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Financial Engineering

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ABSTRACT
This research paper aims to show the growth of financial services all around the world and its increased dependence on operational research to make it more effective and useful for the end users, helping them to take correct decision at correct time. This paper has also introduced the concept of financial engineering which has 5 elements i.e., risk management, portfolio management, derivative, asset management, corporate strategy (merger and acquisition) and capital structure(funding). This paper shows how usage of financial engineering along with application of operation research makes financial instability and future uncertainties more predictable and manageable.

Keywords: *Financial engineering, portfolio management, asset allocation, derivatives pricing, capital structure, corporate strategy, risk management, simplex method.*

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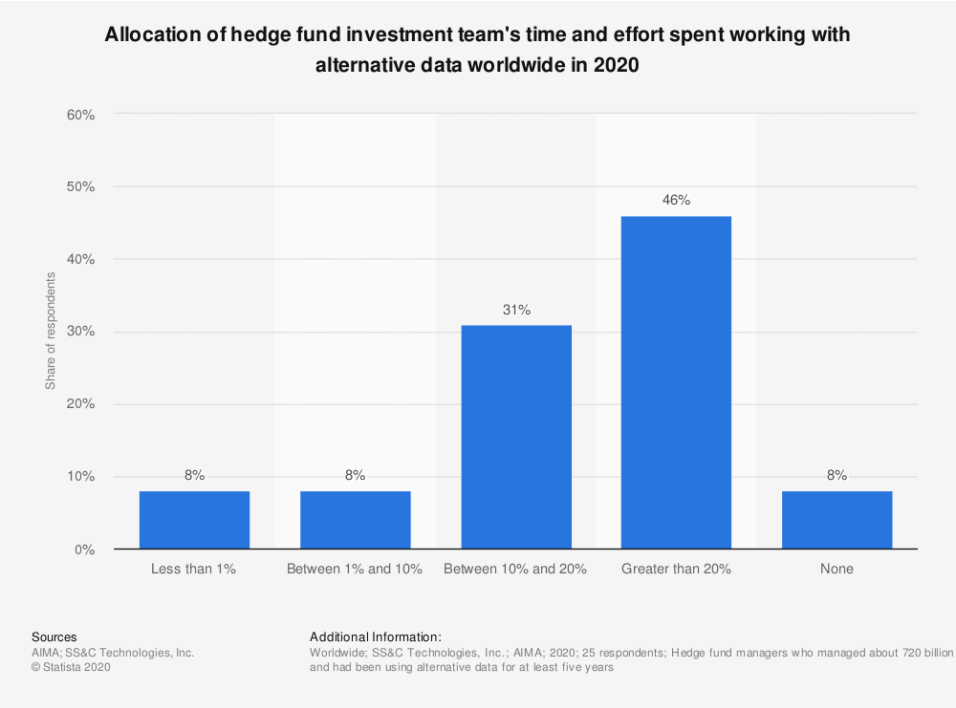
I. INTRODUCTION

The concept of operations research was conceived during the Second World War by military planners. After the end of the war, the techniques used in their operations research were applied to addressing problems and challenges in businesses, the government and society.

Since then, we have come a long way in applying these techniques to optimise various aspects of our life. In particular, OR techniques have swept the world of Finance off its feet, forcing the whole industry to adopt them and change the way we fundamentally approach problems in the world of Finance.


