Jiqiang Lu · Huaqun Guo · Ian McLoughlin ·
Eyasu Getahun Chekole · Umayal Lakshmanan ·
Weizhi Meng · Peng Cheng Wang ·
Nicholas Heng Loong Wong *Editors*

Proceedings of the 9th IRC Conference on Science, Engineering, and Technology

IRC-SET 2023; 19-August, Singapore

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Preface

International Researchers Club (IRC) (www.irc.org.sg) was set up in 2001. The vision of IRC is to create a vibrant and innovative research community for Singapore and beyond, through contributions of technical specialties and occupational experiences from its members, and fostering strong networking and social interactions of expatriates and new citizens with the local community.

With the vision of IRC, it is our great pleasure to organize IRC conference on Science, Engineering and Technology (IRC-SET, www.ircset.org) for the younger talents and researchers. IRC-SET 2015 was the inaugural conference of IRC, and IRC-SET 2023 is now in its ninth run. IRC-SET conference aims to provide a platform for young and talented researchers to share their research findings, to obtain comments and feedback from experts in the field and exchange innovative ideas of leading-edge research in multi-disciplinary areas. Researchers from universities, junior colleges, polytechnics and secondary schools are warmly welcomed to participate in this conference to showcase and present their research projects, results and findings. Unlike other academic conferences, this conference focuses specifically on Education and Youth development and has officially been given technically sponsorship from seven universities, namely National University of Singapore (NUS), Nanyang Technological University (NTU), Singapore Management University (SMU), Singapore University of Technology and Design (SUTD), Singapore Institute of Technology (SIT) and Singapore University of Social Sciences (SUSS). IRC-SET 2023 conference is also supported by IEEE Intelligent Transportation Systems Society (ITSS) Singapore Chapter, IEEE Broadcast Technology Society (BTS) Singapore Chapter and IEEE Singapore Section Women in Engineering (WIE) Affinity Group.

The program of IRC-SET 2023 advocates the importance of innovative technology backed by the strong foundation of science and engineering education. Exposing our young participants to the key technology enablers will encourage more interest into the fields of science, engineering and technology. To select good quality papers, the IRC-SET 2023 Call for Papers was broadcasted to universities, junior colleges, polytechnics and secondary schools. The researchers then submitted their technical papers to the conference online system. To meet the criteria of the conference, the submitted papers (which had to follow the required template) were peer-reviewed by the conference technical program committee, which comprised a few reviewers coming from the IRC researchers, professors, lecturers and teachers. Comments and recommendations based on novelty of the work, scientific, engineering and technology relevance, technical treatment plausible and clarity in writing, tables, graphs and illustrations were then provided back to the authors. Through this rigorous review, the technical program committee has selected these papers to be presented in the IRC-SET 2023 conference, which are now published in this proceeding.

IRC-SET 2023 conference was held online and consisted of opening speech by General Chair Prof. Ian McLoughlin (Professor in Singapore Institute of Technology), guest speech by Prof. Tit Meng Lim (Chief Executive of Singapore Science Centre) and nine parallel presentation sessions. The nine presentation sessions covered the key focus areas which included ITSS Session, BTS Session, WIE Session, Biomedical Science, Computer Engineering, Chemical Engineering, Life Science, Cyber Security and Mechanical Engineering. In the closing ceremony, A/Prof. Huaqun Guo (President of IRC and Associate Professor in Singapore Institute of Technology) announced the winners of best paper awards and best presenter awards and concluded the conference with an introduction to the International Researchers Club and a closing speech.

This proceeding is dedicated to International Researchers Club and its members.

Singapore
September 2023

Jiqiang Lu
Huaqun Guo
Ian McLoughlin
Eyasu Getahun Chekole
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We would like to extend our utmost gratitude to the people who have, in one way or other, inspired, aided and contributed to the successful completion of this book.

First of all, we would like to thank all members of the conference organizing committee who have contributed their time and professional knowledge to make the conference a big success.

Special thanks to all reviewers for their expertise, time, effort and timely response throughout the peer evaluation process.

Special thanks to all Session Chairs for their expertise, time and effort to make the presentations smooth and have the fruitful knowledge sharing at the conference day.

Last but not least, our greatest appreciation to all IRC members for their unity.

Contents

Optimising Travel Routes for Tour Bus Operator

Alessandra Awil, Ryan Raidley Yiap Chang Feng(✉), Zi Hwee Ng, Denzel Low E Loong, Zining Tan, and Huaqun Guo

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Abstract. This project report delves into optimizing tour routes for bus operators serving diverse destinations using heuristics and algorithms. The primary aim is to enhance tourist transportation while optimizing tour bus routes through varied algorithms and heuristics. The study employs the Nearest Neighbour, Nearest Insertion, and Christofides algorithms, along with 2-opt enhancements, for comprehensive analysis and simulations. To further streamline route optimization, K-means clustering is strategically integrated. This approach groups nearby locations, enabling operators to visit a single representative site within each cluster. Passengers can conveniently access adjacent locations on foot from these cluster points. This technique significantly reduces computational complexity, especially when handling numerous locations, thus effectively reducing runtime. Through extensive experimentation involving clustered, dispersed, and varying destination scenarios, the study captures execution times and overall route durations, subjecting them to comparative assessment. This analysis showcases algorithm strengths and limitations under diverse conditions. In summary, this research advances tour route optimization and introduces efficient clustering strategies, offering operators a robust framework for informed decision-making. It empowers operators to create seamless, enjoyable travel experiences while minimizing computational burdens.

