MODELLING COMPETITIVE FACILITY LOCATION PROBLEMS

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NOVEMBER 2023

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Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

NOVEMBER 2023

DEDICATED TO

My Inspiration, My Father
Late N.L. Mishra
And
My Strength, My Mother
Heeravati Mishra

CERTIFICATE

This is to certify that the thesis entitled, "**Modelling Competitive Facility Location Problems**", being submitted by **Mamta Mishra** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is a bonafide record of original research work carried out by her. She has worked under our supervision and has fulfilled all the requirements for the submission of the thesis, which has reached the requisite standard.

The results contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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ACKNOWLEDGEMENT

PhD is not just a degree, but rather a journey. It is a path marked by highs and lows, akin to a sine wave. The journey resembles nurturing a plant, where one patiently provides water, minerals, fertilizer, and light while trying to prevent worm infestations. Sometimes, despite the efforts, the plant may get infected, but one persists and take the necessary steps to preserve it. Eventually, with great patience, one witnesses the growth of a strong tree bearing fruit.

Similarly, PhD journey entails the practice of patience, perseverance, and self-motivation in abundance. It imparts invaluable lessons on how to forge ahead and never give up. I am deeply grateful to all those who have contributed to completing this journey.

I would like to express my deep gratitude and appreciation to my supervisors, Prof. Surya Prakash Singh and Prof. M.P. Gupta, for their invaluable guidance, mentorship, and support throughout my PhD journey. The extensive knowledge, insightful feedback, and patience of Prof. Surya Prakash Singh have been crucial in helping me navigate the complexities of my research. His mentorship has not only enhanced my academic skills but also broadened my perspectives. It was an honour to work under his supervision. I am thankful to Prof. M.P. Gupta for his valuable insights, constant encouragement, and belief in my abilities. His guidance and support have been a driving force in this academic journey. I am thankful to my Student Research Committee for their encouragement and support during various phases of the program.

I would also like to express my heartfelt gratitude to my loving family, who has been a constant source of support and encouragement throughout my PhD journey. First and foremost, I would like to extend my deepest gratitude to my father N. L. Mishra and my mother Heeravati Mishra. Their boundless love and faith have been the pillars of strength that propelled me forward during the highs and lows of this PhD journey. I am immensely grateful to my sister Shashi, and brother-in-law, Ashish. Their unwavering support has been a source of immense strength for me. I sincerely thank my brother, Vishal, for his belief and continuous motivation. His constant support and guidance have played crucial role in shaping my academic journey. I would also like to express my gratitude to my sister-in-law, Aroma, and nephew, Arpan, for their love and constant support. Their presence and positive energy have been a source of inspiration for me. I would like to express my deepest gratitude and appreciation to my loving husband, Piyush Bajpai, for his support and encouragement and for being a ray of positivity in my life. I would like to extend my gratitude to my mother-in-law, Sudha and father-in-law, Awadhesh for their love and support.

I am also deeply thankful to my dear friends who have played an instrumental role in my PhD journey. I am grateful to Priyanit for being my rock and providing support throughout this challenging journey. His presence, as a listening ear and a source of wise advice, has been invaluable to me. I cannot express enough gratitude to Samridhi for her help and the valuable role she has played in my journey. I am genuinely grateful to have Anushruti by my side through thick and thin. I wish to thank Meghna for always being there whenever I was in need. The journey was beautiful, with the presence of genuine kindness and the encouragement of Aishwarya. And to Monika, thank you for your infectious sense of humour and for bringing laughter and fun into our friendship. Your presence has added so much joy to my journey. I am thankful to Ayushi for being a source of comfort and assurance and to Surabhi for her kindness and support. I am also grateful to Abza for being a cheerful and supportive friend. I would also like to extend my sincere gratitude and appreciation to Divya, Shubhangini, Ruchita, Aishwarya, Sazia, and Sonali for their invaluable support throughout my journey. Their presence and encouragement have made a significant impact on my academic pursuits.

