1	9.8	1.4065231	76.540041	-6.0625147	18th
10.7	8.5	9.9	1.5268731	76.578139	-6.1078313	7th
10.7	8.6	9.9	1.5254359	76.579156	-6.1082585	6th
10.7	8.7	9.9	1.5214702	76.580779	-6.1095513	5th
10.7	8.8	9.9	1.511825	76.583184	-6.1130551	3rd
10.7	8.9	9.9	1.4904965	76.586529	-6.1215588	2nd
10.7	9	9.9	1.446923	76.590985	-6.1401975	12th
10.7	9.1	9.9	1.3636582	76.596853	-6.1775826	19th
10.8	8.5	9.5	1.1590425	76.757536	-5.7212962	62nd
10.8	8.6	9.5	1.1583235	76.757987	-5.7215036	63rd
10.8	8.7	9.5	1.1563112	76.758723	-5.7221459	64th
10.8	8.8	9.5	1.1513097	76.759841	-5.7239265	65th
10.8	8.5	9.6	1.2193498	76.815718	-5.7261944	53rd
10.8	8.6	9.6	1.2186314	76.81617	-5.7264017	54th
10.8	8.7	9.6	1.2166203	76.816908	-5.7270441	56th
10.8	8.8	9.6	1.2116214	76.818027	-5.7288246	57th
10.8	8.9	9.6	1.2003057	76.81963	-5.7332493	58th
10.8	9	9.6	1.1765876	76.821844	-5.7431992	60th

10.8	8.5	9.7	1.2883852	76.89438	-5.7448489	44th
10.8	8.6	9.7	1.2876674	76.894833	-5.7450563	45th
10.8	8.7	9.7	1.285657	76.895572	-5.7456986	46th
10.8	8.8	9.7	1.2806609	76.896695	-5.7474792	47th
10.8	8.9	9.7	1.2693509	76.898303	-5.7519039	49th
10.8	9	9.7	1.2456439	76.900531	-5.7618537	51st
10.8	9.1	9.7	1.1990533	76.903613	-5.7823817	55th
10.8	8.5	9.8	1.3244587	76.961186	-5.7879255	33rd
10.8	8.6	9.8	1.3237413	76.961639	-5.7881328	34th
10.8	8.7	9.8	1.3217328	76.962379	-5.7887751	35th
10.8	8.8	9.8	1.3167361	76.963505	-5.7905557	36th
10.8	8.9	9.8	1.3054264	76.965119	-5.7949804	37th
10.8	9	9.8	1.2817267	76.967358	-5.8049302	43rd
10.8	9.1	9.8	1.2351466	76.97046	-5.8254582	50th
10.8	9.2	9.8	1.1484665	76.974899	-5.8648969	59th
10.8	8.5	9.9	1.2790306	76.991057	-5.8761987	38th
10.8	8.6	9.9	1.2783128	76.991511	-5.8764061	39th
10.8	8.7	9.9	1.2763035	76.992251	-5.8770484	40th
10.8	8.8	9.9	1.2713049	76.993378	-5.878829	41st
10.8	8.9	9.9	1.2599914	76.994995	-5.8832536	42nd
10.8	9	9.9	1.2362843	76.997238	-5.8932035	48th
10.8	9.1	9.9	1.1896902	77.00035	-5.9137314	52nd
10.8	9.2	9.9	1.1029841	77.004806	-5.9531702	61st
10.8	9.3	9.9	0.9490262	77.011496	-6.0246774	67th
10.8	9.4	9.9	0.9371869	77.021927	-6.1482741	66th
10.9	8.5	9.5	0.8159972	77.114899	-5.658244	97th
10.9	8.6	9.5	0.8156511	77.115093	-5.6583409	98th
10.9	8.7	9.5	0.8146664	77.115416	-5.658648	99th

10.9	8.8	9.5	0.8121681	77.115919	-5.6595191	100th
10.9	8.5	9.6	0.8447417	77.139121	-5.6597281	89th
10.9	8.6	9.6	0.8443957	77.139315	-5.6598249	90th
10.9	8.7	9.6	0.8434112	77.139638	-5.6601321	91st
10.9	8.8	9.6	0.8409131	77.140142	-5.6610031	93rd
10.9	8.9	9.6	0.8351235	77.140886	-5.6632198	94th
10.9	9	9.6	0.8226643	77.141959	-5.6683362	95th
10.9	8.5	9.7	0.8909944	77.193087	-5.6739454	79th
10.9	8.6	9.7	0.8906487	77.193281	-5.6740423	80th
10.9	8.7	9.7	0.8896645	77.193604	-5.6743495	81st
10.9	8.8	9.7	0.8871673	77.194109	-5.6752205	82nd
10.9	8.9	9.7	0.8813796	77.194856	-5.6774372	83rd
10.9	9	9.7	0.8689242	77.195933	-5.6825536	86th
10.9	9.1	9.7	0.8437363	77.197501	-5.6934162	88th
10.9	8.5	9.8	0.9112015	77.235734	-5.7056322	68th
10.9	8.6	9.8	0.9108559	77.235928	-5.7057291	69th
10.9	8.7	9.8	0.9098718	77.236252	-5.7060362	70th
10.9	8.8	9.8	0.9073757	77.236758	-5.7069073	71st
10.9	8.9	9.8	0.9015881	77.237506	-5.709124	72nd
10.9	9	9.8	0.8891344	77.238587	-5.7142403	73rd
10.9	9.1	9.8	0.8639498	77.240162	-5.725103	85th
10.9	9.2	9.8	0.8156431	77.24255	-5.7466331	92nd
10.9	8.5	9.9	0.870491	77.249997	-5.7709422	74th
10.9	8.6	9.9	0.8701452	77.250192	-5.7710391	75th
10.9	8.7	9.9	0.8691615	77.250516	-5.7713462	76th
10.9	8.8	9.9	0.8666605	77.251022	-5.7722172	77th
10.9	8.9	9.9	0.860874	77.251771	-5.7744339	78th
10.9	9	9.9	0.8484142	77.252852	-5.7795503	84th

10.9	9.1	9.9	0.823225	77.25443	-5.790413	87th
10.9	9.2	9.9	0.7749071	77.256823	-5.8119431	96th
10.9	9.3	9.9	0.686363	77.260626	-5.8522972	102nd
10.9	9.4	9.9	0.6758909	77.266867	-5.9245001	101st
11	8.5	9.5	0.3083583	77.307992	-5.622508	127th
11	8.6	9.5	0.3081977	77.308072	-5.6225516	128th
11	8.7	9.5	0.3077329	77.308208	-5.6226929	130th
11	8.8	9.5	0.3065288	77.308425	-5.6231031	132nd
11	8.9	9.5	0.3036695	77.308756	-5.6241724	135th
11	9	9.5	0.2973492	77.309253	-5.6267069	137th
11	8.5	9.6	0.3095713	77.300956	-5.6197666	125th
11	8.6	9.6	0.3094107	77.301036	-5.6198102	126th
11	8.7	9.6	0.3089462	77.301172	-5.6199516	129th
11	8.8	9.6	0.307742	77.301389	-5.6203617	131st
11	8.9	9.6	0.3048825	77.30172	-5.6214311	134th
11	8.5	9.7	0.3441327	77.342417	-5.6312265	113th
11	8.6	9.7	0.3439721	77.342496	-5.6312701	114th
11	8.7	9.7	0.3435071	77.342632	-5.6314115	116th
11	8.8	9.7	0.3423039	77.34285	-5.6318216	117th
11	8.9	9.7	0.339445	77.343182	-5.632891	119th
11	9	9.7	0.3331264	77.34368	-5.6354255	121st
11	9.1	9.7	0.3199717	77.344442	-5.6409654	123rd
11	9.2	9.7	0.2939498	77.345662	-5.6522978	136th
11	8.5	9.8	0.3577358	77.372387	-5.6542666	103rd
11	8.6	9.8	0.3575752	77.372467	-5.6543102	104th
11	8.7	9.8	0.3571103	77.372603	-5.6544515	105th
11	8.8	9.8	0.3559065	77.372821	-5.6548617	106th
11	8.9	9.8	0.3530486	77.373154	-5.655931	107th

11	9	9.8	0.3467298	77.373653	-5.6584655	108th
11	9.1	9.8	0.3335769	77.374418	-5.6640054	115th
11	9.2	9.8	0.3075573	77.375643	-5.6753378	124th
11	9.3	9.8	0.2583258	77.377697	-5.6973013	138th
11	8.5	9.9	0.3256307	77.379269	-5.7010925	109th
11	8.6	9.9	0.32547	77.379349	-5.701136	110th
11	8.7	9.9	0.3250057	77.379485	-5.7012774	111th
11	8.8	9.9	0.3238037	77.379703	-5.7016876	112th
11	8.9	9.9	0.3209411	77.380035	-5.7027569	118th
11	9	9.9	0.3146264	77.380535	-5.7052914	120th
11	9.1	9.9	0.3014682	77.3813	-5.7108313	122nd
11	9.2	9.9	0.2754426	77.382526	-5.7221637	133rd
11	9.3	9.9	0.2262005	77.384583	-5.7441272	140th
11	9.4	9.9	0.2180791	77.388123	-5.7848139	139th
11	9.5	9.9	-0.0202238	77.394225	-5.8572291	141st
11.1	8.5	9.5	-0.3264716	77.372847	-5.6463515	162nd
11.1	8.6	9.5	-0.3265435	77.372878	-5.6463703	163rd
11.1	8.7	9.5	-0.326755	77.372933	-5.646433	164th
11.1	8.8	9.5	-0.3273147	77.373023	-5.6466189	165th
11.1	8.9	9.5	-0.328677	77.373164	-5.6471156	166th
11.1	8.5	9.7	-0.32208	77.403614	-5.6482924	155th
11.1	8.6	9.7	-0.3221519	77.403645	-5.6483113	156th
11.1	8.7	9.7	-0.3223631	77.4037	-5.6483739	157th
11.1	8.8	9.7	-0.3229231	77.403791	-5.6485598	158th
11.1	8.9	9.7	-0.3242855	77.403932	-5.6490566	159th
11.1	9	9.7	-0.3273803	77.404154	-5.6502661	161st
11.1	9.1	9.7	-0.3340156	77.404509	-5.6529894	167th
11.1	9.2	9.7	-0.3475582	77.40511	-5.6587407	169th

11.1	9.3	9.7	-0.3740288	77.40617	-5.6702701	172nd
11.1	9.4	9.7	-0.3797613	77.40808	-5.6923863	171st
11.1	9.5	9.7	-0.5139268	77.411509	-5.7331715	174th
11.1	8.5	9.8	-0.3086186	77.397824	-5.6655346	142nd
11.1	8.6	9.8	-0.3086904	77.397856	-5.6655535	143rd
11.1	8.7	9.8	-0.3089017	77.397911	-5.6656161	144th
11.1	8.8	9.8	-0.3094616	77.398001	-5.665802	145th
11.1	8.9	9.8	-0.3108239	77.398142	-5.6662988	146th
11.1	9	9.8	-0.3139184	77.398364	-5.6675084	147th
11.1	9.1	9.8	-0.3205533	77.398719	-5.6702316	148th
11.1	8.5	9.9	-0.3290801	77.404612	-5.6985071	149th
11.1	8.6	9.9	-0.329152	77.404644	-5.698526	150th
11.1	8.7	9.9	-0.3293639	77.404699	-5.6985886	151st
11.1	8.8	9.9	-0.3299232	77.404789	-5.6987745	152nd
11.1	8.9	9.9	-0.3312857	77.404931	-5.6992713	153rd
11.1	9	9.9	-0.3343806	77.405152	-5.7004808	154th
11.1	9.1	9.9	-0.3410163	77.405508	-5.7032041	160th
11.1	9.2	9.9	-0.3545601	77.406108	-5.7089554	168th
11.1	9.4	9.9	-0.3867665	77.409079	-5.742601	170th
11.1	9.5	9.9	-0.520936	77.412509	-5.7833862	173rd

Table 2 The set of non-inferior solutions for the case of the correlation coefficient "ρ = 0.95".

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.6	8.5	9.8	1.8237557	76.242936	-6.2247416	151st
10.6	8.6	9.8	1.8218902	76.245073	-6.2249094	150th
10.6	8.7	9.8	1.8160764	76.24839	-6.2255443	149th
10.6	8.8	9.8	1.8011945	76.253146	-6.2280119	148th

10.6	8.5	9.9	1.8915817	76.495123	-6.3169947	156th
10.6	8.6	9.9	1.8897113	76.497267	-6.3171625	155th
10.6	8.7	9.9	1.8839014	76.500599	-6.3177974	154th
10.6	8.8	9.9	1.8690276	76.505385	-6.320265	153rd
10.6	8.9	9.9	1.8355228	76.511795	-6.3285254	152nd
10.7	8.5	9.7	1.5977509	76.58221	-5.9055632	126th
10.7	8.6	9.7	1.5967781	76.583193	-5.905642	125th
10.7	8.7	9.7	1.5937271	76.58475	-5.9059561	123rd
10.7	8.8	9.7	1.5857883	76.587032	-5.9072185	122nd
10.7	8.9	9.7	1.5675279	76.590155	-5.9115507	121st
10.7	9	9.7	1.5292449	76.594229	-5.9236509	119th
10.7	8.5	9.8	1.727634	76.798855	-5.9286065	138th
10.7	8.6	9.8	1.7266628	76.799841	-5.9286852	137th
10.7	8.7	9.8	1.7236167	76.801404	-5.9289994	135th
10.7	8.8	9.8	1.715686	76.803699	-5.9302618	134th
10.7	8.9	9.8	1.6974364	76.806847	-5.9345939	131st
10.7	9	9.8	1.6591879	76.810972	-5.9466942	128th
10.7	9.1	9.8	1.5846902	76.816307	-5.9747011	127th
10.7	8.5	9.9	1.7677534	76.988393	-6.0007951	147th
10.7	8.6	9.9	1.7667827	76.989382	-6.0008739	146th
10.7	8.7	9.9	1.7637309	76.99095	-6.001188	145th
10.7	8.8	9.9	1.7558026	76.993255	-6.0024504	144th
10.7	8.9	9.9	1.7375645	76.996426	-6.0067826	143rd
10.7	9	9.9	1.6993187	77.000596	-6.0188828	142nd
10.7	9.1	9.9	1.6248456	77.006016	-6.0468898	130th
10.7	9.2	9.9	1.4882983	77.013267	-6.1030683	124th
10.7	8.5	10	1.6100951	77.066665	-6.1710231	141st
10.7	8.6	10	1.6091224	77.067654	-6.1711019	140th

10.7	8.7	10	1.6060731	77.069225	-6.171416	139th
10.7	8.8	10	1.5981357	77.071534	-6.1726785	136th
10.7	8.9	10	1.5798721	77.074715	-6.1770106	132nd
10.7	9	10	1.541596	77.078903	-6.1891109	129th
10.8	8.5	9.5	1.1781638	76.789752	-5.7186956	46th
10.8	8.6	9.5	1.1776733	76.790186	-5.7187313	45th
10.8	8.7	9.5	1.176127	76.790888	-5.7188809	44th
10.8	8.5	9.6	1.2610626	76.889006	-5.7193299	52nd
10.8	8.6	9.6	1.2605725	76.889441	-5.7193656	51st
10.8	8.7	9.6	1.2590274	76.890144	-5.7195152	50th
10.8	8.8	9.6	1.2549411	76.891197	-5.7201365	49th
10.8	8.9	9.6	1.2453385	76.892674	-5.7223215	48th
10.8	8.5	9.7	1.3564907	77.019021	-5.7226628	61st
10.8	8.6	9.7	1.3560011	77.019457	-5.7226985	60th
10.8	8.7	9.7	1.3544566	77.020161	-5.7228482	59th
10.8	8.8	9.7	1.3503728	77.021217	-5.7234695	58th
10.8	8.9	9.7	1.3407757	77.022702	-5.7256544	57th
10.8	9	9.7	1.3201495	77.024708	-5.7319062	56th
10.8	8.5	9.8	1.4448634	77.173846	-5.7399112	78th
10.8	8.6	9.8	1.4443744	77.174282	-5.7399469	77th
10.8	8.7	9.8	1.4428322	77.174989	-5.7400966	76th
10.8	8.8	9.8	1.4387489	77.176049	-5.7407179	75th
10.8	8.9	9.8	1.4291541	77.177543	-5.7429028	70th
10.8	9	9.8	1.4085398	77.179567	-5.7491546	67th
10.8	9.1	9.8	1.3672753	77.182308	-5.7640241	64th
10.8	8.5	9.9	1.4672506	77.312812	-5.79427	84th
10.8	8.6	9.9	1.4667616	77.313249	-5.7943057	83rd
10.8	8.7	9.9	1.4652198	77.313958	-5.7944554	82nd

10.8	8.8	9.9	1.461137	77.315022	-5.7950767	81st
10.8	8.9	9.9	1.4515435	77.316523	-5.7972615	80th
10.8	9	9.9	1.4309319	77.318565	-5.8035133	79th
10.8	9.1	9.9	1.3896726	77.321338	-5.8183829	71st
10.8	9.2	9.9	1.3117676	77.325257	-5.8491596	62nd
10.8	9.3	9.9	1.1717027	77.33114	-5.907258	54th
10.8	8.5	10	1.339307	77.372708	-5.9246476	74th
10.8	8.6	10	1.3388173	77.373145	-5.9246833	73rd
10.8	8.7	10	1.3372739	77.373855	-5.9248329	72nd
10.8	8.8	10	1.3331876	77.37492	-5.9254542	69th
10.8	8.9	10	1.3235868	77.376425	-5.9276391	68th
10.8	9	10	1.3029599	77.378474	-5.9338909	66th
10.8	9.1	10	1.2616706	77.381261	-5.9487605	63rd
10.8	9.2	10	1.1837083	77.385207	-5.9795371	55th
10.8	9.3	10	1.0435381	77.39114	-6.0376356	47th
10.8	9.4	10	1.0523002	77.400516	-6.1409748	53rd
10.9	8.5	9.5	0.8286047	77.136536	-5.6262442	40th
10.9	8.6	9.5	0.8283664	77.136721	-5.6262598	41st
10.9	8.7	9.5	0.8276112	77.137026	-5.6263284	42nd
10.9	8.8	9.5	0.8255812	77.137492	-5.6266225	43rd
10.9	8.5	9.6	0.8814161	77.201005	-5.6266835	34th
10.9	8.6	9.6	0.881178	77.20119	-5.6266991	35th
10.9	8.7	9.6	0.8804229	77.201495	-5.6267678	36th
10.9	8.8	9.6	0.8783933	77.201963	-5.6270619	37th
10.9	8.9	9.6	0.8735211	77.202636	-5.6281216	38th
10.9	8.5	9.7	0.9405203	77.285162	-5.6282706	23rd
10.9	8.6	9.7	0.9402824	77.285347	-5.6282862	24th
10.9	8.7	9.7	0.9395276	77.285653	-5.6283549	25th

10.9	8.8	9.7	0.9374987	77.286121	-5.628649	27th
10.9	8.9	9.7	0.9326281	77.286797	-5.6297087	28th
10.9	9	9.7	0.9218942	77.28774	-5.6328155	29th
10.9	9.1	9.7	0.8998026	77.28907	-5.6404113	32nd
10.9	8.5	9.8	0.9997002	77.393322	-5.6409377	6th
10.9	8.6	9.8	0.9994624	77.393508	-5.6409533	5th
10.9	8.7	9.8	0.9987079	77.393814	-5.641022	3rd
10.9	8.8	9.8	0.9966805	77.394284	-5.6413161	1st
10.9	8.9	9.8	0.9918108	77.394962	-5.6423758	2nd
10.9	9	9.8	0.9810803	77.395912	-5.6454826	10th
10.9	9.1	9.8	0.9589957	77.397255	-5.6530784	15th
10.9	9.2	9.8	0.9160288	77.399248	-5.6693062	26th
10.9	8.5	9.9	1.011969	77.493165	-5.6804177	21st
10.9	8.6	9.9	1.0117312	77.493351	-5.6804332	20th
10.9	8.7	9.9	1.0109775	77.493657	-5.6805019	19th
10.9	8.8	9.9	1.0089461	77.494128	-5.680796	18th
10.9	8.9	9.9	1.0040794	77.494809	-5.6818557	17th
10.9	9	9.9	0.993347	77.495765	-5.6849625	13th
10.9	9.1	9.9	0.9712658	77.49712	-5.6925583	4th
10.9	9.2	9.9	0.9283032	77.499136	-5.7087862	16th
10.9	9.3	9.9	0.8485911	77.502336	-5.7405143	31st
10.9	8.5	10	0.9140683	77.539327	-5.7765235	7th
10.9	8.6	10	0.9138303	77.539513	-5.7765391	8th
10.9	8.7	10	0.9130761	77.53982	-5.7766077	9th
10.9	8.8	10	0.9110502	77.540291	-5.7769019	11th
10.9	8.9	10	0.9061742	77.540973	-5.7779616	12th
10.9	9	10	0.8954428	77.541932	-5.7810684	14th
10.9	9.1	10	0.8733433	77.543292	-5.7886641	22nd

10.9	9.2	10	0.8303576	77.54532	-5.804892	30th
10.9	9.3	10	0.7506017	77.54854	-5.8366201	39th
10.9	9.4	10	0.7539147	77.553898	-5.8951802	33rd
10.9	9.5	10	0.3653543	77.562952	-5.9986743	65th
11	8.5	9.7	0.3800187	77.410724	-5.6042254	109th
11	8.6	9.7	0.3799071	77.4108	-5.604232	110th
11	8.7	9.7	0.3795508	77.410927	-5.6042623	111th
11	8.8	9.7	0.3785786	77.411126	-5.6043962	112th
11	8.9	9.7	0.3761916	77.41142	-5.6048905	115th
11	9	9.7	0.3707967	77.411844	-5.6063755	116th
11	9.1	9.7	0.3593762	77.412468	-5.6101089	117th
11	8.5	9.8	0.4208933	77.486346	-5.6136859	92nd
11	8.6	9.8	0.4207818	77.486422	-5.6136925	93rd
11	8.7	9.8	0.4204255	77.48655	-5.6137228	94th
11	8.8	9.8	0.4194529	77.486749	-5.6138568	95th
11	8.9	9.8	0.4170671	77.487044	-5.614351	96th
11	9	9.8	0.4116727	77.48747	-5.6158361	97th
11	9.1	9.8	0.4002552	77.488099	-5.6195694	104th
11	9.2	9.8	0.3773568	77.48908	-5.6278051	108th
11	8.5	9.9	0.428181	77.556981	-5.6415279	85th
11	8.6	9.9	0.4280695	77.557056	-5.6415345	86th
11	8.7	9.9	0.4277139	77.557184	-5.6415648	87th
11	8.8	9.9	0.4267434	77.557384	-5.6416987	88th
11	8.9	9.9	0.4243535	77.55768	-5.642193	89th
11	9	9.9	0.4189647	77.558108	-5.643678	90th
11	9.1	9.9	0.407545	77.55874	-5.6474114	91st
11	9.2	9.9	0.3846468	77.55973	-5.655647	101st
11	9.3	9.9	0.3407922	77.561386	-5.6723278	113th

11	9.4	9.9	0.3415297	77.564277	-5.7042779	107th
11	8.5	10	0.3578965	77.593146	-5.7098247	98th
11	8.6	10	0.3577849	77.593222	-5.7098313	99th
11	8.7	10	0.3574292	77.59335	-5.7098616	100th
11	8.8	10	0.3564583	77.59355	-5.7099956	102nd
11	8.9	10	0.3540743	77.593846	-5.7104898	103rd
11	9	10	0.3486769	77.594275	-5.7119748	105th
11	9.1	10	0.337253	77.59491	-5.7157082	106th
11	9.2	10	0.3143465	77.595904	-5.7239439	114th
11	9.3	10	0.2704754	77.597568	-5.7406246	120th
11	9.4	10	0.2711881	77.600475	-5.7725748	118th
11	9.5	10	0.0468588	77.605608	-5.8312102	133rd
11.9	8.5	9.5	-7.3803355	75.919689	-5.0020876	201st
11.9	8.6	9.5	-7.3803355	75.919689	-5.0020876	202nd
11.9	8.7	9.5	-7.3803356	75.919689	-5.0020876	203rd
11.9	8.8	9.5	-7.3803359	75.919689	-5.0020877	204th
11.9	8.9	9.5	-7.3803367	75.919689	-5.0020878	205th
11.9	9	9.5	-7.380339	75.919689	-5.0020881	206th
11.9	9.1	9.5	-7.3803454	75.919689	-5.0020892	207th
11.9	9.2	9.5	-7.3803625	75.919689	-5.0020925	208th
11.9	9.3	9.5	-7.3804062	75.91969	-5.0021018	209th
11.9	9.4	9.5	-7.3804271	75.919691	-5.0021266	210th
11.9	9.5	9.5	-7.380774	75.919695	-5.0021908	219th
11.9	8.5	9.6	-7.1021939	76.197877	-5.0903965	157th
11.9	8.6	9.6	-7.102194	76.197877	-5.0903965	158th
11.9	8.7	9.6	-7.102194	76.197877	-5.0903965	159th
11.9	8.8	9.6	-7.1021943	76.197877	-5.0903965	160th
11.9	8.9	9.6	-7.1021951	76.197877	-5.0903966	161st