Keywords: Traveling Salesman Problem (TSP) · Nearest Insertion algorithm · Nearest Neighbour algorithm · Christofides algorithm · Route optimization · Combinatorial optimization · Heuristic algorithms · Greedy algorithms

1 Introduction

1.1 Problem Statement

The goal of this project is to effectively transport visitors from their preferred pickup site, drop them off at any other destinations on the itinerary, and then return to the beginning location which could be the bus garage. By taking into account the various stop sites for quick stops, as well as the most effective route to return to the beginning point, the major goal is to employ data structures and algorithms to design the most efficient route for tour companies and their bus drivers.

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This report highlights the potential impact of data-driven strategies in the transportation industry and offers valuable insights for businesses seeking to enhance their operational practices. The following sections delve into the detailed methodology, results, and offer a comprehensive understanding of the optimization process. This report may focus on tourist bus operators, but it is not limited to, and can also be used in other cases such as food or parcel delivery services.

Our platform seeks to demonstrate its efficiency and efficacy in offering the optimal route for bus drivers, consequently decreasing operational expenses and boosting profitability for the tour bus firm, through the execution of various test scenarios, data pre-processing, and data analysis.

Comparing the route optimization outcomes from the various algorithms will be the main topic of the data analysis's discussion and explanation section. In particular, while working with larger datasets and dynamically changing user inputs, the chosen algorithms' advantages in constructing more time efficient routes will be highlighted. We will also discuss any potential restrictions or difficulties observed during the process of data processing and interpretation.

1.2 Method of Approach

We plan to implement three different algorithms: the Nearest Neighbour algorithm, Nearest Insertion algorithm, and the Christofides algorithm combined with 2 opt improvements. The algorithms used can be implemented to obtain results for both minimum spanning trees and find the shortest paths. The algorithms are also utilized to solve the Traveling Salesman Problem (TSP). It would identify the most efficient route to visit each destination once, and return to the starting point, to further reduce the total travel distance and operating costs. Additionally, we employ K-Means clustering to potentially reduce the number of locations by removing locations close to each other and achieve lower run times.

To collect data from a list of tourist destinations, geocoding, facilitated by the geopy library, retrieves the precise latitude and longitude coordinates for each destination based on their names. This geocoded data serves as crucial input for subsequent calculations and graph representation. To model the connections between destinations, a complete graph is created using the networkx library. Each location is represented as a vertex (line), and the distances between locations from the weighted edges (duration) in the graph. The complete graph captures all possible connections between every destination, forming the basis for pathfinding algorithms.

2 Literature Review

2.1 Traveling Salesman Problem

The Traveling Salesman issue (TSP) is a well-known combinatorial optimization issue with many practical applications, e.g., logistics, the production of circuit boards, and DNA sequencing. Finding an accurate solution for big instances of TSP becomes computationally impossible due to its NP-hardness. Thus, heuristic algorithms have been extensively investigated to find approximate solutions that are frequently near to the ideal answer.

2.2 Nearest Neighbour Algorithm

The Nearest Neighbour, Greedy, Genetic, and other heuristic algorithms for the TSP are covered in-depth in an article by OPEX Analytics [1]. The paper assesses the effectiveness of these algorithms and identifies their advantages and disadvantages. To choose the best strategy for a particular TSP instance, it is crucial to comprehend the trade-offs between the various heuristics. Moreover, Ormerod and Penn [2] also looked into the mental mechanisms that humans utilise to tackle TSP-like issues. The knowledge gained from this study into human decision-making processes can be used to create TSP heuristic algorithms that are more efficient [3]. By choosing the next edge based on the closest distance, Nearest Neighbour is effective for small data sets.

2.3 Nearest Insertion Algorithm

A well-liked heuristic for creating TSP solutions is the Nearest Insertion algorithm. The Nearest Insertion technique is thoroughly implemented, and step-by-step visualisations of the algorithm's execution are provided, in a publication by Carnegie Mellon University. The article explains how the computer creates the tour incrementally by choosing the next unexplored city and inserting it at the right spot in the existing trip [4]. The Nearest Insertion Algorithm iteratively inserts the closest unvisited location to the current tour to create a highly optimized solution.

