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An Insight into Operations Research

Applications in Logistics and Supply Chain Management

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The purpose of this thesis was to understand the subject of operations research (OR) and its applications from a logistics and supply chain management point of view and to examine the underlying principles of the different optimization techniques by giving more emphasis to the nature, assumptions and formulation of linear programming upon which most other optimization techniques are based.

Logistics costs account for a significant portion of a company’s costs. By optimizing the activities associated with supply chain and logistics, it is possible to bring huge financial benefits and maintain good customer relations. This thesis discussed different real life cases and success stories obtained by implementing OR.

This paper has examined what the role of an operations research team or professional is in a time when optimization software is abundant and discussed why understanding an operations research approach to optimizing operations is still relevant for logistics and supply chain management students and professionals.

The nature of the thesis was predominantly an exploratory research of a topic that is well established in the curricula of many higher education institutions. As a result the materials used for this thesis are mainly text books. Online resources were also utilized to provide updated information and cases to support the theories.

Keywords	Operations research, linear programming, optimization, logistics, supply chain

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1 Introduction

Logistics is defined in a variety of ways depending on different viewpoints, personal experience and context. But it remains an operative activity of any company. Operations research (also known as Management science) provides mathematical and analytical methods to support decisions that affect operative activities. It uses, as the name suggests, an approach that is to some extent similar to the way scientific research is carried out. (Hillier & Lieberman, 2010: 2)

Using operations research, factors of a given business problem are formulated into a mathematical model for finding the best (optimal) solution. In warehouse management, for example, the different decision factors are: the business objective (for example, maximize profit/minimize cost), storage and transportation capacity and the costs associated with them. Operations research can also be used to formulate a variety of business problems in a variety of industries.

Logistics is widely accepted to be a combination of supply, materials management and distribution activities but the definitions and names associated with it vary because of the diversity and flexibility needed to adapt to different constraints and environment. Some of the names and terms are:

- Physical distribution
- Business logistics
- Materials management
- Procurement and supply
- Product flow
- Marketing logistics
- Supply chain management

and several more. (Rushton;Oxlay;& Croucher, 2005: 4)

The definitions given to logistics have military, economic and other biases. The following two definitions, however, provide emphasis on the business context which matches the scope of this paper.

> Logistics is the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. This definition includes inbound, outbound, internal, and external movements.
>
> (Council of Supply Chain Management Profesionals , 2010)

> ...the identification and management of suppliers, procurement and order processing, and physical supply of materials and services from the source of supply to the manufacturer or producer; the materials handling and inventory management of materials and services during and throughout the manufacturing process; and the subsequent transportation and physical distribution of products from the manufacturer to the ultimate consumer (i.e., customer).

(Blanchard, 2004: 4)

1.1 Objectives and Scope of the Study

The objective of this paper is to investigate the application of the operations research methods that can be applied in logistics and supply chain optimization. The development of linear programming, one of the operation research optimization techniques, has brought huge success for many firms in many industries. An insight in to the nature, formulation, and application of this tool will help understand the whole idea of operations research method. As a result more emphasis will be given to linear programming.

In addition, this paper will examine what the role of an operations research team or professional is in a time when optimization software is abundant and discuss why understanding operations research approach to optimizing operations is still relevant for logistics and supply chain management students and professionals.

1.2 Methodology

The nature of the thesis is predominantly an exploratory research of a topic that is well established in the curricula of many higher education institutes. As a result the materials used for this thesis are mainly text books. Online resources are also utilized to provide updated information and cases to support the theories.

2 Key activities in logistics and supply chain

Logistics executives have to make key decisions concerning inventory management, scheduling, transportation, distribution centers, packaging, import export regulations, documentations and others.

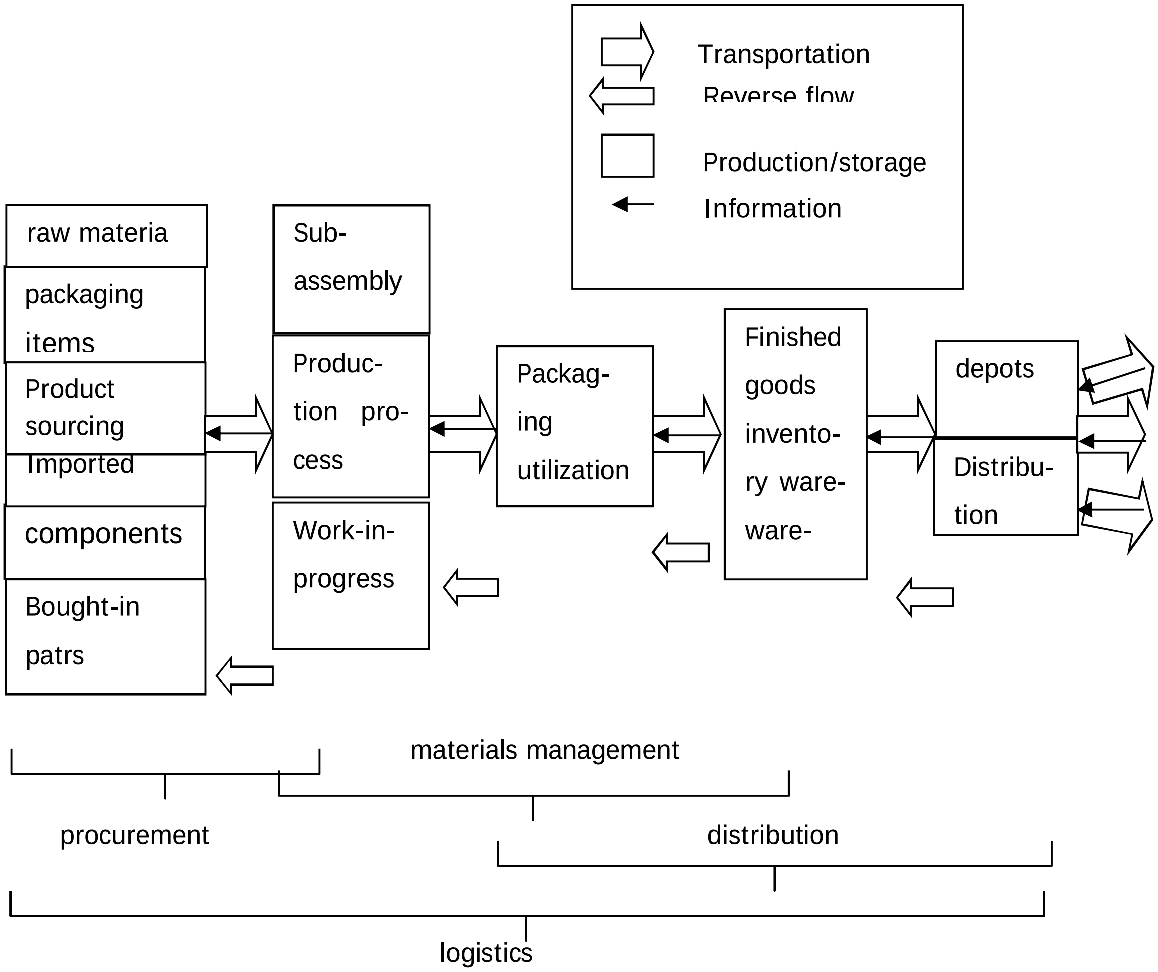

Figure 1. A logistics configuration showing the key components of logistics and the importance of physical flows and information flows. Modified from (Rushton;Oxlay;& Croucher, 2005: 5).

Inventory Management is important because a number of reasons such as consumer behavior and seasonal changes that make it impossible to precisely predict the exact amount that a manufacturer should manufacture to meet the demand of the market without incurring a storage cost or without damaging customer relations. Therefore firms must produce and store a buffer stock to meet fluctuations in demand. But since keeping a buffer stock comes with a cost, firms must decide how much or how many of each product should be stored so that the overall cost of keeping an inventory remains minimal. (Bloomberg;LeMay;& Hanna, 2002: 135)

Transportation is another element of the logistics activity which plays a key role by allowing safe and efficient distribution of goods and services throughout the supply chain. It makes a link between the various logistics and supply chain activities and allows the flow of raw materials in to warehouses and plants plus the outflow of finished products to distribution centers and ultimately to customers. (Bloomberg;LeMay;& Hanna, 2002: 118).

Distribution refers to the activities associated with moving materials from source to destination. It can be associated with movement from a manufacturer or distributor to customers, retailers or other secondary warehousing or distribution points. (Council of Supply Chain Management Profesionals , 2010).

This paper will examine whether mathematical modeling can be used in the above mentioned components of logistics activities. The figure above illustrates the key components of logistics and importance of physical flow and information flow.

3 The role of logistics in a firm’s operation

The elements of logistics, transportation, distribution, and warehousing, have always been among the most important activities of any manufacturing or other type of firm. It is, however, comparatively recently that firms started to see it as a separate function of any business operation. It was in the 1960s and early 1970s that managers started to recognize the relationship between different physical activities such as transportation, storage, materials handling and packaging. (Rushton;Oxlay;& Croucher, 2005: 7).

In the current business environment a properly integrated management of these physical activities and other activities of the firm is mandatory to succeed in any industry.

The role and management of logistics and supply chain has changed over the years with the help of modern computing and information technology plus improved infrastructure for transportation and storage of goods, and for flow of information. A good logistics management ensures a good relationship with material suppliers and customers. It can be safely assumed that customer satisfaction is among the very important competitive advantages for any given firm. Since the 1960s and 70s companies have established marketing departments to understand customer needs and to help design products and services according to the needs of the customer. Cost and availability are two of the most important customer needs.

Logistics costs are recorded and monitored separately and continuously by only a minority of companies. Whereas in a given industry, the total cost of logistics ranges between 5 and 15% of total turnover, in trade companies they can make up between 10 and 25% of turnover. For retailers, the cost of logistics can account for more than one third of the profit margin. (Gudehus & Kotzab, 2012: 129).

Nowadays any improvement of warehouse performance, transportation and distribution might bring a competitive advantage for the company in respect to highly competitive logistics market. In this paper we will examine how these improvements in key logistics activities could be achieved by applying operations research approach.

4 The Concept of Optimization

Optimization is defined as:
An act, process, or methodology of making something (as a design, system, or decision) as fully perfect, functional, or effective as possible; specifically: the mathematical procedures (as finding the maximum of a function) involved in this (Merriam-Webster Dictionary, 2013). As Belegundu and Chandrupatla (1999: 1) discussed “nature has an abundance of examples where an optimal system status is sought… Tall trees form ribs near the base to strengthen them in bending. The honeycomb structure is one of the

most compact packing arrangements.” Belegundu and Chandrupatla further discussed that like nature, organizations and businesses have also strived for perfection (Belegundu et al. 1999: 1). Solutions for most management problems have been based on experience and knowledge. However, for example, as discussed above logistics costs account for a considerably high percentage of a firm’s turnover. A small saving in such activities of a given organization results in high savings. This means in a competitive market which is driven by consumer demand, it is more preferable to obtain an optimal solution rather than just a feasible one.