11.9	9	9.6	-7.1021974	76.197877	-5.0903969	162nd
11.9	9.1	9.6	-7.1022038	76.197878	-5.090398	163rd
11.9	9.2	9.6	-7.1022209	76.197878	-5.0904013	164th
11.9	9.3	9.6	-7.1022645	76.197878	-5.0904106	165th
11.9	9.4	9.6	-7.1022853	76.19788	-5.0904355	166th
11.9	9.5	9.6	-7.1026321	76.197884	-5.0904996	167th
11.9	8.5	9.7	-7.1034507	76.196742	-5.0898428	168th
11.9	8.6	9.7	-7.1034507	76.196742	-5.0898428	169th
11.9	8.7	9.7	-7.1034508	76.196742	-5.0898428	170th
11.9	8.8	9.7	-7.103451	76.196742	-5.0898428	171st
11.9	8.9	9.7	-7.1034518	76.196742	-5.0898429	172nd
11.9	9	9.7	-7.1034542	76.196742	-5.0898432	173rd
11.9	9.1	9.7	-7.1034606	76.196742	-5.0898443	174th
11.9	9.2	9.7	-7.1034776	76.196742	-5.0898476	175th
11.9	9.3	9.7	-7.1035213	76.196743	-5.0898569	176th
11.9	9.4	9.7	-7.1035421	76.196745	-5.0898818	177th
11.9	9.5	9.7	-7.1038888	76.196749	-5.0899459	178th
11.9	8.5	9.8	-7.8955794	75.404902	-4.8583388	245th
11.9	8.6	9.8	-7.8955794	75.404902	-4.8583388	246th
11.9	8.7	9.8	-7.8955795	75.404902	-4.8583388	247th
11.9	8.8	9.8	-7.8955798	75.404902	-4.8583388	248th
11.9	8.9	9.8	-7.8955806	75.404902	-4.8583389	249th
11.9	9	9.8	-7.8955829	75.404902	-4.8583393	250th
11.9	9.1	9.8	-7.8955893	75.404903	-4.8583404	251st
11.9	9.2	9.8	-7.8956064	75.404903	-4.8583437	252nd
11.9	9.3	9.8	-7.8956501	75.404903	-4.858353	253rd
11.9	9.4	9.8	-7.8956712	75.404905	-4.8583778	254th
11.9	9.5	9.8	-7.8960187	75.404908	-4.8584419	255th

11.9	8.5	9.9	-7.614286	75.686839	-4.9365568	234th
11.9	8.6	9.9	-7.614286	75.686839	-4.9365568	235th
11.9	8.7	9.9	-7.6142861	75.686839	-4.9365568	236th
11.9	8.8	9.9	-7.6142864	75.686839	-4.9365568	237th
11.9	8.9	9.9	-7.6142872	75.686839	-4.9365569	238th
11.9	9	9.9	-7.6142895	75.686839	-4.9365572	239th
11.9	9.1	9.9	-7.6142959	75.68684	-4.9365583	240th
11.9	9.2	9.9	-7.6143129	75.68684	-4.9365617	241st
11.9	9.3	9.9	-7.6143567	75.68684	-4.9365709	242nd
11.9	9.4	9.9	-7.6143777	75.686842	-4.9365958	243rd
11.9	9.5	9.9	-7.6147248	75.686846	-4.9366599	244th
11.9	8.5	10	-7.3802407	75.922229	-5.0028329	190th
11.9	8.6	10	-7.3802408	75.922229	-5.0028329	191st
11.9	8.7	10	-7.3802408	75.922229	-5.002833	192nd
11.9	8.8	10	-7.3802411	75.922229	-5.002833	193rd
11.9	8.9	10	-7.3802419	75.922229	-5.0028331	194th
11.9	9	10	-7.3802442	75.922229	-5.0028334	195th
11.9	9.1	10	-7.3802507	75.922229	-5.0028345	196th
11.9	9.2	10	-7.3802677	75.922229	-5.0028378	197th
11.9	9.3	10	-7.3803114	75.92223	-5.0028471	198th
11.9	9.4	10	-7.3803323	75.922232	-5.0028719	199th
11.9	9.5	10	-7.3806792	75.922236	-5.0029361	200th
11.9	8.5	10.1	-7.3817631	75.923363	-5.0041035	211th
11.9	8.6	10.1	-7.3817631	75.923363	-5.0041035	212th
11.9	8.7	10.1	-7.3817632	75.923363	-5.0041035	213th
11.9	8.8	10.1	-7.3817634	75.923363	-5.0041035	214th
11.9	8.9	10.1	-7.3817642	75.923363	-5.0041036	215th
11.9	9	10.1	-7.3817666	75.923363	-5.0041039	216th

11.9	9.1	10.1	-7.3817729	75.923363	-5.0041051	217th
11.9	9.2	10.1	-7.38179	75.923363	-5.0041084	218th
11.9	9.3	10.1	-7.3818337	75.923364	-5.0041176	220th
11.9	9.4	10.1	-7.3818546	75.923365	-5.0041425	221st
11.9	9.5	10.1	-7.3822016	75.923369	-5.0042066	222nd
11.9	8.5	10.2	-7.3855239	75.924598	-5.0067994	223rd
11.9	8.6	10.2	-7.3855239	75.924598	-5.0067994	224th
11.9	8.7	10.2	-7.385524	75.924598	-5.0067994	225th
11.9	8.8	10.2	-7.3855243	75.924598	-5.0067994	226th
11.9	8.9	10.2	-7.3855251	75.924598	-5.0067995	227th
11.9	9	10.2	-7.3855274	75.924598	-5.0067998	228th
11.9	9.1	10.2	-7.3855338	75.924598	-5.0068009	229th
11.9	9.2	10.2	-7.3855509	75.924598	-5.0068042	230th
11.9	9.3	10.2	-7.3855945	75.924599	-5.0068135	231st
11.9	9.4	10.2	-7.3856154	75.9246	-5.0068384	232nd
11.9	9.5	10.2	-7.3859624	75.924604	-5.0069025	233rd
11.9	8.5	10.3	-7.2840771	76.03504	-5.0120062	179th
11.9	8.6	10.3	-7.2840772	76.03504	-5.0120062	180th
11.9	8.7	10.3	-7.2840772	76.03504	-5.0120062	181st
11.9	8.8	10.3	-7.2840775	76.03504	-5.0120062	182nd
11.9	8.9	10.3	-7.2840783	76.03504	-5.0120063	183rd
11.9	9	10.3	-7.2840805	76.03504	-5.0120066	184th
11.9	9.1	10.3	-7.284087	76.03504	-5.0120077	185th
11.9	9.2	10.3	-7.2841044	76.035041	-5.012011	186th
11.9	9.3	10.3	-7.2841475	76.035041	-5.0120203	187th
11.9	9.4	10.3	-7.2841687	76.035043	-5.0120452	188th
11.9	9.5	10.3	-7.2845158	76.035047	-5.0121093	189th
12	8.5	9.5	-8.4559994	75.544012	-4.9056786	278th

12	8.6	9.5	-8.4559994	75.544012	-4.9056786	279th
12	8.7	9.5	-8.4559995	75.544012	-4.9056786	280th
12	8.8	9.5	-8.4559995	75.544012	-4.9056787	281st
12	8.9	9.5	-8.4559998	75.544012	-4.9056787	282nd
12	9	9.5	-8.4560007	75.544012	-4.9056788	283rd
12	9.1	9.5	-8.456003	75.544012	-4.9056792	284th
12	9.2	9.5	-8.4560095	75.544012	-4.9056803	285th
12	9.3	9.5	-8.4560266	75.544012	-4.9056836	286th
12	9.4	9.5	-8.4560365	75.544013	-4.9056929	287th
12	9.5	9.5	-8.4561084	75.544014	-4.9057178	288th
12	8.5	9.8	-9.1896315	74.8106	-4.7005937	322nd
12	8.6	9.8	-9.1896315	74.8106	-4.7005937	323rd
12	8.7	9.8	-9.1896316	74.8106	-4.7005937	324th
12	8.8	9.8	-9.1896316	74.8106	-4.7005937	325th
12	8.9	9.8	-9.1896319	74.8106	-4.7005938	326th
12	9	9.8	-9.1896328	74.8106	-4.7005939	327th
12	9.1	9.8	-9.1896351	74.8106	-4.7005942	328th
12	9.2	9.8	-9.1896416	74.8106	-4.7005954	329th
12	9.3	9.8	-9.1896588	74.810601	-4.7005987	330th
12	9.4	9.8	-9.1896687	74.810601	-4.700608	331st
12	9.5	9.8	-9.1898117	74.810602	-4.7006329	332nd
12	8.5	9.9	-8.7943685	75.206185	-4.8107267	311th
12	8.6	9.9	-8.7943685	75.206185	-4.8107267	312th
12	8.7	9.9	-8.7943685	75.206185	-4.8107267	313th
12	8.8	9.9	-8.7943686	75.206185	-4.8107268	314th
12	8.9	9.9	-8.7943689	75.206185	-4.8107268	315th
12	9	9.9	-8.7943697	75.206185	-4.8107269	316th
12	9.1	9.9	-8.7943721	75.206185	-4.8107273	317th

12	9.2	9.9	-8.7943786	75.206185	-4.8107284	318th
12	9.3	9.9	-8.7943957	75.206185	-4.8107317	319th
12	9.4	9.9	-8.7944056	75.206186	-4.810741	320th
12	9.5	9.9	-8.7945485	75.206187	-4.8107659	321st
12	8.5	10	-8.455959	75.545285	-4.9060323	267th
12	8.6	10	-8.455959	75.545285	-4.9060323	268th
12	8.7	10	-8.455959	75.545285	-4.9060323	269th
12	8.8	10	-8.4559591	75.545285	-4.9060323	270th
12	8.9	10	-8.4559594	75.545285	-4.9060323	271st
12	9	10	-8.4559602	75.545285	-4.9060324	272nd
12	9.1	10	-8.4559626	75.545285	-4.9060328	273rd
12	9.2	10	-8.4559691	75.545285	-4.9060339	274th
12	9.3	10	-8.4559862	75.545286	-4.9060373	275th
12	9.4	10	-8.455996	75.545286	-4.9060466	276th
12	9.5	10	-8.4561388	75.545288	-4.9060714	277th
12	8.5	10.1	-8.4566323	75.546017	-4.9066568	289th
12	8.6	10.1	-8.4566323	75.546017	-4.9066568	290th
12	8.7	10.1	-8.4566323	75.546017	-4.9066568	291st
12	8.8	10.1	-8.4566324	75.546017	-4.9066568	292nd
12	8.9	10.1	-8.4566327	75.546017	-4.9066568	293rd
12	9	10.1	-8.4566335	75.546017	-4.9066569	294th
12	9.1	10.1	-8.4566358	75.546017	-4.9066573	295th
12	9.2	10.1	-8.4566423	75.546017	-4.9066584	296th
12	9.3	10.1	-8.4566594	75.546017	-4.9066618	297th
12	9.4	10.1	-8.4566693	75.546018	-4.9066711	298th
12	9.5	10.1	-8.4568121	75.546019	-4.9066959	299th
12	8.5	10.2	-8.4584068	75.546967	-4.9080238	300th
12	8.6	10.2	-8.4584068	75.546967	-4.9080238	301st

12	8.7	10.2	-8.4584068	75.546967	-4.9080238	302nd
12	8.8	10.2	-8.4584069	75.546967	-4.9080238	303rd
12	8.9	10.2	-8.4584072	75.546967	-4.9080238	304th
12	9	10.2	-8.458408	75.546967	-4.9080239	305th
12	9.1	10.2	-8.4584103	75.546967	-4.9080243	306th
12	9.2	10.2	-8.4584168	75.546967	-4.9080254	307th
12	9.3	10.2	-8.4584339	75.546968	-4.9080288	308th
12	9.4	10.2	-8.4584438	75.546968	-4.9080381	309th
12	9.5	10.2	-8.4585866	75.54697	-4.9080629	310th
12	8.5	10.3	-8.2681369	75.742303	-4.9107579	256th
12	8.6	10.3	-8.2681369	75.742303	-4.9107579	257th
12	8.7	10.3	-8.268137	75.742303	-4.9107579	258th
12	8.8	10.3	-8.2681371	75.742303	-4.9107579	259th
12	8.9	10.3	-8.2681373	75.742303	-4.910758	260th
12	9	10.3	-8.2681382	75.742303	-4.9107581	261st
12	9.1	10.3	-8.2681405	75.742303	-4.9107584	262nd
12	9.2	10.3	-8.2681469	75.742303	-4.9107596	263rd
12	9.3	10.3	-8.2681641	75.742303	-4.9107629	264th
12	9.4	10.3	-8.2681739	75.742304	-4.9107722	265th
12	9.5	10.3	-8.2683166	75.742305	-4.9107971	266th
12.1	8.5	9.5	-9.2880785	75.411922	-4.8022278	333rd
12.1	8.6	9.5	-9.2880785	75.411922	-4.8022278	334th
12.1	8.7	9.5	-9.2880785	75.411922	-4.8022278	335th
12.1	8.8	9.5	-9.2880785	75.411922	-4.8022278	336th
12.1	8.9	9.5	-9.2880786	75.411922	-4.8022278	337th
12.1	9	9.5	-9.2880786	75.411922	-4.8022278	338th
12.1	9.1	9.5	-9.2880789	75.411922	-4.8022279	339th
12.1	9.2	9.5	-9.2880797	75.411922	-4.8022283	340th

12.1	9.3	9.5	-9.2880821	75.411922	-4.8022295	341st
12.1	9.4	9.5	-9.2880844	75.411922	-4.8022328	342nd
12.1	9.5	9.5	-9.2881083	75.411922	-4.8022421	343rd
12.1	8.5	9.8	-10.594838	74.105173	-4.520671	377th
12.1	8.6	9.8	-10.594838	74.105173	-4.520671	378th
12.1	8.7	9.8	-10.594838	74.105173	-4.520671	379th
12.1	8.8	9.8	-10.594838	74.105173	-4.520671	380th
12.1	8.9	9.8	-10.594838	74.105173	-4.520671	381st
12.1	9	9.8	-10.594838	74.105173	-4.5206711	382nd
12.1	9.1	9.8	-10.594839	74.105173	-4.5206712	383rd
12.1	9.2	9.8	-10.594839	74.105173	-4.5206716	384th
12.1	9.3	9.8	-10.594842	74.105173	-4.5206727	385th
12.1	9.4	9.8	-10.594844	74.105173	-4.5206761	386th
12.1	9.5	9.8	-10.594868	74.105173	-4.5206853	387th
12.1	8.5	9.9	-10.089244	74.610804	-4.6701412	355th
12.1	8.6	9.9	-10.089244	74.610804	-4.6701412	356th
12.1	8.7	9.9	-10.089244	74.610804	-4.6701412	357th
12.1	8.8	9.9	-10.089244	74.610804	-4.6701412	358th
12.1	8.9	9.9	-10.089244	74.610804	-4.6701412	359th
12.1	9	9.9	-10.089244	74.610804	-4.6701412	360th
12.1	9.1	9.9	-10.089245	74.610804	-4.6701414	361st
12.1	9.2	9.9	-10.089245	74.610804	-4.6701417	362nd
12.1	9.3	9.9	-10.089248	74.610804	-4.6701429	363rd
12.1	9.4	9.9	-10.08925	74.610804	-4.6701462	364th
12.1	9.5	9.9	-10.089274	74.610805	-4.6701555	365th
12.1	8.5	10.2	-9.28884	75.412335	-4.8033521	344th
12.1	8.6	10.2	-9.28884	75.412335	-4.8033521	345th
12.1	8.7	10.2	-9.28884	75.412335	-4.8033521	346th

12.1	8.8	10.2	-9.28884	75.412335	-4.8033521	347th
12.1	8.9	10.2	-9.28884	75.412335	-4.8033521	348th
12.1	9	10.2	-9.2888401	75.412335	-4.8033521	349th
12.1	9.1	10.2	-9.2888403	75.412335	-4.8033522	350th
12.1	9.2	10.2	-9.2888411	75.412335	-4.8033526	351st
12.1	9.3	10.2	-9.2888435	75.412335	-4.8033538	352nd
12.1	9.4	10.2	-9.2888458	75.412335	-4.8033571	353rd
12.1	9.5	10.2	-9.2888697	75.412336	-4.8033664	354th
12.2	8.5	9.5	-10.702254	74.697746	-4.6878667	388th
12.2	8.6	9.5	-10.702254	74.697746	-4.6878667	389th
12.2	8.7	9.5	-10.702254	74.697746	-4.6878667	390th
12.2	8.8	9.5	-10.702254	74.697746	-4.6878667	391st
12.2	8.9	9.5	-10.702254	74.697746	-4.6878667	392nd
12.2	9	9.5	-10.702254	74.697746	-4.6878667	393rd
12.2	9.1	9.5	-10.702254	74.697746	-4.6878668	394th
12.2	9.2	9.5	-10.702255	74.697746	-4.6878669	395th
12.2	9.3	9.5	-10.702255	74.697746	-4.6878673	396th
12.2	9.4	9.5	-10.702256	74.697746	-4.6878684	397th
12.2	9.5	9.5	-10.702265	74.697746	-4.6878718	398th
12.2	8.5	9.8	-12.165694	73.234311	-4.3159275	421st
12.2	8.6	9.8	-12.165694	73.234311	-4.3159275	422nd
12.2	8.7	9.8	-12.165694	73.234311	-4.3159275	423rd
12.2	8.8	9.8	-12.165694	73.234311	-4.3159275	424th
12.2	8.9	9.8	-12.165694	73.234311	-4.3159275	425th
12.2	9	9.8	-12.165694	73.234311	-4.3159275	426th
12.2	9.1	9.8	-12.165694	73.234311	-4.3159276	427th
12.2	9.2	9.8	-12.165694	73.234311	-4.3159277	428th
12.2	9.3	9.8	-12.165695	73.234311	-4.3159281	429th

12.2	9.4	9.8	-12.165696	73.234311	-4.3159292	430th
12.2	9.5	9.8	-12.165705	73.234311	-4.3159326	431st
12.2	8.5	9.9	-11.497034	73.902987	-4.5112641	399th
12.2	8.6	9.9	-11.497034	73.902987	-4.5112641	400th
12.2	8.7	9.9	-11.497034	73.902987	-4.5112641	401st
12.2	8.8	9.9	-11.497034	73.902987	-4.5112641	402nd
12.2	8.9	9.9	-11.497034	73.902987	-4.5112641	403rd
12.2	9	9.9	-11.497034	73.902987	-4.5112642	404th
12.2	9.1	9.9	-11.497034	73.902987	-4.5112642	405th
12.2	9.2	9.9	-11.497034	73.902987	-4.5112643	406th
12.2	9.3	9.9	-11.497035	73.902987	-4.5112647	407th
12.2	9.4	9.9	-11.497036	73.902987	-4.5112659	408th
12.2	9.5	9.9	-11.497044	73.902987	-4.5112692	409th
12.2	8.5	10.2	-10.348675	75.051868	-4.6883769	366th
12.2	8.6	10.2	-10.348675	75.051868	-4.6883769	367th
12.2	8.7	10.2	-10.348675	75.051868	-4.6883769	368th
12.2	8.8	10.2	-10.348675	75.051868	-4.6883769	369th
12.2	8.9	10.2	-10.348675	75.051868	-4.6883769	370th
12.2	9	10.2	-10.348675	75.051868	-4.6883769	371st
12.2	9.1	10.2	-10.348675	75.051868	-4.688377	372nd
12.2	9.2	10.2	-10.348675	75.051868	-4.6883771	373rd
12.2	9.3	10.2	-10.348676	75.051868	-4.6883775	374th
12.2	9.4	10.2	-10.348677	75.051868	-4.6883786	375th
12.2	9.5	10.2	-10.348686	75.051868	-4.688382	376th
12.3	8.5	9.5	-11.984695	74.115305	-4.5562038	410th
12.3	8.6	9.5	-11.984695	74.115305	-4.5562038	411th
12.3	8.7	9.5	-11.984695	74.115305	-4.5562038	412th
12.3	8.8	9.5	-11.984695	74.115305	-4.5562038	413th

12.3	8.9	9.5	-11.984695	74.115305	-4.5562038	414th
12.3	9	9.5	-11.984695	74.115305	-4.5562038	415th
12.3	9.1	9.5	-11.984695	74.115305	-4.5562038	416th
12.3	9.2	9.5	-11.984695	74.115305	-4.5562038	417th
12.3	9.3	9.5	-11.984695	74.115305	-4.556204	418th
12.3	9.4	9.5	-11.984696	74.115305	-4.5562043	419th
12.3	9.5	9.5	-11.984699	74.115305	-4.5562055	420th
12.3	8.5	9.8	-13.894815	72.205187	-4.0833647	443rd
12.3	8.6	9.8	-13.894815	72.205187	-4.0833647	444th
12.3	8.7	9.8	-13.894815	72.205187	-4.0833647	445th
12.3	8.8	9.8	-13.894815	72.205187	-4.0833647	446th
12.3	8.9	9.8	-13.894815	72.205187	-4.0833647	447th
12.3	9	9.8	-13.894815	72.205187	-4.0833647	448th
12.3	9.1	9.8	-13.894815	72.205187	-4.0833647	449th
12.3	9.2	9.8	-13.894815	72.205187	-4.0833648	450th
12.3	9.3	9.8	-13.894815	72.205187	-4.0833649	451st
12.3	9.4	9.8	-13.894816	72.205187	-4.0833653	452nd
12.3	9.5	9.8	-13.894819	72.205187	-4.0833664	453rd
12.4	8.5	9.5	-13.538757	73.261243	-4.3986531	432nd
12.4	8.6	9.5	-13.538757	73.261243	-4.3986531	433rd
12.4	8.7	9.5	-13.538757	73.261243	-4.3986531	434th
12.4	8.8	9.5	-13.538757	73.261243	-4.3986531	435th
12.4	8.9	9.5	-13.538757	73.261243	-4.3986531	436th
12.4	9	9.5	-13.538757	73.261243	-4.3986531	437th
12.4	9.1	9.5	-13.538757	73.261243	-4.3986531	438th
12.4	9.2	9.5	-13.538757	73.261243	-4.3986531	439th
12.4	9.3	9.5	-13.538757	73.261243	-4.3986531	440th
12.4	9.4	9.5	-13.538757	73.261243	-4.3986532	441st

12.4	9.5	9.5	-13.538758	73.261243	-4.3986536	442nd
12.4	8.5	9.8	-15.775175	71.024826	-3.8202419	454th
12.4	8.6	9.8	-15.775175	71.024826	-3.8202419	455th
12.4	8.7	9.8	-15.775175	71.024826	-3.8202419	456th

Table 3 The set of non-inferior solutions for the case of the correlation coefficient "ρ = 0.8".

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	8.5	9.5	1.230949442	76.17091996	-6.02182623	7th
10.7	8.6	9.5	1.226555488	76.17200414	-6.02413977	5th
10.7	8.7	9.5	1.217075267	76.17367876	-6.02910681	4th
10.7	8.8	9.5	1.197723954	76.17615081	-6.03920977	1st
10.7	8.5	9.6	1.267874199	76.24499651	-6.05778164	17th
10.7	8.6	9.6	1.263481891	76.246084	-6.06009518	16th
10.7	8.7	9.6	1.254004891	76.24776507	-6.06506221	14th
10.7	8.8	9.6	1.234659676	76.25024935	-6.07516517	11th
10.7	8.9	9.6	1.197154894	76.2538005	-6.094698	3rd
10.7	8.5	9.7	1.271954429	76.31577443	-6.12210081	20th
10.7	8.6	9.7	1.267556836	76.31686501	-6.12441442	19th
10.7	8.7	9.7	1.258079515	76.31855226	-6.12938146	18th
10.7	8.8	9.7	1.2387397	76.32104823	-6.13948442	5th
10.7	8.9	9.7	1.201237572	76.32462089	-6.15901717	8th
10.7	9	9.7	1.13190993	76.3296444	-6.19503719	9th
10.7	8.5	9.8	1.208286409	76.3637973	-6.22935412	13th
10.7	8.6	9.8	1.203892726	76.36489002	-6.23166773	12th
10.7	8.7	9.8	1.194409854	76.36658145	-6.23663476	10th
10.7	8.8	9.8	1.175052773	76.36908536	-6.24673772	6th
10.7	8.9	9.8	1.137531354	76.37267257	-6.26627048	2nd

10.8	8.5	9.5	1.108601899	76.73673332	-5.7966258	30th
10.8	8.6	9.5	1.10632648	76.73723559	-5.79781966	31st
10.8	8.7	9.5	1.101310685	76.73803681	-5.80044141	32nd
10.8	8.8	9.5	1.090829585	76.73926579	-5.80590335	34th
10.8	8.9	9.5	1.070001329	76.74110303	-5.81673426	37th
10.8	8.5	9.6	1.124669575	76.78075846	-5.82364509	22nd
10.8	8.6	9.6	1.122395253	76.78126178	-5.82483889	24th
10.8	8.7	9.6	1.1173795	76.78206496	-5.82746063	26th
10.8	8.8	9.6	1.106900476	76.78329777	-5.83292257	29th
10.8	8.9	9.6	1.086074164	76.78514226	-5.84375352	33rd
10.8	9	9.6	1.046561324	76.78787392	-5.86426723	41st
10.8	8.5	9.7	1.11337402	76.8204874	-5.87277011	21st
10.8	8.6	9.7	1.111099449	76.82099159	-5.8739639	23rd
10.8	8.7	9.7	1.106083192	76.82179655	-5.87658565	25th
10.8	8.8	9.7	1.095603183	76.82303283	-5.88204759	28th
10.8	8.9	9.7	1.074775006	76.82488387	-5.89287854	27th
10.8	9	9.7	1.035258743	76.82762757	-5.91339224	40th
10.8	9.1	9.7	0.963419752	76.83170972	-5.95062296	44th
10.8	8.5	9.8	1.043516115	76.83758153	-5.95530745	35th
10.8	8.6	9.8	1.041238649	76.8380861	-5.95650124	36th
10.8	8.7	9.8	1.036221233	76.83889175	-5.95912305	38th
10.8	8.8	9.8	1.025734457	76.84012952	-5.964585	39th
10.8	8.9	9.8	1.004892109	76.84198346	-5.97541588	42nd
10.8	9	9.8	0.965358042	76.84473232	-5.9959296	43rd
10.8	9.1	9.8	0.893476693	76.84882368	-6.03316031	45th
10.9	8.5	9.5	0.780424014	77.0997294	-5.67453509	51st
10.9	8.6	9.5	0.779286109	77.09995296	-5.67512945	53rd
10.9	8.7	9.5	0.776719818	77.10032124	-5.67646533	55th