Allocation of hedge fund investment team's time and effort spent working with alternative data worldwide in 2020
Share of respondents
60%
50%
40%
30%
20%
10%
0%
8%
8%
31%
46%
8%
Less than 1%
Between 1% and 10%
Between 10% and 20%
Greater than 20%
None
Sources
AIMA; SS&C Technologies, Inc.
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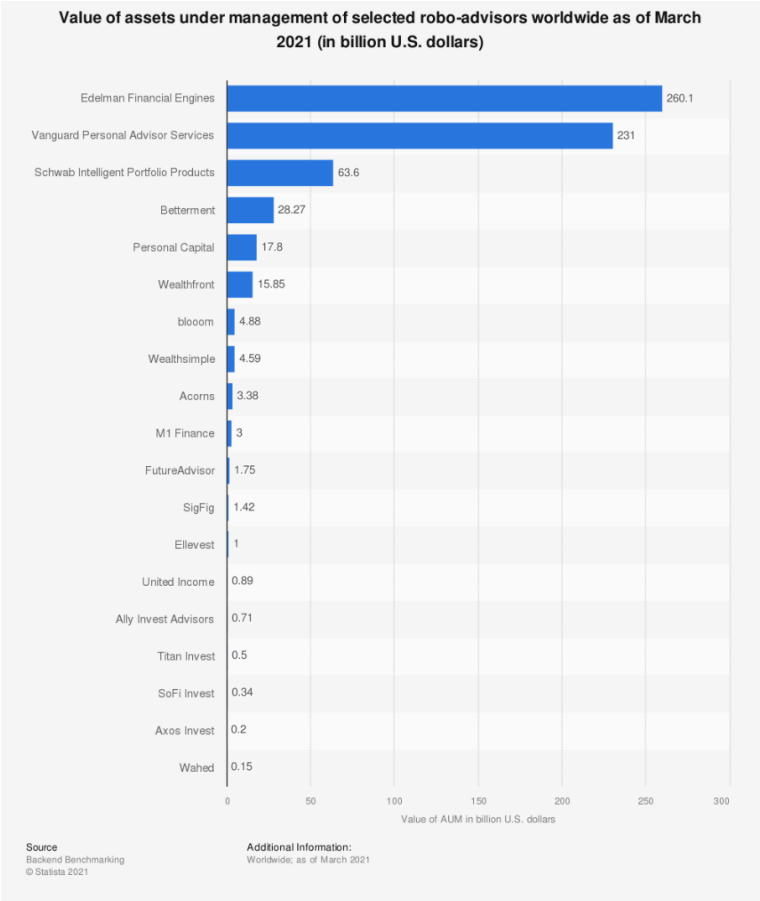
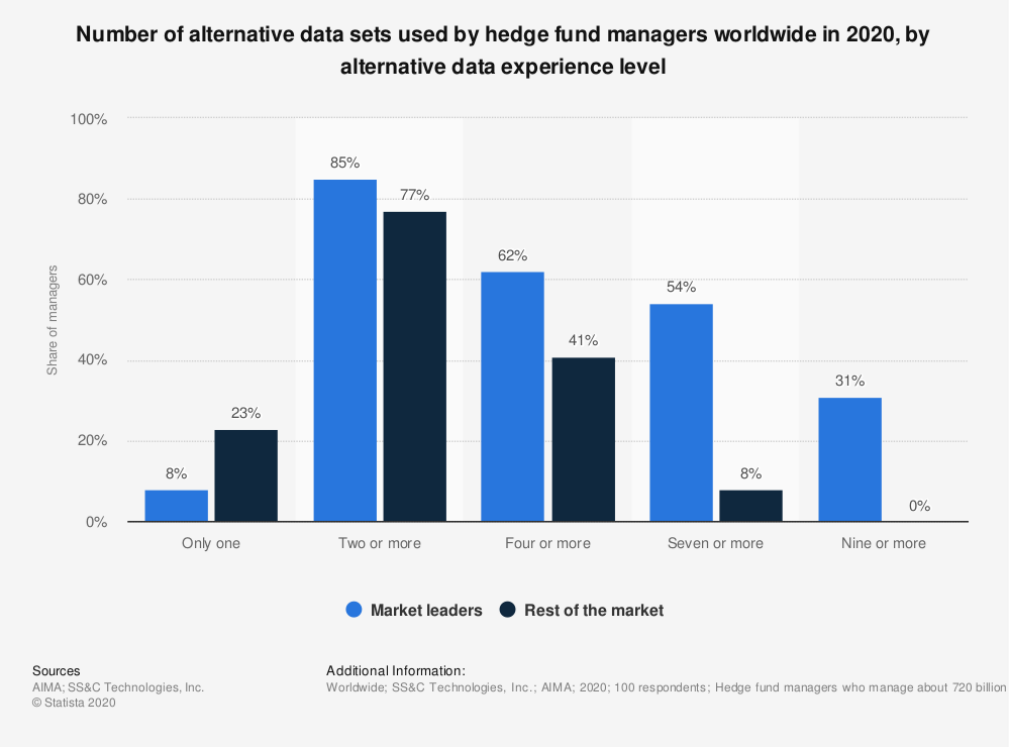
Additional Information:
Worldwide; SS&C Technologies, Inc.; AIMA; 2020; 25 respondents; Hedge fund managers who managed about 720 billion and had been using alternative data for at least five years