Ratliff states on the Georgia Tech website that “supply chain and logistics optimization is neither easy nor cheap but it is the biggest opportunity for most companies to significantly reduce their cost and improve their performance.” (Ratliff, 2013: 1). To show how important optimization could be in reducing logistics cost Ratliff added that “for most supply chain and logistics operations there is an opportunity to reduce cost by 10% to 40% by making better decisions” (Ratliff, 2013: 1).

Luenberger argues that it is a rare situation that when faced with complex decision situation, all the complexities of variable interactions, constraints, and appropriate objectives can be fully represented. As a result, a particular optimization formulation should be considered as an approximation (Luenberger, 2003: 1). On the other hand, from his over 30 years’ experience of developing and implementing supply chain and logistics technologies, Ratliff finds the following ten rules ‘essential’ requirements of success in supply chain and logistics optimization.

1. Objectives - must be quantified and measureable
2. Models – must faithfully represent required logistics process
3. Variability – must be explicitly considered
4. Data – must be accurate, timely, and comprehensive
5. Integration – must support fully automated data transfer
6. Delivery – must provide results in a form that facilitates execution, management and control
7. Algorithms – must intelligently exploit individual problem structure
8. People – must have the domain and technology expertise required to support the models, data, and optimization engines

9. Process – must support optimization and have the ability to continuously improve
10. ROI – must be provable considering the total cost of technology, people and operations

    (Ratliff, 2013: 1-3). A detailed description of the above ten rules is provided in appendix 1.

5 Operations Research and Optimization Techniques

Operations research, as defined in Merriam-Webster dictionary, is the application of scientific and especially mathematical methods to the study and analysis of problems involving complex systems —called also operational research (Merriam-Webster Dictionary, 2013).

Operations research (OR) is believed to have started many decades ago when the scientific method was applied to the management of organizations. But the operations research activity started to be applied widely during World War II when the British and American Militaries brought in a number of people to find a scientific way of allocating scarce resources to the different operations of the war. (Hillier & Lieberman, 2010: 1)

After the fundamental role it played in helping win the war, OR teams tried to apply the scientific technique to optimize business operations and tackle other civilian problems and, inevitably, educational institutes introduced operations research in their curricula in the 1950s (Sankara, 2008: 1). Many of the standard tools of OR, such as linear programming, dynamic programming, queuing theory, and inventory theory were relatively developed before the end of the 1950s (Hillier & Lieberman, 2010: 2).

The computer revolution, especially the development of high speed personal computers since the 1980s, was one of the main contributors to the development of operations research (Hillier & Lieberman, 2010). Today in the computer era many of the OR techniques involve complex computations and hence they take a longer time for providing solutions to real life problems. The development of high speed digital computers made it possible to successfully apply some of the operational research techniques to large problems. The development of recent interactive computers made the job of solving large problems even more simple because of human intervention towards sensitivity analysis (Panneerselvam, 2006: 2).

5.1 Scope of Operation Research

The following industrial, business and public problems can be addressed using OR technique

1. Finance and accounting – portfolio management, capital budgeting, etc.
2. Production – production planning, scheduling, procurement of raw materials, warehousing, inventory control, distribution, etc.
3. Personnel – manpower planning, manpower scheduling, etc.
4. Marketing – order bidding decisions, shipping finished goods, product mix problem
5. Defense applications
6. Public system – planning, design and management of public systems like government institutes, postal system, highways etc.
   (Panneerselvam, 2006: 2; Sankara, 2008: 5-6).

5.2 Optimization Techniques

In OR mathematical models, the decision variables may be integer or continuous, and the objective and constraint functions may be linear or nonlinear. The optimization problems posed by these models give rise to a variety of solution methods, each designed to account for the special mathematical properties of the model (Taha, 1997: 3). Linear programming is without a doubt the most natural mechanism for formulating a vast array of problems with modest effort. A linear programming problem is characterized, as the name implies, by linear functions of the unknowns; the objective is linear in the unknowns, and the constraints are linear equations or linear inequalities in the unknowns (Luenberger, 2003: 2).

Other techniques that deal with other types of mathematical models are dynamic programming, integer programming, nonlinear programming, goal programming, and network programming, to mention only a few.

5.3 Operations Research Modeling

In order to understand complex situations in the real world, sometimes physical or mathematical models are built. The models are only representations of the real-world phenomenon but never a complete and accurate representation (Giordano;Fox;Horton;& Weir, 2009: 1). Mathematical techniques make up most of what is known about operations research and in this paper only mathematical models will be discussed. Yet, OR must be viewed as a science and an art. It is a science by virtue of the embodying mathematical techniques it presents, and it is an art because the success of all phases that precede and succeed the solution of the mathematical model depends largely on the creativity and experience of the operations research team (Taha, 1997: 5). In mathematical models algebraic symbolism will be used to mirror the internal relationships in the object being modeled (Williams, 1999: 1). A model simplifies reality and allows us to reach mathematical conclusions about the behavior of real-world problem (Giordano;Fox;Horton;& Weir, 2009: 1-2) as illustrated below.

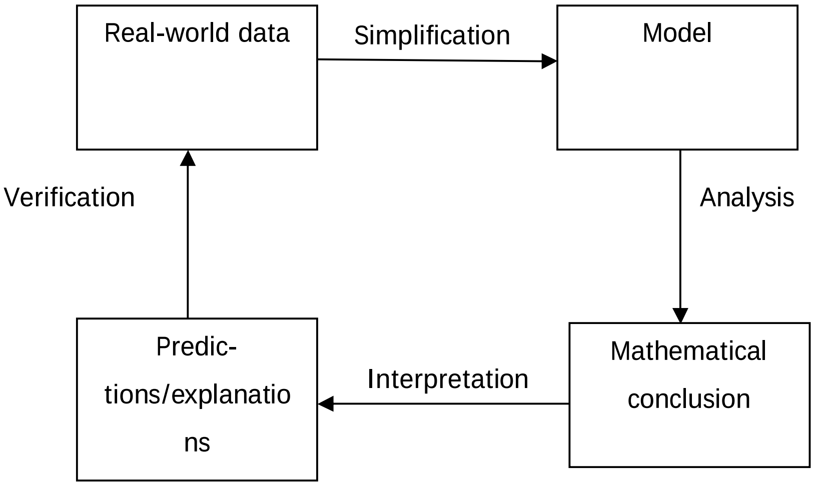

Figure 2. A flow of the modeling process beginning with an examination of real-world data. Modified from (Giordano;Fox;Horton;& Weir, 2009: 1).

OR practice and implementation is carried out in the following general sequence of phases

1. Define the problem and gather relevant data
2. Construct mathematical model to represent the problem
3. Develop procedures to drive solution to the problem
4. Validate the model and refine as needed
5. Implement the solution

   (Hillier & Lieberman, 2010: 8)

Of all the five phases, only phase 3 dealing with model solution is the best defined and the easiest to implement in an OR study because it deals with mostly precise mathematical theory. The implementation of the remaining phases is more an art than a theory (Taha, 1997: 5).

6 Linear Programming

Linear programming (LP) is a mathematical modeling technique designed to optimize the usage of limited resources. It should be pointed out immediately that mathematical programming is very different from computer programming. Mathematical programming is ‘programming’ in the sense of planning (Williams, 1999: 5).

Successful applications of LP exist in the areas of military, industry, agriculture, transportation, economics, health systems, and even behavioral and social sciences (Taha, 1997: 11). Today it is a standard tool that saved many thousands or millions of dollars for many companies or businesses of even moderate size in the various industrialized countries in the world, and its use in other sectors of society has been spreading rapid (Hillier & Lieberman, 2010: 23).

According to Luenburger (2003: 2-3) the popularity of linear programming lies primarily with the formulation phase of analysis rather than the solution phase. For example if one formulates a problem with a budget constraint restricting the total amount of money to be allocated among two different commodities, the budget constraint takes the form $x_1 + x_2 \leq B$, where x_i, i = 1, 2, is the amount allocated to the activity i, and B is the budget. Similarly, if the objective is, for example, maximum weight, then it can be expressed as $w_1x_1 + w_2x_2$, where w_i, i = 1, 2, is the unit weight of the commodity i. The overall problem would be expressed as

$$\begin{aligned} &\text{Maximize } w_1x_1 + w_2x_2 \\ &\text{Subject to } x_1 + x_2 \leq B \\ &\qquad\qquad X_1 \geq 0,\ x_2 \geq 0, \end{aligned}$$

Which is an elementary linear problem. The linearity of the budget constraint is extremely natural in this case and does not represent simply an approximation to a more general functional form. Another reason why linear programming is popular is the fact that any problem whose mathematical description fits the very general format for the linear programming model is a linear programming problem (Hillier & Lieberman, 2010: 23).

6.1 Elements and assumptions of Linear Programming

Linear functions, decision variables, objective function, and constraints are the elements that make up linear programming problems. A linear function has the following form:

$$a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + . . . + a_n x_n = 0$$

Where $a_{i,}$ i = 0, 1, ..., n represent the coefficients also called parameters and x_i, i = 0, 1,...,n represent the variables.
The decisions variables in a linear program are a set of quantities which must be defined and determined in order to solve the problem. The LP problem is solved when the best values of the variables have been found.

Objectives are goals that we aim to optimize. Normally the objective is to maximize or minimize some numerical value which could, for example, be cost of transportation, profit, amount of product produced, etc.

Constraints are the possible values the variables of a linear programming problem that we need to satisfy (Taha, 1997: 12).

The following assumptions are made in linear programming problems.

1. Linearity. The amount of resource required for a given activity level is directly proportional to the level of that activity (Panneerselvam, 2006: 12). For example if the number of containers needed to store 10 units of a certain product is 5, then the number of containers needed to store 20 units of the same product is 10 containers of the same size. This is also referred to as proportionality in many other text books.
2. Divisibility. Decision variables in a linear programming model are allowed to have any values, including noninteger values that satisfy the functionality and non-negativity constraints. Thus this variables are not restricted to just integer values. Since each decision variable represent the level of some activity, it is being assumed that the activities can be run at fractional levels (Hillier & Lieberman, 2010: 41).
3. Non-negativity. This means that the decision variables are permitted to have the values which are greater than or equal to zero.
4. Additivity. This means that the total output for a given levels is the algebric sum of the output of each individual process (Panneerselvam, 2006: 12).

6.2 General Linear Programming Model

In mathematical terms, the linear programming model can be expressed as the maximization (or minimization) of an objective function, subject to a given set of linear constraints. Specifically, the linear programming problem can be described as finding the values of n decision variables, x_1, x_2, . . . , x_n, such that they maximize the objective function z where,

$$z = c_1x_1 + c_2x_2 + \cdot\cdot\cdot + c_nx_n, \tag{1}$$

subject to the following constraints:

$$\begin{array}{c} a_{11}x_1 + a_{12}x_2 + \cdot\cdot\cdot + a_{1n}x_n \leq b_1, \\ a_{21}x_1 + a22x_2 + \cdot\cdot\cdot + a_{2n}x_n \leq b_2, \\ \vdots \qquad\qquad \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \cdot\cdot\cdot + a_{mn}x_n \leq b_m, \end{array} \tag{2}$$

and, usually,

$$x_1 \geq 0,\ x_2 \geq 0,\ .\ .\ .\ ,\ x_n \geq 0, \tag{3}$$

where c_j , a_{ij} , and b_i are given constants.