10.9	8.8	9.5	0.771228079	77.10090828	-5.67931743	57th
10.9	8.9	9.5	0.760033855	77.10182677	-5.68512144	60th
10.9	8.5	9.6	0.785144762	77.12469845	-5.69415842	46th
10.9	8.6	9.6	0.784006907	77.12492228	-5.69475277	47th
10.9	8.7	9.6	0.78144072	77.12529111	-5.69608866	48th
10.9	8.8	9.6	0.775949192	77.12587926	-5.69894076	49th
10.9	8.9	9.6	0.76475538	77.12679993	-5.70474477	58th
10.9	9	9.6	0.742942268	77.12823566	-5.71604104	61st
10.9	8.5	9.7	0.767713309	77.14485225	-5.73028281	50th
10.9	8.6	9.7	0.766575269	77.1450763	-5.73087717	52nd
10.9	8.7	9.7	0.76400869	77.14544556	-5.73221306	54th
10.9	8.8	9.7	0.758516384	77.14603461	-5.73506516	56th
10.9	8.9	9.7	0.747321727	77.14695704	-5.74086917	59th
10.9	9	9.7	0.725505061	77.1483961	-5.75216544	62nd
10.9	9.1	9.7	0.684722662	77.15065758	-5.77325898	63rd
10.9	9.2	9.7	0.611369185	77.15425099	-5.81115155	64th
10.9	9.3	9.7	0.484106884	77.16000149	-5.87678174	65th
10.9	9.4	9.7	0.431327894	77.16919067	-5.98656075	60th
11	8.5	9.5	0.284352303	77.29721688	-5.63349869	70th
11	8.6	9.5	0.283802331	77.29731251	-5.63378426	71st
11	8.7	9.5	0.282533292	77.29747529	-5.63444149	73rd
11	8.8	9.5	0.279750224	77.29774502	-5.63588029	74th
11	8.9	9.5	0.273927828	77.29818655	-5.63888669	76th
11	9	9.5	0.262266581	77.2989103	-5.64490261	83rd
11	8.5	9.6	0.283741339	77.31072343	-5.64729917	67th
11	8.6	9.6	0.283191431	77.31081914	-5.64758473	68th
11	8.7	9.6	0.281922318	77.31098206	-5.64824197	69th
11	8.8	9.6	0.279138967	77.31125208	-5.64968076	72nd

11	8.9	9.6	0.273316881	77.31169422	-5.65268716	75th
11	9	9.6	0.261655581	77.31241915	-5.65870308	81st
11	9.1	9.6	0.239225274	77.31361887	-5.67026592	86th
11	9.5	9.6	-0.21966457	77.33373468	-5.90588387	84th
11	8.5	9.7	0.265827022	77.31947134	-5.67287897	77th
11	8.6	9.7	0.265277026	77.31956709	-5.67316454	78th
11	8.7	9.7	0.264007723	77.31973011	-5.67382177	79th
11	8.8	9.7	0.261223976	77.32000032	-5.67526057	80th
11	8.9	9.7	0.255401091	77.32044285	-5.67826697	82nd
11	9	9.7	0.243738228	77.32116855	-5.68428288	85th
11	9.1	9.7	0.221304956	77.3223697	-5.69584573	87th
11	9.2	9.7	0.179754655	77.3243765	-5.71724646	88th
11	9.3	9.7	0.105481281	77.32773879	-5.75546327	89th
11	9.4	9.7	0.068154741	77.33333592	-5.82140699	90th
11	9.5	9.7	-0.23764436	77.34251456	-5.93146367	91st
11.1	8.5	9.5	-0.34211137	77.36618881	-5.65350337	92nd
11.1	8.6	9.5	-0.34236815	77.36622817	-5.6536358	93rd
11.1	8.7	9.5	-0.34297464	77.36629744	-5.65394808	94th
11.1	8.8	9.5	-0.34433864	77.36641682	-5.65464945	98th
11.1	8.9	9.5	-0.34726916	77.36662125	-5.65615506	100th
11.1	9	9.5	-0.35330479	77.36697322	-5.65925408	102nd
11.1	8.5	9.6	-0.34541566	77.37236087	-5.66262015	95th
11.1	8.6	9.6	-0.34567252	77.37240025	-5.66275259	96th
11.1	8.7	9.6	-0.3462793	77.37246955	-5.66306486	97th
11.1	8.8	9.6	-0.3476432	77.37258899	-5.66376623	99th
11.1	8.9	9.6	-0.35057359	77.37279356	-5.66527184	101st
11.1	9	9.6	-0.35660978	77.37314581	-5.66837087	103rd
11.1	9.1	9.6	-0.36856115	77.37375844	-5.67450443	110th

11.1	9.5	9.6	-0.63746915	77.38547402	-5.8121809	115th
11.1	8.5	9.7	-0.35949212	77.37650345	-5.68051624	104th
11.1	8.6	9.7	-0.35974901	77.37654284	-5.68064868	105th
11.1	8.7	9.7	-0.36035585	77.37661216	-5.68096095	106th
11.1	8.8	9.7	-0.36171991	77.37673164	-5.68166233	107th
11.1	8.9	9.7	-0.3646506	77.3769363	-5.68316793	108th
11.1	9	9.7	-0.37068742	77.37728873	-5.68626696	109th
11.1	9.1	9.7	-0.38264002	77.37790173	-5.69240052	111th
11.1	9.2	9.7	-0.40544969	77.37897535	-5.70410022	112th
11.1	9.3	9.7	-0.44748214	77.38085335	-5.72564679	113th
11.1	9.4	9.7	-0.47258661	77.38410351	-5.76400598	114th
11.1	9.5	9.7	-0.65157505	77.38962532	-5.83007699	116th

Table 4 The set of non-inferior solutions for the case of the correlation coefficient "ρ = 0.75".

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	8.5	9.5	1.1071554	76.028135	-6.051098	11th
10.7	8.6	9.5	1.1022219	76.029366	-6.055172	8th
10.7	8.7	9.5	1.0920356	76.031367	-6.0632092	6th
10.7	8.8	9.5	1.0717027	76.034413	-6.0784165	3rd
10.7	8.5	9.6	1.109258	76.052306	-6.1022086	15th
10.7	8.6	9.6	1.1043246	76.053539	-6.1062827	13th
10.7	8.7	9.6	1.0941386	76.055543	-6.11432	10th
10.7	8.8	9.6	1.0738062	76.058594	-6.1295272	4th
10.7	8.9	9.6	1.0348045	76.062994	-6.1571775	1st
10.7	8.5	9.7	1.0782618	76.067246	-6.1852364	9th
10.7	8.6	9.7	1.0733262	76.06848	-6.1893104	7th
10.7	8.7	9.7	1.0631362	76.070486	-6.1973476	5th

10.7	8.8	9.7	1.0427966	76.073541	-6.2125549	2nd
10.8	8.5	9.5	1.0185319	76.632407	-5.8181961	12th
10.8	8.6	9.5	1.015919	76.632996	-5.820368	14th
10.8	8.7	9.5	1.0104109	76.633984	-5.8247533	17th
10.8	8.8	9.5	0.9991862	76.635549	-5.8332552	20th
10.8	8.9	9.5	0.9771867	76.637914	-5.8491101	22nd
10.8	9	9.5	0.9358071	76.641383	-5.8776042	24th
10.8	9.1	9.5	0.8610864	76.646427	-5.9270334	26th
10.8	9.2	9.5	0.7313016	76.653802	-6.0099162	28th
10.8	8.5	9.6	1.0045626	76.634794	-5.8571808	16th
10.8	8.6	9.6	1.0019493	76.635382	-5.8593526	18th
10.8	8.7	9.6	0.9964404	76.636371	-5.863738	19th
10.8	8.8	9.6	0.9852141	76.637936	-5.8722399	21st
10.8	8.9	9.6	0.9632114	76.640301	-5.8880948	23rd
10.8	9	9.6	0.9218258	76.643772	-5.9165888	25th
10.8	9.1	9.6	0.8470948	76.648817	-5.9660181	27th
10.9	8.5	9.5	0.7173857	77.026437	-5.6899576	29th
10.9	8.6	9.5	0.7160451	77.026708	-5.691077	30th
10.9	8.7	9.5	0.7131587	77.027179	-5.6933919	31st
10.9	8.8	9.5	0.7071503	77.027955	-5.6979928	32nd
10.9	8.9	9.5	0.6951109	77.029182	-5.7067978	33rd
10.9	9	9.5	0.6719271	77.031082	-5.7230514	34th
10.9	9.1	9.5	0.629005	77.034006	-5.7520352	35th
10.9	9.2	9.5	0.5524685	77.038527	-5.8020267	36th
10.9	9.3	9.5	0.4207195	77.045564	-5.8855124	37th
10.9	9.4	9.5	0.3469729	77.056515	-6.0206081	38th
11	8.5	9.5	0.2415957	77.247382	-5.6441549	39th
11	8.6	9.5	0.2409295	77.247503	-5.644713	40th

11	8.7	9.5	0.2394637	77.247719	-5.6458955	41st
11	8.8	9.5	0.2363453	77.24809	-5.6483063	42nd
11	8.9	9.5	0.2299529	77.248705	-5.6530434	43rd
11	9	9.5	0.2173433	77.249707	-5.6620291	44th
11	9.1	9.5	0.193394	77.251331	-5.6785069	45th
11	9.2	9.5	0.1495293	77.253973	-5.7077504	46th
11	9.3	9.5	0.0719007	77.258274	-5.758023	47th
11	9.4	9.5	0.0204495	77.265232	-5.8417931	48th
11	9.5	9.5	-0.2819797	77.276332	-5.9771575	49th
11.1	8.5	9.5	-0.3700862	77.33352	-5.6606208	50th
11.1	8.6	9.5	-0.3704068	77.333572	-5.66089	51st
11.1	8.7	9.5	-0.3711281	77.333668	-5.6614747	52rd
11.1	8.8	9.5	-0.3726973	77.33384	-5.6626982	53rd
11.1	8.9	9.5	-0.3759902	77.334138	-5.6651677	54th
11.1	9	9.5	-0.382648	77.334647	-5.6699834	55th
11.1	9.1	9.5	-0.3956263	77.335515	-5.6790676	56th
11.1	9.2	9.5	-0.4200522	77.336992	-5.6956605	57th
11.1	9.3	9.5	-0.4645101	77.339499	-5.7250298	58th
11.1	9.4	9.5	-0.4988194	77.343706	-5.7754308	59th
11.1	9.5	9.5	-0.6768416	77.350642	-5.8593235	60th

Tables from 5 to 14 give the set non-inferior solutions for each case of change in the penalty cost parameters.

Table 5 The set of non-inferior solutions for the case of the penalty cost parameters "+10%".

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	8.5	9.5	1.167674	76.085324	-6.0891388	19th

10.7	8.6	9.5	1.165607	76.08647	-6.0902013	20th
10.7	8.7	9.5	1.160432	76.088303	-6.0928703	21st
10.7	8.8	9.5	1.1485352	76.091024	-6.0990186	23rd
10.7	8.5	9.6	1.2441908	76.183908	-6.1020634	1st
10.7	8.6	9.6	1.2421261	76.185057	-6.1031259	2nd
10.7	8.7	9.6	1.2369556	76.186896	-6.1057949	4th
10.7	8.8	9.6	1.2250677	76.189629	-6.1119432	6th
10.7	8.9	9.6	1.1997591	76.193441	-6.125046	10th
10.7	8.5	9.7	1.3145403	76.300192	-6.1376722	18th
10.7	8.6	9.7	1.3124776	76.301344	-6.1387346	17th
10.7	8.7	9.7	1.3073113	76.30319	-6.1414037	15th
10.7	8.8	9.7	1.2954316	76.305937	-6.147552	14th
10.7	8.9	9.7	1.2701386	76.309775	-6.1606547	9th
10.7	9	9.7	1.2198495	76.314908	-6.1867107	3rd
10.7	8.5	9.8	1.3313862	76.403801	-6.2107731	26th
10.7	8.6	9.8	1.329324	76.404957	-6.2118356	25th
10.7	8.7	9.8	1.3241599	76.406809	-6.2145046	24th
10.7	8.8	9.8	1.312283	76.409567	-6.2206529	22nd
10.7	8.9	9.8	1.2869889	76.413428	-6.2337557	16th
10.7	9	9.8	1.2367107	76.418604	-6.2598117	7th
10.7	8.5	9.9	1.2393065	76.461143	-6.3429328	13th
10.7	8.6	9.9	1.2372417	76.4623	-6.3439953	12th
10.7	8.7	9.9	1.2320654	76.464155	-6.3466644	11th
10.7	8.8	9.9	1.2201777	76.466921	-6.3528126	8th
10.7	8.9	9.9	1.19487	76.470794	-6.3659153	5th
10.8	8.5	9.5	1.0670762	76.679228	-5.8420285	50th
10.8	8.6	9.5	1.0660305	76.679746	-5.8425658	51st
10.8	8.7	9.5	1.0633639	76.680597	-5.8439408	54th

10.8	8.8	9.5	1.057105	76.681901	-5.8471743	56th
10.8	8.5	9.6	1.1060252	76.734532	-5.851013	39th
10.8	8.6	9.6	1.1049801	76.735052	-5.8515505	40th
10.8	8.7	9.6	1.1023148	76.735904	-5.8529254	41st
10.8	8.8	9.6	1.0960585	76.737211	-5.8561589	45th
10.8	8.9	9.6	1.0824275	76.739104	-5.8632116	47th
10.8	9	9.6	1.0546331	76.741753	-5.8775991	53rd
10.8	8.5	9.7	1.1468508	76.809945	-5.879309	31st
10.8	8.6	9.7	1.1458063	76.810465	-5.8798465	32nd
10.8	8.7	9.7	1.1431416	76.81132	-5.8812213	33rd
10.8	8.8	9.7	1.1368875	76.812632	-5.8844549	34th
10.8	8.9	9.7	1.1232614	76.814533	-5.8915076	36th
10.8	9	9.7	1.095476	76.817198	-5.905895	38th
10.8	9.1	9.7	1.0420236	76.82092	-5.9335693	52nd
10.8	8.5	9.8	1.1436881	76.873235	-5.9366163	27th
10.8	8.6	9.8	1.1426436	76.873756	-5.9371537	28th
10.8	8.7	9.8	1.1399801	76.874613	-5.9385286	29th
10.8	8.8	9.8	1.1337239	76.875928	-5.9417621	30th
10.8	8.9	9.8	1.1200946	76.877837	-5.9488148	35th
10.8	9	9.8	1.0923099	76.880516	-5.9632023	37th
10.8	9.1	9.8	1.0388555	76.884264	-5.9908766	49th
10.8	8.5	9.9	1.0533959	76.899523	-6.0409017	42nd
10.8	8.6	9.9	1.0523502	76.900044	-6.0414391	43rd
10.8	8.7	9.9	1.049684	76.900902	-6.042814	44th
10.8	8.8	9.9	1.0434224	76.902218	-6.0460476	46th
10.8	8.9	9.9	1.0297826	76.90413	-6.0531002	48th
10.8	9	9.9	1.0019779	76.906816	-6.0674877	55th
10.8	9.1	9.9	0.9484866	76.910574	-6.095162	57th

10.8	9.2	9.9	0.850687	76.91596	-6.1457182	58th
10.9	8.5	9.5	0.7546087	77.062797	-5.7041598	76th
10.9	8.6	9.5	0.7540983	77.063022	-5.7044214	77th
10.9	8.7	9.5	0.7527724	77.063401	-5.7051033	78th
10.9	8.8	9.5	0.7495933	77.063999	-5.7067419	79th
10.9	8.5	9.6	0.764268	77.084114	-5.7084573	71st
10.9	8.6	9.6	0.7637578	77.084339	-5.7087189	72nd
10.9	8.7	9.6	0.7624318	77.084718	-5.7094008	73rd
10.9	8.8	9.6	0.7592527	77.085317	-5.7110394	74th
10.9	8.9	9.6	0.7521616	77.086218	-5.7146996	75th
10.9	9	9.6	0.7373222	77.087539	-5.7223642	82nd
10.9	8.5	9.7	0.7894327	77.134331	-5.7306305	59th
10.9	8.6	9.7	0.7889227	77.134557	-5.7308921	61st
10.9	8.7	9.7	0.7875971	77.134937	-5.731574	63rd
10.9	8.8	9.7	0.7844187	77.135538	-5.7332126	65th
10.9	8.9	9.7	0.7773291	77.136441	-5.7368728	67th
10.9	9	9.7	0.7624926	77.137768	-5.7445374	69th
10.9	9.1	9.7	0.7331403	77.139727	-5.7597033	80th
10.9	8.5	9.8	0.7784104	77.17229	-5.7741371	60th
10.9	8.6	9.8	0.7779003	77.172515	-5.7743987	62nd
10.9	8.7	9.8	0.7765746	77.172896	-5.7750806	64th
10.9	8.8	9.8	0.7733965	77.173498	-5.7767192	66th
10.9	8.9	9.8	0.7663056	77.174404	-5.7803794	68th
10.9	9	9.8	0.7514679	77.175735	-5.788044	70th
10.9	9.1	9.8	0.7221131	77.177702	-5.8032099	81st
10.9	9.2	9.8	0.6668301	77.180692	-5.8317622	89th
10.9	9.4	9.8	0.5397014	77.192956	-5.9722205	92nd
10.9	8.5	9.9	0.6994715	77.180925	-5.8534683	83rd

10.9	8.6	9.9	0.6989609	77.18115	-5.8537299	84th
10.9	8.7	9.9	0.6976347	77.181531	-5.8544118	85th
10.9	8.8	9.9	0.6944504	77.182133	-5.8560504	86th
10.9	8.9	9.9	0.6873575	77.18304	-5.8597106	87th
10.9	9	9.9	0.6725078	77.184372	-5.8673753	88th
10.9	9.1	9.9	0.6431376	77.186341	-5.8825412	90th
10.9	9.2	9.9	0.5878236	77.189335	-5.9110934	91st
10.9	9.3	9.9	0.4880799	77.194044	-5.9625277	93rd
10.9	9.4	9.9	0.4605368	77.201616	-6.0515517	94th
11	8.5	9.5	0.2692018	77.27457	-5.6522094	105th
11	8.6	9.5	0.2689618	77.274664	-5.6523319	106th
11	8.7	9.5	0.2683258	77.274826	-5.6526577	107th
11	8.8	9.5	0.2667673	77.27509	-5.6534579	108th
11	8.9	9.5	0.2632051	77.275501	-5.6552897	110th
11	9	9.5	0.25555	77.276133	-5.6592298	112th
11	9.1	9.5	0.2399659	77.277117	-5.667254	119th
11	8.5	9.6	0.2516808	77.26504	-5.6506402	113th
11	8.6	9.6	0.2514406	77.265134	-5.6507627	114th
11	8.7	9.6	0.2508049	77.265296	-5.6510884	116th
11	8.8	9.6	0.2492461	77.265559	-5.6518886	118th
11	8.5	9.7	0.2721968	77.303015	-5.6684584	95th
11	8.6	9.7	0.2719568	77.303109	-5.6685809	96th
11	8.7	9.7	0.2713205	77.303271	-5.6689066	97th
11	8.8	9.7	0.2697626	77.303535	-5.6697068	100th
11	8.9	9.7	0.2662003	77.303948	-5.6715387	103rd
11	9	9.7	0.2585456	77.304581	-5.6754787	109th
11	9.1	9.7	0.2429617	77.305568	-5.6835029	115th
11	9.2	9.7	0.2127119	77.307155	-5.6990783	120th

11	8.5	9.8	0.2627025	77.328269	-5.7008994	98th
11	8.6	9.8	0.2624624	77.328362	-5.7010219	99th
11	8.7	9.8	0.261826	77.328525	-5.7013477	101st
11	8.8	9.8	0.2602674	77.328789	-5.7021479	102nd
11	8.9	9.8	0.2567055	77.329202	-5.7039797	104th
11	9	9.8	0.2490495	77.329838	-5.7079198	111th
11	9.1	9.8	0.2334652	77.330828	-5.715944	117th
11	9.2	9.8	0.2032133	77.332419	-5.7315194	121st
11	9.3	9.8	0.1469282	77.335059	-5.7604851	122nd
11	9.4	9.8	0.1275971	77.339504	-5.8122896	123rd
11	9.5	9.8	-0.1279232	77.346963	-5.9016076	125th
11	9.4	9.9	0.0649066	77.340261	-5.8707431	124th
11	9.5	9.9	-0.1906917	77.34772	-5.9600611	126th
11.1	8.5	9.5	-0.3512255	77.352185	-5.6646713	133rd
11.1	8.6	9.5	-0.3513344	77.352222	-5.6647265	135th
11.1	8.7	9.5	-0.3516286	77.352289	-5.6648764	136th
11.1	8.8	9.5	-0.3523656	77.3524	-5.6652531	137th
11.1	8.9	9.5	-0.3540931	77.352581	-5.6661373	138th
11.1	9	9.5	-0.357908	77.352872	-5.6680921	139th
11.1	9.1	9.5	-0.3659043	77.353349	-5.6721916	140th
11.1	8.5	9.6	-0.399686	77.308993	-5.6555623	144th
11.1	8.6	9.6	-0.399795	77.309031	-5.6556175	145th
11.1	8.7	9.6	-0.4000892	77.309097	-5.6557674	146th
11.1	8.8	9.6	-0.4008266	77.309209	-5.6561441	147th
11.1	8.9	9.6	-0.4025548	77.309389	-5.6570283	148th
11.1	9	9.6	-0.406371	77.309678	-5.6589831	149th
11.1	9.1	9.6	-0.4143703	77.310153	-5.6630826	150th
11.1	8.5	9.7	-0.3422292	77.378157	-5.6791091	127th

11.1	8.6	9.7	-0.342338	77.378194	-5.6791643	128th
11.1	8.7	9.7	-0.3426319	77.378261	-5.6793142	129th
11.1	8.8	9.7	-0.3433692	77.378373	-5.6796909	130th
11.1	8.9	9.7	-0.3450967	77.378554	-5.6805752	131st
11.1	9	9.7	-0.3489114	77.378846	-5.6825299	132nd
11.1	9.1	9.7	-0.356907	77.379324	-5.6866294	134th
11.1	9.2	9.7	-0.3729124	77.380137	-5.6948369	141th
11.1	9.3	9.7	-0.4036562	77.381552	-5.7105993	142nd
11.1	9.4	9.7	-0.4164843	77.384043	-5.7397341	143rd
11.1	9.5	9.7	-0.5619847	77.388387	-5.7916741	151st

Table 6 The set of non-inferior solutions for the case of the penalty cost parameters "+15%".