2.4 Christofides Algorithm

A popular approximation approach for the TSP is the Christofides algorithm. The Christofides algorithm builds an approximation solution using a minimum spanning tree and a least-cost perfect matching, which ensures that the solution is within a factor of 3/2 times the ideal tour duration for metric TSP instances. The steps of the technique are described in the original work by Christofides [5], which includes building a minimum weight spanning tree and locating a minimum-weight perfect match on the odd-degree vertices of the tree to create a tour. Wang [6] presented the practical implementation and step of the Christofides method, in detail on how it is applied to the TSP. Because it strikes a balance between computational effectiveness and solution quality, the Christofides method is still widely used.

To further improve the Christofides method, we chose to integrate 2-opt and apply a present number of iterations based on the input. By making these changes, we are hoping to outperform more conventional Christofides implementations in terms of results.

2.5 K-Means Clustering

We employed k-means clustering to group nearby locations, effectively reducing algorithm run time, and aid bus operators in planning visits to only one location within each cluster. This strategy saves valuable time and optimizes the overall efficiency of the process.

3 Designed Solution and Implementation

3.1 Designed Solution

In addition to the previous algorithms, Google Maps was used to dynamically generate user-defined locations via the GUI (Graphic User Interface). The objective was to assess the platform's capacity to manage various user inputs and generate efficient routes as a result.

As we did not use static datasets, addressing user input from the GUI was part of the data pre-processing procedure. The software takes user input of desired location names to retrieve the relevant geographic coordinates (latitude and longitude) from Google Maps. The graph data structure representing the road network and locations is then built using these coordinates. Lastly, the user-defined locations are converted into a format that is compatible with the algorithms during the data preprocessing stage.

Figure 1 illustrates the project system flowchart, Fig. 2 shows GUI of our project using Python Flask, and Figure displays output in GUI.

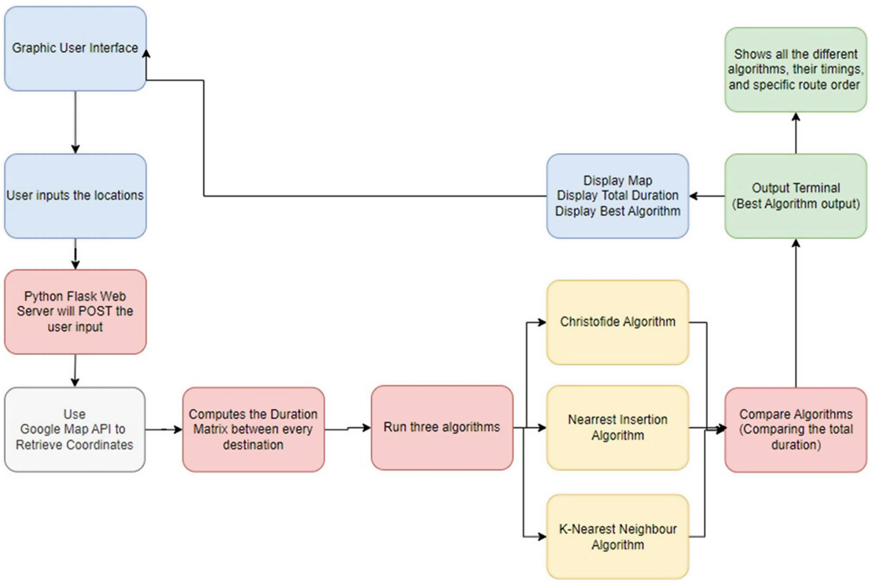


Fig. 1. Project system flowchart

3.2 Implementation

As showed in Fig. 2, users can interact with the system and enter their preferred places for route optimization using the user interface component. An easy-to-use interface allows users to enter location input. The first location keyed in would be their starting and ending point.