Linear programming can be applied to solve a variety of problems which can be formulated in the form shown above. It can be said that the application of linear programming is limited only by one’s imagination and creativity. This paper intends to show the application of linear programming in solving problems related to logistics and supply chain management.

The formulation process is carried out by following the following general steeps:

Step 1. Identify the variables
Step 2. Write down the objective function
Step 3. Write down the constraints and,
Step 4. Write down the entire problem
(University of California San Diego, 2013)

The formulation process and the general model discussed above can be better understood with the following example modified from OR – Notes by J E Beasley (Beasley, 2009)

Example:

A cargo plane has three compartments for storing cargo: front, centre and rear. These compartments have the following limits on both weight and space:

Compartment	Weight capacity (tonnes)	Space capacity (cubic metres)
Front	10	6800
Centre	16	8700
Rear	8	5300

Furthermore, the weight of the cargo in the respective compartments must be the same proportion of that compartment's weight capacity to maintain the balance of the plane.

The following four cargoes are available for shipment on the next flight:

Cargo	Weight (tonnes)	Volume (cubic metres/tonne)	Profit (£/tonne)
C1	18	480	310
C2	15	650	380
C3	23	580	350
C4	12	390	285

Any proportion of these cargoes can be accepted. The objective is to determine *how much* (if any) of each cargo C1, C2, C3 and C4 should be accepted and *how to distribute* each among the compartments so that the total profit for the flight is maximized.

Formulation process

1. Identify the variables

It should be decided how much of each of the four cargoes is put in each of the three compartments. Hence let:

x_{ij} be the number of tonnes of cargo i (i=1,2,3,4 for C1, C2, C3 and C4 respectively) that is put into compartment j (j=1 for Front, j=2 for Centre and j=3 for Rear) where $x_{ij} >= 0$ i=1,2,3,4; j=1,2,3

Note here it was allowed to split the cargoes into any proportions (fractions) as needed.

2. Identify constraints

- cannot pack more of each of the four cargoes than is available

$x_{11} + x_{12} + x_{13} \leq 18$

$x_{21} + x_{22} + x_{23} \leq 15$

$x_{31} + x_{32} + x_{33} \leq 23$

$x_{41} + x_{42} + x_{43} \leq 12$

- the weight capacity of each compartment must be respected

$x_{11} + x_{21} + x_{31} + x_{41} \leq 10$

$x_{12} + x_{22} + x_{32} + x_{42} \leq 16$

$x_{13} + x_{23} + x_{33} + x_{43} \leq 8$

- the volume (space) capacity of each compartment must be respected

$480x_{11} + 650x_{21} + 580x_{31} + 390x_{41} \leq 6800$

$480x_{12} + 650x_{22} + 580x_{32} + 390x_{42} \leq 8700$

$480x_{13} + 650x_{23} + 580x_{33} + 390x_{43} \leq 5300$

- the weight of the cargo in the respective compartments must be the same proportion of that compartment's weight capacity to maintain the balance of the plane

$[x_{11} + x_{21} + x_{31} + x_{41}]/10 = [x_{12} + x_{22} + x_{32} + x_{42}]/16 = [x_{13} + x_{23} + x_{33} + x_{43}]/8$

3. Objective

The objective is to maximise total profit, i.e.

maximise $310[x_{11}+ x_{12}+x_{13}] + 380[x_{21}+ x_{22}+x_{23}] + 350[x_{31}+ x_{32}+x_{33}] + 285[x_{41}+ x_{42}+x_{43}]$

The basic assumptions are:

- that each cargo can be split into whatever proportions/fractions desired
- that each cargo can be split between two or more compartments if desired
- that the cargo can be packed into each compartment (for example if the cargo was spherical it would not be possible to pack a compartment to volume capacity, some free space is inevitable in sphere packing)
- all the data/numbers given are accurate

The computations in linear programming, as in most operations research models, are typically voluminous and tedious, and hence require the use of computer (Taha, 1997: 11). According to Beasley, using a software package to solve the above linear program rather than a judgmental approach actually minimizes profit. In addition it makes the cargo loading decision a type which can be solved in a routine operational manner on a computer, rather than having to exercise judgment each and every time a solution is needed. Furthermore, problems that can be appropriately formulated as linear programs are almost always better solved by computers than by people (Beasley, 2009).

6.3 Solving Linear Programming Problems

Linear programming problems can be analyzed and solved by using different techniques and algorithms. In this study the graphical method, the simplex method, and application of computer programs will be discussed briefly.

6.3.1 Graphical Method

The graph of constraints defined in terms of inequalities helps determine the feasible region. The simplest way to draw constraint lines is by connecting horizontal and vertical intercepts of each constraint equation. After the constraint lines are drawn the valid side of the constraints can be determined by substituting coordinates of a point (usually the origin (0,0)) and see if the constraint inequality is satisfied with the values of that coordinate. If the inequality is satisfied with the coordinates of a point, it implies that all other points in the same side also satisfy the inequality and hence are in the feasible region.

The region of the graph which satisfies all constraint inequalities is called the feasible solution region. Any point in this region gives a valid solution to the problem.

The following diagram represents a graphical solution for the following maximization problem.

Maximize R = –2x + 5y, subject to:

100 < x < 200

80 < y < 170

y > –x + 200

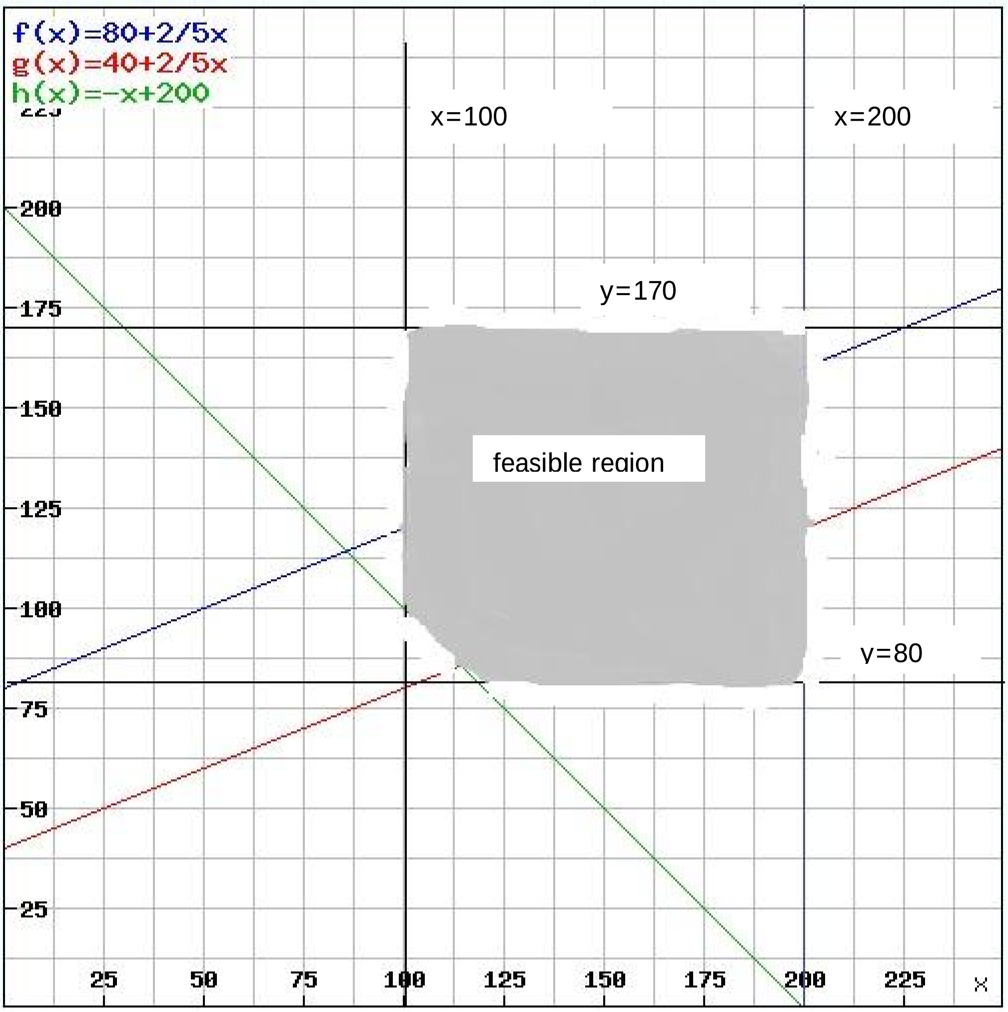

Figure 3. Graphical interpretation of a linear program

The non-negativity assumption discussed earlier states that the decision variables (x and y in the above example) can only have a value which is greater than or equal to zero. Hence the feasible region and the optimal solution will always exist in the first quadrant of the graph.

Once the feasible region is determined the next step of finding the optimal solution is carried out by drawing two lines parallel to the line of the objective function to determining the direction of improvement. Improvement happens in the direction of higher value when the objective function is to maximize, and in the direction of smaller value when the objective function is minimizing the given situation. In the above example we can see that the value of R increases further and further away from the origin (0,0).

The optimal solution always lies at the corners. The last point in the feasible solution region which is touched by a line that is parallel to the two objective function lines is the most attractive corner where the optimal solution lies. It is possible for more than one corner to correspond to the optimal solution. In the example above the optimal solution is the corner that lies at the coordinate (100, 170).

6.3.2 The Simplex Method

The graphical method discussed in the previous section is not applicable in the presence of more than two variables in the problem. Many problems could have much more variables. A different method is used to solve these problems of many variables, namely the simplex method or the simplex algorithm. According to Hillier and Lieberman (2010: 89), the simplex method to solve linear programming problems, which was developed by the American mathematician George Dantzig in 1947, has proved to be a remarkably efficient method that is used routinely to solve huge problems on today’s computers. The simplex method is carried out using computers because the manual solution of a linear programming model using the simplex method can be a lengthy and tedious process.

This method is a general algebraic solution method for solving linear programming problems. In the simplex method, the model formulated is arranged into the form of a table, and then a number of arithmetic operations are carried out on the table. These arithmetic steps in effect are replicas of the solution process in graphical analysis of moving from one feasible solution on the solution region to the other as briefly discussed in the previous section. In the graphical method the optimal solution is found by moving from one feasible solution to the next. But in the simplex method the optimal solution is obtained by iterating from one better solution to the next better solution until ultimately the optimal solution is obtained.