Value of assets under management of selected robo-advisors worldwide as of March 2021 (in billion U.S. dollars)
Edelman Financial Engines 260.1
Vanguard Personal Advisor Services 231
Schwab Intelligent Portfolio Products 63.6
Betterment 28.27
Personal Capital 17.8
Wealthfront 15.85
blooom 4.88
Wealthsimple 4.59
Acorns 3.38
M1 Finance 3
FutureAdvisor 1.75
SigFig 1.42
Ellevest 1
United Income 0.89
Ally Invest Advisors 0.71
Titan Invest 0.5
SoFi Invest 0.34
Axos Invest 0.2
Wahed 0.15
0
50
100
150
200
250
300
Value of AUM in billion U.S. dollars
Source
Backend Benchmarking
© Statista 2021
Additional Information:
Worldwide; as of March 2021



The ever-increasing use of Alternative Data and Operations research techniques by Hedge Funds.

We have seen the rise of Quant Hedge Funds, that dominate the asset management industry, who purely use statistical analysis and operations research on alternative data sets to find and implement optimal trading strategies to maximize returns and effectively minimizing the risk that arises due to human errors and biases. We have also seen leading investment banks using quantitative analysis to accurately carry out financial modelling and valuation of companies, whilst evaluating them for mergers, acquisitions or IPOs. This is evident from the graphs above.

So why is the financial world rapidly adopting techniques from the realm of OR?

Well, finance problems, particularly those involving financial markets, lend themselves very well to OR analysis. These are very complex problems and OR makes life easy for investor analysts by quantifying these problems into mathematical problems and in doing so, provide a viable solution. OR makes use of programming techniques like linear programming, Quadratic, Integer and also Goal and Dynamic programming to help a company to find better prospects of investment, minimize its cost, help others to grow through proper allocation of resources, etc. the strategies may aid companies in avoiding investments in areas that may turn out to be unprofitable. These issues are typically separable and well defined, with a clear goal (often to maximize profit or reduce risk) and have variables that can be quantified in monetary terms. In financial models, the relationships between the variables are frequently stable and well defined, leading in an OR model that accurately represents the situation. Because some financial problems involve substantial sums of money, even a minor enhancement in the solution's quality is worthwhile to adopt. Also, such problems tend to recur, possibly many times per day, spreading the costs of developing an OR solution over a large number of transactions. This scale and repetition make the development of an OR model more attractive than for small or one-off decisions. The use of OR approaches is likely to skyrocket in the next years, thanks to new data sources, operational research software tools, intermediaries, and growing data-exchange standards.

II. LITERATURE REVIEW

Financial engineering involves the creation and implementation of various unique financial instruments and processes, and the formulation of innovative solutions to problems in finance. During last two decades, we have seen an increased use of operations research techniques for many diverse aspects of financial engineering. Operations research tools such as decision making, simulation, stochastic processes are becoming very important in several areas of financial operations.

Derivatives Pricing: In today's world of financial economics, the problem of deriving an appropriate price of a derivative security also referred to as option pricing, has gained serious importance (Nishihara, Yagiura, & Ibaraki, 2005).When lattice and tree-based techniques are used, the computational cost of such

traditional valuation methods, increases rapidly with increase in the number of underlying securities. In the recent years, several methods have been proposed in order to try and address this curse of dimensionality. (Haugh & Kogan, 2001).The goal of stochastic programming is to accurately determine an optimal decision in problems that contain some uncertain data. Stochastic programming is different from deterministic in the sense that stochastic has some random data, Programming means that some parts of the problem can be modelled as linear or nonlinear mathematical programs (Birge & Louveaux, 2011). Realistic stochastic models developed for underlying securities, help in deriving more precise prices for derivative securities and also helps in creating better algorithms for computing option prices swiftly. (Agarwal, Pruthi, Kandpal, & Chaudhary, 2019) Although European style call and put options can be valued using the Black-Scholes model, which provides a good closed form solution, OR techniques have made a significant contribution to the pricing of more complicated derivatives. In 1977, the use of Monte Carlo simulation was proposed as an alternative to the binomial model for pricing options for which a closed form solution is not readily available. Monte Carlo simulation has an edge compared to the binomial model. The convergence rate of Monte Carlo is not dependent on the state variables such as the number of underlying asset prices and interest rates, at the same time binomial model is dependent of the number of state variables (Broad, Ziemba, & Sutcliffe, 2003).