I am truly fortunate to have such exceptional individuals in my life, and I will always cherish their presence and influence on my academic and personal journey.

(Mamta Mishra)

ABSTRACT

Organizations continuously endeavour to enhance their decision-making processes due to the fast-paced and competitive nature of the business environment. To maintain a competitive edge in the market, it is essential to thoroughly assess the factors that influence facility location decision. This includes analysing competitors strategies, monitoring market trends, understanding customer behaviour, identifying market opportunities, anticipating potential disruptions, and other pertinent considerations. The existing research and models in the field of competitive facility location (CFL) face significant gaps and challenges that impede decision-makers from making informed and efficient decisions.

One such gap is the overlooking of market dynamics and demand fluctuation. Many CFL models assume fixed demand; however, in the real world, demand can fluctuate based on the attractiveness of a product or service.

Another significant gap is related to the customer choice rule. The most commonly used customer choice rules in CFL models are binary and proportional. In the binary choice rule, it is assumed that customer spends all the buying power on one facility that has the maximum attraction to the customer. In contrast, the proportional rule dictates that customers patronise all available facilities in proportion to their attractiveness. The attractiveness may be based on proximity, utility, or customer may have some personal preferences. These assumptions may not hold in the real world. These assumptions may not hold in the real world. Firstly, these rules assume that customers will select at least one facility, even if they customer is not attracted to any facility, ignoring the possibility of customers switching to alternative options or unmet demand. This can result in inaccurate demand modelling and flawed decision-making processes. Secondly, the proportional rule assumes that demand is distributed proportionally between all firms, which may not be realistic in the age of e-commerce. Studies show that

delivery costs significantly impact customer purchase decisions, and splitting demand among several firms can result in high delivery costs due to contingent free shipping policies. Also, in retail shopping, it can lead to high travel costs. Customer choice modelling inaccuracies can result in sub-optimal location design, pricing strategies and flawed decision-making.

Another important factor that impacts the accuracy of CFL models is quality of the facility. Quality refers to characteristics other than distance that attract customer toward the facility (Feranandez *et al*., 2007). The location of facilities and their quality are two most important forces that influence customer behaviour (Fernandez *et al*., 2019). While, only a few recent articles have incorporated quality as a variable, and it is often treated as a fixed parameter. Additionally, pricing is a crucial determinant of customer behaviour.

Finally, in location decision-making, an essential factor is the ability to meet customer demand during disruptive circumstances. Such circumstances can impede the delivery of products and hinder facilities from fulfilling customer orders, posing a challenge to maintaining operational efficiency and cost-effectiveness.

It is crucial to have accurate solutions to make effective location decisions, as small variations in location and design choices can lead to significant profit losses. However, the CFL model is complex and difficult to solve using exact algorithms, making it challenging to obtain accurate solutions.

This thesis addresses these gaps between the current models and practical location decision-making scenarios. To address the aforementioned gaps, the thesis proposes a novel foresight location equilibria model that incorporates price-elastic demand. Additionally, a customer choice model is developed to allow for demand flexibility and capture the multi-layered decision-making process of customers. To address disruptions, the thesis offers strategies businesses can use to handle such events cost-effectively. Moreover, a two-phase approximation algorithm is suggested to solve the complicated CFL model optimally.

The customer choice model proposed in this thesis considers various factors, including the online shopping environment, delivery costs, a minimum attractiveness threshold, the potential for unfulfilled demand, and demand shifts. These components are integrated to reflect real-world customer behaviour more accurately. Moreover, the study emphasises the significance of pricing, quality, and location in influencing customer purchasing decisions. It also considers the concept of price discrimination, a common pricing approach firms utilise in real-world markets. The study also emphasises the importance of considering the dynamic nature of the market and provides a foresight planning strategy that can help businesses in competitive markets. Decision-makers can use this strategy to gain a competitive advantage by anticipating changes in demand, supply, and other market conditions.