The development of increasingly powerful digital computers since the 1980s literally gave millions of individuals access to software which can be used to solve complex problems (Hillier & Lieberman, 2010: 2). knowledge of the simplex method can greatly enhance one’s understanding of linear programming. Computer software programs like Solver for Windows or Excel spreadsheets provide solutions to linear programming problems, but they do not provide an in-depth understanding of how those solutions are derived (KAZANÇOĞLU, 2010). Demonstration of the lengthy manual calculation of the simplex method can be found in every operations research text book.

6.3.3 Using Software

Linear programming problems can be solved using software. Solver add-in for Microsoft Excel is a good example. Solver can be applied to solve small problems since Excel is used extensively among people working in logistics and almost all other industries. Appendix 2 demonstrates how Solver can be used for simple linear problems. Modeling and manipulating complicated algebraic equations and constraints, however, requires more powerful solutions which will be discussed in the following section.

7 Other Optimization Techniques

There are of course other methods of solving discrete optimization problems as mentioned in section 5.2. Many of them are collectively known as mathematical programming methods. It is beyond the scope of this paper to provide a deep insight of these methods. In this section only basic principles and defining characteristics of selected optimization methods will be discussed briefly.

Dynamic Programming is a method that in general solves optimization problems that involve making a sequence of decisions by determining, for each decision, subproblems that can be solved in like fashion (Lew & Mauch, 2007: 1). In contrast to linear programming, there does not exist a standard mathematical formulation of “the” dynamic programming problem. Rather, dynamic programming is a general type of approach to problem solving, and particular equations used must be developed to fit each situation (Hillier & Lieberman, 2010: 424).

This method is based on Bellman’s Principle of Optimality, as quoted in Lew and Mauch (2007: 5). An optimal policy has the property that whatever the initial state and initial decisions are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision. In other words the general principle is that in order to solve a particular problem, first subproblems (different parts of the problem) must be solved and then combined to give a comprehensive solution to the bigger problem.

Integer Programming differs from linear programming only because it requires that the decision variables should have integer values. In section 6.1 it was pointed out that the decision variables can have integer values. This is applicable only for problems with decision variables that represent activities that can be run at fractional levels. But this assumption is not applicable for problems that include variables which represent amounts that cannot be represented by fractions. For example it is not possible to build 5.5 computers. In this type of situation integer programming is applied. The mathematical model for integer programming is the linear programming model with the one additional restriction that the variables must have integer values (Hillier & Lieberman, 2010: 464).

The basic assumption for linear programming as discussed in section 6.1 is that all objective and constraint functions are linear. This assumption is applicable for many real world problems. Yet, there are many cases where this assumption does not hold. As a result nonlinear programming problems are handled using different techniques. Linear programming is applicable, for example, on the transportation problem which seeks to determine an optimal plan for shipping goods from multiple sources to multiple destinations.

Simulation is a mathematical technique for testing the performance of a system due to uncertain inputs and/or uncertain system configuration options. Simulation produces probability distributions for the behavior (outputs) of a system (Council of Supply Chain Management Profesionals , 2010).

Simulation technique offers a good alternative when mathematical solution is not possible due to the complexity of the real life situation as a result of complexity in problem formulation, stochastic (random) nature of problems, or the conflicting information required to describe the given problem in a suitable manner (Sharma , 2006: 1). Simulation is probably the most flexible tool available.

There are two broad categories of simulation - A *discrete event simulation* and a *continuous simulation*. Continuous simulation deals with processes that are continuous and are modeled as continuous. Growth of plants, movement of vehicles, and temperature are typical examples (Eiselt & Sandblon, 2010: 395). On the other hand discrete event simulation deals with systems whose behavior changes only at given instants. A typical example occurs in waiting lines when the average waiting time or the length of the waiting line is measured. From the standpoint of collecting statistics, change occurs only when a customer enters or leaves the system (Taha, 1997: 679).

Simulation plays important role in OP studies. Mathematical programming techniques are sometimes inefficient as a result of the complexity of systems and the underlying simplifying assumptions needed. Using simulation techniques along with OR (simulation for evaluation, and OR for optimization) might become more beneficial (van Dijk;van der Sluis;Haijema;Al-Ibrahim;& van der Wal, 2005). A simulation technique synthesizes the system by building it up component by component and event by event. Because the simulation runs typically require generating and processing a vast amount of data, these simulated statistical experiments are inevitably performed on a computer (Hillier & Lieberman, 2010: 935).

8 Disadvantages of Operations Research

Although operations research has been successfully applied to address problems in many industries, it has been used to solve only a limited amount of administrative problems. The following are few of the limitations.

High computational requirement

The first drawback relates to the magnitude of mathematical and computing requirements. OR techniques try to find out an optimal solution taking into account all the factors involved. In modern business environment, these factors are enormous and expressing them in quantity and establishing relationships among them requires voluminous calculations that can only be handled by computers (Universal Teacher, 2010).

Deals only with quantifiable factors

Even from the discussions in the previous sections of this paper, it can be inferred that OR is applied only on problems which have quantifiable decision factors. It excludes other complex factors such as human behavior. Which means decisions will continue to be made based on personal judgment and experience. Here it should be pointed out that probabilities and approximations are being substituted for factors that could not be measured. Yet, a major proportion of managerial decisions involve qualitative factors (CiteMAN, 2007).

Time and cost

Priyanka points out that in order to carry out an effective research and implementation, a company needs to invest time and effort. A team of professionals must be hired to conduct research and that comes with high cost (Priyanka, 2012). As a result OR is not feasible for problems which do not involve big amount of money. Data collection by itself may consume a large portion of time and money (Sankara, 2008: 2).

Gap between management and OR team

Yet another limitation is the gap between practicing managers and trained operation researchers. Managers in general lack a knowledge and appreciation of mathematics, just as mathematicians lack an understanding of managerial problems. This gap is being dealt with, to an increasing extent, by the business schools and, more often, by business firms that team up managers with operations research. But it is still the major reasons why firms are slow to use operations research.

9 Packaged Optimization Software Solutions

A number of software packages are used by companies in the logistics and supply chain industry to optimize their operations. Some of the optimization solutions are:

- LINGO
- AIMMS
- Ortec planning and optimization Software
- SAS/OR
- JDA
- SAP

LINGO is a comprehensive tool designed by Lindo Systems Inc. to make building and solving Linear, Nonlinear (convex & nonconvex/Global), Quadratic, Quadratically Constrained, Second Order Cone, Stochastic, and Integer optimization models faster, easier and more efficient (Lindo Systems Inc, 2013).

TNT Express has implemented efficient methods that have saved the company more than $260 million while simultaneously reducing their carbon footprint by 283,000 metric tons. This optimization success was achieved by using AIMMS and operations research (AIMMS, 2013).

Ortec optimization software is used by the likes of DHL, KUHNE+NAGEL, and DB SCHENKER to improve vehicle routing and dispatching saving huge amount of cost in the process (Ortec, 2013).

JDA Strategy is a comprehensive linear programming tool set designed to analyze the key factors and optimization strategies associated with operating an end-to-end supply network, including costs, capacity and locations, and then optimize the network to help achieve the lowest total landed cost and the highest possible profits (JDA, 2013).

SAP Enterprise Inventory Optimization can help organizations determine optimal time-varying inventory targets for every item at every location throughout the supply chain (SAP, 2013).

According to Schruben software companies are claiming that all problems can be solved by their software in order to compete with each other which he says is not true. In these sense, he believes, embedded or packaged solutions are probably hindering the advancement of OR in business practice (Hines, 2008).

10 Real World application of Operations research

In section 5 the different operational functions of a company or a public organization where operations research can be applied were discussed briefly. This section will provide real world applications of operations research and optimization techniques and the result obtained as a result of it.

Operations research is a tool that has saved many thousands or millions of dollars for many companies in supply chain and warehouse costs as shown in the table below. It has also been used widely in other sectors of business and society. In a recent survey of Fortune 500 companies, 85% of those responding said that they had used linear programming (Springer, 2009: 1883).

Table 1. Selected real case applications of operations research. Modified from Hillier and Lieberman (2010: 4) and PHP Simplex (2012).

Organization	Application	Annual Savings
Electric Power Research Institute	Administration of oil and coal inventories for the electric service with the aim of balancing inventories' costs and risks of remainings.	$59 millions
Citgo Petroleum Corp.	Optimization of refinement, offer, distribution and commercialization of products operations	$70 millions
IBM	Integration of a national spare parts inventory net to improve the service support	$20 millions + $250 millions in minor inventory
Hewlett-Packard	Redesign of security inventories' size and location at printer production line to obey the production goals	$280 million of additional revenue
Time Inc.	Management of distribution channels for magazines	$3.5 million more profit
US military	Logistical planning of operations desert storm	Not estimated

Samsung Electronics	Reduce manufacturing time an inventory level	$200 million more revenue
Welch’s	Optimize use and movement of raw materials	$150,000
Federal Express	Logistics planning for shipment	Not estimated
Procter and Gamble	Redesign of the North American production and distribution system to reduce costs and to improve the incoming rapidity to the market	$200 millions

Nowadays OR implementations are carried out with the help of packaged software solutions provided by software and OR consulting companies. Vehicle routing solutions are among the most frequently advertised success stories by the consulting companies who also happen to be software providers.

Selected cases

3663 First for Foodservice, UK *(adopted and modified from The Science of Better)*

The leading foodservice wholesale distributor in UK, 3663 First for Foodservices, provides dedicated frozen, fresh, chilled and full multi temperature delivery using 38 depots and a fleet of single and multi-temperature vehicles to serve up to 53,000 customers. The company operates in a highly competitive market means good customer service is vital and there is pressure on margins. As a result, profitability depends on efficiency. As discussed in section 3, reducing logistics cost through improved efficiency is a key to profitability.

OR consultants worked closely with 3663 First for Foodservice to gain a complete understanding of the business requirement and legal constraints. After a depot review, new plans were introduced using planning software with the objective of improved vehicle utilization. The number of vehicles, mileage, and fuel consumption were reduced as a result of it. (Society, 2013)

Zara, Worldwide *(adopted and modified from informs online)*

The Spanish clothing manufacturer and retailer Zara, has a supply chain including two primary warehouses located in Spain. The warehouses periodically receive shipments

of finished clothes from suppliers across the world and ship replenishment inventory directly to every Zara store in the world twice a week. Determining the exact number of each size of each article that should be included in each shipment to the more than 1,500 stores worldwide was a challenge OR professionals brought in by Zara were faced with. One shipment involves up to 3,000 clothes of up to eight different sizes.
The solution is crucial for Zara's daily business activity but the challenge is difficult because the amount of relevant data is huge and the number of associated shipment decisions reaches several millions. In addition the available warehouse inventory is limited. Shipment decisions must also be made in a matter of hours.

An alternative to the previous decision process was developed by an OR team using analytical methods, including forecasting algorithms, stochastic analysis, and large-scale mixed-integer programming model. Implementing the new decision process came with different technical difficulties and human challenges. However, the development of this new process was completed in 2007 to all stores and all products sold worldwide. A pilot field experiment was conducted on a limited number of articles and half of the outlet stores worldwide.