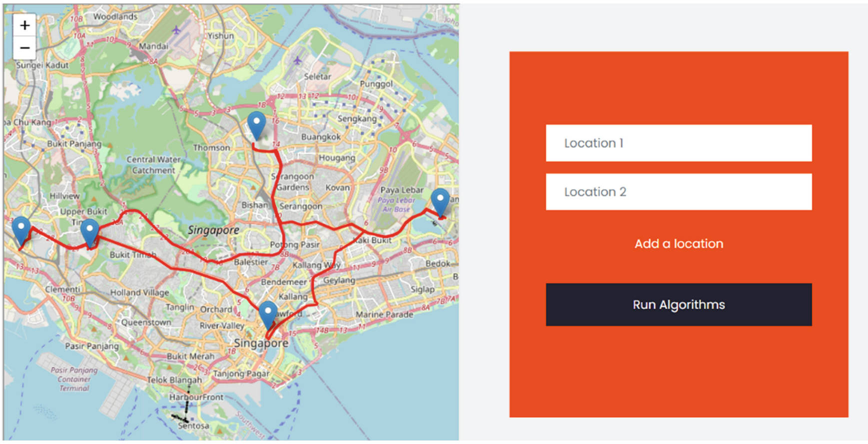


Fig. 2. GUI of our project using Python Flask

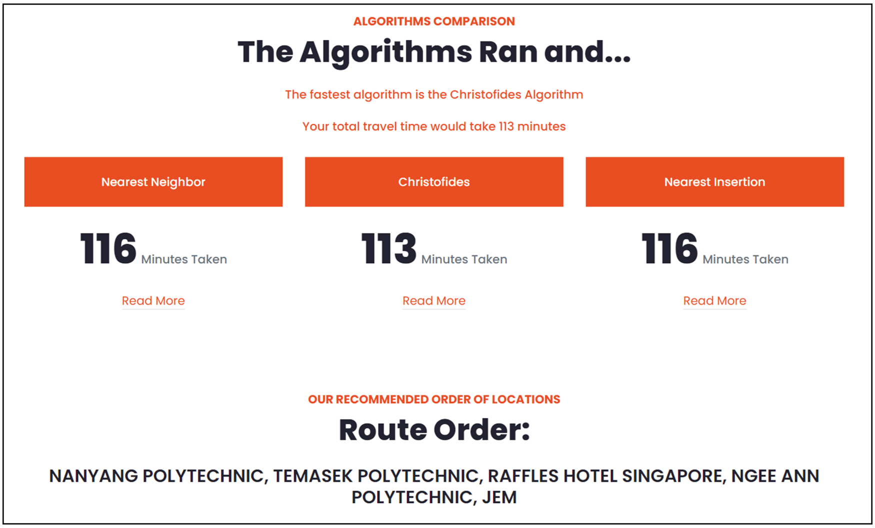
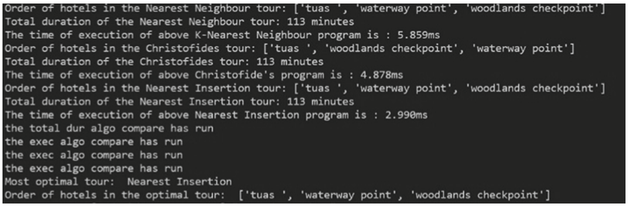


Fig. 3. Output in GUI

In the User Interface of Fig. 3, normally the total time calculated for the route to be travelled would be different for all three algorithms. However, in this case, we can see that all three algorithms gave out the same total time taken. In such events, the best algorithm chosen is based on the least amount of time it takes to finish executing in the code.

The terminal in Fig. 4 is used to show in-depth on how the code is run. It includes items such as ‘Order of hotels’, or locations in this case, as well as **‘total duration’ of the algorithm, which shows how long it would take to get from point A to all other destinations and back**. The terminal would also print out **‘The time of execution of**

above algorithm', which **means the total time it takes for the specific algorithm to run**. It will also print out 'the total dur algo compare has run', which compares the total duration of each algorithm to get the shortest total duration, which is also the best algorithm. The code for 'the exec algo compare has run' will only run if there is more than one algorithm with the same shortest overall total duration, and thus will choose the algorithm with the shortest execution time as the best algorithm.



```
Order of hotels in the Nearest Neighbour tour: ['tuas ', 'waterway point', 'woodlands checkpoint']
Total duration of the Nearest Neighbour tour: 113 minutes
The time of execution of above K-Nearest Neighbour program is : 5.859ms
Order of hotels in the Christofides tour: ['tuas ', 'woodlands checkpoint', 'waterway point']
Total duration of the Christofides tour: 113 minutes
The time of execution of above Christofide's program is : 4.878ms
Order of hotels in the Nearest Insertion tour: ['tuas ', 'waterway point', 'woodlands checkpoint']
Total duration of the Nearest Insertion tour: 113 minutes
The time of execution of above Nearest Insertion program is : 2.990ms
the total dur algo compare has run
the exec algo compare has run
the exec algo compare has run
the exec algo compare has run
Most optimal tour:  Nearest Insertion
Order of hotels in the optimal tour:  ['tuas ', 'waterway point', 'woodlands checkpoint']
```

Fig. 4. Output in the terminal

4 K-Means Clustering

4.1 Implementation

K-Means clustering efficiently groups places in graph G using distance metrics like Euclidean distance, with the "k" parameter determining the clusters. Starting from a random or user-defined point, K-Means assigns locations iteratively to nearby clusters, optimizing groupings to minimize distances within each cluster.

Our system employs K-Means clustering to enhance travel efficiency by grouping nearby locations based on walking distance, significantly saving customers' time.

Our rationale was that while K-Means clustering may lead to occasional suboptimal groupings, our method leverages its benefits to streamline travel plans by grouping close-by locations, resulting in considerable time savings.

4.2 Results

As shown in Fig. 5, the K-Means algorithm clusters the locations which are within walking distance to one another and chooses the point at the center of the cluster for the passengers to alight. This would help the drivers to save fuel as they wouldn't need to U-turn just to drop passengers right at the opposite of the previous site.

5 Test Cases with Results and Comparisons

5.1 Result Comparison

Based on all the test cases, we can group our observations based on the two following scenarios (Tables 1 and 2).