Portfolio Management: Operational research is the discipline of using quantitative or qualitative models to aid decision – making in complex implementation problems. It has been used extensively to solve problems in finance during the last half century. Multi-objective optimization (MO) is the problem faces when two or more conflicting objectives are optimized at the same time. Many problems in the real-world contain conflicting objectives which need to be optimized at the same time and portfolio management is a characteristic example of this category(J. Haddock, 2004). The various objectives such as risk and return are usually in conflict with each other and each time one of them is optimized further, the other one suffers as a result. Markowitz's seminal paper addressed the same and it looked at portfolio selection as an optimization problem in which an asset mix is chosen so that the portfolio variance is minimum for any given degree of anticipated return, and simultaneously, the anticipated return is maximum for any given degree of portfolio variance (Bertsimas, 2008). A fundamental problem with the original Markowitz analysis and the generalized mean-risk models that have sprung from the mean-variance approach is their *single period nature*. Multi-objective Evolutionary Algorithms (MOEAs) helps in extending the classical portfolio model to operate two or more conflicting objectives subject to numerous constraints. The objective of MOEAs is to find an efficient solution that provides a trade off between risk and return(K.Metaxiotis, 2012). Many models have been created on the basis of MOEAs to manage portfolios such as CY. Cy is a wealth control platform that creates a personalized funding answer optimized to the client's personal wishes in minutes from a universe of over 30,000 funding strategies. It takes into consideration 20 years of historic data and illustrates how an advocated portfolio might have carried out over 2 major bear and bull market cycles. For customers in or coming near retirement, Cy models income withdrawals immediately and is able to model and onboard more than one portfolio at one time.

Funding- Capital Structure: Operations Research is used to determine, decide and help in finding the optimal method and ratio in which firms raise capital from financial markets to fund their operations and business. (Ivan E. Brick, 1983) constructed a model that involved chance constrained Linear Programming to compute the values of the debt-equity ratio which maximized the value of the firm in that particular period, while other studies have used a linear goal programming problem to reach the same goal. An important question that arose when evaluating the feasibility of investment and capital sources was determining the appropriate cost of capital, i.e. the price that is to be paid in the financial markets to finance the project. (Moore, 1983) used linear goal programming to estimate the cost of capital for divisions by incorporating corporate prior beliefs concerning betas. The objective of this section is to review each of these models for their merits and shortfalls and provide a conclusion as to which model can be used in the current market scenario to help a firm maximise its value through the optimal capital structure and corporate strategies.

Corporate Strategy- Mergers and Acquisitions: Stock market traders usually prefer trading at the most attractive prices and block trades are often divided into a chain of smaller trades to minimise the price impact. This is observed as a strategic problem with the objective of conceiving the optimal strategy for trading the large number of shares. The initial trades heavily impact and influence the price of subsequent trades. Thus, executing the block trade at the lowest cost possible is the dynamic problem. Stochastic dynamic programming is used by (W.Lo, 30 April 1998) to devise the "best execution" and design the optimal trading strategy. (Powers, 1987) used game theory in the situation where an organization has 2 major shareholders, and a large number of very small shareholders. This was modelled as an oceanic game, in which the two large players behave strategically while the large number of small shareholders (the ocean) do not. This approach is used to derive the highest price that a large shareholder would be willing to pay in the market for corporate control. The

objective of this section is to review each of these models for their merits and shortfalls and provide a conclusion as to which model can be used in the current market scenario to help a firm maximise its value through the optimal capital structure and corporate strategies.