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	8.5	9.5	1.12376985	76.0414194	-6.13304184	19th
10.7	8.5	9.6	1.20406172	76.1437788	-6.14219151	2nd
10.7	8.6	9.6	1.20204189	76.144973	-6.14320793	3rd
10.7	8.7	9.6	1.19693997	76.1468803	-6.145806	4th
10.7	8.8	9.6	1.18514685	76.149708	-6.15185494	6th
10.7	8.9	9.6	1.15995527	76.1536372	-6.16483179	10th
10.7	8.5	9.7	1.27919806	76.2648496	-6.17301354	17th
10.7	8.6	9.7	1.27718041	76.2660472	-6.17402996	16th
10.7	8.7	9.7	1.27208293	76.2679617	-6.17662802	15th
10.7	8.8	9.7	1.26029858	76.2708035	-6.18267696	13th
10.7	8.9	9.7	1.23512368	76.2747596	-6.19565382	8th
10.7	9	9.7	1.18496422	76.280023	-6.22156596	1st
10.7	8.5	9.8	1.30164819	76.3740635	-6.24051036	23rd
10.7	8.6	9.8	1.29963119	76.3752643	-6.24152677	22nd

10.7	8.7	9.8	1.29453639	76.3771853	-6.24412484	21st
10.7	8.8	9.8	1.28275534	76.3800398	-6.25017378	20th
10.7	8.9	9.8	1.2575807	76.3840202	-6.26315064	18th
10.7	9	9.8	1.2074344	76.3893281	-6.28906286	7th
10.7	8.5	9.9	1.2155875	76.437424	-6.36665122	14th
10.7	8.6	9.9	1.21356801	76.4386267	-6.36766764	12th
10.7	8.7	9.9	1.20846129	76.4405513	-6.37026579	11th
10.7	8.8	9.9	1.19667027	76.4434133	-6.37631465	9th
10.7	8.9	9.9	1.17148327	76.4474078	-6.3892915	5th
10.8	8.5	9.5	1.03692579	76.6490774	-5.8721785	48th
10.8	8.6	9.5	1.03590001	76.6496158	-5.87269555	49th
10.8	8.7	9.5	1.03326444	76.650498	-5.87403862	50th
10.8	8.8	9.5	1.02704907	76.651845	-5.87722687	51st
10.8	8.5	9.6	1.07830483	76.7068121	-5.87873314	38th
10.8	8.6	9.6	1.07727967	76.7073512	-5.87925028	40th
10.8	8.7	9.6	1.07464543	76.708235	-5.88059334	41st
10.8	8.8	9.6	1.06843272	76.7095855	-5.88378151	43rd
10.8	8.9	9.6	1.05485683	76.7115331	-5.89077593	45th
10.8	8.5	9.7	1.12227948	76.7853738	-5.90388012	28th
10.8	8.6	9.7	1.12125492	76.7859139	-5.90439725	29th
10.8	8.7	9.7	1.11862137	76.7868001	-5.90574023	30th
10.8	8.8	9.7	1.11241119	76.7881552	-5.90892849	32nd
10.8	8.9	9.7	1.09884042	76.7901119	-5.9159229	33rd
10.8	9	9.7	1.07111718	76.7928396	-5.93024289	35th
10.8	8.5	9.8	1.12287753	76.8524244	-5.95742664	24th
10.8	8.6	9.8	1.12185306	76.8529656	-5.95794369	25th
10.8	8.7	9.8	1.1192208	76.8538537	-5.95928675	26th
10.8	8.8	9.8	1.1130087	76.8552128	-5.96247493	27th

10.8	8.9	9.8	1.0994353	76.8571773	-5.96946934	31st
10.8	9	9.8	1.07171352	76.8599199	-5.98378935	34th
10.8	9.1	9.8	1.01832102	76.8637292	-6.01139341	46th
10.8	8.5	9.9	1.03669864	76.8828256	-6.05759878	36th
10.8	8.6	9.9	1.03567299	76.8833672	-6.05811583	37th
10.8	8.7	9.9	1.03303822	76.8842561	-6.05945889	39th
10.8	8.8	9.9	1.02682095	76.885617	-6.06264715	42nd
10.8	8.9	9.9	1.0132375	76.8875851	-6.06964156	44th
10.8	9	9.9	0.98549663	76.8903344	-6.08396151	47th
10.8	9.1	9.9	0.93206886	76.8941562	-6.11156557	52th
10.8	9.2	9.9	0.83432301	76.8995956	-6.16205625	53rd
10.9	8.5	9.5	0.73460754	77.0427956	-5.72416086	71st
10.9	8.6	9.5	0.7341057	77.0430291	-5.72441379	72nd
10.9	8.7	9.5	0.73279322	77.0434217	-5.72508198	73rd
10.9	8.8	9.5	0.72963339	77.0440396	-5.7267007	75th
10.9	8.5	9.6	0.74577404	77.0656197	-5.72695116	66th
10.9	8.6	9.6	0.74527235	77.0658534	-5.72720408	67th
10.9	8.7	9.6	0.74395988	77.0662463	-5.72787227	68th
10.9	8.8	9.6	0.7408001	77.0668649	-5.729491	69th
10.9	8.9	9.6	0.73373382	77.0677905	-5.73312524	70th
10.9	9	9.6	0.71892275	77.0691399	-5.74075946	77th
10.9	8.5	9.7	0.77293391	77.1178325	-5.74712925	56th
10.9	8.6	9.7	0.77243239	77.1180664	-5.74738217	58th
10.9	8.7	9.7	0.7711203	77.1184601	-5.74805036	59th
10.9	8.8	9.7	0.76796131	77.1190802	-5.74966908	61st
10.9	8.9	9.7	0.76089663	77.1200089	-5.75330333	63rd
10.9	9	9.7	0.74608874	77.1213644	-5.76093754	65th
10.9	9.1	9.7	0.7167649	77.1233515	-5.77607135	76th

10.9	8.5	9.8	0.76434094	77.15822	-5.78820655	54th
10.9	8.6	9.8	0.76383937	77.1584542	-5.78845947	55th
10.9	8.7	9.8	0.76252716	77.1588484	-5.78912766	57th
10.9	8.8	9.8	0.75936859	77.1594697	-5.79074638	60th
10.9	8.9	9.8	0.75230273	77.1604008	-5.79438063	62nd
10.9	9	9.8	0.73749383	77.161761	-5.80201484	64th
10.9	9.1	9.8	0.7081681	77.163757	-5.81714864	74th
10.9	9.2	9.8	0.65290977	77.166772	-5.84567057	84th
10.9	9.4	9.8	0.52579857	77.179053	-5.98608387	87th
10.9	8.5	9.9	0.68810671	77.1695599	-5.86483312	78th
10.9	8.6	9.9	0.68760465	77.1697942	-5.86508605	79th
10.9	8.7	9.9	0.68629207	77.1701886	-5.86575424	80th
10.9	8.8	9.9	0.68312724	77.1708102	-5.86737296	81th
10.9	8.9	9.9	0.67605957	77.171742	-5.8710072	82nd
10.9	9	9.9	0.66123907	77.1731035	-5.87864142	83rd
10.9	9.1	9.9	0.63189843	77.175102	-5.89377523	85th
10.9	9.2	9.9	0.57661026	77.1781216	-5.92229715	86th
10.9	9.3	9.9	0.47688401	77.1828485	-5.97370575	88th
10.9	9.4	9.9	0.44934633	77.1904251	-6.06271045	89th
11	8.5	9.5	0.25639638	77.2617645	-5.66501485	100th
11	8.6	9.5	0.25615981	77.2618617	-5.66513382	101st
11	8.7	9.5	0.25552945	77.2620294	-5.66545386	102nd
11	8.8	9.5	0.25397915	77.2623014	-5.66624571	103rd
11	8.9	9.5	0.25042774	77.2627237	-5.66806645	106th
11	9	9.5	0.24278503	77.2633682	-5.67199332	107th
11	8.5	9.6	0.23977599	77.2531353	-5.6625449	110th
11	8.6	9.6	0.23953937	77.2532325	-5.66266388	111th
11	8.7	9.6	0.23890925	77.2534002	-5.66298392	112th

11	8.8	9.6	0.23735865	77.2536721	-5.66377577	113th
11	8.5	9.7	0.26150921	77.2923274	-5.67914598	90th
11	8.6	9.7	0.26127264	77.2924247	-5.67926496	91st
11	8.7	9.7	0.26064199	77.2925926	-5.67958499	94th
11	8.8	9.7	0.25909236	77.2928651	-5.68037684	96th
11	8.9	9.7	0.25554083	77.2932882	-5.68219758	98th
11	9	9.7	0.24789863	77.2939345	-5.68612445	104th
11	9.1	9.7	0.23232763	77.2949343	-5.69413454	108th
11	9.2	9.7	0.20208901	77.2965317	-5.70969642	114th
11	8.5	9.8	0.25352522	77.3190913	-5.7100767	92nd
11	8.6	9.8	0.25328864	77.3191886	-5.71019568	93rd
11	8.7	9.8	0.25265792	77.3193567	-5.71051572	95th
11	8.8	9.8	0.25110751	77.3196295	-5.71130757	97th
11	8.9	9.8	0.24755642	77.3200534	-5.7131283	99th
11	9	9.8	0.23991307	77.3207013	-5.71705518	105th
11	9.1	9.8	0.22434183	77.3217043	-5.72506526	109th
11	9.2	9.8	0.19410143	77.3233076	-5.74062714	115th
11	9.3	9.8	0.13782408	77.3259551	-5.76958136	117th
11	9.4	9.8	0.11849527	77.330402	-5.82137702	118th
11	9.5	9.8	-0.13703047	77.3378556	-5.91068903	120th
11	9.1	9.9	0.16344924	77.3241714	-5.7818077	116th
11	9.4	9.9	0.0575185	77.3328724	-5.87811947	119th
11	9.5	9.9	-0.19808306	77.3403291	-5.96743148	121st
11.1	8.5	9.5	-0.35913262	77.3442776	-5.67257836	129th
11.1	8.6	9.5	-0.35924013	77.3443165	-5.6726322	130th
11.1	8.7	9.5	-0.35953201	77.3443853	-5.67277981	131st
11.1	8.8	9.5	-0.36026574	77.3445003	-5.6731531	132nd
11.1	8.9	9.5	-0.36198876	77.3446856	-5.6740328	133rd

11.1	9	9.5	-0.36579833	77.3449817	-5.67598205	134th
11.1	9.1	9.5	-0.37378924	77.3454644	-5.6800756	135th
11.1	8.5	9.6	-0.40707459	77.3016047	-5.66295085	139th
11.1	8.6	9.6	-0.40718218	77.3016435	-5.6630047	140th
11.1	8.7	9.6	-0.40747418	77.3017122	-5.6631523	141st
11.1	8.8	9.6	-0.40820822	77.3018269	-5.66352559	142nd
11.1	8.9	9.6	-0.4099319	77.3020116	-5.66440529	143rd
11.1	9	9.6	-0.41374286	77.3023065	-5.66635454	144th
11.1	9.1	9.6	-0.4217366	77.3027867	-5.6704481	145th
11.1	8.5	9.7	-0.34890288	77.3714831	-5.68578276	122nd
11.1	8.6	9.7	-0.34901032	77.371522	-5.6858366	123rd
11.1	8.7	9.7	-0.34930196	77.3715909	-5.6859842	124th
11.1	8.8	9.7	-0.35003591	77.3717061	-5.6863575	125th
11.1	8.9	9.7	-0.35175891	77.3718917	-5.6872372	126th
11.1	9	9.7	-0.35556826	77.3721887	-5.68918644	127th
11.1	9.1	9.7	-0.36355836	77.3726729	-5.69328	128th
11.1	9.2	9.7	-0.37955876	77.3734902	-5.70148177	136th
11.1	9.3	9.7	-0.41029902	77.3749094	-5.71723913	137th
11.1	9.4	9.7	-0.423126	77.3774012	-5.74637009	138th
11.1	9.5	9.7	-0.56862854	77.3817436	-5.79830745	146th

Table 7 The set of non-inferior solutions for the case of the penalty cost parameters “+20%”.

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	8.5	9.6	1.16393262	76.1036497	-6.18231962	2nd
10.7	8.6	9.6	1.16195768	76.1048888	-6.18328998	3rd
10.7	8.7	9.6	1.15692436	76.1068647	-6.18581708	4th
10.7	8.8	9.6	1.14522597	76.1097871	-6.19176666	6th

10.7	8.9	9.6	1.12015146	76.1138334	-6.20461763	10th
10.7	8.5	9.7	1.24385581	76.2295073	-6.2083549	17th
10.7	8.6	9.7	1.24188319	76.23075	-6.20932527	16th
10.7	8.7	9.7	1.2368546	76.2327334	-6.21185237	15th
10.7	8.8	9.7	1.22516553	76.2356705	-6.21780194	11th
10.7	8.9	9.7	1.20010877	76.2397447	-6.23065291	8th
10.7	9	9.7	1.15007892	76.2451377	-6.25642126	1st
10.7	8.5	9.8	1.27191022	76.3443255	-6.27024758	25th
10.7	8.6	9.8	1.26993842	76.3455716	-6.27121795	24th
10.7	8.7	9.8	1.26491284	76.3475617	-6.27374505	22nd
10.7	8.8	9.8	1.25322771	76.3505122	-6.27969462	19th
10.7	8.9	9.8	1.22817246	76.3546119	-6.29254559	18th
10.7	9	9.8	1.17815806	76.3600518	-6.31831402	7th
10.7	8.5	9.9	1.19186848	76.413705	-6.39036966	14th
10.7	8.6	9.9	1.18989435	76.414953	-6.39134002	13th
10.7	8.7	9.9	1.1848572	76.4169473	-6.3938672	12th
10.7	8.8	9.9	1.17316282	76.4199059	-6.3998167	9th
10.7	8.9	9.9	1.14809654	76.424021	-6.41266767	5th
10.8	8.5	9.5	1.00677542	76.6189271	-5.90232854	47th
10.8	8.6	9.5	1.00576955	76.6194854	-5.90282526	48th
10.8	8.7	9.5	1.00316495	76.6203985	-5.90413648	49th
10.8	8.5	9.6	1.05058442	76.6790917	-5.90645324	39th
10.8	8.6	9.6	1.0495792	76.6796507	-5.90695005	40th
10.8	8.7	9.6	1.04697601	76.6805656	-5.90826126	41st
10.8	8.8	9.6	1.04080699	76.6819598	-5.91140412	42nd
10.8	8.9	9.6	1.02728614	76.6839624	-5.91834028	44th
10.8	8.5	9.7	1.09770813	76.7608024	-5.92845119	27th
10.8	8.6	9.7	1.09670356	76.7613626	-5.928948	28th

10.8	8.7	9.7	1.09410115	76.7622799	-5.93025913	29th
10.8	8.8	9.7	1.08793483	76.7636788	-5.93340207	31st
10.8	8.9	9.7	1.07441948	76.765691	-5.94033823	32nd
10.8	9	9.7	1.04675833	76.7684808	-5.95459073	36th
10.8	8.5	9.8	1.10206697	76.8316139	-5.97823696	20th
10.8	8.6	9.8	1.10106254	76.8321751	-5.97873369	21st
10.8	8.7	9.8	1.09846153	76.8330944	-5.9800449	23rd
10.8	8.8	9.8	1.09229352	76.8344976	-5.98318776	26th
10.8	8.9	9.8	1.07877598	76.836518	-5.99012392	30th
10.8	9	9.8	1.05111712	76.8393235	-6.00437645	33rd
10.8	9.1	9.8	0.9977865	76.8431947	-6.03191026	45th
10.8	8.5	9.9	1.02000138	76.8661283	-6.07429585	34th
10.8	8.6	9.9	1.01899582	76.86669	-6.07479258	35th
10.8	8.7	9.9	1.01639242	76.8676103	-6.07610379	37th
10.8	8.8	9.9	1.01021948	76.8690155	-6.07924673	38th
10.8	8.9	9.9	0.99669237	76.8710399	-6.08618289	43rd
10.8	9	9.9	0.96901534	76.8738531	-6.10043536	46th
10.8	9.1	9.9	0.91565114	76.8777385	-6.12796918	50th
10.8	9.2	9.9	0.81795899	76.8832316	-6.17839429	51st
10.9	8.5	9.5	0.71460642	77.0227945	-5.74416189	70th
10.9	8.6	9.5	0.71411308	77.0230364	-5.74440619	71st
10.9	8.7	9.5	0.71281408	77.0234426	-5.74506063	72nd
10.9	8.5	9.6	0.72728012	77.0471258	-5.74544499	64th
10.9	8.6	9.6	0.72678694	77.047368	-5.74568928	65th
10.9	8.7	9.6	0.72548798	77.0477744	-5.74634371	66th
10.9	8.8	9.6	0.72234753	77.0484123	-5.74794257	67th
10.9	8.9	9.6	0.71530608	77.0493628	-5.7515509	68th
10.9	9	9.6	0.70052331	77.0507405	-5.75915468	77th

10.9	8.5	9.7	0.7564351	77.1013337	-5.76362798	55th
10.9	8.6	9.7	0.7559421	77.1015761	-5.76387227	56th
10.9	8.7	9.7	0.75464353	77.1019833	-5.76452672	58th
10.9	8.8	9.7	0.75150394	77.1026229	-5.76612557	59th
10.9	8.9	9.7	0.74446421	77.1035765	-5.7697339	61st
10.9	9	9.7	0.72968484	77.1049605	-5.77733767	63rd
10.9	9.1	9.7	0.70038948	77.106976	-5.79243938	73rd
10.9	8.5	9.8	0.75027145	77.1441505	-5.80227597	52nd
10.9	8.6	9.8	0.74977841	77.1443932	-5.80252026	53rd
10.9	8.7	9.8	0.74847977	77.1448011	-5.8031747	54th
10.9	8.8	9.8	0.74534066	77.1454418	-5.80477356	57th
10.9	8.9	9.8	0.73829989	77.146398	-5.80838189	60th
10.9	9	9.8	0.7235198	77.147787	-5.81598566	62nd
10.9	9.1	9.8	0.69422308	77.149812	-5.83108736	69th
10.9	9.2	9.8	0.63898941	77.1528516	-5.85957896	81st
10.9	8.5	9.9	0.67674189	77.1581951	-5.87619789	74th
10.9	8.6	9.9	0.67624838	77.1584379	-5.87644219	75th
10.9	8.7	9.9	0.6749494	77.1588459	-5.87709663	76th
10.9	8.8	9.9	0.6718041	77.1594871	-5.87869548	78th
10.9	8.9	9.9	0.66476169	77.1604441	-5.8823038	79th
10.9	9	9.9	0.64997032	77.1618347	-5.88990759	80th
10.9	9.1	9.9	0.62065929	77.1638629	-5.90500929	82nd
10.9	9.2	9.9	0.56539689	77.1669082	-5.93350088	83rd
10.9	9.3	9.9	0.46568816	77.1716526	-5.98488383	84th
10.9	9.4	9.9	0.43815587	77.1792347	-6.07386915	85th
11	8.5	9.5	0.24359095	77.248959	-5.67782026	96th
11	8.6	9.5	0.24335787	77.2490597	-5.67793571	97th
11	8.7	9.5	0.24273314	77.2492331	-5.67825004	98th

11	8.8	9.5	0.24119103	77.2495133	-5.67903351	101st
11	8.9	9.5	0.23765033	77.2499463	-5.68084316	102nd
11	9	9.5	0.23002007	77.2506032	-5.68475684	103rd
11	8.5	9.6	0.22787123	77.2412305	-5.67444964	106th
11	8.6	9.6	0.2276381	77.2413312	-5.67456509	107th
11	8.7	9.6	0.22701362	77.2415045	-5.67487942	108th
11	8.8	9.6	0.22547123	77.2417846	-5.67566289	109th
11	8.9	9.6	0.22192981	77.2422174	-5.67747254	110th
11	8.5	9.7	0.25082157	77.2816398	-5.6898336	88th
11	8.6	9.7	0.2505885	77.2817406	-5.68994905	90th
11	8.7	9.7	0.24996349	77.2819141	-5.69026338	91st
11	8.8	9.7	0.24842209	77.2821948	-5.69104685	93rd
11	8.9	9.7	0.24488133	77.2826287	-5.6928565	95th
11	9	9.7	0.2372517	77.2832876	-5.69677018	100th
11	9.1	9.7	0.22169356	77.2843003	-5.70476617	105th
11	8.5	9.8	0.24434795	77.309914	-5.71925395	86th
11	8.6	9.8	0.24411486	77.3100149	-5.71936941	87th
11	8.7	9.8	0.2434898	77.3101886	-5.71968374	89th
11	8.8	9.8	0.24194764	77.3104696	-5.72046721	92nd
11	8.9	9.8	0.23840737	77.3109044	-5.72227686	94th
11	9	9.8	0.23077668	77.311565	-5.72619054	99th
11	9.1	9.8	0.21521847	77.3125809	-5.73418653	104th
11	9.2	9.8	0.18498954	77.3141957	-5.74973492	115th
11	9.3	9.8	0.12872002	77.316851	-5.77867759	119th
11	9.4	9.8	0.1093934	77.3213001	-5.83046444	120th
11	9.5	9.8	-0.14613772	77.3287483	-5.91977044	122nd
11	8.5	9.9	0.18517888	77.3140915	-5.77428539	111th
11	8.7	9.9	0.18432087	77.3143662	-5.77471517	112th

11	8.8	9.9	0.18277992	77.3146473	-5.77549863	113th
11	8.9	9.9	0.17923388	77.3150822	-5.77730829	114th
11	9	9.9	0.17160509	77.315743	-5.78122197	116th
11	9.1	9.9	0.15603728	77.3167594	-5.78921795	117th
11	9.2	9.9	0.12579453	77.3183751	-5.80476635	118th
11	9.4	9.9	0.05013037	77.3254843	-5.88549587	121st
11	9.5	9.9	-0.20547443	77.3329377	-5.97480187	123rd
11.1	8.5	9.5	-0.36703969	77.3363705	-5.68048543	131st
11.1	8.6	9.5	-0.36714583	77.3364108	-5.68053788	132nd
11.1	8.7	9.5	-0.36743545	77.3364819	-5.68068321	133rd
11.1	8.8	9.5	-0.36816584	77.3366002	-5.68105311	134th
11.1	8.9	9.5	-0.36988441	77.3367899	-5.68192825	135th
11.1	9	9.5	-0.37368871	77.3370913	-5.683872	136th
11.1	9.1	9.5	-0.38167413	77.3375795	-5.68795961	138th
11.1	8.5	9.6	-0.41446318	77.2942161	-5.67033943	141st
11.1	8.6	9.6	-0.41456938	77.2942563	-5.67039189	142nd
11.1	8.7	9.6	-0.41485913	77.2943273	-5.67053721	143rd
11.1	8.8	9.6	-0.41558982	77.2944453	-5.67090711	144th
11.1	8.9	9.6	-0.41730904	77.2946345	-5.67178225	145th
11.1	9	9.6	-0.42111473	77.2949347	-5.673726	146th
11.1	9.1	9.6	-0.42910295	77.2954203	-5.67781361	147th
11.1	8.5	9.7	-0.35557655	77.3648094	-5.69245642	124th
11.1	8.6	9.7	-0.35568262	77.3648497	-5.69250888	125th
11.1	8.7	9.7	-0.35597199	77.3649209	-5.6926542	126th
11.1	8.8	9.7	-0.35670259	77.3650394	-5.6930241	127h
11.1	8.9	9.7	-0.35842113	77.3652295	-5.69389924	128th
11.1	9	9.7	-0.36222517	77.3655317	-5.69584299	129th
11.1	9.1	9.7	-0.37020971	77.3660216	-5.6999306	130th

11.1	9.2	9.7	-0.38620512	77.3668438	-5.70812661	137th
11.1	9.3	9.7	-0.41694187	77.3682666	-5.72387898	139th
11.1	9.4	9.7	-0.4297677	77.3707595	-5.75300608	140th
11.1	9.5	9.7	-0.57527242	77.3750997	-5.80494078	148th

Table 8 The set of non-inferior solutions for the case of the penalty cost parameters "+25%".

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	8.5	9.6	1.1238035	76.063521	-6.222448	2nd
10.7	8.6	9.6	1.1218735	76.064805	-6.223372	3rd
10.7	8.7	9.6	1.1169088	76.066849	-6.225828	4th
10.7	8.8	9.6	1.1053051	76.069866	-6.231678	7th
10.7	8.5	9.7	1.2085136	76.194165	-6.243696	15th
10.7	8.6	9.7	1.206586	76.195453	-6.244621	13th
10.7	8.7	9.7	1.2016263	76.197505	-6.247077	11th
10.7	8.8	9.7	1.1900325	76.200537	-6.252927	9th
10.7	8.9	9.7	1.1650939	76.20473	-6.265652	5th
10.7	9	9.7	1.1151936	76.210252	-6.291277	1st
10.7	8.5	9.8	1.2421723	76.314588	-6.299985	26th
10.7	8.6	9.8	1.2402456	76.315879	-6.300909	24th
10.7	8.7	9.8	1.2352893	76.317938	-6.303365	23rd
10.7	8.8	9.8	1.2237001	76.320985	-6.309215	21st
10.7	8.9	9.8	1.1987642	76.325204	-6.321941	17th
10.7	9	9.8	1.1488817	76.330775	-6.347565	8th
10.7	8.5	9.9	1.1681494	76.389986	-6.414088	16th
10.7	8.6	9.9	1.1662207	76.391279	-6.415012	14th
10.7	8.7	9.9	1.1612531	76.393343	-6.417469	12th
10.7	8.8	9.9	1.1496554	76.396398	-6.423319	10th

10.7	8.9	9.9	1.1247098	76.400634	-6.436044	6th
10.8	8.5	9.5	0.9766251	76.588777	-5.932479	46th
10.8	8.6	9.5	0.9756391	76.589355	-5.932955	47th
10.8	8.5	9.6	1.022864	76.651371	-5.934173	38th
10.8	8.6	9.6	1.0218787	76.65195	-5.93465	39th
10.8	8.7	9.6	1.0193066	76.652896	-5.935929	41st
10.8	8.8	9.6	1.0131813	76.654334	-5.939027	42nd
10.8	8.9	9.6	0.9997155	76.656392	-5.945905	44th
10.8	8.5	9.7	1.0731368	76.736231	-5.953022	25th
10.8	8.6	9.7	1.0721522	76.736811	-5.953499	27th
10.8	8.7	9.7	1.0695809	76.73776	-5.954778	29th
10.8	8.8	9.7	1.0634585	76.739202	-5.957876	30th
10.8	8.9	9.7	1.0499985	76.74127	-5.964754	31st
10.8	9	9.7	1.0223995	76.744122	-5.978939	36th
10.8	8.5	9.8	1.0812564	76.810803	-5.999047	18th
10.8	8.6	9.8	1.080272	76.811385	-5.999524	19th
10.8	8.7	9.8	1.0777023	76.812335	-6.000803	20th
10.8	8.8	9.8	1.0715783	76.813782	-6.003901	22nd
10.8	8.9	9.8	1.0581167	76.815859	-6.010779	28th
10.8	9	9.8	1.0305207	76.818727	-6.024964	32nd
10.8	9.1	9.8	0.977252	76.82266	-6.052427	43rd
10.8	8.5	9.9	1.0033041	76.849431	-6.090993	33rd
10.8	8.6	9.9	1.0023187	76.850013	-6.091469	34th
10.8	8.7	9.9	0.9997466	76.850965	-6.092749	35th
10.8	8.8	9.9	0.993618	76.852414	-6.095846	37th
10.8	8.9	9.9	0.9801472	76.854495	-6.102724	40th
10.8	9	9.9	0.9525341	76.857372	-6.116909	45th
10.8	9.1	9.9	0.8992334	76.861321	-6.144373	48th

10.8	9.2	9.9	0.801595	76.866868	-6.194732	49th
10.9	8.5	9.6	0.7087862	77.028632	-5.763939	62nd
10.9	8.6	9.6	0.7083015	77.028883	-5.764174	63rd
10.9	8.7	9.6	0.7070161	77.029303	-5.764815	64th
10.9	8.8	9.6	0.703895	77.02996	-5.766394	65th
10.9	8.9	9.6	0.6968783	77.030935	-5.769977	67th
10.9	9	9.6	0.6821239	77.032341	-5.77755	73rd
10.9	8.5	9.7	0.7399363	77.084835	-5.780127	54th
10.9	8.6	9.7	0.7394518	77.085086	-5.780362	55th
10.9	8.7	9.7	0.7381668	77.085507	-5.781003	56th
10.9	8.8	9.7	0.7350466	77.086165	-5.782582	57th
10.9	8.9	9.7	0.7280318	77.087144	-5.786164	59th
10.9	9	9.7	0.7132809	77.088557	-5.793738	61st
10.9	9.1	9.7	0.6840141	77.090601	-5.808807	68th
10.9	8.5	9.8	0.736202	77.130081	-5.816345	50th
10.9	8.6	9.8	0.7357175	77.130332	-5.816581	51st
10.9	8.7	9.8	0.7344324	77.130754	-5.817222	52nd
10.9	8.8	9.8	0.7313127	77.131414	-5.818801	53rd
10.9	8.9	9.8	0.724297	77.132395	-5.822383	58th
10.9	9	9.8	0.7095458	77.133813	-5.829956	60th
10.9	9.1	9.8	0.6802781	77.135867	-5.845026	66th
10.9	9.2	9.8	0.625069	77.138931	-5.873487	76th
10.9	8.5	9.9	0.6653771	77.14683	-5.887563	69th
10.9	8.6	9.9	0.6648921	77.147082	-5.887798	70th
10.9	8.7	9.9	0.6636067	77.147503	-5.888439	71st
10.9	8.8	9.9	0.660481	77.148164	-5.890018	72nd
10.9	8.9	9.9	0.6534638	77.149146	-5.8936	74th
10.9	9	9.9	0.6387016	77.150566	-5.901174	75th