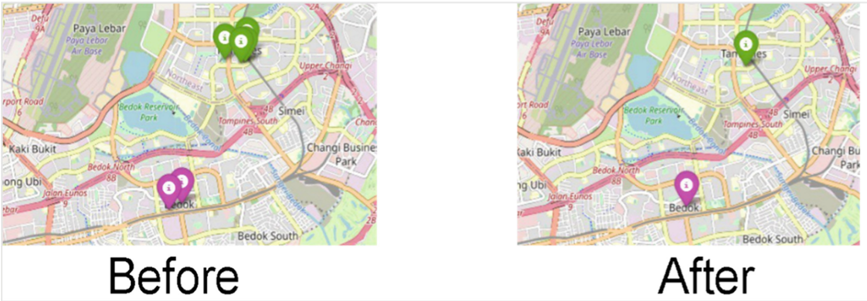


Fig. 5. Results of K means clustering

Table 1. Comparing results for far apart location test cases: Scenario 1

Clustered locations			
No. of locations set	Total time taken for distance to be travelled calculated		
	Nearest Neighbour	Christofides	Nearest Insertion
3	*13*	13	13
5	*28*	32	32
10	*62*	66	67
20	*121*	128	144

The Nearest Neighbour Algorithm consistently outperformed both the Christofides and Nearest Insertion Algorithm for both 3 and 5 clustered locations by being able to effectively explore and capture the local structure of closely clustered destinations.

For the test case with 3 clustered locations, as all three algorithms had the same total time, the code will choose the algorithm with the shortest execution time as the best algorithm. In terms of execution time, the Nearest Neighbour Algorithm (2.97 ms) outperformed the other two (4.005 ms and 3.002 ms). By progressively selecting the closest unvisited neighbour, the Nearest Neighbour Algorithm effectively captured the local structure of densely populated areas, producing superior results.

The Christofides Algorithm + 2 Opt, on the other hand, demonstrated its strength as the number of locations increased to 10 and 20 clustered locations. Although the total time for distance calculated is still more than the Nearest Neighbour, we can see that the difference in total time overall to get a low but also reliable result in comparison is not far from the Nearest Neighbour algorithm result, compared to Nearest Insertion which progressively gets worse. Compared to the Nearest Neighbour Algorithm and the Nearest Insertion Algorithm, the Christofides Algorithm + 2 Opt consistently provided a reliable and short time in these situations as well.

In conclusion, the properties of the issue cases determine which method is best appropriate for solving the Travelling Salesman issue. The Nearest Neighbour Algorithm shines for small, clustered sites because it can successfully capture the local structure, and Christofides Algorithm shines when there is a larger number of edges by being reliable.

Table 2. Comparing results for far apart location test cases: Scenario 2

Dispersed locations			
No. of locations set	Total time taken for distance to be travelled calculated		
	Nearest Neighbour	Christofides	Nearest Insertion
3	113	113	*113*
5	94	*87*	94
10	181	172	*169*
20	319	*291*	346

The Nearest Insertion Algorithm confirmed its supremacy by creating the most ideal trips for 5 or lesser remote or far apart places. The Nearest Neighbour Algorithm and the Christofides Algorithm + 2 Opt were outperformed by its method of iteratively inserting the closest unvisited location to the current tour in order to reduce the overall distance between widely separated destinations.

In this case, the 3 dispersed locations have the same total time. When comparing in terms of execution time, the Nearest Insertion Algorithm (2.990 ms) did better than the other two (5.859 ms and 4.878 ms). This test case shows how Nearest Insertion performs better in comparison to Nearest Neighbour in small sets of locations, but with widely scattered locations.

The Christofides Algorithm + 2 Opt demonstrated its power as the number of locations increased to 10 and 20 distant locations. The Christofides Algorithm + 2 Opt consistently produced close to optimal solutions thanks to its guaranteed approximation ratio and the 2-Opt optimization for fine-tuning the tour. It handled larger instances and dispersed destinations effectively, outperforming the Nearest Insertion Algorithm and the Nearest Neighbour Algorithm in these scenarios.

In conclusion, the number of locations and their distribution have a significant impact on the decision of the best appropriate method for the Travelling Salesman Problem. The Christofides Algorithm + 2 Opt consistently a more optimised route for dispersed locations. However, depending on the particulars of the problem cases, the Nearest Insertion Algorithm and the Nearest Neighbour Algorithm may perform better in scenarios with small or clustered locations. When choosing the best algorithm to produce effective and precise solutions, we need to take into account the distribution and size of the sites.

6 Conclusion

In this project, we developed a route optimisation tool to generate the shortest routes to the specified locations by the users. The team has used the Nearest Insertion, Christofides with 2-opt enhancement, and Nearest Neighbour algorithms for route optimisation.

These methods were applied to a weighted, undirected graph that reflected the locations of the locations and the road network. Table 3 shows the overall algorithm conclusion.