Asset Allocation: Pioneered by Markowitz, is one of the most popular approaches to asset allocation; the mean- variance framework. In this the investor aims at maximising the expected return of the portfolio for a given level of variance with a given set of investment constraints (Meucci, 2007). One of the grave problems with this framework is its inability to take into consideration a holistic and ever changing view of the investors based on different market approaches. In today's highly asymmetrical markets, investors have a new found support for the measures of risk as it emphasises on the potential downside of an allocation more than its benefits. This is due to the ever-changing markets and new emergence disruptions (Meucci, 2007). As given in the paper, the most appropriate risk estimation technique for asset allocation usually depends on a transaction between model error and estimation error. The main point to be considered in this is the known and unknown parameters. A theoretically inferior model may perform better if all of its parameters are known than a complex model with unknown sections (Elizabeth Sheedy, 2014). Another regime-switching asset allocation model by Ang and Bekaert focuses on return volatility and higher correlations. It states that if investors firmly change their allocations of assets to various cash, bonds and equity they can obtain high returns in the bear market (BlakePhillips, 2014). It is commonly anticipated that any form of deterioration in economic conditions results in fewer equity investment and more money market funds, an anticipated opposite also results in opposite investments. Popular advice also makes a huge impact on asset allocation. In the paper "An Asset Allocation Puzzle", the findings prove that explaining popular advice using legalised frameworks is difficult to a rational investor on the other hand if an investor is looking for nominal returns then it becomes easier to explain than a real returns investor (DavidN.Wel, AN ASSET ALLOCATION PUZZLE, 1994)

Risk Management: Industries all around the world are heavily affected due to various factors like natural disasters, unpredictable incidents, health crisis like covid-19, etc. Such factors hit hard on the economic stability of a company. Since occurrence of such events or factors are full of uncertainty, the risk management has emerged has an important parameter for an organization's future. The definition of risk can be differing from person to person depending on their point of views, attitudes, and experience. But to conclude what is risk from various point of views it is basically a probabilistic event which may occur and push the activities of an organization in a negative or a positive direction. There are also various types of risk based on their effect on the activities of the organization on its occurrence and they are financial risk, fiscal risk, legal risk, regulatory risk, operations risk, and few more. The management of this risks through creation of various techniques, models and instruments is known as risk management.(W, 2013). The financial engineer recognizes and measures the risks associated with different instruments and then create an instrument to achieve the target of the company by mitigating these risks. Risk management became a topic of discussion among in financial institutions in 1990s. Due to availability of various sophisticated quantitative models and optimization tools the risk can be dealt with more efficiency and effectiveness. Since the scope of risk is too large so usage of every optimization tool isn't possible and therefore the focus is on asset-liability holdings combination of a company to reduce risk via multistage stochastic optimization. This multistage optimization brings together all financial related decision under a particular structure and integrates investments and saving strategies. The globalization of financial markets has also added to the volatility and risk of various instruments. Also keeping a track of uncertainties like investment rates, future borrowing rates, external deposit streams, etc. is a must in a financial planning.(mulvey, Rosenbaum, & Shetty, 1996)

PROBLEM SOLVING: RISK AND PORTFOLIO MANAGEMENT

Problem: Jay has 40,000 to invest in three Securities A, B, and C. Security A is offering a return of 4% and has a low risk. Security B offers a return of 8% and has a medium risk. Security C offers a return of 10% but has a high risk. To be on the safe side, John invests no more than $6000 in C and at least twice as much as in A than in B. If the rates hold till the end of the year, what amounts should he invest in each Security to maximize the year-end return?

Solution:

STEP 1-Problem formulation.

Let x1 be the amount invested in A, x2 the amount invested in B and x3 the amount invested in C.