10.9	9.1	9.9	0.6094202	77.152624	-5.916243	77th
10.9	9.2	9.9	0.5541835	77.155695	-5.944705	78th
10.9	9.3	9.9	0.4544923	77.160457	-5.996062	79th
10.9	9.4	9.9	0.4269654	77.168044	-6.085028	80th
11	8.5	9.5	0.2307855	77.236154	-5.690626	93rd
11	8.6	9.5	0.2305559	77.236258	-5.690738	94th
11	8.7	9.5	0.2299368	77.236437	-5.691046	95th
11	8.8	9.5	0.2284029	77.236725	-5.691821	96th
11	8.9	9.5	0.2248729	77.237169	-5.69362	97th
11	9	9.5	0.2172551	77.237838	-5.69752	98th
11	8.5	9.6	0.2159665	77.229326	-5.686354	101st
11	8.6	9.6	0.2157368	77.22943	-5.686466	102nd
11	8.7	9.6	0.215118	77.229609	-5.686775	103rd
11	8.8	9.6	0.2135838	77.229897	-5.68755	104th
11	8.9	9.6	0.2100531	77.230341	-5.689349	105th
11	8.5	9.7	0.2401339	77.270952	-5.700521	84th
11	8.6	9.7	0.2399044	77.271056	-5.700633	85th
11	8.7	9.7	0.239285	77.271236	-5.700942	87th
11	8.8	9.7	0.2377518	77.271525	-5.701717	88th
11	8.9	9.7	0.2342218	77.271969	-5.703515	90th
11	9	9.7	0.2266048	77.272641	-5.707416	92nd
11	9.1	9.7	0.2110595	77.273666	-5.715398	100th
11	8.5	9.8	0.2351707	77.300737	-5.728431	81st
11	8.6	9.8	0.2349411	77.300841	-5.728543	82nd
11	8.7	9.8	0.2343217	77.30102	-5.728852	83rd
11	8.8	9.8	0.2327878	77.30131	-5.729627	86th
11	8.9	9.8	0.2292583	77.301755	-5.731425	89th
11	9	9.8	0.2216403	77.302429	-5.735326	91st

11	9.1	9.8	0.2060951	77.303458	-5.743308	99th
11	9.2	9.8	0.1758776	77.305084	-5.758843	111th
11	9.3	9.8	0.1196159	77.307747	-5.787774	115th
11	9.4	9.8	0.1002915	77.312198	-5.839552	116th
11	9.5	9.8	-0.155245	77.319641	-5.928852	119th
11	8.5	9.9	0.1777126	77.306625	-5.781752	106th
11	8.6	9.9	0.1774829	77.30673	-5.781864	107th
11	8.7	9.9	0.1768638	77.306909	-5.782172	108th
11	8.8	9.9	0.1753311	77.307198	-5.782947	109th
11	8.9	9.9	0.1717959	77.307644	-5.784746	110th
11	9	9.9	0.1641799	77.308318	-5.788646	112th
11	9.1	9.9	0.1486253	77.309347	-5.796628	113th
11	9.2	9.9	0.1183944	77.310975	-5.812163	114th
11	9.3	9.9	0.0621085	77.313641	-5.841094	117th
11	9.4	9.9	0.0427422	77.318096	-5.892872	118th
11	9.5	9.9	-0.212866	77.325546	-5.982172	120th
11.1	8.5	9.5	-0.374947	77.328463	-5.688393	128th
11.1	8.6	9.5	-0.375052	77.328505	-5.688444	129th
11.1	8.7	9.5	-0.375339	77.328578	-5.688587	130th
11.1	8.8	9.5	-0.376066	77.3287	-5.688953	131st
11.1	8.9	9.5	-0.37778	77.328894	-5.689824	132nd
11.1	9	9.5	-0.381579	77.329201	-5.691762	133rd
11.1	9.1	9.5	-0.389559	77.329695	-5.695844	135th
11.1	8.5	9.6	-0.421852	77.286828	-5.677728	138th
11.1	8.6	9.6	-0.421957	77.286869	-5.677779	139th
11.1	8.7	9.6	-0.422244	77.286942	-5.677922	140th
11.1	8.8	9.6	-0.422971	77.287064	-5.678289	141st
11.1	8.9	9.6	-0.424686	77.287257	-5.679159	142nd

11.1	9	9.6	-0.428487	77.287563	-5.681097	143rd
11.1	9.1	9.6	-0.436469	77.288054	-5.685179	144th
11.1	8.5	9.7	-0.36225	77.358136	-5.69913	121st
11.1	8.6	9.7	-0.362355	77.358177	-5.699181	122nd
11.1	8.7	9.7	-0.362642	77.358251	-5.699324	123rd
11.1	8.8	9.7	-0.363369	77.358373	-5.699691	124th
11.1	8.9	9.7	-0.365083	77.358567	-5.700561	125th
11.1	9	9.7	-0.368882	77.358875	-5.7025	126th
11.1	9.1	9.7	-0.376861	77.35937	-5.706581	127th
11.1	9.2	9.7	-0.392851	77.360197	-5.714771	134th
11.1	9.3	9.7	-0.423585	77.361624	-5.730519	136th
11.1	9.4	9.7	-0.436409	77.364118	-5.759642	137th
11.1	9.5	9.7	-0.581916	77.368456	-5.811574	145th

Table 9 The set of non-inferior solutions for the case of the penalty cost parameters "+50%".

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	8.5	9.7	1.031802332	76.01745385	-6.4204031	9th
10.7	8.6	9.7	1.030099902	76.01896673	-6.42109713	7th
10.7	8.7	9.7	1.025484648	76.02136346	-6.42319842	4th
10.7	8.8	9.7	1.014367248	76.02487219	-6.42855181	2nd
10.7	8.9	9.7	0.990019301	76.02965524	-6.4406475	1st
10.7	8.5	9.8	1.093482413	76.16589772	-6.44867095	32nd
10.7	8.6	9.8	1.091781774	76.16741491	-6.44936498	31st
10.7	8.7	9.8	1.087171519	76.16982042	-6.45146627	30th
10.7	8.8	9.8	1.076061987	76.17334646	-6.45681966	28th
10.7	8.9	9.8	1.051723014	76.17816248	-6.46891535	16th
10.7	9	9.8	1.002499995	76.18439371	-6.49382096	3rd

10.7	8.5	9.9	1.049554307	76.27139083	-6.53268029	25th
10.7	8.6	9.9	1.047852392	76.27291109	-6.53337432	23rd
10.7	8.7	9.9	1.043232687	76.27532274	-6.5354757	18th
10.7	8.8	9.9	1.032118133	76.27886118	-6.540829	13th
10.7	8.9	9.9	1.007776154	76.28370064	-6.55292468	11th
10.8	8.5	9.6	0.884261988	76.51276925	-6.07277382	36th
10.8	8.6	9.6	0.883376406	76.51344792	-6.07314871	37th
10.8	8.7	9.6	0.880959525	76.51454912	-6.0742688	38th
10.8	8.5	9.7	0.950280055	76.61337433	-6.07587763	14th
10.8	8.6	9.7	0.949395383	76.61405438	-6.07625251	15th
10.8	8.7	9.7	0.946979845	76.6151586	-6.0773725	17th
10.8	8.8	9.7	0.94107671	76.61682071	-6.08024359	19th
10.8	8.9	9.7	0.927893851	76.61916536	-6.08683021	27th
10.8	9	9.7	0.900605239	76.62232769	-6.10067781	33rd
10.8	8.5	9.8	0.977203621	76.70675051	-6.10309892	5th
10.8	8.6	9.8	0.976319421	76.70743195	-6.10347371	6th
10.8	8.7	9.8	0.973905913	76.70853878	-6.1045938	8th
10.8	8.8	9.8	0.968002447	76.71020652	-6.10746478	10th
10.8	8.9	9.8	0.954820028	76.71256206	-6.1140514	12th
10.8	9	9.8	0.927538715	76.71574509	-6.12789904	22nd
10.8	9.1	9.8	0.874579381	76.71998757	-6.15501139	35th
10.8	8.5	9.9	0.919817817	76.76594475	-6.1744783	20th
10.8	8.6	9.9	0.918932826	76.766627	-6.17485308	21st
10.8	8.7	9.9	0.916517652	76.76773555	-6.17597317	24th
10.8	8.8	9.9	0.910610689	76.7694067	-6.17884426	26th
10.8	8.9	9.9	0.897421578	76.77176913	-6.18543088	29th
10.8	9	9.9	0.870127599	76.7749654	-6.19927844	34th
10.8	9.1	9.9	0.817144772	76.77923209	-6.22639079	39th

10.8	9.2	9.9	0.719774847	76.78504742	-6.27642256	40th
10.9	8.5	9.6	0.61631663	76.93616234	-5.85640795	59th
10.9	8.6	9.6	0.615874526	76.93645554	-5.85660046	60th
10.9	8.7	9.6	0.614656555	76.936943	-5.85717238	61st
10.9	8.8	9.6	0.611632103	76.93769692	-5.85865203	62nd
10.9	8.9	9.6	0.604739623	76.93879632	-5.86210485	63rd
10.9	8.5	9.7	0.657442205	77.00234078	-5.8626204	46th
10.9	8.6	9.7	0.657000361	77.0026344	-5.86281292	47th
10.9	8.7	9.7	0.655782946	77.00312276	-5.86338484	48th
10.9	8.8	9.7	0.652759698	77.00387861	-5.86486448	49th
10.9	8.9	9.7	0.645869652	77.00498193	-5.8683173	51st
10.9	9	9.7	0.631261462	77.00653712	-5.87573845	52nd
10.9	8.5	9.8	0.665854474	77.05973354	-5.88669254	41st
10.9	8.6	9.8	0.665412683	77.06002752	-5.88688506	42nd
10.9	8.7	9.8	0.664195394	77.06051668	-5.88745697	43rd
10.9	8.8	9.8	0.661173055	77.06127419	-5.88893662	44th
10.9	8.9	9.8	0.654282832	77.0623809	-5.89238944	45th
10.9	9	9.8	0.639675623	77.06394278	-5.89981059	50th
10.9	9.1	9.8	0.610552968	77.06614191	-5.91471969	56th
10.9	9.2	9.8	0.55546725	77.06932944	-5.94302926	66th
10.9	8.5	9.9	0.608552936	77.09000617	-5.94438651	53rd
10.9	8.6	9.9	0.608110773	77.09030033	-5.94457904	54th
10.9	8.7	9.9	0.60689337	77.09078991	-5.94515096	55th
10.9	8.8	9.9	0.603865317	77.0915483	-5.94663061	57th
10.9	8.9	9.9	0.596974414	77.09265681	-5.95008342	58th
10.9	9	9.9	0.582357812	77.09422221	-5.95750457	64th
10.9	9.1	9.9	0.553224454	77.09642807	-5.97241367	65th
10.9	9.2	9.9	0.498116648	77.099628	-6.00072324	67th

10.9	9.3	9.9	0.398513051	77.10447751	-6.05195229	68th
10.9	9.4	9.9	0.371013054	77.11209185	-6.14082137	69th
11	8.5	9.6	0.156442683	77.16980199	-5.74587804	84th
11	8.6	9.6	0.156230502	77.16992361	-5.74597235	85th
11	8.7	9.6	0.155639838	77.17013074	-5.74625241	87th
11	8.8	9.6	0.154146724	77.17046013	-5.74698562	90th
11	8.9	9.6	0.150669744	77.17095732	-5.74872876	92nd
11	9	9.6	0.143113716	77.17168879	-5.75256327	94th
11	8.5	9.7	0.186695729	77.21751395	-5.7539593	75th
11	8.6	9.7	0.186483633	77.2176357	-5.75405361	76th
11	8.7	9.7	0.185892484	77.21784314	-5.75433367	77th
11	8.8	9.7	0.184400462	77.21817318	-5.75506688	78th
11	8.9	9.7	0.18092436	77.21867175	-5.75681002	80th
11	9	9.7	0.173370122	77.21940604	-5.76064453	81st
11	9.1	9.7	0.157889135	77.22049585	-5.76855595	83rd
11	8.5	9.8	0.189284314	77.25485035	-5.77431747	70th
11	8.6	9.8	0.189072225	77.25497221	-5.77441178	71st
11	8.7	9.8	0.188481083	77.25517987	-5.77469185	72nd
11	8.8	9.8	0.186988422	77.25551043	-5.77542506	73rd
11	8.9	9.8	0.18351307	77.25601009	-5.7771682	74th
11	9	9.8	0.17595831	77.25674659	-5.78100271	79th
11	9.1	9.8	0.16047831	77.25784075	-5.78891412	82nd
11	9.2	9.8	0.130318186	77.25952433	-5.80438158	96th
11	8.5	9.9	0.140381337	77.269294	-5.81908283	86th
11	8.6	9.9	0.140169111	77.2694159	-5.81917714	88th
11	8.7	9.9	0.139578345	77.26962366	-5.8194572	89th
11	8.8	9.9	0.138087036	77.26995442	-5.8201904	91st
11	8.9	9.9	0.134606214	77.2704545	-5.82193355	93rd

11	9	9.9	0.127053961	77.27119185	-5.82576806	95th
11	9.1	9.9	0.111565559	77.2722877	-5.83367946	97th
11	9.2	9.9	0.081393892	77.27397448	-5.84914693	98th
11	9.3	9.9	0.025150632	77.27668269	-5.87802036	99th
11	9.4	9.9	0.00580158	77.2811555	-5.92975428	100th
11	9.5	9.9	-0.24982266	77.28858953	-6.0190242	101st
11.1	8.5	9.5	-0.41448215	77.28892808	-5.72792785	109th
11.1	8.6	9.5	-0.41458004	77.28897659	-5.72797199	110th
11.1	8.7	9.5	-0.4148561	77.2890612	-5.72810364	111th
11.1	8.8	9.5	-0.41556642	77.28919963	-5.72845316	112th
11.1	8.9	9.5	-0.41725829	77.28941605	-5.72930096	113th
11.1	9	9.5	-0.42103099	77.28974907	-5.73121172	114th
11.1	8.5	9.6	-0.4587947	77.24988459	-5.71467091	124th
11.1	8.6	9.6	-0.45889264	77.24993304	-5.71471506	125th
11.1	8.7	9.6	-0.45916883	77.25001756	-5.7148467	126th
11.1	8.8	9.6	-0.45987943	77.25015573	-5.71519622	127th
11.1	8.9	9.6	-0.46157191	77.25037162	-5.71604402	128th
11.1	9	9.6	-0.46534589	77.2507035	-5.71795479	129th
11.1	9.1	9.6	-0.47330104	77.25122225	-5.72200671	131st
11.1	8.5	9.7	-0.39561857	77.32476741	-5.73249841	102nd
11.1	8.6	9.7	-0.39571637	77.32481596	-5.73254256	103rd
11.1	8.7	9.7	-0.39599218	77.32490068	-5.73267419	104th
11.1	8.8	9.7	-0.39670265	77.32503932	-5.73302372	105th
11.1	8.9	9.7	-0.3983944	77.32525625	-5.73387152	106th
11.1	9	9.7	-0.40216661	77.3255903	-5.73578228	107th
11.1	9.1	9.7	-0.41011782	77.32611348	-5.7398342	108th
11.1	9.2	9.7	-0.42608331	77.32696565	-5.74799564	115th
11.1	9.3	9.7	-0.45679896	77.32840949	-5.76371807	120th

11.1	8.5	9.9	-0.45668787	77.33155679	-5.77582151	116th
11.1	8.6	9.9	-0.45678575	77.33160535	-5.77586566	117th
11.1	8.7	9.9	-0.45706239	77.33169009	-5.7759973	118th
11.1	8.8	9.9	-0.45777258	77.33182877	-5.77634682	119th
11.1	8.9	9.9	-0.45946517	77.33204579	-5.77719462	121st
11.1	9	9.9	-0.46323916	77.33238004	-5.77910539	122nd
11.1	9.1	9.9	-0.47119398	77.33290362	-5.78315731	123rd
11.1	9.2	9.9	-0.48716727	77.33375658	-5.79131875	130th
11.1	9.3	9.9	-0.51789581	77.33520194	-5.80704118	132nd
11.1	9.4	9.9	-0.53074045	77.33770445	-5.83614514	133th
11.1	9.5	9.9	-0.67630273	77.3420366	-5.88806388	134th

Table 10 The set of non-inferior solutions for the case of the penalty cost parameters “-10%”.

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.6	8.5	9.7	1.4645917	75.777198	-6.332447	31st
10.6	8.6	9.7	1.4602709	75.77926	-6.334869	30th
10.6	8.5	9.8	1.4855514	75.907165	-6.45436	34th
10.6	8.6	9.8	1.4812318	75.909233	-6.456782	33rd
10.6	8.7	9.8	1.4709815	75.912486	-6.462379	32nd
10.7	8.5	9.5	1.3432905	76.26094	-5.913527	23rd
10.7	8.6	9.5	1.3410445	76.261907	-5.914773	24th
10.7	8.7	9.5	1.3355959	76.263467	-5.917726	26th
10.7	8.8	9.5	1.323322	76.265811	-5.924272	28th
10.7	8.9	9.5	1.2975314	76.269136	-5.937878	29th
10.7	8.5	9.6	1.4047072	76.344424	-5.941551	5th
10.7	8.6	9.6	1.4024629	76.345394	-5.942798	6th
10.7	8.7	9.6	1.397018	76.346958	-5.945751	9th

10.7	8.8	9.6	1.3847513	76.349312	-5.952296	11th
10.7	8.9	9.6	1.3589743	76.352656	-5.965903	16th
10.7	9	9.6	1.3081459	76.357232	-5.992534	27th
10.7	8.5	9.7	1.4559093	76.441561	-5.996307	18th
10.7	8.6	9.7	1.4536665	76.442533	-5.997553	17th
10.7	8.7	9.7	1.4482246	76.444103	-6.000506	15th
10.7	8.8	9.7	1.4359638	76.446469	-6.007052	14th
10.7	8.9	9.7	1.4101982	76.449834	-6.020658	8th
10.7	9	9.7	1.3593907	76.454449	-6.04729	10th
10.7	8.5	9.8	1.450338	76.522753	-6.091824	22nd
10.7	8.6	9.8	1.4480951	76.523728	-6.093071	21st
10.7	8.7	9.8	1.4426542	76.525303	-6.096024	20th
10.7	8.8	9.8	1.4303934	76.527678	-6.10257	19th
10.7	8.9	9.8	1.4046219	76.531061	-6.116176	13th
10.7	9	9.8	1.3538161	76.53571	-6.142807	4th
10.7	9.1	9.8	1.2591734	76.542041	-6.192147	25th
10.7	8.5	9.9	1.3341826	76.556019	-6.248059	3rd
10.7	8.6	9.9	1.3319363	76.556995	-6.249306	1st
10.7	8.7	9.9	1.3264817	76.558572	-6.252259	2nd
10.7	8.8	9.9	1.3142075	76.560951	-6.258804	7th
10.7	8.9	9.9	1.2884169	76.564341	-6.272411	12th
10.8	8.5	9.5	1.1876776	76.799829	-5.721428	53rd
10.8	8.6	9.5	1.1865523	76.800268	-5.722047	55th
10.8	8.7	9.5	1.1837618	76.800995	-5.723549	56th
10.8	8.8	9.5	1.1773288	76.802125	-5.726964	58th
10.8	8.9	9.5	1.1634743	76.803792	-5.73425	63rd
10.8	8.5	9.6	1.2169069	76.845414	-5.740133	45th
10.8	8.6	9.6	1.215782	76.845854	-5.740751	46th

10.8	8.7	9.6	1.2129925	76.846582	-5.742254	48th
10.8	8.8	9.6	1.2065614	76.847714	-5.745668	50th
10.8	8.9	9.6	1.1927103	76.849387	-5.752954	51st
10.8	9	9.6	1.1646703	76.85179	-5.767612	59th
10.8	8.5	9.7	1.2451362	76.90823	-5.781025	37th
10.8	8.6	9.7	1.2440117	76.908671	-5.781643	38th
10.8	8.7	9.7	1.2412225	76.909401	-5.783146	40th
10.8	8.8	9.7	1.234793	76.910537	-5.786561	42st
10.8	8.9	9.7	1.2209451	76.912217	-5.793846	44th
10.8	9	9.7	1.1929114	76.914634	-5.808504	49th
10.8	9.1	9.7	1.1392176	76.918114	-5.836459	61st
10.8	8.5	9.8	1.2269303	76.956477	-5.853375	35th
10.8	8.6	9.8	1.2258057	76.956918	-5.853994	36th
10.8	8.7	9.8	1.2230171	76.95765	-5.855496	39th
10.8	8.8	9.8	1.2165846	76.958789	-5.858911	41st
10.8	8.9	9.8	1.2027319	76.960474	-5.866196	43rd
10.8	9	9.8	1.1746955	76.962902	-5.880854	47th
10.8	9.1	9.8	1.1209936	76.966402	-5.908809	60th
10.8	9.2	9.8	1.0230571	76.971566	-5.959628	66th
10.8	8.6	9.9	1.1190588	76.966753	-5.974732	52nd
10.8	8.7	9.9	1.1162672	76.967485	-5.976234	54th
10.8	8.8	9.9	1.1098283	76.968624	-5.979649	57th
10.8	8.9	9.9	1.0959632	76.970311	-5.986935	62nd
10.8	9	9.9	1.0679031	76.972741	-6.001592	64th
10.8	9.1	9.9	1.0141575	76.976245	-6.029548	65th
10.8	9.2	9.9	0.9161431	76.981416	-6.080366	67th
10.9	8.5	9.5	0.8346132	77.142801	-5.624156	84th
10.9	8.6	9.5	0.8340688	77.142992	-5.624452	85th

10.9	8.7	9.5	0.8326889	77.143317	-5.625189	86th
10.9	8.8	9.5	0.8294327	77.143839	-5.626907	88th
10.9	8.9	9.5	0.8222418	77.144639	-5.630671	89th
10.9	8.5	9.6	0.8382436	77.158089	-5.634482	79th
10.9	8.6	9.6	0.8376994	77.15828	-5.634778	80th
10.9	8.7	9.6	0.8363194	77.158606	-5.635515	81st
10.9	8.8	9.6	0.833063	77.159128	-5.637233	83rd
10.9	8.9	9.6	0.8258725	77.159929	-5.640997	87th
10.9	9	9.6	0.81092	77.161137	-5.648783	91st
10.9	9.1	9.6	0.78145	77.162972	-5.664078	93rd
10.9	8.5	9.7	0.855428	77.200327	-5.664636	68th
10.9	8.6	9.7	0.8548838	77.200518	-5.664932	69th
10.9	8.7	9.7	0.8535041	77.200844	-5.665669	70th
10.9	8.8	9.7	0.8502482	77.201367	-5.667387	71st
10.9	8.9	9.7	0.8430588	77.202171	-5.67115	76th
10.9	9	9.7	0.8281082	77.203384	-5.678937	78th
10.9	9.1	9.7	0.798642	77.205229	-5.694231	90th
10.9	8.5	9.8	0.8346884	77.228567	-5.717859	72nd
10.9	8.6	9.8	0.8341441	77.228759	-5.718155	73rd
10.9	8.7	9.8	0.8327641	77.229085	-5.718892	74th
10.9	8.8	9.8	0.8295083	77.229609	-5.72061	75th
10.9	8.9	9.8	0.8223169	77.230415	-5.724374	77th
10.9	9	9.8	0.807364	77.231631	-5.732161	82nd
10.9	9.1	9.8	0.7778932	77.233482	-5.747455	92nd
10.9	9.2	9.8	0.7225116	77.236374	-5.776129	94th
10.9	9.3	9.8	0.6227652	77.241015	-5.827665	95th
10.9	9.4	9.8	0.5953127	77.248567	-5.916767	96th
11	8.5	9.5	0.3204236	77.325792	-5.600988	100th

11	8.6	9.5	0.3201695	77.325871	-5.601124	101st
11	8.7	9.5	0.319511	77.326011	-5.601473	103rd
11	8.8	9.5	0.3179197	77.326242	-5.602307	104th
11	8.9	9.5	0.3143147	77.326611	-5.604183	109th
11	9	9.5	0.3066098	77.327193	-5.608176	113th
11	9.1	9.5	0.2909753	77.328126	-5.616256	116th
11	8.5	9.7	0.3149474	77.345766	-5.625708	97th
11	8.6	9.7	0.3146934	77.345845	-5.625844	98th
11	8.7	9.7	0.3140345	77.345985	-5.626193	99th
11	8.8	9.7	0.3124437	77.346216	-5.627027	102nd
11	8.9	9.7	0.3088383	77.346586	-5.628903	107th
11	9	9.7	0.3011333	77.347169	-5.632896	112th
11	9.1	9.7	0.285498	77.348105	-5.640976	115th
11	9.2	9.7	0.2552037	77.349646	-5.656606	118th
11	8.5	9.8	0.2994116	77.364978	-5.66419	105th
11	8.6	9.8	0.2991575	77.365057	-5.664327	106th
11	8.7	9.8	0.2984985	77.365197	-5.664676	108th
11	8.8	9.8	0.2969069	77.365429	-5.665509	110th
11	8.9	9.8	0.2933017	77.365799	-5.667386	111th
11	9	9.8	0.285595	77.366383	-5.671378	114th
11	9.1	9.8	0.2699586	77.367321	-5.679459	117th
11	9.2	9.8	0.2396609	77.368867	-5.695088	119th
11	9.3	9.8	0.1833444	77.371475	-5.7241	120th
11	9.4	9.8	0.1640046	77.375911	-5.77594	121st
11	9.5	9.8	-0.091494	77.383392	-5.865282	122nd
11.1	8.5	9.5	-0.319597	77.383813	-5.633043	129th
11.1	8.6	9.5	-0.319712	77.383845	-5.633104	130th
11.1	8.7	9.5	-0.320015	77.383903	-5.633263	131st

11.1	8.8	9.5	-0.320765	77.384001	-5.633653	132nd
11.1	8.9	9.5	-0.322511	77.384164	-5.634556	133rd
11.1	9	9.5	-0.326346	77.384434	-5.636532	135th
11.1	9.1	9.5	-0.334365	77.384889	-5.640656	136th
11.1	9.2	9.5	-0.350391	77.385679	-5.648886	138th
11.1	8.5	9.7	-0.315535	77.404851	-5.652414	123rd
11.1	8.6	9.7	-0.315649	77.404883	-5.652475	124th
11.1	8.7	9.7	-0.315952	77.404941	-5.652634	125th
11.1	8.8	9.7	-0.316703	77.405039	-5.653024	126th
11.1	8.9	9.7	-0.318448	77.405203	-5.653927	127th
11.1	9	9.7	-0.322284	77.405473	-5.655904	128th
11.1	9.1	9.7	-0.330302	77.40593	-5.660027	134th
11.1	9.2	9.7	-0.346327	77.406722	-5.668258	137th
11.1	9.3	9.7	-0.377085	77.408124	-5.68404	139th
11.1	9.4	9.7	-0.389917	77.41061	-5.71319	140th
11.1	9.5	9.7	-0.535409	77.414963	-5.765141	141st

Table 11 The set of non-inferior solutions for the case of the penalty cost parameters "-15%".