The financial benefit obtained from sales alone can be estimated at about $353 million in 2008 in additional revenue or $42.4 million in additional net income in the year 2008. This financial income was predicted to grow by 13% in following years. In addition Zara was able to maintain its warehouse inventory allocation team at its previous level of 60 individuals worldwide without having to increase the number in proportion to the sales growth. (informs online, 2010)

11 The Future of Operations Research

Lee W. Schruben is a professor and former chair of Industrial Engineering and Operations Research at UC Berkeley, and one of the world's leading authorities on simulation theory and practice. In an interview with cbsnews.com about the future of operations research, he pointed out that it should be realized that what OR professionals do is forecasting and that what researchers try to model is what will happen in the future. That, according to Schruben, is the biggest practical problem. How to get away from models with static assumptions (models built based on assumptions thought to be reasonable at the time of data collection) and develop predictive models that can respond in real time to changes in the world will be the focus of operations research in the future (Hines, 2008).

But there are some measures already taken by some companied to address this problems. UPS express service which according to a 2011 article by Tyre Sperling handles more than 15 million packages each day, is a good example. Due to the complexity of the process behind delivery of a package to its final destination, UPS has an entire operations research team composed of advanced analysts, programmers and business experts to make sure the process is running as efficiently as possible and even more efficiently in the future. To continuously assess and update driving routes for package delivery and to fulfill immediate customer pick up orders, the OR team uses real time GPS data from a device used by truck drivers (Sperling, 2011).

The author had the pleasure of briefly discussing the future of operations research with Professor Markku Kuula of Aalto University who has also served as chairman of Finnish Operations Research Society (FORS) in the past. According to him, there used to be many operations research professionals and activities in the 1980s and 90s. That seemed to have slowed down in the past decade. Now the new generation of professionals has powerful computers at their disposal to conduct enormous calculations and run simulations of complex situations. As a result the new generation of OR professionals have a chance of solving problems that were not possible for the previous generation to tackle. And, therefore, in the future operations research will have different frontiers.

12 Conclusion

The impact of operations research in logistics and supply chain management and in all other business operations and public administration has been second to none. The relevance of OR remains high today. OR can basically be applied in any field where improvement is needed.

OR is conducted by a team of professionals whose first task is to understand how the system they are going to try to improve works at present. For the best outcome, it is important that the OR team and other functional departments of the company understand the principle, process, and implementation of the research. Nowadays companies are increasingly using packaged optimization software like Lindo and SAP to plan their operations in a better way. This might, as Schruben pointed out, be hindering OR in practice (Hines, 2008).

It was discussed that one of the drawbacks of operations research is the gap between management and OR professionals. This gap can be dealt with if/when business professionals try to have a basic understanding of OR principles and techniques. And when similar effort is made by OR professionals, usually mathematicians, to understand management, economics, and related areas. This paper was written in an attempt to understand how mathematical modeling is used to improve real life problems. Learning about a particular mathematical technique or just getting introduced to the world of operations research may not take very far but it helps facilitate collaboration, build discipline, ask the right questions and be an informed software user.

Most of the underlying principles of linear programming and other optimization techniques were developed after the late 1940’s. But there has not been a significant development in the last 20 years. In order to give this thesis better validity and reliability, books published in relatively recent years were chosen and recent real life applications were discussed. The subject is broad and could have been presented in many other alternative ways to meet the same objective. It is important to remember that the author’s own bias might have an effect on the whole structure of the thesis. Nevertheless, it can safely be stated that information presented is valid and reliable.

The importance of understanding the concept of optimization for logistics and supply chain professionals can be seen from the fact that companies can gain great financial benefit for themselves and their client companies by optimizing their supply chain as shown by the real life cases and examples in the thesis. This understanding will at least make the logistics or supply chain professional recognize situations where OR can be utilized and it also creates a better atmosphere for collaboration.

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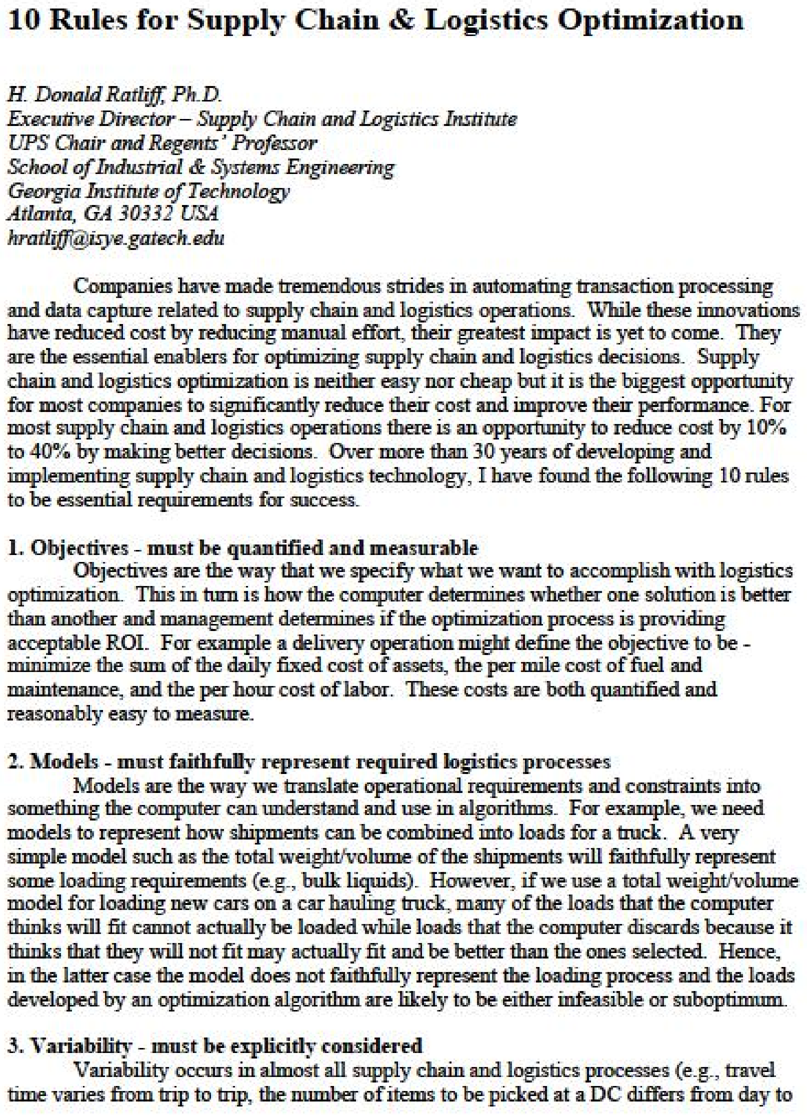
Appendix 1: 10 Rules for Supply Chain and Logistics Optimization



10 Rules for Supply Chain & Logistics Optimization

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Companies have made tremendous strides in automating transaction processing and data capture related to supply chain and logistics operations. While these innovations have reduced cost by reducing manual effort, their greatest impact is yet to come. They are the essential enablers for optimizing supply chain and logistics decisions. Supply chain and logistics optimization is neither easy nor cheap but it is the biggest opportunity for most companies to significantly reduce their cost and improve their performance. For most supply chain and logistics operations there is an opportunity to reduce cost by 10% to 40% by making better decisions. Over more than 30 years of developing and implementing supply chain and logistics technology, I have found the following 10 rules to be essential requirements for success.

1. Objectives - must be quantified and measurable

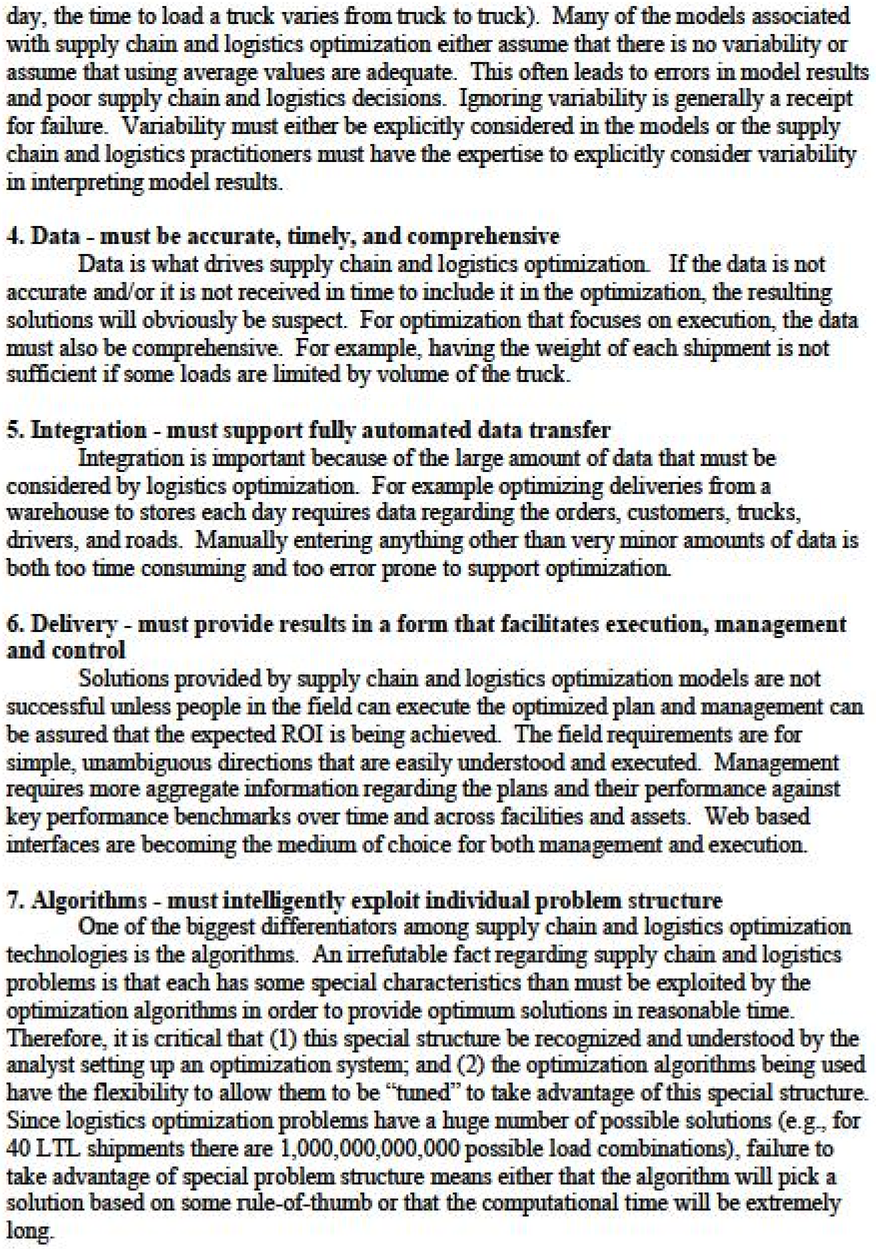
Objectives are the way that we specify what we want to accomplish with logistics optimization. This in turn is how the computer determines whether one solution is better than another and management determines if the optimization process is providing acceptable ROI. For example a delivery operation might define the objective to be - minimize the sum of the daily fixed cost of assets, the per mile cost of fuel and maintenance, and the per hour cost of labor. These costs are both quantified and reasonably easy to measure.