$x1 + x2 + x3 = 40{,}000$

$x3 = 40{,}000 - (x1 + x2)$

Objective function(max) = $0.04x_1 + 0.08x_2 + 0.1x_3$

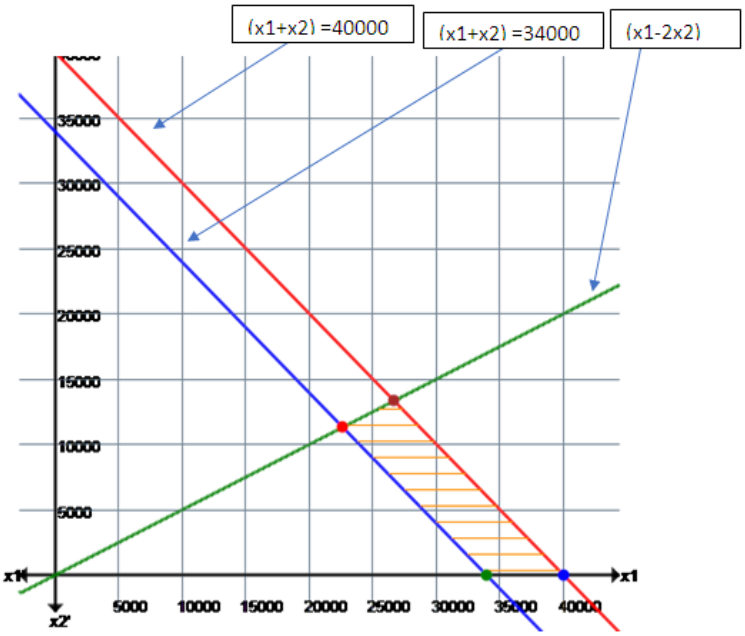
$= 0.04x_1 + 0.08x_2 + 0.10\ (40{,}000 - (x_1 + x_2))$

{substituted the value of Z from above}

$=4000 - 0.06\ x_1 - 0.02\ x_2$

Subject to constraints: A) x3<=6000
40000-(x_1 +x_2) <=6000
(x_1+x2)>=34000
B) x_1>=2x_2
C) x_1>=0
D)x_2>=0
E) x3>=0
40000-(x_1+x_2)>=0
(x_1+x_2) <=40000
STEP 2-Line Coordinatesx_1
1) (x_1+x_2) =34000
x_1=0, x_2=34000; x_2=0, x_1=3400
2) (x_1-2x_2) =0
x_1=0, x_2=0; x_2=10000,x_1=20000
3) (x_1+x2) <=40000
x_1=0, x_2=40000; x_2=0, x_1=40000

max z = 40000-0.06x_1-0.02x_2
subject to
x_1+ x2 <= 40000
x_1+2x2 >= 0
x_1+x2 >= 34000
and x_1, x_2>= 0



EXTREME END POINTS	Z= 40000-0.06x1-0.02x2
A (22666.67, 11333.33)	=40000-0.06(22666.67)-0.02(11333.33) =38413.33
B (34000,0)	=40000-0.06(34000)-0.02(0)=37960
C (40000,0)	=40000-0.06(40000)-0.02(0) =-37600
D (26666.67,13333.33)	=40000-0.06(26666.67)-0.02(13333.33) =38133.33

III. CONCLUSION:

Therefore, as seen above, the maximum return earned by Jay will be 38,413.33 by investing in around 22667 in Instrument A, 11333 in Instrument B and 6000 in Instrument C.

Problem: Mr. Bond wants to allocate his funds in three shares in the derivatives market. He has a capital of Rs. 150,000/- that he can use to buy these shares. Also, he wants to limit the amount of brokerage he pays to Rs. 4000/-. He must also invest at least 40000 in Infosys and at least 30000 in TCS. Find a solution to this problem that maximizes his profit.

Name of the share	Profit per rupee invested	Brokerage per rupee invested
Infosys	3	0.02
Reliance	2	0.03
TCS	4	0.04

Step 1: Problem Formation
Let Infosys, Reliance and TCS bex_1, x_2 and x_3 respectively.
Max Z = 3*x_1 + 2*x2 + 4*x_3
Subject to constraints:

- x_1+ x_2+ x_3<= 150,000
- 0.02*x_1 + 0.03*x_2+ 0.04*x_3<=4000
- x_1>= 40000
- x_3>= 30000
- x_1, x_2, x_3>= 0

Step 2: Standardization
Introducing x_5 and x6; such that
$x_1 - x_5$ = 40000 ->x_1 = 40000 + x_5
$x_3 - x_6$ = 30000 ->x_3= 30000+ x_6

Max Z = 3*(40000 + x_5) +2*x_2 + 4*(30000+ x_6)
Max Z = 120,000 + 3*x_5 + 2*x_2 + 120,000 + 4*x_6

ST.