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.6	8.5	9.7	1.5137638	75.826371	-6.283277	33rd
10.6	8.6	9.7	1.5093455	75.828334	-6.2858	32nd
10.6	8.7	9.7	1.4989443	75.831425	-6.291548	31st
10.6	8.5	9.8	1.5266836	75.948297	-6.41323	36th
10.6	8.6	9.8	1.5222659	75.950268	-6.415753	35th
10.6	8.7	9.8	1.5118682	75.953373	-6.421501	34th
10.7	8.5	9.5	1.3871947	76.304844	-5.869624	23rd
10.7	8.6	9.5	1.3849038	76.305767	-5.870916	24th

10.7	8.7	9.5	1.3793868	76.307258	-5.87394	25th
10.7	8.8	9.5	1.3670187	76.309508	-5.880585	28th
10.7	8.9	9.5	1.3411119	76.312717	-5.894317	30th
10.7	8.5	9.6	1.4448363	76.384553	-5.901423	4th
10.7	8.6	9.6	1.4425471	76.385478	-5.902716	7th
10.7	8.7	9.6	1.4370336	76.386974	-5.90574	8th
10.7	8.8	9.6	1.4246722	76.389233	-5.912385	12th
10.7	8.9	9.6	1.3987781	76.39246	-5.926117	19th
10.7	9	9.6	1.347822	76.396908	-5.952892	27th
10.7	8.5	9.7	1.4912515	76.476903	-5.960965	16th
10.7	8.6	9.7	1.4889637	76.477831	-5.962258	15th
10.7	8.7	9.7	1.4834529	76.479332	-5.965282	14th
10.7	8.8	9.7	1.4710969	76.481602	-5.971927	11th
10.7	8.9	9.7	1.4452132	76.484849	-5.985659	1st
10.7	9	9.7	1.394276	76.489335	-6.012434	13th
10.7	9.1	9.7	1.2995168	76.495484	-6.061922	29th
10.7	8.5	9.8	1.480076	76.552491	-6.062087	22nd
10.7	8.6	9.8	1.4777878	76.553421	-6.06338	21st
10.7	8.7	9.8	1.4722777	76.554927	-6.066404	20th
10.7	8.8	9.8	1.4599211	76.557206	-6.073049	17th
10.7	8.9	9.8	1.4340302	76.56047	-6.086781	9th
10.7	9	9.8	1.3830925	76.564986	-6.113556	5th
10.7	9.1	9.8	1.2883231	76.571191	-6.163043	26th
10.7	8.5	9.9	1.3579017	76.579738	-6.224341	2nd
10.7	8.6	9.9	1.35561	76.580669	-6.225633	3rd
10.7	8.7	9.9	1.3500858	76.582176	-6.228657	6th
10.7	8.8	9.9	1.337715	76.584458	-6.235302	10th
10.7	8.9	9.9	1.3118037	76.587728	-6.249034	18th

10.8	8.5	9.5	1.217828	76.82998	-5.691278	54th
10.8	8.6	9.5	1.2166828	76.830399	-5.691917	55th
10.8	8.7	9.5	1.2138613	76.831095	-5.693451	56th
10.8	8.8	9.5	1.2073848	76.832181	-5.696912	57th
10.8	8.9	9.5	1.1934755	76.833793	-5.704255	61st
10.8	8.5	9.6	1.2446273	76.873135	-5.712413	47th
10.8	8.6	9.6	1.2434825	76.873554	-5.713052	48th
10.8	8.7	9.6	1.2406619	76.874252	-5.714586	49th
10.8	8.8	9.6	1.2341871	76.87534	-5.718046	52nd
10.8	8.9	9.6	1.2202809	76.876957	-5.72539	53rd
10.8	9	9.6	1.1921796	76.879299	-5.740115	58th
10.8	8.5	9.7	1.2697076	76.932802	-5.756454	37th
10.8	8.6	9.7	1.2685631	76.933222	-5.757093	39th
10.8	8.7	9.7	1.2657427	76.933921	-5.758627	41st
10.8	8.8	9.7	1.2592693	76.935013	-5.762087	43rd
10.8	8.9	9.7	1.2453661	76.936638	-5.769431	45th
10.8	9	9.7	1.2172703	76.938993	-5.784156	50th
10.8	9.1	9.7	1.1635161	76.942413	-5.812181	59th
10.8	8.5	9.8	1.2477409	76.977288	-5.832565	38th
10.8	8.6	9.8	1.2465962	76.977709	-5.833204	40th
10.8	8.7	9.8	1.2437764	76.978409	-5.834738	42nd
10.8	8.8	9.8	1.2372998	76.979504	-5.838198	44th
10.8	8.9	9.8	1.2233913	76.981133	-5.845542	46th
10.8	9	9.8	1.1952919	76.983498	-5.860267	51st
10.8	9.1	9.8	1.1415281	76.986936	-5.888292	60th
10.8	9.2	9.8	1.0435409	76.992049	-5.939176	64th
10.8	9.3	9.8	0.8724918	76.999873	-6.027696	66th
10.8	9	9.9	1.0843844	76.989222	-5.985118	62nd

10.8	9.1	9.9	1.0305752	76.992663	-6.013144	63rd
10.8	9.2	9.9	0.9325071	76.99778	-6.064028	65th
10.9	8.5	9.5	0.8546143	77.162802	-5.604155	82nd
10.9	8.6	9.5	0.8540614	77.162985	-5.604459	83rd
10.9	8.7	9.5	0.8526681	77.163297	-5.60521	85th
10.9	8.8	9.5	0.8493925	77.163799	-5.606948	86th
10.9	8.9	9.5	0.8421769	77.164575	-5.610738	88th
10.9	8.5	9.6	0.8567375	77.176583	-5.615988	78th
10.9	8.6	9.6	0.8561848	77.176766	-5.616293	79th
10.9	8.7	9.6	0.8547913	77.177078	-5.617044	80th
10.9	8.8	9.6	0.8515155	77.17758	-5.618782	81st
10.9	8.9	9.6	0.8443003	77.178357	-5.622571	87th
10.9	9	9.6	0.8293194	77.179537	-5.630388	89th
10.9	9.1	9.6	0.7998214	77.181344	-5.645715	92nd
10.9	8.5	9.7	0.8719268	77.216825	-5.648137	67th
10.9	8.6	9.7	0.8713741	77.217008	-5.648442	68th
10.9	8.7	9.7	0.8699809	77.217321	-5.649192	69th
10.9	8.8	9.7	0.8667056	77.217824	-5.65093	70th
10.9	8.9	9.7	0.8594912	77.218603	-5.65472	74th
10.9	9	9.7	0.8445121	77.219788	-5.662537	77th
10.9	9.1	9.7	0.8150175	77.221604	-5.677863	90th
10.9	8.5	9.8	0.8487579	77.242637	-5.70379	71st
10.9	8.6	9.8	0.8482051	77.24282	-5.704095	72nd
10.9	8.7	9.8	0.8468115	77.243133	-5.704845	73rd
10.9	8.8	9.8	0.8435362	77.243637	-5.706583	75th
10.9	8.9	9.8	0.8363198	77.244418	-5.710373	76th
10.9	9	9.8	0.821338	77.245605	-5.71819	84th
10.9	9.1	9.8	0.7918382	77.247427	-5.733516	91st

10.9	9.2	9.8	0.7364319	77.250294	-5.76222	93rd
10.9	9.3	9.8	0.63667	77.254919	-5.813783	94th
10.9	9.4	9.8	0.6092155	77.26247	-5.902904	95th
11	8.5	9.5	0.333229	77.338597	-5.588182	97th
11	8.6	9.5	0.3329715	77.338673	-5.588323	99th
11	8.7	9.5	0.3323074	77.338807	-5.588677	101st
11	8.8	9.5	0.3307078	77.33903	-5.589519	103rd
11	8.9	9.5	0.3270921	77.339388	-5.591406	105th
11	9	9.5	0.3193748	77.339958	-5.595412	112th
11	9.1	9.5	0.3037276	77.340879	-5.603507	115th
11	8.5	9.7	0.325635	77.356453	-5.61502	96th
11	8.6	9.7	0.3253775	77.35653	-5.61516	98th
11	8.7	9.7	0.324713	77.356664	-5.615515	100th
11	8.8	9.7	0.323114	77.356887	-5.616357	102nd
11	8.9	9.7	0.3194978	77.357245	-5.618244	104th
11	9	9.7	0.3117802	77.357816	-5.62225	111th
11	9.1	9.7	0.2961321	77.358739	-5.630345	114th
11	9.2	9.7	0.2658266	77.360269	-5.645988	117th
11	8.5	9.8	0.3085889	77.374155	-5.655013	106th
11	8.6	9.8	0.3083313	77.374231	-5.655153	107th
11	8.7	9.8	0.3076666	77.374365	-5.655508	108th
11	8.8	9.8	0.3060667	77.374589	-5.65635	109th
11	8.9	9.8	0.3024507	77.374948	-5.658237	110th
11	9	9.8	0.2947314	77.37552	-5.662243	113th
11	9.1	9.8	0.279082	77.376444	-5.670338	116th
11	9.2	9.8	0.2487728	77.377979	-5.68598	118th
11	9.3	9.8	0.1924485	77.38058	-5.715004	119th
11	9.4	9.8	0.1731065	77.385013	-5.766853	120th

11	9.5	9.8	-0.082387	77.392499	-5.856201	121st
11.1	8.5	9.5	-0.31169	77.39172	-5.625136	128th
11.1	8.6	9.5	-0.311806	77.391751	-5.625198	129th
11.1	8.7	9.5	-0.312111	77.391806	-5.625359	130th
11.1	8.8	9.5	-0.312865	77.391901	-5.625753	131st
11.1	8.9	9.5	-0.314615	77.392059	-5.62666	132nd
11.1	9	9.5	-0.318456	77.392324	-5.628642	134th
11.1	9.1	9.5	-0.32648	77.392774	-5.632772	135th
11.1	9.2	9.5	-0.342511	77.393559	-5.641008	137th
11.1	8.5	9.7	-0.308861	77.411525	-5.645741	122nd
11.1	8.6	9.7	-0.308977	77.411556	-5.645803	123rd
11.1	8.7	9.7	-0.309282	77.411611	-5.645964	124th
11.1	8.8	9.7	-0.310036	77.411706	-5.646358	125th
11.1	8.9	9.7	-0.311786	77.411865	-5.647265	126th
11.1	9	9.7	-0.315627	77.41213	-5.649247	127th
11.1	9.1	9.7	-0.32365	77.412581	-5.653376	133rd
11.1	9.2	9.7	-0.339681	77.413368	-5.661613	136th
11.1	9.3	9.7	-0.370442	77.414767	-5.6774	138th
11.1	9.4	9.7	-0.383276	77.417251	-5.706554	139th
11.1	9.5	9.7	-0.528765	77.421607	-5.758507	140th

Table 12 The set of non-inferior solutions for the case of the penalty cost parameters “-20%”.

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.6	8.5	9.7	1.56293596	75.8755427	-6.2341075	33rd
10.6	8.6	9.7	1.55842008	75.8774089	-6.2367308	32nd
10.6	8.7	9.7	1.54787246	75.8803534	-6.2426315	31st
10.6	8.5	9.8	1.56781567	75.9894288	-6.3720998	37th

10.6	8.6	9.8	1.56330003	75.9913017	-6.3747232	36th
10.6	8.7	9.8	1.552755	75.9942595	-6.3806238	35th
10.6	8.8	9.8	1.52978053	75.998612	-6.3931431	34th
10.7	8.5	9.5	1.43109881	76.3487484	-5.8257205	23rd
10.7	8.6	9.5	1.42876317	76.3496261	-5.8270593	24th
10.7	8.7	9.5	1.42317782	76.3510487	-5.8301542	25th
10.7	8.8	9.5	1.41071538	76.3532045	-5.8368987	26th
10.7	8.9	9.5	1.38469233	76.3562973	-5.8507567	30th
10.7	8.5	9.6	1.48496544	76.4246826	-5.8612948	4th
10.7	8.6	9.6	1.48263136	76.4255625	-5.8626336	5th
10.7	8.7	9.6	1.4770492	76.4269896	-5.8657284	9th
10.7	8.8	9.6	1.46459304	76.4291542	-5.8724729	15th
10.7	8.9	9.6	1.43858195	76.4322639	-5.8863309	21st
10.7	9	9.6	1.3874982	76.4365841	-5.9132497	27th
10.7	8.5	9.7	1.52659378	76.5122453	-5.925624	14th
10.7	8.6	9.7	1.52426091	76.5131277	-5.9269628	13th
10.7	8.7	9.7	1.51868121	76.51456	-5.9300576	10th
10.7	8.8	9.7	1.50622991	76.5167348	-5.9368021	3rd
10.7	8.9	9.7	1.48022807	76.519864	-5.9506601	1st
10.7	9	9.7	1.42916135	76.5242201	-5.9775789	16th
10.7	9.1	9.7	1.33427959	76.530247	-6.027214	29th
10.7	8.5	9.8	1.50981397	76.5822293	-6.0323498	20th
10.7	8.6	9.8	1.50748061	76.5831137	-6.0336886	19th
10.7	8.7	9.8	1.50190127	76.5845502	-6.0367834	18th
10.7	8.8	9.8	1.48944868	76.5867332	-6.0435279	12th
10.7	8.9	9.8	1.46343839	76.5898779	-6.0573859	2nd
10.7	9	9.8	1.41236881	76.5942625	-6.0843048	8th
10.7	9.1	9.8	1.31747284	76.6003405	-6.1339398	28th

10.7	8.5	9.9	1.3816207	76.6034572	-6.2006222	6th
10.7	8.6	9.9	1.37928362	76.6043423	-6.201961	7th
10.7	8.7	9.9	1.37368989	76.6057799	-6.2050559	11th
10.7	8.8	9.9	1.36122241	76.6079655	-6.2118003	17th
10.7	8.9	9.9	1.33519039	76.6111149	-6.2256583	22nd
10.8	8.5	9.5	1.24797839	76.86013	-5.6611283	55th
10.8	8.6	9.5	1.24681324	76.860529	-5.6617876	56th
10.8	8.7	9.5	1.2439608	76.8611944	-5.6633536	57th
10.8	8.8	9.5	1.2374407	76.8622366	-5.666859	58th
10.8	8.9	9.5	1.22347666	76.8637942	-5.6742612	60th
10.8	8.5	9.6	1.27234766	76.9008549	-5.6846925	48th
10.8	8.6	9.6	1.27118292	76.9012544	-5.6853518	49th
10.8	8.7	9.6	1.26833133	76.9019209	-5.6869179	50th
10.8	8.8	9.6	1.26181286	76.9029657	-5.6904232	52nd
10.8	8.9	9.6	1.24785163	76.9045279	-5.6978254	54th
10.8	9	9.6	1.21968887	76.9068084	-5.7126178	59th
10.8	8.5	9.7	1.2942789	76.9573732	-5.7318826	38th
10.8	8.6	9.7	1.29311447	76.9577735	-5.732542	39th
10.8	8.7	9.7	1.29026289	76.9584416	-5.734108	41st
10.8	8.8	9.7	1.28374567	76.9594897	-5.7376134	44th
10.8	8.9	9.7	1.26978699	76.9610585	-5.7450156	46th
10.8	9	9.7	1.24162911	76.9633516	-5.759808	51st
10.8	9.1	9.7	1.18781466	76.966711	-5.7879037	61st
10.8	8.5	9.8	1.26855144	76.9980983	-5.8117543	40th
10.8	8.6	9.8	1.2673867	76.9984992	-5.8124137	42nd
10.8	8.7	9.8	1.26453568	76.9991685	-5.8139797	43rd
10.8	8.8	9.8	1.25801496	77.000219	-5.8174851	45th
10.8	8.9	9.8	1.24405058	77.0017926	-5.8248873	47th

10.8	9	9.8	1.21588832	77.0040947	-5.8396797	53rd
10.8	9.1	9.8	1.16206266	77.0074708	-5.8677754	62nd
10.8	9.2	9.8	1.06402469	77.0125331	-5.918725	63rd
10.8	9.3	9.8	0.89294643	77.0203279	-6.0072991	65th
10.8	9.2	9.9	0.94887117	77.0141437	-6.0476899	64th
10.9	8.5	9.5	0.87461542	77.1828035	-5.5841537	81st
10.9	8.6	9.5	0.87405407	77.1829774	-5.584467	82nd
10.9	8.7	9.5	0.87264724	77.1832757	-5.5852314	83rd
10.9	8.8	9.5	0.86935239	77.1837586	-5.5869892	85th
10.9	8.9	9.5	0.86211199	77.1845097	-5.5908049	87th
10.9	8.5	9.6	0.87523145	77.1950772	-5.5974944	77th
10.9	8.6	9.6	0.87467017	77.1952512	-5.5978077	78th
10.9	8.7	9.6	0.87326321	77.1955497	-5.5985722	79th
10.9	8.8	9.6	0.8699681	77.1960329	-5.60033	80th
10.9	8.9	9.6	0.86272801	77.1967847	-5.6041456	86th
10.9	9	9.6	0.84771887	77.197936	-5.6119929	88th
10.9	9.1	9.6	0.81819281	77.1997153	-5.6273514	91st
10.9	8.5	9.7	0.88842562	77.2333242	-5.6316381	66th
10.9	8.6	9.7	0.88786443	77.2334985	-5.6319514	67th
10.9	8.7	9.7	0.88645765	77.2337975	-5.6327159	68th
10.9	8.8	9.7	0.88316292	77.2342818	-5.6344737	69th
10.9	8.9	9.7	0.87592361	77.2350359	-5.6382894	73rd
10.9	9	9.7	0.86091601	77.2361917	-5.6461366	76th
10.9	9.1	9.7	0.83139288	77.2379794	-5.6614951	89th
10.9	8.5	9.8	0.86282741	77.2567065	-5.6897205	70th
10.9	8.6	9.8	0.86226606	77.2568809	-5.6900339	71st
10.9	8.7	9.8	0.86085893	77.2571802	-5.6907983	72nd
10.9	8.8	9.8	0.85756413	77.2576653	-5.6925561	74th

10.9	8.9	9.8	0.85032263	77.2584207	-5.6963718	75th
10.9	9	9.8	0.83531205	77.2595792	-5.7042191	84th
10.9	9.1	9.8	0.80578323	77.2613722	-5.7195776	90th
10.9	9.2	9.8	0.75035229	77.2642145	-5.7483119	92nd
10.9	9.3	9.8	0.6505748	77.2688242	-5.7999	93rd
10.9	9.4	9.8	0.62311835	77.2763728	-5.8890403	94th
11	8.5	9.5	0.34603444	77.3514025	-5.575377	95th
11	8.6	9.5	0.34577344	77.3514753	-5.5755206	96th
11	8.7	9.5	0.34510368	77.3516036	-5.5758806	97th
11	8.8	9.5	0.34349596	77.3518182	-5.5767311	101st
11	8.9	9.5	0.33986955	77.3521655	-5.5786295	103rd
11	9	9.5	0.33213976	77.3527229	-5.5826487	109th
11	9.1	9.5	0.31647997	77.3536309	-5.5907575	113th
11	8.5	9.7	0.33632269	77.3671409	-5.6043326	98th
11	8.6	9.7	0.33606166	77.3672137	-5.6044763	99th
11	8.7	9.7	0.33539149	77.3673421	-5.6048363	100th
11	8.8	9.7	0.33378425	77.367557	-5.6056868	102nd
11	8.9	9.7	0.33015729	77.3679047	-5.6075851	104th
11	9	9.7	0.32242713	77.3684631	-5.6116044	111th
11	9.1	9.7	0.30676613	77.3693728	-5.6197131	114th
11	9.2	9.7	0.27644958	77.3708923	-5.6353694	116th
11	8.5	9.8	0.31776613	77.3833322	-5.6458359	105th
11	8.6	9.8	0.31750505	77.383405	-5.6459796	106th
11	8.7	9.8	0.31683477	77.3835336	-5.6463396	107th
11	8.8	9.8	0.31522659	77.3837486	-5.6471901	108th
11	8.9	9.8	0.31159977	77.3840968	-5.6490884	110th
11	9	9.8	0.30386783	77.3846561	-5.6531077	112th
11	9.1	9.8	0.28820535	77.3855678	-5.6612164	115th

11	9.2	9.8	0.25788468	77.3870908	-5.6768727	117th
11	9.3	9.8	0.20155256	77.3896836	-5.7059077	118th
11	9.4	9.8	0.18220832	77.394115	-5.7577651	119th
11	9.5	9.8	-0.0732797	77.4016063	-5.8471192	120th
11.1	8.5	9.5	-0.3037831	77.3996272	-5.6172289	127th
11.1	8.6	9.5	-0.3039002	77.3996564	-5.6172924	128th
11.1	8.7	9.5	-0.3042079	77.3997094	-5.617456	129th
11.1	8.8	9.5	-0.3049651	77.399801	-5.617853	130th
11.1	8.9	9.5	-0.3067192	77.3999551	-5.6187646	131st
11.1	9	9.5	-0.3105657	77.4002144	-5.6207524	133rd
11.1	9.1	9.5	-0.318595	77.4006587	-5.6248876	134th
11.1	9.2	9.5	-0.3346307	77.4014389	-5.6331297	136th
11.1	8.5	9.7	-0.3021872	77.4181988	-5.6390671	121st
11.1	8.6	9.7	-0.3023043	77.4182281	-5.6391306	122nd
11.1	8.7	9.7	-0.3026117	77.4182811	-5.6392942	123rd
11.1	8.8	9.7	-0.3033692	77.4183728	-5.6396913	124th
11.1	8.9	9.7	-0.3051234	77.4185272	-5.6406029	125th
11.1	9	9.7	-0.3089699	77.418787	-5.6425906	126th
11.1	9.1	9.7	-0.3169989	77.4192324	-5.6467258	132nd
11.1	9.2	9.7	-0.3330342	77.4200148	-5.6549679	135th
11.1	9.3	9.7	-0.3637991	77.4214094	-5.6707602	137th
11.1	9.4	9.7	-0.3766341	77.4238931	-5.6999181	138th
11.1	9.5	9.7	-0.5221214	77.4282507	-5.7518741	139th

Table 13 The set of non-inferior solutions for the case of the penalty cost parameters “-25%”.