Additionally, this thesis also addresses the research gap pertaining to challenges against environmental factors, which serve as an essential and critical factor in location decision problems for meeting demand during disruptions. The thesis proposes a model and approaches to provide strategies to meet demand for relief organization to meet with disruptive circumstances economically and efficiently. By considering the impact of disruptions on facility location decisions, organisations can make better decisions and prepare for any potential disruptions. This can ultimately lead to increased operational efficiency, cost-effectiveness, and improved customer satisfaction.

A novel two-phase heuristic algorithm with exploration and exploitation phase is introduced in this thesis to optimally solve the prosed CFL models. The effectiveness of the algorithm is compared with seven well-known heuristic and hybrid heuristic. The result shows that the proposed heuristic outperformed existing heuristics.

The models and solutions proposed in this thesis aims to fill the gaps and challenges in the current research in various areas, such as CFL, customer behaviour modelling, and humanitarian relief operations. By incorporating key factors such as market competition,

customer preferences, and logistics constraints, decision-makers can make more practical and realistic decisions that enhance their competitive edge in the market.

Keyword: Competitive facility location, Customer choice rule, Approximation algorithm, Foresight planning

सार

कारोबारी माहौल की तेज गति और प्रतिस्पर्धी प्रकृति के कारण संगठन लगातार अपनी निर्णय लेने की प्रक्रिया को बढ़ाने का प्रयास करते हैं। बाजार में प्रतिस्पर्धात्मक बढ़त बनाए रखने के लिए, स्थान निर्णयों को प्रभावित करने वाले कारकों, जैसे प्रतिस्पर्धी रणनीतियों, बाजार के रुझान, ग्राहक व्यवहार, मूल्य निर्धारण दृष्टिकोण, बाजार के अवसरों, संभावित व्यवधानों और अन्य प्रासंगिक विचारों को प्रभावित करने वाले कारकों का पूरी तरह से आकलन करना आवश्यक है। प्रतिस्पर्धी सुविधा स्थान के क्षेत्र में मौजूदा अनुसंधान और मॉडल महत्वपूर्ण अंतराल और चुनौतियों का सामना करते हैं जो निर्णयकर्ताओं को सूचित और कुशल निर्णय लेने से रोकते हैं। ऐसा ही एक अंतर बाजार की गतिशीलता और मांग में उतार-चढ़ाव की अनदेखी है। कई सीएफएल मॉडल स्थिर मांग मानते हैं; हालाँकि, वास्तविक दुनिया में, किसी उत्पाद या सेवा के आकर्षण के आधार पर मांग में उतार-चढ़ाव हो सकता है।

एक और महत्वपूर्ण अंतर ग्राहक की पसंद के नियम से संबंधित है। सीएफएल मॉडल में सबसे अधिक उपयोग किए जाने वाले ग्राहक विकल्प नियम बाइनरी और आनुपातिक हैं। द्विआधारी विकल्प नियम में, यह माना जाता है कि ग्राहक उच्चतम आकर्षण के साथ सुविधा का संरक्षण करते हैं। इसके विपरीत, आनुपातिक नियम में, ग्राहक सभी सुविधाओं को उनके आकर्षण के अनुपात में संरक्षण देते हैं। ये धारणाएँ वास्तविक दुनिया में नहीं हो सकती हैं। सबसे पहले, ये