Table 3. Overall algorithms conclusion

Nearest Neighbor algorithm	Christofides algorithm	Nearest Insertion algorithm
Clustered settings	Dispersed locations	Dispersed locations
• Effectively explores local structure • It quickly finds the Nearest Neighbors without checking all locations • Delivers nearly ideal answers for densely populated areas	• 2-Opt optimization ensures near-optimality	• By effectively minimizing distance between locations that are far apart
Christofides algorithm would be more effective overall since it works well in both clustered and scattered circumstances and provides nearly optimal solutions using the 2-Opt optimization, making it a flexible option for different kinds of location distributions		

The route planning tool successfully handled dynamically input user-defined sites through Google Maps. By including the data processing of user inputs and creating the graph-based data structure, the software efficiently controlled the road network and locations, enabling quicker route computations.

Through numerous iterations of testing and analysis, we analysed how well these algorithms determined the best paths for various scenarios. In comparison to all, the Christofides algorithm performed the best depending on the quantity of places and the distance of the routes from one another.

Overall, our experiment demonstrated the performance and dependability of the Christofides algorithm and showed that it is the best reliable alternative for route optimisation when users can input their own locations. This application is helpful for delivery services, tour bus companies, and any other business where route optimisation is crucial for reducing costs and increasing efficiency. With further development and enhancements, this route optimisation programme has the potential to greatly assist enterprises and individuals in strategically and effectively planning their travel.

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Investigating Renewable Energy Landscape and Climate Change Mitigation in Southeast Asia

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Abstract. The paper examines Southeast Asia's response to climate change and the region's development in adopting renewable energy sources. It also explores challenges and opportunities that accompany the development of various climate change mitigation approaches. By highlighting the risks posed by rising sea levels and densely populated coastal areas, the paper emphasizes the need for sustainable energy solutions to curb carbon emissions. An increasing number of countries have shown support for adopting renewable energy sources in Southeast Asia, particularly on wind and solar power. Their strong commitment contributes to the region's collective efforts to transition towards cleaner and more sustainable energy systems. The paper also addresses the obstacles that hinder renewable energy development, while highlighting the potential for long-term viable solutions and increasing support for renewable energy policies.

Keywords: Alternative energy sources · Climate change · Renewable energy · Southeast Asia · Solar Photovoltaics (PV)

1 Introduction

1.1 The Vulnerable Coastal Communities of Southeast Asia

While many of us have fond memories of a pleasant vacation spent on immaculate white sands collecting seashells, due to the exacerbated rise in sea levels the prospect of future generations setting their feet on pristine sandy beaches may seem increasingly remote. The scenario will actualize if people do not take fast action to mitigate that which is rapidly transforming the landscape – the climate crisis. Scientists predict that by the 2080s, millions of people will face the plight of recurring flooding due to rising sea levels. In 2019, Indonesia had already lost 29,261 ha of coastal areas, almost the size of its capital Jakarta. The magnitude of such an impact is most significant in densely populated and low-lying mega-deltas of Asia and Africa. Coastal and low-lying regions are most susceptible to climate-change-induced rising sea levels and this vulnerability is further compounded in areas with dense human populations where the inundation could

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cause widespread destruction of habitats and disruption to people's lives. Are humans attuned to the pressing reality that ice glaciers are receding at an alarming pace due to the inexorable forces of global warming? Are people aware of the possibility that by 2100, the sea level may surge by a magnitude exceeding two feet?

Southeast Asia's coastlines are a renowned haven for tourists who love pristine beaches but the dismaying truth is that many countries in this region have been identified by the World Bank study as risky coastal areas with low elevation, including the Philippines, Indonesia, Malaysia, Myanmar and Vietnam. Coastal communities in these nations face worsening impacts of climate change such as heightened flooding without adequate resilience measures.

1.2 Climate Change-Related Deaths and Economic Losses

The Global Humanitarian Forum reported in 2009 that climate change caused 300,000 deaths and $125 billion in economic losses [1] each year, with several Asian countries hit the hardest from climate-related deaths caused by floods and droughts. Climate-associated disasters include hydrological, meteorological, and climatological subgroups. From a study, there was a notable rise in the occurrence of severe natural disasters between the 1980s and 2020, and the frequency of these events nearly quadrupled from 1970–1980 to 2001–2020. Specifically, hydro-meteorological disasters comprising two-thirds of all intense natural disasters during this period contributed to 70% of the overall increase observed between 1971–1980 and 2001–2010 (Fig. 1).