2. Models - must faithfully represent required logistics processes

Models are the way we translate operational requirements and constraints into something the computer can understand and use in algorithms. For example, we need models to represent how shipments can be combined into loads for a truck. A very simple model such as the total weight/volume of the shipments will faithfully represent some loading requirements (e.g., bulk liquids). However, if we use a total weight/volume model for loading new cars on a car hauling truck, many of the loads that the computer thinks will fit cannot actually be loaded while loads that the computer discards because it thinks that they will not fit may actually fit and be better than the ones selected. Hence, in the latter case the model does not faithfully represent the loading process and the loads developed by an optimization algorithm are likely to be either infeasible or suboptimum.

3. Variability - must be explicitly considered

Variability occurs in almost all supply chain and logistics processes (e.g., travel time varies from trip to trip, the number of items to be picked at a DC differs from day to



day, the time to load a truck varies from truck to truck). Many of the models associated with supply chain and logistics optimization either assume that there is no variability or assume that using average values are adequate. This often leads to errors in model results and poor supply chain and logistics decisions. Ignoring variability is generally a receipt for failure. Variability must either be explicitly considered in the models or the supply chain and logistics practitioners must have the expertise to explicitly consider variability in interpreting model results.

4. Data - must be accurate, timely, and comprehensive

Data is what drives supply chain and logistics optimization. If the data is not accurate and/or it is not received in time to include it in the optimization, the resulting solutions will obviously be suspect. For optimization that focuses on execution, the data must also be comprehensive. For example, having the weight of each shipment is not sufficient if some loads are limited by volume of the truck.

5. Integration - must support fully automated data transfer

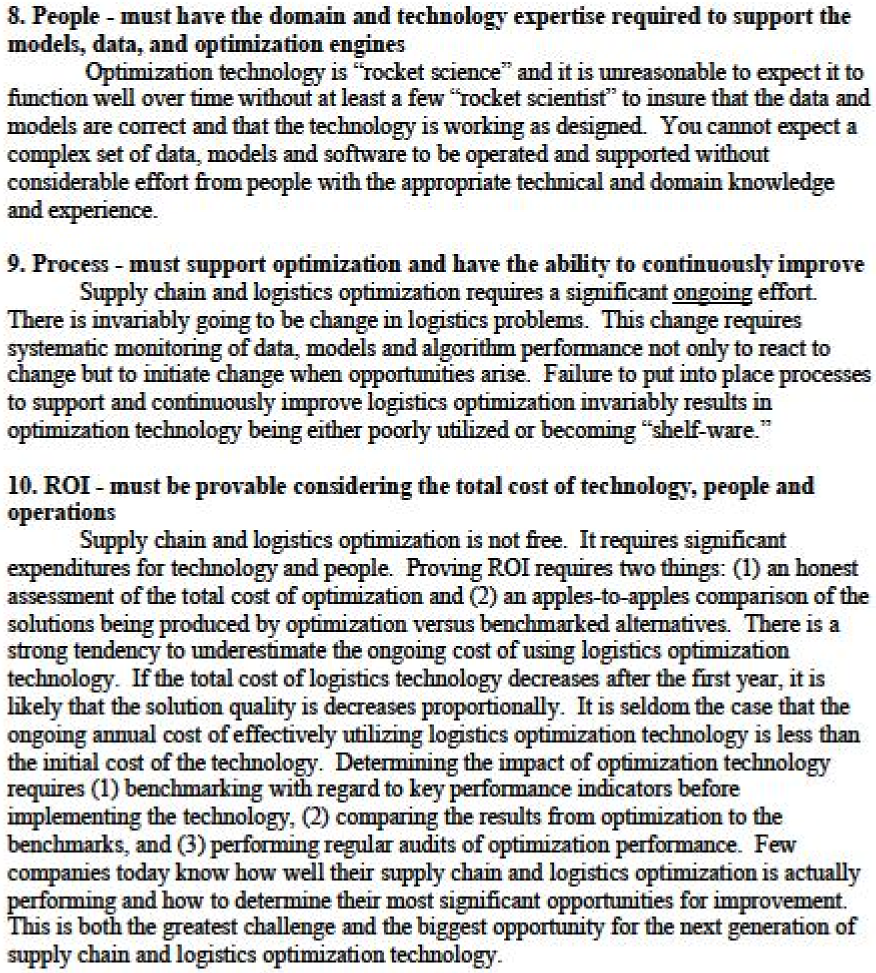
Integration is important because of the large amount of data that must be considered by logistics optimization. For example optimizing deliveries from a warehouse to stores each day requires data regarding the orders, customers, trucks, drivers, and roads. Manually entering anything other than very minor amounts of data is both too time consuming and too error prone to support optimization.

6. Delivery - must provide results in a form that facilitates execution, management and control

Solutions provided by supply chain and logistics optimization models are not successful unless people in the field can execute the optimized plan and management can be assured that the expected ROI is being achieved. The field requirements are for simple, unambiguous directions that are easily understood and executed. Management requires more aggregate information regarding the plans and their performance against key performance benchmarks over time and across facilities and assets. Web based interfaces are becoming the medium of choice for both management and execution.

7. Algorithms - must intelligently exploit individual problem structure

One of the biggest differentiators among supply chain and logistics optimization technologies is the algorithms. An irrefutable fact regarding supply chain and logistics problems is that each has some special characteristics than must be exploited by the optimization algorithms in order to provide optimum solutions in reasonable time. Therefore, it is critical that (1) this special structure be recognized and understood by the analyst setting up an optimization system; and (2) the optimization algorithms being used have the flexibility to allow them to be “tuned” to take advantage of this special structure. Since logistics optimization problems have a huge number of possible solutions (e.g., for 40 LTL shipments there are 1,000,000,000,000 possible load combinations), failure to take advantage of special problem structure means either that the algorithm will pick a solution based on some rule-of-thumb or that the computational time will be extremely long.



8. People - must have the domain and technology expertise required to support the models, data, and optimization engines

Optimization technology is “rocket science” and it is unreasonable to expect it to function well over time without at least a few “rocket scientist” to insure that the data and models are correct and that the technology is working as designed. You cannot expect a complex set of data, models and software to be operated and supported without considerable effort from people with the appropriate technical and domain knowledge and experience.

9. Process - must support optimization and have the ability to continuously improve

Supply chain and logistics optimization requires a significant ongoing effort. There is invariably going to be change in logistics problems. This change requires systematic monitoring of data, models and algorithm performance not only to react to change but to initiate change when opportunities arise. Failure to put into place processes to support and continuously improve logistics optimization invariably results in optimization technology being either poorly utilized or becoming “shelf-ware.”

10. ROI - must be provable considering the total cost of technology, people and operations

Supply chain and logistics optimization is not free. It requires significant expenditures for technology and people. Proving ROI requires two things: (1) an honest assessment of the total cost of optimization and (2) an apples-to-apples comparison of the solutions being produced by optimization versus benchmarked alternatives. There is a strong tendency to underestimate the ongoing cost of using logistics optimization technology. If the total cost of logistics technology decreases after the first year, it is likely that the solution quality is decreases proportionally. It is seldom the case that the ongoing annual cost of effectively utilizing logistics optimization technology is less than the initial cost of the technology. Determining the impact of optimization technology requires (1) benchmarking with regard to key performance indicators before implementing the technology, (2) comparing the results from optimization to the benchmarks, and (3) performing regular audits of optimization performance. Few companies today know how well their supply chain and logistics optimization is actually performing and how to determine their most significant opportunities for improvement. This is both the greatest challenge and the biggest opportunity for the next generation of supply chain and logistics optimization technology.