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.6	8.5	9.7	1.61210809	75.9247148	-6.1849381	34th

10.6	8.6	9.7	1.60749467	75.9264834	-6.1876618	33rd
10.6	8.7	9.7	1.59680063	75.9292816	-6.1937146	31st
10.6	8.8	9.7	1.57362292	75.93341	-6.2064434	28th
10.6	8.5	9.8	1.60894779	76.030561	-6.3309699	38th
10.6	8.6	9.8	1.60433413	76.0323358	-6.3336937	37th
10.6	8.7	9.8	1.59364175	76.0351463	-6.3397465	36th
10.6	8.8	9.8	1.57046671	76.0392982	-6.3524753	35th
10.7	8.5	9.5	1.47500295	76.3926525	-5.7818175	23rd
10.7	8.6	9.5	1.47262252	76.3934854	-5.7832023	24th
10.7	8.7	9.5	1.46696879	76.3948397	-5.7863682	25th
10.7	8.8	9.5	1.45441207	76.3969011	-5.793212	26th
10.7	8.9	9.5	1.42827279	76.3998777	-5.8071959	30th
10.7	8.5	9.6	1.52509454	76.4648117	-5.8211667	9th
10.7	8.6	9.6	1.52271557	76.4656467	-5.8225515	10th
10.7	8.7	9.6	1.5170648	76.4670052	-5.8257174	13th
10.7	8.8	9.6	1.50451392	76.4690751	-5.8325612	17th
10.7	8.9	9.6	1.47838576	76.4720677	-5.8465451	21st
10.7	9	9.6	1.42717437	76.4762603	-5.8736077	27th
10.7	8.5	9.7	1.56193603	76.5475875	-5.8902826	7th
10.7	8.6	9.7	1.55955812	76.548425	-5.8916675	6th
10.7	8.7	9.7	1.55390954	76.5497883	-5.8948333	4th
10.7	8.8	9.7	1.54136295	76.5518679	-5.9016771	2nd
10.7	8.9	9.7	1.51524298	76.5548789	-5.915661	3rd
10.7	9	9.7	1.46404666	76.5591054	-5.9427236	19th
10.7	9.1	9.7	1.36904235	76.5650098	-5.9925064	32nd
10.7	8.5	9.8	1.53955194	76.6119672	-6.0026125	12th
10.7	8.6	9.8	1.53717339	76.6128065	-6.0039974	11th
10.7	8.7	9.8	1.53152482	76.6141737	-6.0071632	8th

10.7	8.8	9.8	1.51897631	76.6162608	-6.0140071	5th
10.7	8.9	9.8	1.49284663	76.6192861	-6.027991	1st
10.7	9	9.8	1.44164516	76.6235389	-6.0550536	14th
10.7	9.1	9.8	1.34662256	76.6294902	-6.1048363	29th
10.7	8.5	9.9	1.40533973	76.6271763	-6.1769037	15th
10.7	8.6	9.9	1.40295728	76.628016	-6.1782886	16th
10.7	8.7	9.9	1.39729397	76.629384	-6.1814545	18th
10.7	8.8	9.9	1.38472986	76.6314729	-6.1882983	20th
10.7	8.9	9.9	1.35857712	76.6345016	-6.2022822	22nd
10.8	8.5	9.5	1.27812876	76.8902804	-5.6309782	56th
10.8	8.6	9.5	1.2769437	76.8906595	-5.6316579	57th
10.8	8.7	9.5	1.27406028	76.8912938	-5.6332558	58th
10.8	8.8	9.5	1.26749665	76.8922926	-5.6368065	59th
10.8	8.9	9.5	1.25347784	76.8937953	-5.6442669	61st
10.8	8.5	9.6	1.30006807	76.9285753	-5.6569724	49th
10.8	8.6	9.6	1.29888339	76.9289549	-5.6576521	50th
10.8	8.7	9.6	1.29600075	76.9295903	-5.65925	51st
10.8	8.8	9.6	1.2894386	76.9305914	-5.6628006	52nd
10.8	8.9	9.6	1.27542232	76.9320986	-5.6702611	55th
10.8	9	9.6	1.24719817	76.9343177	-5.685121	60th
10.8	8.5	9.7	1.31885025	76.9819445	-5.7073115	39th
10.8	8.6	9.7	1.31766583	76.9823248	-5.7079912	40th
10.8	8.7	9.7	1.31478311	76.9829619	-5.7095891	41st
10.8	8.8	9.7	1.30822202	76.983966	-5.7131398	45th
10.8	8.9	9.7	1.29420793	76.9854794	-5.7206003	47th
10.8	9	9.7	1.26598796	76.9877104	-5.7354601	53st
10.8	9.1	9.7	1.21211316	76.9910096	-5.7636261	62nd
10.8	8.5	9.8	1.289362	77.0189089	-5.790944	42nd

10.8	8.6	9.8	1.28817722	77.0192897	-5.7916237	43rd
10.8	8.7	9.8	1.28529495	77.0199278	-5.7932216	44th
10.8	8.8	9.8	1.27873014	77.0209342	-5.7967722	46th
10.8	8.9	9.8	1.26470991	77.0224519	-5.8042327	48th
10.8	9	9.8	1.23648472	77.0246911	-5.8190926	54th
10.8	9.1	9.8	1.18259718	77.0280054	-5.8472586	63rd
10.8	9.2	9.8	1.08450851	77.033017	-5.8982737	64th
10.8	9.3	9.8	0.91340102	77.0407825	-5.9869026	65th
10.9	8.5	9.5	0.89461655	77.2028046	-5.5641526	80th
10.9	8.6	9.5	0.89404669	77.20297	-5.5644746	81st
10.9	8.7	9.5	0.89262638	77.2032549	-5.5652528	83rd
10.9	8.8	9.5	0.88931224	77.2037185	-5.5670305	84th
10.9	8.9	9.5	0.8820471	77.2044448	-5.5708721	87th
10.9	9	9.5	0.86700943	77.2055666	-5.5787498	90th
10.9	8.5	9.6	0.89372537	77.2135711	-5.5790005	76th
10.9	8.6	9.6	0.89315557	77.2137366	-5.5793225	77th
10.9	8.7	9.6	0.89173512	77.2140216	-5.5801007	79th
10.9	8.8	9.6	0.88842067	77.2144855	-5.5818784	82nd
10.9	8.9	9.6	0.88115576	77.2152124	-5.58572	85th
10.9	9	9.6	0.86611832	77.2163355	-5.5935977	88th
10.9	9.1	9.6	0.83656423	77.2180867	-5.6089883	92nd
10.9	8.5	9.7	0.90492444	77.249823	-5.6151394	66th
10.9	8.6	9.7	0.90435472	77.2499888	-5.6154613	67th
10.9	8.7	9.7	0.90293441	77.2502742	-5.6162395	68th
10.9	8.8	9.7	0.8996203	77.2507392	-5.6180172	69th
10.9	8.9	9.7	0.89235604	77.2514683	-5.6218588	72nd
10.9	9	9.7	0.87731991	77.2525956	-5.6297365	78th
10.9	9.1	9.7	0.8477683	77.2543549	-5.6451271	89th

10.9	9.2	9.7	0.79232418	77.2571639	-5.6738917	93rd
10.9	8.5	9.8	0.87689691	77.270776	-5.6756511	70th
10.9	8.6	9.8	0.87632701	77.2709418	-5.6759731	71st
10.9	8.7	9.8	0.87490632	77.2712276	-5.6767513	73rd
10.9	8.8	9.8	0.87159207	77.2716932	-5.678529	74th
10.9	8.9	9.8	0.86432548	77.2724235	-5.6823706	75th
10.9	9	9.8	0.84928608	77.2735532	-5.6902483	86th
10.9	9.1	9.8	0.81972825	77.2753172	-5.7056389	91st
10.9	9.2	9.8	0.76427265	77.2781348	-5.7344035	94th
10.9	9.3	9.8	0.66447961	77.282729	-5.7860173	95th
10.9	9.4	9.8	0.63702118	77.2902756	-5.875177	96th
11	8.5	9.5	0.35883988	77.364208	-5.5625716	97th
11	8.6	9.5	0.35857539	77.3642772	-5.5627187	98th
11	8.7	9.5	0.35789999	77.3643999	-5.5630845	99th
11	8.8	9.5	0.35628408	77.3646063	-5.5639433	100th
11	8.9	9.5	0.35264695	77.3649429	-5.5658527	105th
11	9	9.5	0.34490472	77.3654879	-5.5698852	110th
11	9.1	9.5	0.32923232	77.3663832	-5.578008	115th
11	8.5	9.7	0.34701033	77.3778285	-5.593645	101st
11	8.6	9.7	0.3467458	77.3778979	-5.5937922	102nd
11	8.7	9.7	0.34606999	77.3780206	-5.5941579	103rd
11	8.8	9.7	0.34445452	77.3782272	-5.5950168	104th
11	8.9	9.7	0.34081679	77.3785642	-5.5969262	106th
11	9	9.7	0.33307406	77.37911	-5.6009587	112th
11	9.1	9.7	0.3174002	77.3800069	-5.6090815	116th
11	9.2	9.7	0.28707252	77.3815152	-5.6247513	118th
11	8.5	9.8	0.3269434	77.3925094	-5.6366587	107th
11	8.6	9.8	0.32667882	77.3925788	-5.6368058	108th

11	8.7	9.8	0.32600289	77.3927017	-5.6371716	109th
11	8.8	9.8	0.32438646	77.3929085	-5.6380304	111th
11	8.9	9.8	0.32074882	77.3932458	-5.6399398	113th
11	9	9.8	0.31300423	77.3937925	-5.6439723	114th
11	9.1	9.8	0.29732871	77.3946912	-5.6520951	117th
11	9.2	9.8	0.26699657	77.3962027	-5.6677649	119th
11	9.3	9.8	0.21065663	77.3987876	-5.6968115	120th
11	9.4	9.8	0.19131019	77.4032169	-5.7486777	121st
11	9.5	9.8	-0.0641724	77.4107136	-5.8380378	122nd
11.1	8.5	9.5	-0.295876	77.4075342	-5.6093218	129th
11.1	8.6	9.5	-0.2959945	77.4075621	-5.6093867	130th
11.1	8.7	9.5	-0.2963045	77.4076128	-5.6095526	131st
11.1	8.8	9.5	-0.297065	77.4077011	-5.609953	132nd
11.1	8.9	9.5	-0.2988236	77.4078508	-5.6108692	133rd
11.1	9	9.5	-0.3026753	77.4081048	-5.6128624	135th
11.1	9.1	9.5	-0.3107101	77.4085436	-5.6170036	136th
11.1	9.2	9.5	-0.3267506	77.4093189	-5.6252514	138th
11.1	8.5	9.7	-0.2955135	77.4248725	-5.6323934	123rd
11.1	8.6	9.7	-0.295632	77.4249003	-5.6324584	124th
11.1	8.7	9.7	-0.2959417	77.4249511	-5.6326242	125th
11.1	8.8	9.7	-0.2967025	77.4250395	-5.6330247	126th
11.1	8.9	9.7	-0.2984612	77.4251894	-5.6339408	127th
11.1	9	9.7	-0.302313	77.4254439	-5.6359341	128th
11.1	9.1	9.7	-0.3103475	77.4258838	-5.6400752	134th
11.1	9.2	9.7	-0.3263878	77.4266611	-5.6483231	137th
11.1	9.3	9.7	-0.3571562	77.4280522	-5.6641203	139th
11.1	9.4	9.7	-0.3699923	77.4305348	-5.6932822	140th
11.1	9.5	9.7	-0.5154775	77.4348946	-5.7452408	141st

Table 14 The set of non-inferior solutions for the case of the penalty cost parameters "-50%".

T^*	${w_2}^*$	${w_1}^*$	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.6	8.5	9.5	1.7645414	75.989835	-5.7220927	3rd
10.6	8.6	9.5	1.759434	75.991106	-5.7253186	4th
10.6	8.7	9.5	1.747997	75.993151	-5.7321319	9th
10.6	8.5	9.6	1.8245066	76.078432	-5.8116345	6th
10.6	8.6	9.6	1.8194034	76.079707	-5.8148605	5th
10.6	8.7	9.6	1.8079734	76.081762	-5.8216737	2nd
10.6	8.8	9.6	1.7837943	76.084876	-5.8354504	1st
10.6	8.5	9.7	1.8579688	76.170575	-5.9390907	27th
10.6	8.6	9.7	1.8528676	76.171856	-5.9423166	26th
10.6	8.7	9.7	1.8414415	76.173922	-5.9491299	24th
10.6	8.8	9.7	1.8172699	76.177057	-5.9629065	19th
10.6	8.9	9.7	1.7690112	76.181587	-5.989511	12th
10.6	8.5	9.8	1.8146084	76.236222	-6.1253204	34th
10.6	8.6	9.8	1.8095046	76.237506	-6.1285464	32nd
10.6	8.7	9.8	1.7980755	76.23958	-6.1353597	31st
10.6	8.8	9.8	1.7738976	76.242729	-6.1491363	25th
10.7	8.5	9.5	1.6945236	76.612173	-5.5623023	33rd
10.7	8.6	9.5	1.6919193	76.612782	-5.5639174	35th
10.7	8.7	9.5	1.6859236	76.613795	-5.5674381	36th
10.7	8.8	9.5	1.6728955	76.615385	-5.5747787	37th
10.7	8.9	9.5	1.6461751	76.61778	-5.589392	39th
10.7	9	9.5	1.5943127	76.621313	-5.6171737	42nd
10.7	8.5	9.6	1.7257401	76.665457	-5.6205262	20th
10.7	8.6	9.6	1.7231366	76.666068	-5.6221413	21st
10.7	8.7	9.6	1.7171428	76.667083	-5.625662	22nd

10.7	8.8	9.6	1.7041183	76.668679	-5.6330026	23rd
10.7	8.9	9.6	1.6774048	76.671087	-5.6476159	30th
10.7	9	9.6	1.6255552	76.674641	-5.6753976	38th
10.7	8.5	9.7	1.7386473	76.724299	-5.7135758	7th
10.7	8.6	9.7	1.7360442	76.724911	-5.7151909	10th
10.7	8.7	9.7	1.7300512	76.72593	-5.7187116	13th
10.7	8.8	9.7	1.7170282	76.727533	-5.7260522	15th
10.7	8.9	9.7	1.6903175	76.729953	-5.7406655	17th
10.7	9	9.7	1.6384732	76.733532	-5.7684472	28th
10.7	9.1	9.7	1.5428562	76.738824	-5.8189685	40th
10.7	8.5	9.8	1.6882418	76.760657	-5.8539264	8th
10.7	8.6	9.8	1.6856373	76.76127	-5.8555415	11th
10.7	8.7	9.8	1.6796426	76.762291	-5.8590622	14th
10.7	8.8	9.8	1.6666144	76.763899	-5.8664029	16th
10.7	8.9	9.8	1.6398878	76.766327	-5.8810162	18th
10.7	9	9.8	1.5880269	76.769921	-5.9087978	29th
10.7	9.1	9.8	1.4923711	76.775239	-5.9593191	41st
10.8	8.5	9.5	1.4288806	77.041032	-5.480228	59th
10.8	8.6	9.5	1.427596	77.041312	-5.4810093	60th
10.8	8.7	9.5	1.4245577	77.041791	-5.4827665	61st
10.8	8.8	9.5	1.4177764	77.042572	-5.4865437	63rd
10.8	8.9	9.5	1.4034837	77.043801	-5.4942955	65th
10.8	9	9.5	1.3749507	77.045708	-5.5094927	67th
10.8	8.5	9.6	1.4386701	77.067177	-5.5183719	52nd
10.8	8.6	9.6	1.4373857	77.067457	-5.5191532	53rd
10.8	8.7	9.6	1.4343478	77.067937	-5.5209103	54th
10.8	8.8	9.6	1.4275673	77.06872	-5.5246876	56th
10.8	8.9	9.6	1.4132757	77.069952	-5.5324393	58th

10.8	9	9.6	1.3847446	77.071864	-5.5476366	64th
10.8	9.1	9.6	1.3305662	77.074846	-5.5761538	69th
10.8	8.5	9.7	1.441707	77.104801	-5.5844562	43rd
10.8	8.6	9.7	1.4404226	77.105082	-5.5852375	44th
10.8	8.7	9.7	1.4373842	77.105563	-5.5869946	45th
10.8	8.8	9.7	1.4306038	77.106348	-5.5907719	46th
10.8	8.9	9.7	1.4163126	77.107584	-5.5985236	50th
10.8	9	9.7	1.3877822	77.109505	-5.6137209	57th
10.8	9.1	9.7	1.3336057	77.112502	-5.6422381	66th
10.8	9.4	9.7	1.0277215	77.137014	-5.9308218	71st
10.8	8.5	9.8	1.3934148	77.122962	-5.6868924	47th
10.8	8.6	9.8	1.3921298	77.123242	-5.6876737	48th
10.8	8.7	9.8	1.3890913	77.123724	-5.6894308	49th
10.8	8.8	9.8	1.382306	77.12451	-5.6932081	51st
10.8	8.9	9.8	1.3680065	77.125749	-5.7009598	55th
10.8	9	9.8	1.3394667	77.127673	-5.7161571	62nd
10.8	9.1	9.8	1.2852698	77.130678	-5.7446743	68th
10.8	9.2	9.8	1.1869276	77.135436	-5.7960172	70th
10.8	9.3	9.8	1.015674	77.143056	-5.8849199	72nd
10.9	8.5	9.5	0.9946222	77.30281	-5.4641475	80th
10.9	8.6	9.5	0.9940098	77.302933	-5.4645126	82nd
10.9	8.7	9.5	0.9925221	77.303151	-5.4653596	85th
10.9	8.8	9.5	0.9891115	77.303518	-5.4672366	88th
10.9	8.9	9.5	0.9817227	77.30412	-5.4712078	92nd
10.9	9	9.5	0.9665444	77.305102	-5.4792377	95th
10.9	8.5	9.6	0.9861949	77.306041	-5.4865314	83rd
10.9	8.6	9.6	0.9855826	77.306164	-5.4868965	84th
10.9	8.7	9.6	0.9840946	77.306381	-5.4877435	86th

10.9	8.8	9.6	0.9806835	77.306748	-5.4896205	89th
10.9	8.9	9.6	0.9732945	77.307351	-5.4935917	93rd
10.9	9	9.6	0.9581155	77.308333	-5.5016216	96th
10.9	9.1	9.6	0.9284213	77.309944	-5.5171727	99th
10.9	8.5	9.7	0.9874185	77.332317	-5.5326457	73rd
10.9	8.6	9.7	0.9868062	77.33244	-5.5330108	74th
10.9	8.7	9.7	0.9853182	77.332658	-5.5338578	75th
10.9	8.8	9.7	0.9819072	77.333026	-5.5357348	76th
10.9	8.9	9.7	0.9745182	77.33363	-5.539706	77th
10.9	9	9.7	0.9593394	77.334615	-5.5477359	90th
10.9	9.1	9.7	0.9296454	77.336232	-5.563287	97th
10.9	9.2	9.7	0.874083	77.338923	-5.5922033	100th
10.9	9.4	9.7	0.7468236	77.350958	-5.7332019	102nd
10.9	8.5	9.8	0.9472444	77.341123	-5.605304	78th
10.9	8.6	9.8	0.9466318	77.341247	-5.6056691	79th
10.9	8.7	9.8	0.9451433	77.341465	-5.6065161	81st
10.9	8.8	9.8	0.9417317	77.341833	-5.6083931	87th
10.9	8.9	9.8	0.9343397	77.342438	-5.6123643	91st
10.9	9	9.8	0.9191562	77.343423	-5.6203942	94th
10.9	9.1	9.8	0.8894533	77.345042	-5.6359453	98th
10.9	9.2	9.8	0.8338744	77.347737	-5.6648616	101st
10.9	9.3	9.8	0.7340037	77.352253	-5.7166036	104th
10.9	9.4	9.8	0.7065353	77.35979	-5.8058602	103rd
11	8.5	9.5	0.4228671	77.428235	-5.4985445	105th
11	8.6	9.5	0.4225851	77.428287	-5.4987093	106th
11	8.7	9.5	0.4218816	77.428382	-5.4991036	107th
11	8.8	9.5	0.4202247	77.428547	-5.5000043	108th
11	8.9	9.5	0.416534	77.42883	-5.5019692	109th

11	9	9.5	0.4087295	77.429313	-5.5060676	114th
11	9.1	9.5	0.3929941	77.430145	-5.5142609	122nd
11	9.2	9.5	0.362616	77.431597	-5.5299982	126th
11	9.3	9.5	0.3062572	77.434139	-5.5591024	129th
11	9.5	9.5	0.0315437	77.44606	-5.7004029	132nd
11	8.5	9.7	0.4004485	77.431267	-5.5402069	110th
11	8.6	9.7	0.4001665	77.431319	-5.5403717	111th
11	8.7	9.7	0.3994625	77.431413	-5.540766	112th
11	8.8	9.7	0.3978059	77.431579	-5.5416668	113th
11	8.9	9.7	0.3941143	77.431862	-5.5436316	115th
11	9	9.7	0.3863087	77.432345	-5.54773	119th
11	9.1	9.7	0.3705706	77.433177	-5.5559234	124th
11	9.2	9.7	0.3401872	77.43463	-5.5716606	127th
11	9.5	9.7	0.0090612	77.449101	-5.7420654	133rd
11	8.5	9.8	0.3728298	77.438396	-5.5907724	116th
11	8.6	9.8	0.3725477	77.438448	-5.5909372	117th
11	8.7	9.8	0.3718435	77.438542	-5.5913315	118th
11	8.8	9.8	0.3701858	77.438708	-5.5922322	120th
11	8.9	9.8	0.3664941	77.438991	-5.5941971	121st
11	9	9.8	0.3586862	77.439474	-5.5982955	123rd
11	9.1	9.8	0.3429455	77.440308	-5.6064888	125th
11	9.2	9.8	0.312556	77.441762	-5.622226	128th
11	9.3	9.8	0.256177	77.444308	-5.6513303	130th
11	9.4	9.8	0.2368195	77.448726	-5.7032406	131st
11	9.5	9.8	-0.0186362	77.45625	-5.7926308	134th
11.1	8.5	9.5	-0.2563406	77.44707	-5.5697864	140th
11.1	8.6	9.5	-0.256466	77.447091	-5.5698583	141st
11.1	8.7	9.5	-0.2567873	77.44713	-5.5700356	142nd

11.1	8.8	9.5	-0.2575645	77.447202	-5.570453	143rd
11.1	8.9	9.5	-0.2593453	77.447329	-5.5713919	145th
11.1	9	9.5	-0.2632234	77.447557	-5.5734126	146th
11.1	9.1	9.5	-0.2712856	77.447968	-5.5775835	148th
11.1	9.2	9.5	-0.2873503	77.448719	-5.5858602	150th
11.1	8.5	9.7	-0.2621452	77.458241	-5.5990251	135th
11.1	8.6	9.7	-0.2622705	77.458262	-5.599097	136th

Appendix C

Appendix c contains the sets of non-inferior solutions for the three sensitivity analysis cases conducted on chapter five, “multi-objective process targeting model with sampling plan error-free inspection system”. The three sensitivity analysis cases are conducted on the parameters, the process standard deviation σ, the cost parameters (c, g, R and I) and the sampling plan parameters (n,d_1 and d_2).

Tables from 1 to 6 give the set non-inferior solutions for each case of change in the process standard deviation.

Table 1 The set of non-inferior solutions for the case of the process standard deviation “+25%”.

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.1	10.07472601	77.08842988	-6.642660803	3rd
11.2	9.826429212	77.1907462	-6.193699062	1st
11.3	9.301315744	77.17004416	-6.047053157	2nd

Table 2 The set of non-inferior solutions for the case of the process standard deviation “+50%”.

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	8.355732176	76.64641191	-7.05725555	3rd
11.4	8.094171794	76.72193444	-6.629192048	1st
11.5	7.595742405	76.70234241	-6.457740837	2nd
11.6	6.962265828	76.61637574	-6.431747957	4th

Table 3 The set of non-inferior solutions for the case of the process standard deviation “+75%”.

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.5	6.66639708	76.22292492	-7.444326095	2nd
11.6	6.382860945	76.2721561	-7.046868637	1st
11.7	5.897128526	76.24670817	-6.866258977	3rd
11.8	5.285839051	76.16563256	-6.819991542	4th

Table 4 The set of non-inferior solutions for the case of the process standard deviation -25%”.

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	13.65979111	78.07480013	-5.668341674	3rd
10.8	13.34754949	78.19930768	-5.280750716	1st
10.9	12.70027655	78.12441887	-5.259194178	2nd

Table 5 the set of non-inferior solutions for the case of the process standard deviation “-50%”.

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.5	15.5644735	78.66354526	-5.069315758	2nd
10.6	15.09869166	78.72272001	-4.848154617	1st

Table 6 The set of non-inferior solutions for the case of the process standard deviation “-75%”.

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.3	17.49710676	79.32102114	-4.456025046	1st

Tables from 7 to 6 give the set non-inferior solutions for each case of change in the cost parameters.

Table 7 The set of non-inferior solutions for the case of the cost parameters "+5%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	8.455403447	77.46401177	-6.450326342	2nd
11	8.171237462	77.57921514	-6.010780861	1st
11.1	7.5625362	77.53450984	-5.918399995	3rd

Table 8 The set of non-inferior solutions for the case of the cost parameters "+10%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	5.074441551	77.36917408	-6.714147274	2nd
11	4.762366971	77.47548644	-6.280702365	1st
11.1	4.117763726	77.42173611	-6.19445751	3rd

Table 9 The set of non-inferior solutions for the case of the cost parameters "+15%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	1.693479654	77.27433639	-6.977968206	1st
11	1.35349648	77.37175774	-6.550623869	2nd
11.1	0.672991253	77.30896238	-6.470515025	3rd

Table 10 The set of non-inferior solutions for the case of the cost parameters "+20%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	-1.687482242	77.1794987	-7.241789138	1st
11	-2.055374012	77.26802904	-6.820545373	2nd
11.1	-2.77178122	77.19618865	-6.74657254	3rd

Table 11 The set of non-inferior solutions for the case of the cost parameters "+25%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	-5.068444139	77.08466101	-7.50561007	1st
11	-5.464244503	77.16430035	-7.090466876	2nd
11.1	-6.216553694	77.08341492	-7.022630055	3rd

Table 12 The set of non-inferior solutions for the case of the cost parameters "+50%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	-21.97325362	76.61047255	-8.824714731	2nd
11	-22.50859696	76.64565686	-8.440074395	1st
11.1	-23.44041606	76.51954628	-8.402917629	3rd

Table 13 The set of non-inferior solutions for the case of the cost parameters "-5%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	15.21732724	77.65368715	-5.922684478	3rd
11	14.98897844	77.78667253	-5.470937854	1st
11.1	14.45208115	77.76005729	-5.366284965	2nd

Table 14 The set of non-inferior solutions for the case of the cost parameters "-10%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	18.59828914	77.74852484	-5.658863546	3rd
11	18.39784894	77.89040123	-5.20101635	1st
11.1	17.89685362	77.87283102	-5.09022745	2nd

Table 15 The set of non-inferior solutions for the case of the cost parameters "-15%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	21.97925103	77.84336253	-5.395042613	3rd
11	21.80671943	77.99412993	-4.931094846	1st
11.1	21.34162609	77.98560475	-4.814169935	2nd

Table 16 The set of non-inferior solutions for the case of the cost parameters "-20%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	25.36021293	77.93820022	-5.131221681	3rd
11	25.21558992	78.09785862	-4.661173342	1st
11.1	24.78639857	78.09837848	-4.53811242	2nd

Table 17 The set of non-inferior solutions for the case of the cost parameters "-25%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	28.74117483	78.03303791	-4.867400749	3rd
11	28.62446041	78.20158732	-4.391251839	2nd
11.1	28.23117104	78.21115221	-4.262054905	1st

Table 17 The set of non-inferior solutions for the case of the cost parameters "-50%".

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11	45.66881287	78.72023081	-3.04164432	3rd
11.1	45.45503341	78.77502085	-2.88176733	1st
11.2	45.13323419	78.74536234	-2.863589664	2nd

Tables from 19 to 44 give the set non-inferior solutions for each case of change in the sampling plan parameters.