- x_5 + 40000 + x_2 + x_6 + 30000 = 150,000 **→x_5+ x_2 + x_6= 80000**
- 0.02*(x_5 + 40000) + 0.03*x_2 + 0.04*(x_6 + 30000) = 4000 **→0.02*x_5 + 0.03*x_2 + 0.04*x6 = 2000**

x_5, x_2, x_6>= 0
Introducing Slack variables s_1 and s_2
x_5+ x_2 + x_6 + s_1 = 80000
0.02*x_5 + 0.03*x_2 + 0.04*x_6 + s2 = 2000

Max Z = **120,000 + 3*x_5 + 2x_2+s_2+s_1= 2000**

- x_5, x_6, x_2, s_1, s_2>= 0

Step 3: First Simplex Table

Basis		X5	X2	X6	S1	S2	Bi	Bi/x6
S1	0	1	1	1	1	0	80000	80000
S2	0	0.02	0.03	0.04	0	1	2000	50000
	cj	3	2	4	0	0	Since all delta j are	
	Solution	0	0	0	80000	2000	not <= 0 not	
	zj	0	0	0	0	0	optimal and theta =	
	Delta j	3	2	4	0	0	0.04	

incoming variable. outgoing variable

Step 4: Second Simplex Table
R2 → r2/0.04
R1 → r1-r2'

Basis		X5	X2	X6	S1	S2	Bi	Bi/x1
S1	0	0.5	0.25	0	1	-2.5	30000	60000
X6	4	0.5	0.75	1	0	2.5	50000	100000
	cj	3	2	4	0	0	Since all delta j are	
	Solution	0	0	50000	30000	0	not <= 0 not	
	zj	2	3	4	0	10	optimal and theta =	
	Delta j	1	-1	0	0	-10	0.5	

outgoing variable
incoming variable

Step 5: Third Simplex Table
R1 → R1/0.5
R2 → R2-R1'/2

Basis		X5	X2	X6	S1	S2	Bi	
X5	3	1	0.5	0	2	-5	60000	
X6	4	0	0.5	1	-0.5	5	20000	
	cj	3	2	4	0	0	Since all delta j are <= 0 it is optimal	
	Solution	60000	0	20000	0	0		
	zj	3	3.5	4	4	5		
	Delta j	0	-1.5	0	-4	-5		

Type equation here.

Step 6: Solutions
x_5 = 60000 → x_1= 100,000
x_6 = 20000 → x_3= 50,000

IV. CONCLUSION

In today's day and age where technology is so easily accessible these OR techniques can be used by anyone who is interested in investing in the stock market. There used to be a lot of errors before in case of big calculation but in the current phase, it is very easy to make these calculations. The use of OR techniques has influenced the way financial markets function since they permit traders to make better decisions in less time. From our research on the financial markets, we got to know that there are many techniques that could be used to find various things like where to invest, when to sell, when to purchase, stock market highs and lows, how worthy a company is and what is its liquidity status. Mathematical programming is the OR procedure that has been most generally applied in financial markets. Most kinds of mathematical programming were employed – linear, quadratic, nonlinear, integer, goal, chance-constrained, stochastic, fractional, DEA, and dynamic. OR techniques play an important role in financial decision making and, with the recent dramatic improvements in the real time availability of data and in computer speed, this role will increase. This will create the opportunity for OR techniques to play an even greater role in financial decision making.

Limitations of operations research in Financial Engineering:

Higher cost: Operations research has a high upfront cost for everything, including thorough analysis, professional assessment, and consultation fees. Because the field of study is so detailed, most companies need to pay a consultant for an operations research analysis. Also, the storage of information, data and records are humongous in size and take up lots of storage, which is mainly stored on cloud networks, which becomes an expensive undertaking.
Highly skilled labour required: The employees who conduct operations research, more commonly called "Quants", need to have an extremely specialized skillset, equipped with intensive knowledge about Quantitative Modelling and Operations Research.
Relying on technology: The math required to analyse situations needs to be done by a computer. If technology fails or you lose records somehow, the operations of the company would be affected.
Not accounting for the human element: While math is important and impartial in assessment, there is always a human element to business. For example, an investor with the greatest number of shares in your company may demand that a certain percentage of funding be used in a scenario that isn't the best according to operations research.
Estimates used may be wrong: In many cases, you'll need to rely on estimates in operations research. A misleading result could be one you use for making a decision.

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