Appendix 2: Linear Programming Using Excel

Linear Programming Using Excel

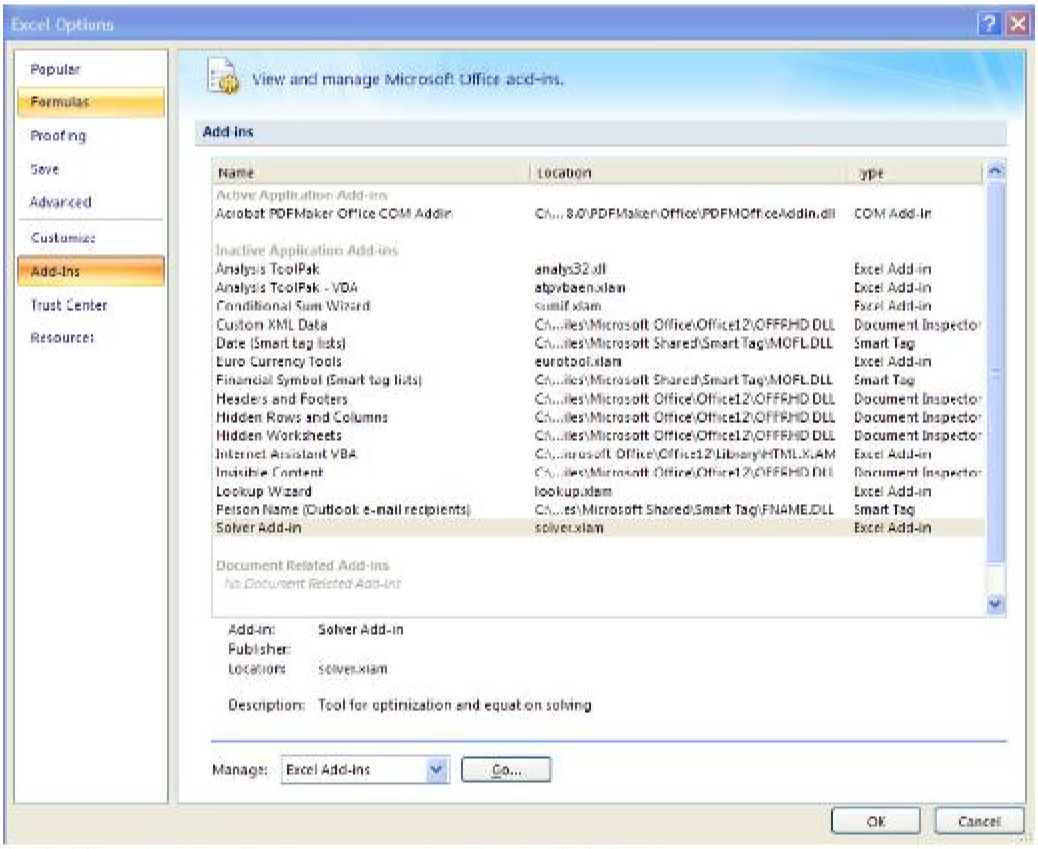
Subject: Linear Programming using Excel

Application: Microsoft Excel 2007

Task: Solving a Linear Program Using Excel

Tutorial Date: 25th February, 2010 by Nathan Smith

Install the Solver Add-In



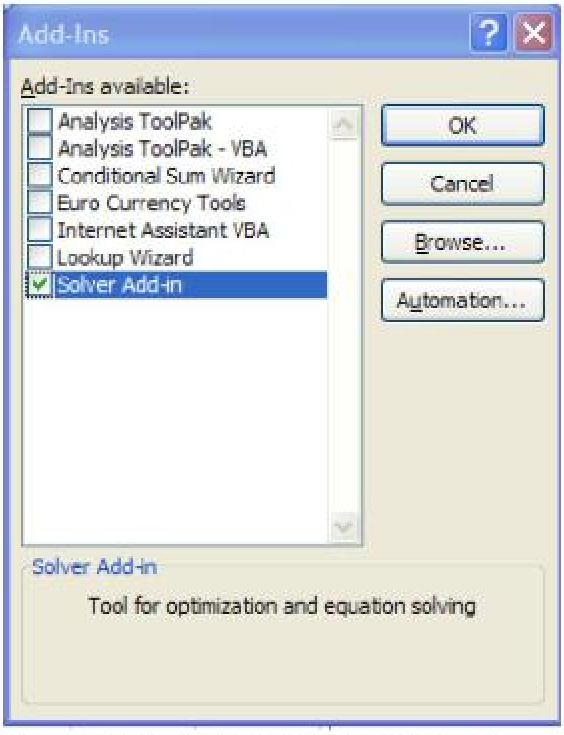
Name	Location	ype
Active Application Add-ins		
Acrobat PDFMaker Office COM Addin	C:\... 8.0\PDFMaker\Office\PDFMOfficeAddin.dll	COM Add-in
Inactive Application Add-ins		
Analysis ToolPak	analys32.xll	Excel Add-in
Analysis ToolPak - VBA	atpvbaen.xlam	Excel Add-in
Conditional Sum Wizard	sumif.xlam	Excel Add-in
Custom XML Data	C:\...iles\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Date (Smart tag lists)	C:\...iles\Microsoft Shared\Smart Tag\MOFL.DLL	Smart Tag
Euro Currency Tools	eurotool.xlam	Excel Add-in
Financial Symbol (Smart tag lists)	C:\...iles\Microsoft Shared\Smart Tag\MOFL.DLL	Smart Tag
Headers and Footers	C:\...iles\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Hidden Rows and Columns	C:\...iles\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Hidden Worksheets	C:\...iles\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Internet Assistant VBA	C:\...crosoft Office\Office12\Library\HTML.XLAM	Excel Add-in
Invisible Content	C:\...iles\Microsoft Office\Office12\OFFRHD.DLL	Document Inspector
Lookup Wizard	lookup.xlam	Excel Add-in
Person Name (Outlook e-mail recipients)	C:\...es\Microsoft Shared\Smart Tag\FNAME.DLL	Smart Tag
Solver Add-in	solver.xlam	Excel Add-in
Document Related Add-ins		
No Document Related Add-ins		

Add-in: Solver Add-in
Publisher:
Location: solver.xlam

Description: Tool for optimization and equation solving

1. In the Microsoft Office button, go to excel options to click Add-ins
2. In the Add-Ins box, select Solver Add-In and click Go...

Install the Solver Add-In (continue)



Add-Ins available:

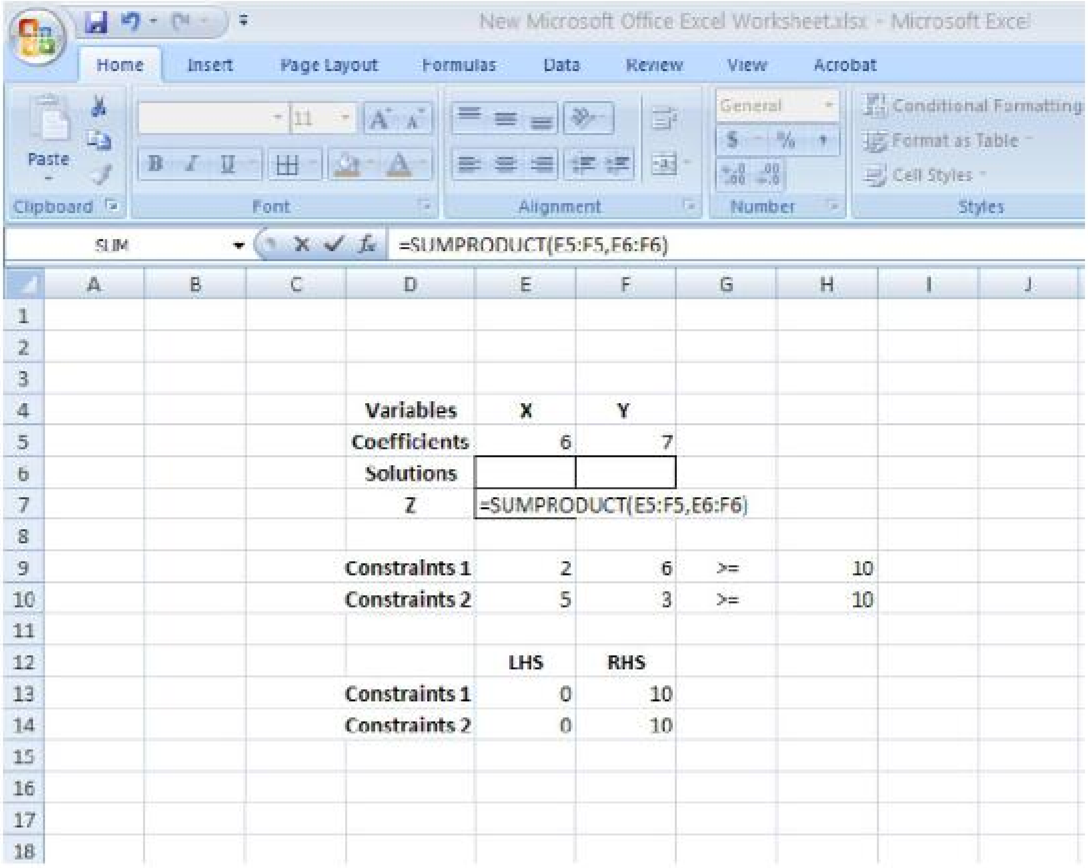
☐ Analysis ToolPak
☐ Analysis ToolPak - VBA
☐ Conditional Sum Wizard
☐ Euro Currency Tools
☐ Internet Assistant VBA
☐ Lookup Wizard
☑ Solver Add-in

Solver Add-in

Tool for optimization and equation solving

3. In the Add-Ins available box, check the Analysis ToolPak and then OK

Setting Up the Problem on the Spreadsheet



=SUMPRODUCT(E5:F5,E6:F6)

	A	B	C	D	E	F	G	H	I	J
1										
2										
3										
4				Variables	X	Y				
5				Coefficients	6	7				
6				Solutions						
7				Z	=SUMPRODUCT(E5:F5,E6:F6)					
8										
9				Constraints 1	2	6	>=	10		
10				Constraints 2	5	3	>=	10		
11										
12					LHS	RHS				
13				Constraints 1	0	10				
14				Constraints 2	0	10				
15										
16										
17										
18										

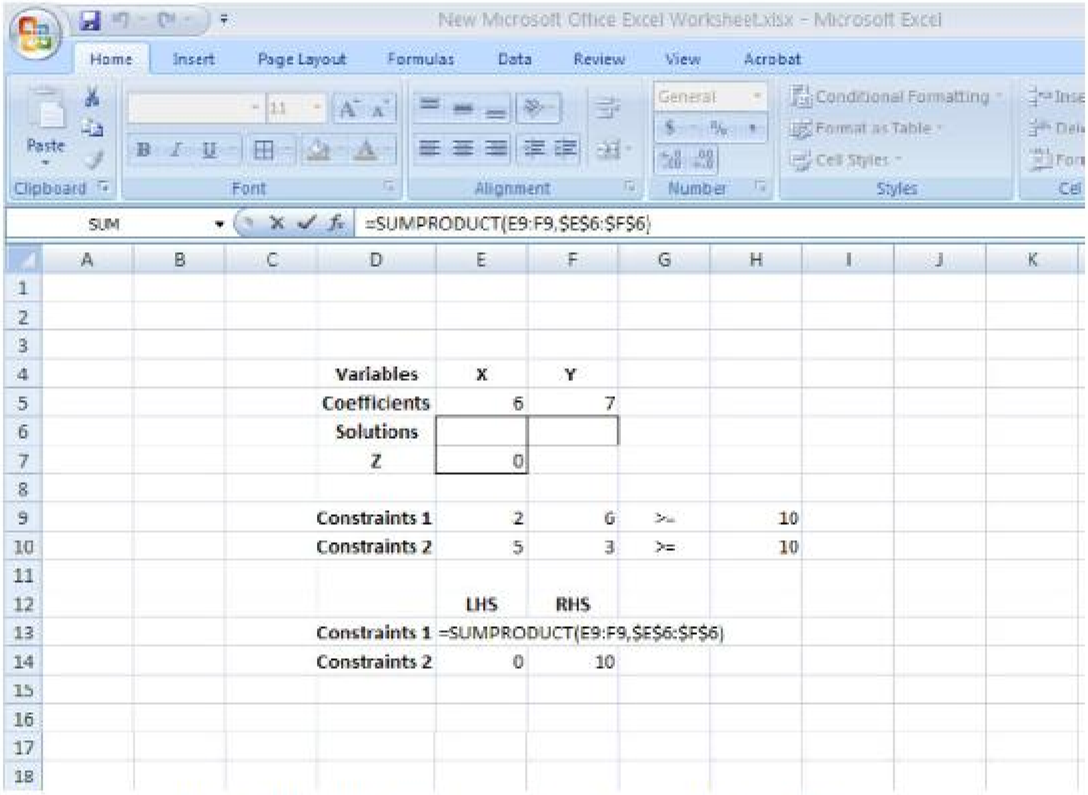
Example

Min Z = 6X + 7Y

s.t 2X + 6Y â‰¥ 10
5X + 3Y â‰¥ 10
X,Y â‰¥ 0

Linear Programming Using Excel - 3

(continued)