Table 19 The set of non-inferior solutions for the case of the sampling plan n=10 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{0}, \mathbf{1})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	9.360474119	76.77561268	-6.655982416	2^{nd}
11.3	9.042489841	76.92723085	-6.298109225	1^{st}
11.4	8.501254315	76.94108915	-6.177481789	3^{rd}

Table 20 The set of non-inferior solutions for the case of the sampling plan n=10 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{0}, \mathbf{2})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.1	9.753242295	76.39321719	-6.898224109	3^{rd}
11.2	9.53641877	76.76067507	-6.453546915	1^{st}
11.3	9.101314997	76.92211925	-6.230768263	2^{nd}
11.4	8.519387855	76.93952299	-6.156901291	4^{th}

Table 21 The set of non-inferior solutions for the case of the sampling plan n=10 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{0}, \mathbf{3})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.1	9.77129749	76.39178637	-6.877317149	3^{rd}
11.2	9.540285505	76.76034678	-6.44908508	1^{st}
11.3	9.102048908	76.92205548	-6.229927306	2^{nd}
11.4	8.519511692	76.9395123	-6.156760703	4^{th}

Table 22 The set of non-inferior solutions for the case of the sampling plan n=10 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{1}, \mathbf{3})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.8	12.18375682	77.09782023	-6.466255673	4th
10.9	12.09350013	77.53273739	-5.878449542	1st
11	11.65217974	77.67550697	-5.65486333	2nd
11.1	11.02499717	77.64548605	-5.62143552	3rd

Table 23 The set of non-inferior solutions for the case of the sampling plan n=10 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{1}, \mathbf{4})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.8	12.26386554	77.09026018	-6.369701878	4th
10.9	12.11019388	77.53104214	-5.85835768	1st
11	11.65511223	77.67520438	-5.651359889	2nd
11.1	11.02543349	77.64544172	-5.62091966	3rd

Table 24 The set of non-inferior solutions for the case of the sampling plan n=10 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{2}, \mathbf{3})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	13.26242657	77.87013541	-6.113472421	3rd
10.8	13.10326887	78.01733228	-5.546749215	1st
10.9	12.55039299	77.98963025	-5.420989624	2nd

Table 25 The set of non-inferior solutions for the case of the sampling plan n=10 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{2}, \mathbf{4})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	13.57646639	77.83578515	-5.728152316	2nd
10.8	13.18213576	78.00853039	-5.45019542	1st

10.9	12.56695834	77.9878066	-5.400897762	3rd

Table 26 The set of non-inferior solutions for the case of the sampling plan n=10 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{3}, \mathbf{4})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.6	14.33949263	78.15612992	-5.667376398	2nd
10.7	13.95437091	78.21368967	-5.349963065	1st
10.8	13.32410365	78.15049828	-5.308036399	3rd

Table 27 The set of non-inferior solutions for the case of the sampling plan n=15 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{0}, \mathbf{1})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	8.744479718	76.41928726	-7.294068097	4th
11.3	8.736985786	76.71593105	-6.605187458	2nd
11.4	8.347186725	76.8231002	-6.325299884	1st
11.5	7.758694927	76.80175157	-6.255269059	3rd

Table 28 The set of non-inferior solutions for the case of the sampling plan n=15 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{0}, \mathbf{2})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	9.142436937	76.38809215	-6.84076428	3rd
11.3	8.871735463	76.70473266	-6.451686605	1st
11.4	8.389062904	76.81957049	-6.277889096	2nd
11.5	7.770678497	76.80075482	-6.241826845	4th

Table 29 The set of non-inferior solutions for the case of the sampling plan n=15 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{0}, \mathbf{3})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE

11.1	9.157758964	75.79076508	-7.483816658	5th
11.2	9.156596674	76.38698219	-6.824528632	3rd
11.3	8.874463958	76.70450591	-6.448571601	1st
11.4	8.389527443	76.81953134	-6.277362808	2nd
11.5	7.770748677	76.80074899	-6.241748107	4th

Table 30 The set of non-inferior solutions for the case of the sampling plan n=15 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{1}, \mathbf{2})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11	11.13211418	77.45151326	-6.213513937	3rd
11.1	10.84852833	77.55049018	-5.799741391	1st
11.2	10.24449243	77.49014764	-5.735878891	2nd

Table 31 The set of non-inferior solutions for the case of the sampling plan n=15 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{1}, \mathbf{3})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.45855927	76.99695957	-6.52013588	4th
11	11.3775661	77.42731479	-5.922886479	1st
11.1	10.91122914	77.54423525	-5.725828834	2nd
11.2	10.25840192	77.48878744	-5.719643243	3rd

Table 32 The set of non-inferior solutions for the case of the sampling plan n=15 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{1}, \mathbf{4})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.54990293	76.98859681	-6.411374261	4th
11	11.39463373	77.42563214	-5.902589276	1st
11.1	10.91387843	77.54397096	-5.722702448	2nd
11.2	10.25874674	77.48875372	-5.719240666	3rd

Table 33 The set of non-inferior solutions for the case of the sampling plan n=15 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{2}, \mathbf{3})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.8	12.40218186	77.72568937	-6.312950355	3rd
10.9	12.34760583	77.88600613	-5.630515426	1st
11	11.79631618	77.84606487	-5.503233813	2nd

Table 34 The set of non-inferior solutions for the case of the sampling plan n=15 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{2}, \mathbf{4})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.8	12.79389989	77.68442364	-5.839468984	2nd
10.9	12.43759694	77.87629082	-5.521753807	1st
11	11.81326494	77.84426335	-5.48293661	3rd

Table 35 The set of non-inferior solutions for the case of the sampling plan n=15 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{3}, \mathbf{4})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.7	13.44030909	78.004418	-5.914977208	3rd
10.8	13.20034592	78.09086967	-5.432521854	1st
10.9	12.58096026	78.01965413	-5.378079369	2nd

Table 36 The set of non-inferior solutions for the case of the sampling plan n=20 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{0}, \mathbf{1})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	8.405659994	76.51153815	-6.941653628	3rd
11.4	8.184904886	76.70733943	-6.482698061	1st
11.5	7.676400607	76.73992795	-6.329197102	2nd
11.6	7.022580119	76.66877679	-6.328003508	4th

Table 37 The set of non-inferior solutions for the case of the sampling plan n=20and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{0}, \mathbf{2})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	8.753126819	76.031185	-7.225249485	4th
11.3	8.645135666	76.49251677	-6.670303649	2nd
11.4	8.259910745	76.70117058	-6.397997562	1st
11.5	7.697967041	76.73815734	-6.305036827	3rd

Table 38 The set of non-inferior solutions for the case of the sampling plan n=20 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{0}, \mathbf{3})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	8.787386522	76.02871098	-7.186211357	4th
11.3	8.651838223	76.49198439	-6.662679231	1st
11.4	8.261062202	76.70107588	-6.39669571	2nd
11.5	7.698141892	76.73814298	-6.304840879	3rd

Table 39 The set of non-inferior solutions for the case of the sampling plan n=20 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{1}, \mathbf{2})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.1	10.61357049	77.4250351	-6.040739284	1st
11.2	10.1637556	77.44181378	-5.810152878	2nd

Table 40 The set of non-inferior solutions for the case of the sampling plan n=20 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{1}, \mathbf{3})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11	11.01133371	77.11539346	-6.287607158	3rd
11.1	10.76062865	77.41072445	-5.868072466	1st
11.2	10.1972451	77.43856956	-5.771114749	2nd

Table 41 The set of non-inferior solutions for the case of the sampling plan n=20 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{1}, \mathbf{4})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11	11.06566177	77.11034998	-6.223393792	2nd
11.1	10.76941823	77.40986911	-5.857725789	1st
11.2	10.19842084	77.43845566	-5.769743438	3rd

Table 42 The set of non-inferior solutions for the case of the sampling plan n=20 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{2}, \mathbf{3})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.94056178	77.71513527	-6.068296461	3rd
11	11.68716532	77.79122507	-5.610220254	1st
11.1	11.05264501	77.70274081	-5.575079744	2nd

Table 43 The set of non-inferior solutions for the case of the sampling plan n=20 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{2}, \mathbf{4})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	12.20852788	77.68717252	-5.746797985	1st
11	11.74088638	77.78557459	-5.546006889	2nd

Table 44 The set of non-inferior solutions for the case of the sampling plan n=20 and $(\mathbf{d_1}, \mathbf{d_2}) = (\mathbf{3}, \mathbf{4})$

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.8	12.87093703	77.96007474	-5.788951635	2nd
10.9	12.50780416	77.98644881	-5.446779763	1st

Appendix D

Appendix D contains the sets of non-inferior solutions for the sensitivity analysis case conducted on chapter six, "multi-objective process targeting model with sampling plan error-prone inspection system". The sensitivity analysis conducted on that chapter is on 48 different combinations of type I and type II errors.

Tables from 1 to 7 give the set non-inferior solutions seven different probabilities of type II error, while type I error probability is $\boldsymbol{e_1}$**= 0**

Table 1 The set of non-inferior solutions $\boldsymbol{e_2}$= 0

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.83636534	77.55884946	-6.18650541	3rd
11	11.58010795	77.68294383	-5.740859358	1st
11.1	11.00730867	77.64728356	-5.64234248	2nd

Table 2 The set of non-inferior solutions $\boldsymbol{e_2}$= 0.01

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.85324691	77.56727199	-6.168226926	3rd
11	11.58629229	77.68676201	-5.734287174	1st
11.1	11.00942879	77.64882447	-5.640134637	2nd

Table 3 The set of non-inferior solutions $\boldsymbol{e_2}$= 0.05

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.91874836	77.60042383	-6.097352844	3rd
11	11.61030315	77.70174185	-5.708796153	1st

11.1	11.01766782	77.65485607	-5.631562559	2nd

Table 4 The set of non-inferior solutions e_2= 0.1

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.9961083	77.6406154	-6.0137623	2nd
11	11.6386958	77.7197957	-5.6787105	1st
11.1	11.0274275	77.6620953	-5.6214258	3rd

Table 5 The set of non-inferior solutions e_2= 0.15

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	12.06851167	77.67936055	-5.935666905	2nd
11	11.66530939	77.73708494	-5.650573686	1st
11.1	11.03659453	77.66899603	-5.611923423	3rd

Table 6 The set of non-inferior solutions e_2= 0.2

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.8	12.14222604	77.48589247	-6.58944645	4th
10.9	12.13602774	77.7165932	-5.86299356	2nd
11	11.69016788	77.75358872	-5.62435584	1st
11.1	11.04517588	77.67555278	-5.60304672	3rd

Table 7 The set of non-inferior solutions e_2= 0.25

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.8	12.30080469	77.55808261	-6.416513524	4th
10.9	12.19872859	77.75224463	-5.795662874	1st
11	11.71329611	77.76928571	-5.60002589	2nd

11.1	11.05317866	77.68176014	-5.594786633	3rd

Tables from 8 to 14 give the set non-inferior solutions seven different probabilities of type II error, while type I error probability is e_1= **0.01**

Table 8 The set of non-inferior solutions e_2= 0

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.30587	77.31458	-6.76223	4th
11	11.2433	77.49357	-6.10149	2nd
11.1	10.79213	77.50691	-5.8691	1st
11.2	10.15981	77.42343	-5.83446	3rd

Table 9 The set of non-inferior solutions e_2= 0.01

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.32838	77.32427	-6.73778	4th
11	11.25277	77.4985	-6.0913	1st
11.1	10.79609	77.50928	-5.86489	2nd
11.2	10.1615	77.42454	-5.83269	3rd

Table 10 The set of non-inferior solutions e_2= 0.05

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.41626	77.36259	-6.64233	4th
11	11.28985	77.51799	-6.05142	1st
11.1	10.81166	77.51867	-5.84837	2nd
11.2	10.16814	77.42895	-5.82571	3rd

Table 11 The set of non-inferior solutions e_2= 0.1

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE

10.9	11.5213	77.40952	-6.52825	4th
11	11.33443	77.54181	-6.00353	1st
11.1	10.83051	77.53017	-5.82838	2nd
11.2	10.17625	77.43437	-5.81721	3rd

Table 12 The set of non-inferior solutions e_2= 0.15

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.62105	77.45531	-6.41996	3rd
11	11.37704	77.56504	-5.95779	1st
11.1	10.84867	77.5414	-5.80914	2nd
11.2	10.18414	77.43969	-5.80895	4th

Table 13 The set of non-inferior solutions e_2= 0.2

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.71557	77.49992	-6.31742	3rd
11	11.41772	77.58764	-5.9142	1st
11.1	10.86617	77.55236	-5.79063	2nd

Table 14 The set of non-inferior solutions e_2= 0.25

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
10.9	11.80492	77.54329	-6.22057	2nd
11	11.45647	77.6096	-5.87272	1st
11.1	10.88299	77.56304	-5.77285	3rd

Tables from 14 to 21 give the set non-inferior solutions seven different probabilities of type II error, while type I error probability is e_1**= 0.05**

Table 15 The set of non-inferior solutions e_2= 0

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.1	8.427359	76.52136	-8.40026	2nd
11.2	8.14389	76.52859	-7.98265	1st
11.3	7.641951	76.45911	-7.80053	3rd
11.4	7.013931	76.34143	-7.7548	4th

Table 16 The set of non-inferior solutions e_2= 0.01

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.1	8.440416	76.52562	-8.38642	2nd
11.2	8.150784	76.53097	-7.97534	1st
11.3	7.645589	76.4604	-7.79668	3rd
11.4	7.015833	76.34211	-7.7528	4th

Table 17 The set of non-inferior solutions e_2= 0.05

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.1	8.492287	76.54263	-8.33141	2nd
11.2	8.178235	76.54047	-7.94624	1st
11.3	7.660102	76.46557	-7.78135	3rd
11.4	7.023429	76.34484	-7.74482	4th

The 18 the set of non-inferior solutions e_2= 0.1

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11	8.573064	76.47001	-8.96787	4th
11.1	8.556324	76.56379	-8.26344	2nd
11.2	8.212275	76.55231	-7.91013	1st
11.3	7.678155	76.47202	-7.76227	3rd

11.4	7.032898	76.34826	-7.73486	5th

Table 19 The set of non-inferior solutions e_2= 0.15

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11	8.691677	76.50659	-8.84235	4th
11.1	8.619473	76.58486	-8.19635	2nd
11.2	8.246012	76.56411	-7.87434	1st
11.3	7.696111	76.47845	-7.74329	3rd
11.4	7.042337	76.35167	-7.72493	5th

Table 20 The set of non-inferior solutions e_2= 0.2

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11	8.807857	76.54295	-8.71917	4th
11.1	8.681736	76.60582	-8.13014	1st
11.2	8.279445	76.57587	-7.83885	2nd
11.3	7.71397	76.48488	-7.7244	3rd
11.4	7.051748	76.35508	-7.71503	5th

Table 21 The set of non-inferior solutions e_2= 0.25

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11	8.921619	76.57907	-8.59834	3rd
11.1	8.743116	76.62668	-8.06482	1st
11.2	8.312576	76.5876	-7.80366	2nd
11.3	7.731732	76.49129	-7.70562	4th
11.4	7.061129	76.35848	-7.70516	5th

Tables from 22 to 28 give the set non-inferior solutions seven different probabilities of type II error, while type I error probability is $\boldsymbol{e_1}$= **0.1**

Table 22 The set of non-inferior solutions $\boldsymbol{e_2}$= 0

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	1.551619	74.89266	-14.5677	1st
11.3	1.340049	74.86548	-14.0983	2nd
11.4	0.880425	74.78455	-13.865	3rd
11.5	0.271272	74.67018	-13.7753	4th
11.6	-0.42587	74.53588	-13.7705	5th

Table 23 The set of non-inferior solutions $\boldsymbol{e_2}$= 0.01

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	1.566841	74.89559	-14.5535	1st
11.3	1.348401	74.86711	-14.0905	2nd
11.4	0.884912	74.78542	-13.8608	3rd
11.5	0.273618	74.67064	-13.7731	4th
11.6	-0.42469	74.5361	-13.7694	5th

Table 24 The set of non-inferior solutions $\boldsymbol{e_2}$= 0.05

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	1.627573	74.90733	-14.4968	1st
11.3	1.381762	74.87364	-14.0593	2nd
11.4	0.902846	74.78893	-13.844	3rd
11.5	0.283001	74.67246	-13.7644	4th

Table 25 The set of non-inferior solutions e_2= 0.1

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	1.703138	74.92199	-14.4262	1st
11.3	1.42335	74.8818	-14.0203	2nd
11.4	0.925229	74.79332	-13.8231	3rd
11.5	0.294719	74.67473	-13.7534	4th

Table 26 The set of non-inferior solutions e_2= 0.15

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	1.778315	74.93663	-14.3558	1st
11.3	1.464814	74.88995	-13.9814	2nd
11.4	0.947575	74.7977	-13.8022	3rd
11.5	0.306427	74.67701	-13.7425	4th

Table 27 The set of non-inferior solutions e_2= 0.2

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.1	1.89618	74.93871	-14.9167	2nd
11.2	1.853107	74.95126	-14.2856	1st
11.3	1.506154	74.8981	-13.9425	3rd
11.4	0.969883	74.80209	-13.7813	4th
11.5	0.318125	74.67928	-13.7316	5th

Table 28 The set of non-inferior solutions e_2= 0.25

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.1	2.027957	74.96406	-14.7938	2nd
11.2	1.927512	74.96587	-14.2158	1st
11.3	1.54737	74.90624	-13.9038	3rd

11.4	0.992154	74.80647	-13.7604	4th
11.5	0.329812	74.68156	-13.7207	5th

Tables from 29 to 35 give the set non-inferior solutions seven different probabilities of type II error, while type I error probability is $\boldsymbol{e_1}$**= 0.15**

Table 29 The set of non-inferior solutions $\boldsymbol{e_2}$= 0

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-10.7319	73.0165	-24.0286	1st
11.4	-11.0358	72.96396	-23.6728	2nd
11.5	-11.5814	72.87685	-23.4954	3rd
11.6	-12.2705	72.76909	-23.4248	4th
11.7	-13.0419	72.64951	-23.4158	5th

Table 30 The set of non-inferior solutions $\boldsymbol{e_2}$= 0.01

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-10.7173	73.01833	-24.0181	1st
11.4	-11.0279	72.96495	-23.6671	2nd
11.5	-11.5773	72.87737	-23.4924	3rd
11.6	-12.2684	72.76935	-23.4233	4th
11.7	-13.0408	72.64964	-23.4151	5th

Table 31 The set of non-inferior solutions $\boldsymbol{e_2}$= 0.05

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	-10.6924	73.02998	-24.5776	3rd
11.3	-10.659	73.02567	-23.9761	1st
11.4	-10.9963	72.96891	-23.6443	2nd

11.5	-11.5606	72.87943	-23.4804	4th
11.6	-12.2599	72.77039	-23.4172	5th
11.7	-13.0367	72.65014	-23.4121	6th

Table 32 The set of non-inferior solutions e_2= 0.1

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	-10.5617	73.04641	-24.4842	3rd
11.3	-10.5863	73.03485	-23.9236	1st
11.4	-10.9569	72.97385	-23.6158	2nd
11.5	-11.5399	72.882	-23.4654	4th
11.6	-12.2493	72.77168	-23.4096	5th
11.7	-13.0315	72.65076	-23.4084	6th

Table 33 The set of non-inferior solutions e_2= 0.15

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	-10.4316	73.06281	-24.391	2nd
11.3	-10.5137	73.04401	-23.8712	1st
11.4	-10.9174	72.9788	-23.5873	3rd
11.5	-11.5191	72.88458	-23.4505	4th
11.6	-12.2387	72.77298	-23.402	5th

Table 34 The set of non-inferior solutions e_2= 0.2

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	-10.302	73.0792	-24.2979	2nd
11.3	-10.4413	73.05317	-23.8189	1st
11.4	-10.8781	72.98375	-23.5588	3rd
11.5	-11.4983	72.88716	-23.4356	4th

11.6	-12.2282	72.77427	-23.3945	5th

Table 35 The set of non-inferior solutions e_2= 0.25

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	-10.1729	73.09558	-24.2049	1st
11.3	-10.3691	73.06233	-23.7666	2nd
11.4	-10.8388	72.98869	-23.5304	3rd
11.5	-11.4776	72.88973	-23.4206	4th
11.6	-12.2176	72.77556	-23.3869	5th

Tables from 36 to 42 give the set non-inferior solutions seven different probabilities of type II error, while type I error probability is e_1**= 0.2**

Table 36 The set of non-inferior solutions e_2= 0

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-30.857	70.89631	-35.9077	1st
11.4	-31.0009	70.87233	-35.5081	2nd
11.5	-31.5113	70.81087	-35.2901	3rd
11.6	-32.24	70.72705	-35.1817	4th
11.7	-33.0941	70.63042	-35.1368	5th
11.8	-34.0177	70.52676	-35.1275	6th

Table 37 The set of non-inferior solutions e_2= 0.01

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-30.8333	70.89848	-35.8963	1st
11.4	-30.988	70.87351	-35.5018	2nd
11.5	-31.5045	70.81149	-35.2868	3rd
11.6	-32.2365	70.72736	-35.18	4th

11.7	-33.0924	70.63057	-35.136	5th
11.8	-34.0169	70.52683	-35.1271	6th

Table 38 The set of non-inferior solutions e_2= 0.05

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-30.7384	70.90717	-35.8504	1st
11.4	-30.9364	70.8782	-35.4767	2nd
11.5	-31.4773	70.81394	-35.2735	3rd
11.6	-32.2226	70.72859	-35.1733	4th
11.7	-33.0856	70.63117	-35.1327	5th
11.8	-34.0136	70.52711	-35.1256	6th

Table 39 The set of non-inferior solutions e_2= 0.1

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-30.62	70.91803	-35.793	1st
11.4	-30.872	70.88406	-35.4454	2nd
11.5	-31.4433	70.81699	-35.257	3rd
11.6	-32.2053	70.73013	-35.1649	4th
11.7	-33.077	70.63192	-35.1286	5th
11.8	-34.0096	70.52746	-35.1236	6th

Table 40 The set of non-inferior solutions e_2= 0.15

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-30.5019	70.92887	-35.7356	1st
11.4	-30.8077	70.88992	-35.414	2nd
11.5	-31.4093	70.82005	-35.2405	3rd
11.6	-32.1879	70.73168	-35.1565	4th

11.7	-33.0685	70.63267	-35.1245	5th
11.8	-34.0055	70.52781	-35.1217	6th

Table 41 The set of non-inferior solutions e_2= 0.2

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-30.3841	70.9397	-35.6783	1st
11.4	-30.7434	70.89578	-35.3827	2nd
11.5	-31.3754	70.82311	-35.224	3rd
11.6	-32.1706	70.73322	-35.1481	4th
11.7	-33.0599	70.63342	-35.1204	5th
11.8	-34.0015	70.52816	-35.1198	6th

Table 42 The set of non-inferior solutions e_2= 0.25

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.2	-30.2554	70.95692	-36.0899	3rd
11.3	-30.2665	70.95052	-35.6209	1st
11.4	-30.6793	70.90163	-35.3513	2nd
11.5	-31.3415	70.82617	-35.2075	4th
11.6	-32.1533	70.73476	-35.1397	5th
11.7	-33.0514	70.63416	-35.1163	6th

Tables from 43 to 49 give the set non-inferior solutions seven different probabilities of type II error, while type I error probability is e_1**= 0.25**

Table 43 The set of non-inferior solutions e_2= 0

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.4	-63.3472	68.26897	-47.6209	1st

11.5	-63.8471	68.23486	-47.4011	2nd
11.6	-64.6769	68.17417	-47.2796	3rd
11.7	-65.6964	68.09827	-47.2154	4th
11.8	-66.821	68.014	-47.1833	5th
11.9	-68.0015	67.92534	-47.1687	6th
12	-69.2104	67.83445	-47.1636	7th
12.1	-70.4332	67.74247	-47.1635	8th

Table 44 The set of non-inferior solutions e_2= 0.01

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.4	-63.3263	68.27051	-47.6149	1st
11.5	-63.8361	68.23566	-47.3979	2nd
11.6	-64.6713	68.17457	-47.278	3rd
11.7	-65.6936	68.09846	-47.2146	4th
11.8	-66.8197	68.0141	-47.1829	5th
11.9	-68.0009	67.92538	-47.1686	6th
12	-69.2101	67.83446	-47.1635	7th

Table 45 The set of non-inferior solutions e_2= 0.05

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-63.2086	68.27261	-47.9479	3rd
11.4	-63.2427	68.27664	-47.5908	1st
11.5	-63.792	68.23887	-47.3852	2nd
11.6	-64.6487	68.17619	-47.2715	4th
11.7	-65.6825	68.09925	-47.2114	5th
11.8	-66.8144	68.01447	-47.1814	6th
11.9	-67.9984	67.92555	-47.1679	7th

12	-69.2091	67.83454	-47.1632	8th

Table 46 The set of non-inferior solutions e_2= 0.1

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-63.017	68.28679	-47.893	3rd
11.4	-63.1384	68.2843	-47.5606	1st
11.5	-63.7369	68.24287	-47.3693	2nd
11.6	-64.6206	68.17821	-47.2634	4th
11.7	-65.6687	68.10023	-47.2075	5th
11.8	-66.8078	68.01493	-47.1796	6th
11.9	-67.9954	67.92576	-47.167	7th
12	-69.2077	67.83463	-47.1628	8th

Table 47 The set of non-inferior solutions e_2= 0.15

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-62.8259	68.30094	-47.8381	2nd
11.4	-63.0341	68.29195	-47.5305	1st
11.5	-63.6818	68.24687	-47.3533	3rd
11.6	-64.5924	68.18023	-47.2553	4th
11.7	-65.6548	68.10122	-47.2035	5th
11.8	-66.8012	68.01539	-47.1777	6th
11.9	-67.9924	67.92597	-47.1662	7th
12	-69.2064	67.83472	-47.1625	8th

Table 48 The set of non-inferior solutions e_2= 0.2

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-62.6352	68.31508	-47.7831	2nd

11.4	-62.93	68.2996	-47.5004	1st
11.5	-63.6267	68.25087	-47.3374	3rd
11.6	-64.5643	68.18225	-47.2473	4th
11.7	-65.6409	68.1022	-47.1996	5th
11.8	-66.7946	68.01585	-47.1758	6th
11.9	-67.9894	67.92617	-47.1653	7th
12	-69.2051	67.83481	-47.1621	8th

Table 49 The set of non-inferior solutions e_2= 0.25

T	PROFIT	INCOME	UNIFORMITY	PREFERENCE
11.3	-62.4449	68.32919	-47.7281	1st
11.4	-62.8261	68.30724	-47.4702	2nd
11.5	-63.5717	68.25487	-47.3215	3rd
11.6	-64.5362	68.18427	-47.2392	4th
11.7	-65.6271	68.10319	-47.1956	5th
11.8	-66.7881	68.01631	-47.174	6th
11.9	-67.9864	67.92638	-47.1645	7th
12	-69.2037	67.8349	-47.1617	8th

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