नियम मानते हैं कि ग्राहक कम से कम एक सुविधा का चयन करेंगे, भले ही वे ग्राहक किसी भी सुविधा के लिए आकर्षित न हों, ग्राहकों के वैकल्पिक विकल्पों पर स्विच करने या मांग पूरी न होने की संभावना को नज़रअंदाज़ करते हुए। इसका परिणाम गलत मांग मॉडलिंग और त्रुटिपूर्ण निर्णय लेने की प्रक्रिया में हो सकता है। दूसरे, आनुपातिक नियम मानता है कि मांग सभी फर्मों के बीच आनुपातिक रूप से वितरित की जाती है, जो ई-कॉमर्स के युग में यथार्थवादी नहीं हो सकती है। डिलीवरी की लागत ग्राहक के खरीद निर्णयों को महत्वपूर्ण रूप से प्रभावित करती है, और कई फर्मों के बीच बंटवारे की मांग के परिणामस्वरूप आकस्मिक मुफ्त शिपिंग नीतियों के कारण उच्च वितरण लागत हो सकती है। साथ ही, खुदरा खरीददारी में, यह उच्च यात्रा लागतों को जन्म दे सकता है। ग्राहक की पसंद मॉडलिंग की गलतियाँ उप-इष्टतम स्थान, डिज़ाइन और मूल्य निर्धारण रणनीतियों और त्रुटिपूर्ण निर्णय लेने की प्रक्रियाओं को जन्म दे सकती हैं।

सीएफएल मॉडल की सटीकता को प्रभावित करने वाला एक अन्य महत्वपूर्ण कारक गुणवत्ता है। जबकि आकर्षण को आम तौर पर दूरी और गुणवत्ता दोनों के कार्य के रूप में देखा जाता है, हाल ही के कुछ लेखों में गुणवत्ता को एक चर के रूप में शामिल किया गया है, और इसे अक्सर एक निश्चित पैरामीटर के रूप में माना जाता है। इसके अतिरिक्त, मूल्य निर्धारण ग्राहक व्यवहार का एक महत्वपूर्ण निर्धारक है।

अंत में, स्थान निर्णय लेने में, विघटनकारी परिस्थितियों के दौरान ग्राहक की मांग को पूरा करने की क्षमता एक आवश्यक कारक है। ऐसी परिस्थितियाँ उत्पादों की डिलीवरी को बाधित कर

सकती हैं और सुविधाओं को ग्राहक के आदेशों को पूरा करने से रोक सकती हैं, परिचालन दक्षता और लागत-प्रभावशीलता को बनाए रखने के लिए एक चुनौती बन सकती हैं।

प्रभावी स्थान निर्णय लेने के लिए सटीक समाधान होना महत्वपूर्ण है, क्योंकि स्थान और डिज़ाइन विकल्पों में छोटे बदलाव से महत्वपूर्ण लाभ हानि हो सकती है। हालांकि, सीएफएल मॉडल सटीक एल्गोरिदम का उपयोग करके हल करने के लिए जटिल और कठिन है, जिससे सटीक समाधान प्राप्त करना चुनौतीपूर्ण हो जाता है।

यह थीसिस वर्तमान मॉडलों और व्यावहारिक स्थान निर्णय लेने के परिदृश्यों के बीच इन अंतरालों को संबोधित करती है। उपरोक्त अंतराल को संबोधित करने के लिए, थीसिस एक उपन्यास दूरदर्शिता स्थान संतुलन मॉडल का प्रस्ताव करती है जिसमें मूल्य-लोचदार मांग शामिल होती है। इसके अतिरिक्त, ग्राहकों की पसंद के लचीलेपन की अनुमति देने और ग्राहकों की बहुस्तरीय निर्णय लेने की प्रक्रिया पर कब्जा करने के लिए एक ग्राहक पसंद मॉडल विकसित किया गया है। व्यवधानों को दूर करने के लिए, थीसिस ऐसी रणनीतियों की पेशकश करती है जिनका उपयोग व्यवसाय इस तरह की घटनाओं को लागत प्रभावी ढंग से संभालने के लिए कर सकते हैं। इसके अलावा, जटिल सीएफएल मॉडल को बेहतर ढंग से हल करने के लिए एक दो-चरण सन्निकटन एल्गोरिथ्म का सुझाव दिया गया है।

इस थीसिस में प्रस्तावित ग्राहक पसंद मॉडल विभिन्न कारकों पर विचार करता है, जिसमें ऑनलाइन शॉपिंग वातावरण, वितरण लागत, न्यूनतम आकर्षण सीमा, अधूरी मांग की संभावना