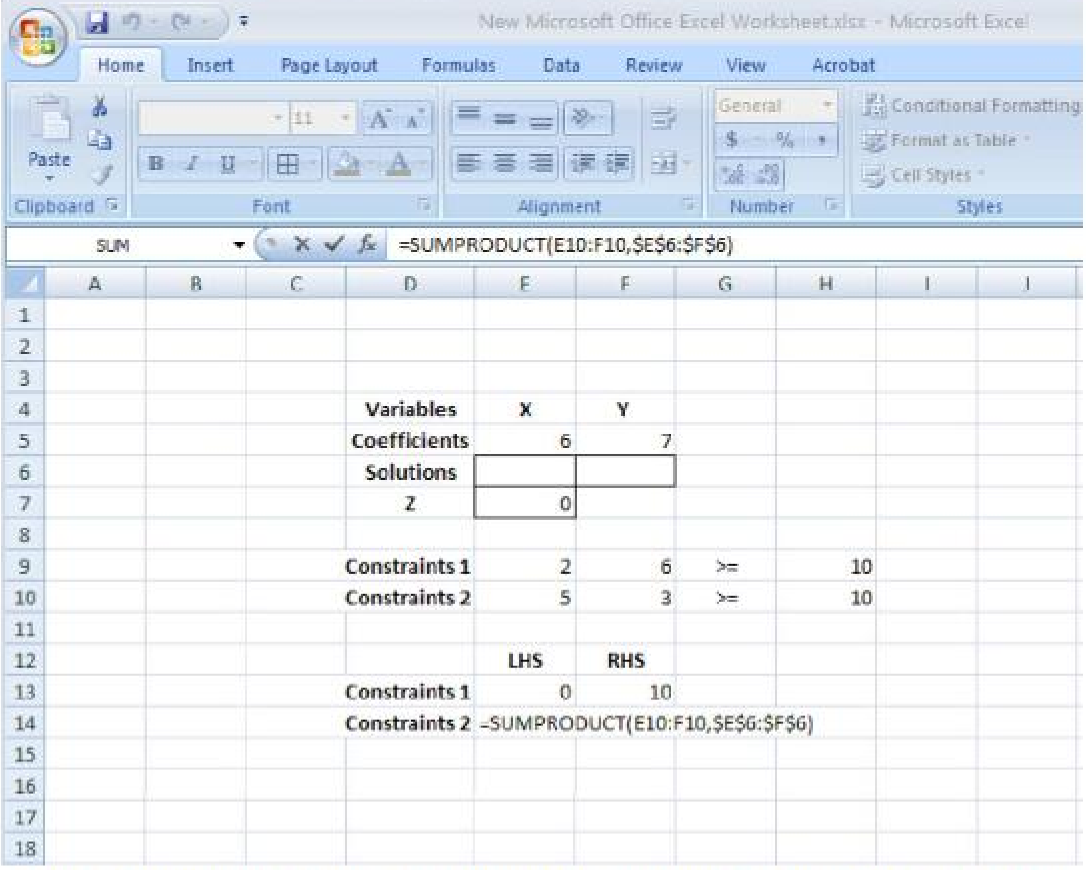


SUM =SUMPRODUCT(E9:F9,$E$6:$F$6)

	A	B	C	D	E	F	G	H	I	J	K
1											
2											
3											
4				**Variables**	**X**	**Y**					
5				**Coefficients**	6	7					
6				**Solutions**							
7				**Z**	0						
8											
9				**Constraints 1**	2	6	>=	10			
10				**Constraints 2**	5	3	>=	10			
11											
12					**LHS**	**RHS**					
13				**Constraints 1**	=SUMPRODUCT(E9:F9,$E$6:$F$6)						
14				**Constraints 2**	0	10					
15											
16											
17											
18											

1. Enter the coefficients of the objective function Z i.e., (6, 7) in cells E5 and F5.
2. Enter the coefficients of the Constraint-1 i.e., (2,6) and RHS value 10 in cells E9, F9 and H9 respectively
3. Enter the coefficients of the Constraint-2 i.e., (5,3) and RHS value 10 in cells E10, F10 and H10 respectively

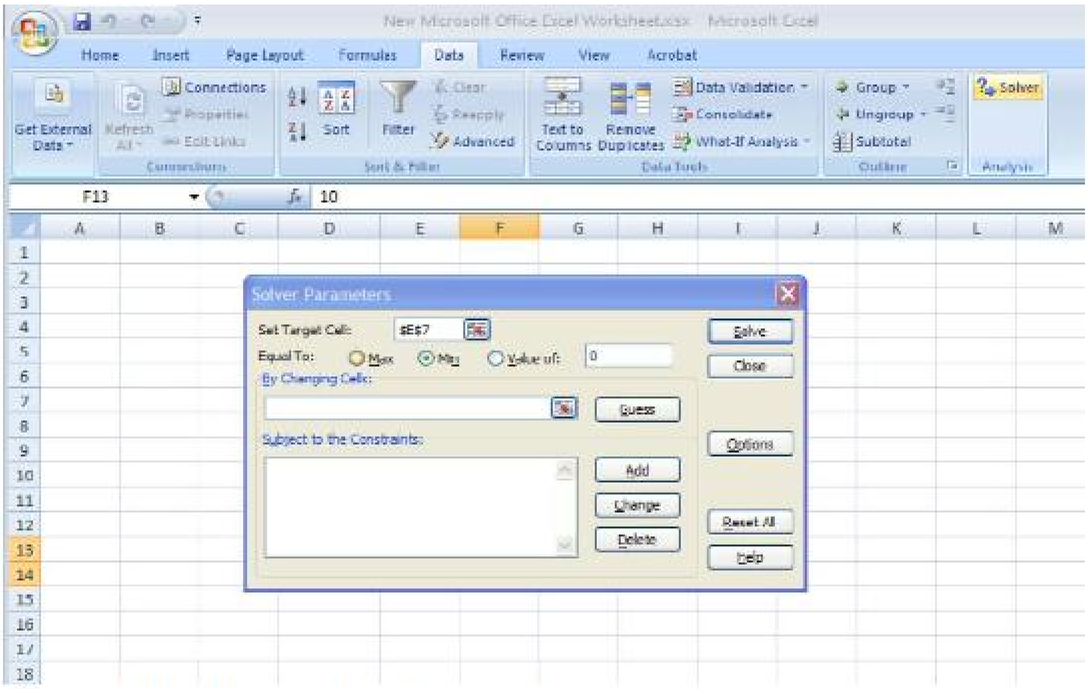
(continued)



SUM =SUMPRODUCT(E10:F10,$E$6:$F$6)

	A	B	C	D	E	F	G	H	I	J
1										
2										
3										
4				**Variables**	**X**	**Y**				
5				**Coefficients**	6	7				
6				**Solutions**						
7				**Z**	0					
8										
9				**Constraints 1**	2	6	>=	10		
10				**Constraints 2**	5	3	>=	10		
11										
12					**LHS**	**RHS**				
13				**Constraints 1**	0	10				
14				**Constraints 2**	=SUMPRODUCT(E10:F10,$E$6:$F$6)					
15										
16										
17										
18										

1. For the Objective function value, enter the formula for computing Z = **SUMPRODUCT(E5:F5,E6:F6)**. This formula uses the coefficient values and also the solution values for variables X and Y, which are supposed to be solved.
2. Similarly enter the formula for LHS of the Constraints 1 & 2 i.e., **SUMPRODUCT(E9:F9,$E$6:$F$6) & SUMPRODUCT(E10:F10,$E$6:$F$6)** respectively



F13 10

Set Target Cell: $E$7

Equal To: ○ Max ● Min ○ Value of: 0

Now Excel Solver will be used, in the Data tab click Solver.
The solver box appears as follows.

(continued)

Set Target Cell: $E$7

Equal To: ○ Max ● Min ○ Value of: 0

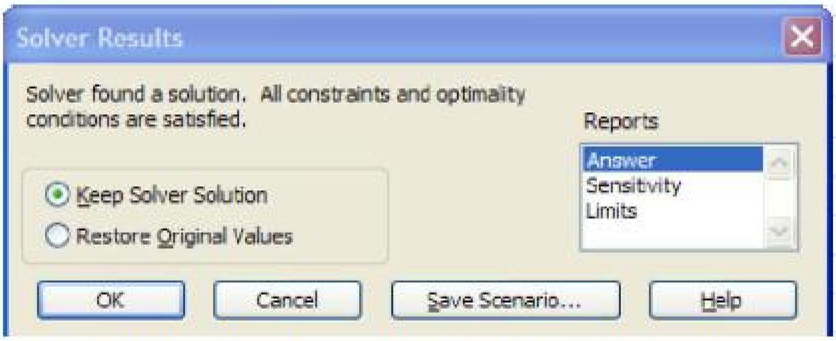
By Changing Cells: $E$6:$F$6

Subject to the Constraints:
$E$13:$E$14 >= $F$13:$F$14
$E$6:$F$6 >= 0

1. Set the Target Cell for the Objective Function Z value i.e., $E$7
2. Check the Equal to Min i.e., Minimum Option.
3. For Changing Cell, select the solution values of the variables X & 7 i.e., $E$6:$F$6

4. For subject to the constraints, LHS >=RHS i.e., click on the Add option and select $E$13:$E$14 >= $E$13:$E$14
5. Also all the solution values needs to be positive, select $E$6:$F$6 >= 0
6. Now click the Solve button.

(continued)



Solver Results

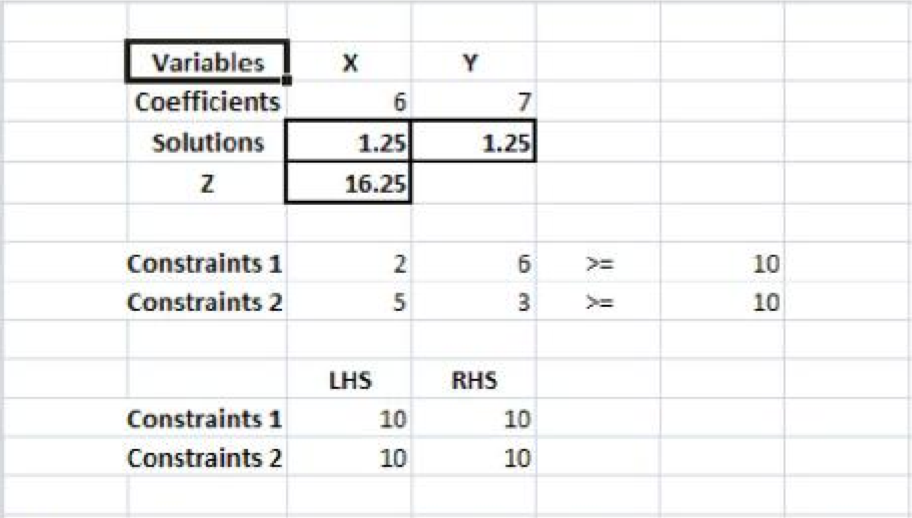
Solver found a solution. All constraints and optimality conditions are satisfied.

● Keep Solver Solution
○ Restore Original Values

Reports
Answer
Sensitivity
Limits

After selecting the solve button the solver results appears a window, the default option has a keep solver solution and click on the Answer in the Reports Section on the Right hand side. Finally click the the OK Button to get the results.

(continued)



Variables	X	Y		
Coefficients	6	7		
Solutions	1.25	1.25		
Z	16.25			
Constraints 1	2	6	>=	10
Constraints 2	5	3	>=	10
	LHS	RHS		
Constraints 1	10	10		
Constraints 2	10	10		

Finally the Excel Solver gives the solution values for variables X & Y and for the objective function Z.