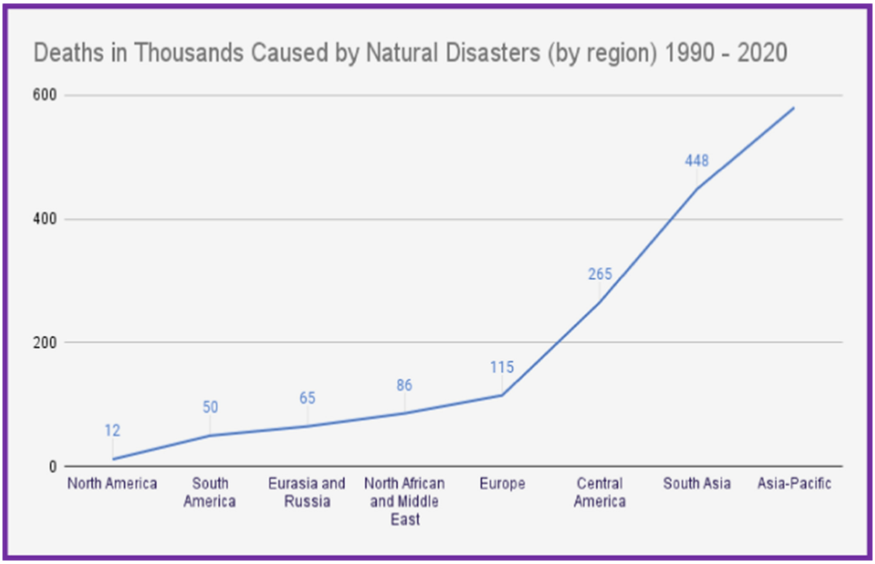

Fig. 1. Deaths from natural disasters (in thousands) 1990–2020 (Source: plotted by How Yun Hsuen Inge, 2023)

Intense hydrometeorological disasters were particularly prominent in Asia and the Pacific, accounting for 72% of the frequency of intense natural disasters recorded during

1971–2010 in the region, which constituted more than half of the increase in the frequency of intense hydrometeorological disasters recorded globally since the late twentieth century. The Asia-Pacific region witnessed the highest number of people being displaced because of climate-related hazards including droughts, extreme temperatures, seasonal floods and storms between 2008 and 2019. Almost 25 million people in 2019 were displaced in the Asia-Pacific region with China, India, and the Philippines accounting for 53% of the displacements (Fig. 2).

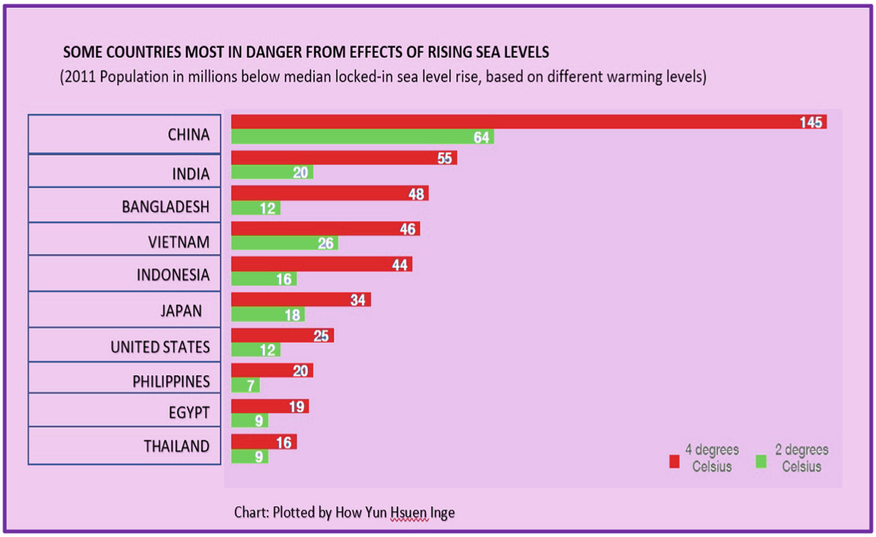

Fig. 2. Countries most in danger from effects of sea level rise based on statistics of 2011 total population (Source: plotted by How Yun Hsuen Inge, 2023)

Fast-developing Southeast Asia is facing a dilemma in balancing sustainable progress and securing energy resources in its development of renewable energy. The combustion of fossil fuels, of which coal is a major culprit, is traditionally utilized by these countries to generate energy. This process regrettably releases copious greenhouse gases into the atmosphere and accelerates global warming. Given its high population growth rate and substantial coastal population, the region has compelling reasons to adopt sustainable energy sources to curb carbon emissions. While traditionally reliant on fossil fuels, Asian countries are increasingly prioritizing renewable energy to reduce reliance on imported fuels and tackle environmental issues.

2 Renewable Energy Development: A Brief Literature Review

Asia has become home to some of the world's largest renewable energy projects, with China, India and Japan leading the way in terms of installed capacity. The Renewables 2020 Global Status Report [2], published by the Renewable Energy Policy Network for the 21st Century (REN21), states that China is the world's largest renewable energy producer with 28.1% of the world's renewable energy capacity in 2019. India ranks fourth in the world with 9.2% of the world's renewable energy capacity while Japan ranks seventh, with 4.5% of the world's renewable energy capacity. Within Southeast Asia, wind and solar power have emerged as the most prevalent forms of renewable energy, providing a crucial alternative to traditional energy sources. While hydropower and bioenergy have also played significant roles in certain countries, the region's potential for other sustainable energy sources such as geothermal and ocean energy has yet to be fully explored and harnessed. Despite the growing demand for renewable energy, there remains a need for further exploration and investment in these untapped sources of sustainable power to fully capitalize on the potential of the region's diverse and abundant renewable resources.