और मांग में बदलाव शामिल हैं। इन घटकों को वास्तविक दुनिया के ग्राहक व्यवहार को अधिक सटीक रूप से दर्शाने के लिए एकीकृत किया गया है। इसके अलावा, अध्ययन ग्राहक क्रय निर्णयों को प्रभावित करने में मूल्य निर्धारण, गुणवत्ता और स्थान के महत्व पर जोर देता है। यह मूल्य भेदभाव की अवधारणा पर भी विचार करता है, एक सामान्य मूल्य निर्धारण दृष्टिकोण फर्म वास्तविक दुनिया के बाजारों में उपयोग करते हैं। अध्ययन बाजार की गतिशील प्रकृति पर विचार करने के महत्व पर भी जोर देता है और एक दूरदर्शिता योजना रणनीति प्रदान करता है जो प्रतिस्पर्धी बाजारों में व्यवसायों की सहायता कर सकता है। निर्णयकर्ता इस रणनीति का उपयोग मांग, आपूर्ति और अन्य बाजार स्थितियों में परिवर्तन की आशंका से प्रतिस्पर्धात्मक लाभ प्राप्त करने के लिए कर सकते हैं।

इसके अतिरिक्त, यह थीसिस आर्थिक और कुशलता से विघटनकारी परिस्थितियों से निपटने के लिए राहत संगठन की मांग को पूरा करने के लिए रणनीति प्रदान करने के लिए एक मॉडल और दृष्टिकोण प्रस्तावित करती है। सुविधा स्थान निर्णयों पर व्यवधानों के प्रभाव पर विचार करके, संगठन बेहतर निर्णय ले सकते हैं और किसी भी संभावित व्यवधान के लिए तैयार हो सकते हैं। इससे अंततः परिचालन दक्षता, लागत-प्रभावशीलता और बेहतर ग्राहक संतुष्टि में वृद्धि हो सकती है।

इस थीसिस में अन्वेषण और शोषण चरण के साथ एक उपन्यास दो-चरण हेयुरिस्टिक एल्गोरिथम पेश किया गया है ताकि प्रोज्ड सीएफएल मॉडल को इष्टतम रूप से हल किया जा सके।

एल्गोरिदम की प्रभावशीलता की तुलना सात प्रसिद्ध ह्यूरिस्टिक और हाइब्रिड ह्यूरिस्टिक से की जाती है। परिणाम से पता चलता है कि प्रस्तावित अनुमानी ने मौजूदा अनुमान से बेहतर प्रदर्शन किया।

इस थीसिस में प्रस्तावित मॉडल और समाधान का उद्देश्य प्रतिस्पर्धी सुविधा स्थान, ग्राहक व्यवहार मॉडलिंग और मानवीय राहत कार्यों जैसे विभिन्न क्षेत्रों में वर्तमान शोध में अंतराल और चुनौतियों को भरना है। बाजार प्रतिस्पर्धा, ग्राहकों की पसंद और रसद बाधाओं जैसे प्रमुख कारकों को शामिल करके, निर्णय लेने वाले अधिक व्यावहारिक और यथार्थवादी निर्णय ले सकते हैं जो बाजार में उनकी प्रतिस्पर्धात्मक बढ़त को बढ़ाते हैं।

कीवर्ड: प्रतिस्पर्धी सुविधा स्थान, ग्राहक पसंद नियम, सन्निकटन एल्गोरिथम, दूरदर्शिता योजना

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LIST OF INDICES, VARIABLES, PARAMETERS AND FUNCTIONS

List of indices

C_j : Capaity of DC j

f : Index of entrant firm

i : Index of demand points ∀ i =1….. n

J : Index for DCs ($j = 1, 2..........s$)

Λ : Penalty cost associated with unsatisfied demand

List of parameters

a_i : Location of demand points (x_i, y_i) ($i = 1,2..........n$)

B_i : Buying power of demand point i

d_i : Maximum possible demand by customer at i

F : Fixed cost of the goods

k : Number of existing firm of chain

l : Number of competitor firms

L_f : Search space, firm f $X_f = (x_f, y_f)$, $X_f \subset L_f$

m : the parameter used to adjust quality

n : Number of demands

PF : Monopolistic price

R^2 : Planar search space for facility location of firm

X_f : location of new firm f, $X_f = (x_f, y_f)$, $X_f \subset R^2$

$X_{f'}$: location of existing firm f', $X_{f'} = (x_{f'}, y_{f'})$, $X_{f'} \subset R^2$

α : Quality value

λ	: Elasticity constant
β_c	: Threshold of attractiveness
$\psi_{i0}^{f}, \psi_{i1}^{f}$	:The parameters used to adjust the distance of transportation cost
ε	: Constant with large value

List of functions

$c_f(X_f)$	: Unit location cost of firm *f* at location X_f
$c_f(\alpha_f)$	: quality cost
D_i^f	: Demand placed by customer *i* $=d_i e^{-\lambda q_i^{f'}}$
MC_f	: Market share attracted by new firm *f* from the market influenced by existing competitor
$q_i^f(X_f, \alpha_f)$	:Unit price that firm *f* from location X_f offer to demand point *i*
$q_i^f(X_{f'}, \alpha_{f'})$	: Unit price that firm *f'* from location $X_{f'}$ offer to demand point *i*
$T(X_{f'}, X_f)$	: Total cost if each customer served with minimum cost
$t_i^f(X_f)$	: Unit cost of transportation cost by firm *f*, if transporting from location X_f to demand *i*
$\bar{\beta}_i^f$	: Binary function for attractivess criteria for chain firm
$\bar{\beta}_i^{f'}$	: Binary function for attractivess criteria for competitor firm
$\bar{\beta}c_i^f$	: Cost determinant function for chain firm
$\bar{\beta}c_i^f$	: Cost determinant function for competitive firm
$d(X_f A_i)$	: Distance from location X_f to customer *i*
$d^j(x_j, a_i)$	: Distance between DC*j* and demand point *i*

D_i : Demand at the demand point

$f(d(X_f, a_i))$: Function of delivery time

M : Total available demand share

M_f : Fixed market share attracted by new firm f

MD_{dcj} : Maximum possible delivery distance of DC

MD_f : Maximum possible delivery distance of the existing firm

M_f : Market share attracted by firm f

M_j : Market share attracted by DC j

M_u : Unsatisfied demand points

MSC : Market share of chain

MSE :Market share for new firm

MSE_C :Market share for entrant firm of the chain

P_{rf} : Profit earned by firm f

UN : Unsatisfied demand

UN_c :Unsatisfied demand in chain case

W : Total demand

γ_i^f : Attractiveness of the firm

$\gamma_i^{f'}$: Attractiveness of the competitor firm

μ_i^f : Binary value to check customer attraction toward atleast one firm of the chain

$\mu_i^{f'}$: Binary value to check customer attraction toward competitive firm

List of decision variables

q_i^f :Unit demand cost offered by firm f from location X_f to market i

m :Number of DC

X_f : Firm location f, $X_f = (x_f, y_f)$, $X_f \subset L_f$

X_j : DC location j, $X_j = (x_j, y_j)$, $X_j \subset L_j$

LIST OF ABBREVIATIONS

C	Capacitated
CFL	Competitive Facility Location
CL	Closest
CR	Carnot game
D	Discrete
DY	Dynamic
E	Elastic
F	Foresight
FMINCON	Find minimum of constrained nonlinear multivariable function
GA	Genetic Algorithm
IN	Inelastic
L	Location
L-C	Location-capacity
L-D	Location-Design
L-L	Location-Logistic
L-P	Location-Price
LI	Linear
M	Multi
MS	Multi start
N	Network
N	Nash game
PL	Planar
PS	Pattern Search

R	Random
S	Stackelberg game
SI	Single
ST	Static
UTD	Utility-based-deterministic
UTP	Utility-based-probabilistic