Despite the progress made in recent years, there are still significant challenges to the development of renewable energy in Asia. One major obstacle is the lack of supportive policies and regulations in some countries, which can hinder investment in renewable energy projects. Yan and Liang [3] discuss the challenges to renewable energy development in Asia, including policy barriers, market barriers, technical barriers, and social barriers. The authors argue that the lack of supportive policies and regulations is a major obstacle to renewable energy development in the region. In addition, funding for renewable energy projects can pose a challenge in certain countries, particularly in less developed countries where the cost of renewable energy technologies may still be relatively high. As Ahmad and Al-Zahrani [4] have pointed out, financing for renewable energy projects can be difficult to secure in these countries, particularly for smaller projects or those located in remote areas. The writers have discussed a few financing options available for renewable energy projects in emerging market countries, including equity, debt and hybrid financing. The "Renewable Energy Market Analysis: Southeast Asia" sheds light on a host of challenges that impede renewable energy development in the region of Southeast Asia, including the dearth of robust policy frameworks, inadequate institutional capacity and a shortage of financing options.

Some other challenges to the development of renewable energy include the intermittency of some renewable energy sources which can make them less reliable than traditional energy sources and the need for infrastructure upgrades to support the integration of renewable energy into existing power grids. The author of [5] pointed out that the intermittency of some renewable energy sources such as solar and wind power can make them less reliable than traditional energy sources since their availability is not constant nor always predictable. This characteristic may cause them to be less dependable than traditional energy sources including fossil fuels and nuclear power, which have the capacity to produce electricity in a more constant and predictable manner.

Notwithstanding these obstacles, there are also significant opportunities for renewable energy development in Asia. The region's burgeoning populace and thriving economy render it an attractive hub for the proliferation of renewable energy technologies. Additionally, the potential for off-grid renewable energy solutions in rural areas where many people still lack access to reliable electricity presents a significant opportunity for development. The increasing focus on climate change and environmental sustainability in the region is also likely to lead to further support for renewable energy policies and initiatives.

The heartening news is, to reduce reliance on fossil fuels, several countries in Asia have started to adopt alternative energy sources like wind or solar power. According to the International Renewable Energy Agency's report [6] in 2017, multiple Southeast Asian nations - notably Indonesia, Vietnam, Malaysia, Thailand and the Philippines - collectively produced an impressive 51.14 million kW of renewable electricity, marking a remarkable 130% progress compared to 2007. The report highlights some interesting examples of how renewables are helping countries manage prevailing energy security challenges.

3 Analysis and Case Studies of Cost-Effective Energy Approaches

The Levelized Cost of Energy (LCOE) is a widely used metric in the energy industry to assess the cost-effectiveness of different energy sources. It represents the average cost of generating electricity over the lifetime of a power plant, taking into account all costs, including initial investment, fuel, operations and maintenance, and decommissioning. While LCOE provides a valuable indicator of the economic viability of different technologies, other metrics and factors are also considered in the decision-making process. Other factors such as policy frameworks, grid integration, local resource availability, and social acceptance also play a significant role in the decision-making process. More details will be discussed in the following subsections.

3.1 Wind Power: Gales of Change

Wind power as a sustainable and infinitely renewable energy source presents an outstanding alternative to fossil fuels, which are exhaustible and limited in supply. By harnessing the kinetic energy of wind flow to drive electric generators via turbines, wind energy offers an eco-friendly solution for a clean, long-term power supply. The winds of change have begun to blow in Southeast Asian countries regarding the usage of wind energy. The Bangui Wind Farm in the Philippines is one of the most prominent wind farms in Southeast Asia. It boasts an impressive installation of 20 wind turbines that have the capacity to generate a staggering 33 MW of electricity. The wind farm was developed by NorthWind Power Development Corporation and has been operational since 2005.

The remote and isolated location of Bangui Bay makes the deployment of wind turbines as an energy source highly advantageous, considering the inconvenience and costs that would have been incurred in connecting the location to a traditional electricity supply. Wind power presents itself as a compelling alternative for remote areas such as off-grid villages or distant research facilities where accessibility is a challenge. However, the erratic nature of wind speed creates a fluctuating energy output, posing a challenge for a reliable and continuous power supply and the initial expenses associated with setting up wind turbines are quite significant. Moreover, wind turbines are typically deployed in active wind sites, which tend to be located in remote rural areas, necessitating the installation of extensive transmission lines to transport the generated electricity to urban hubs.

Bangui Wind Farm has significantly contributed to the Philippines' renewable energy production, reducing the country's reliance on non-renewable energy sources such as