Project Notes:

Project Title: **Route Optimization of Garbage Trucks to Reduce Traffic with A-Star**
Name: Kaz Erdos

Note Well: There are NO SHORT-cuts to reading journal articles and taking notes from them. Comprehension is paramount. You will most likely need to read it several times so set aside enough time in your schedule.

Contents:

Knowledge Gaps:

This list provides a brief overview of the major knowledge gaps for this project, how they were resolved and where to find the information.

Knowledge Gap	Resolved By	Information is located	Date resolved
What are some possible environments to run and test a model for this project?	Observing the methodology from the articles and finding the development environment	Page 15, article #3 Page 24, article #6	10/05/20
What existing algorithm could this project be based on?	Very similar to the first knowledge gap; it turns out that many algorithms that are similar to the one that I am proposing are based on A-Star	In almost every article, but article #3 on page 15 explains it the best	09/28/20
How can traffic data be accurately measured?	An article that describes various methods of measuring and predicting traffic.	Page 30, article #8	10/10/20

Literature Search Parameters:

These searches were performed between September 2020 and 10/15/2020
List of keywords and databases used during this project.

Database/search engine	Keywords	Summary of search
WPI Gordon Library	A-Star, Routing, Search Algorithms, Traffic, prediction, heuristic, garbage truck, shortest path	The majority of my research is done in this library. Keywords are gathered from previous articles read and used to find more articles.
Google Scholar	A-Star, Routing, Wireless search	I find that this engine is not as good as the Gordon Library in terms of available articles, but I used its powerful search engine to find articles to look up in the Gordon Library, which most likely would have them.
Google Patents	Traffic, modeling, Routing, Condition	Just used for the patent search. Very effective at finding patents and very useful in providing the proper citations.

Article Notes Template

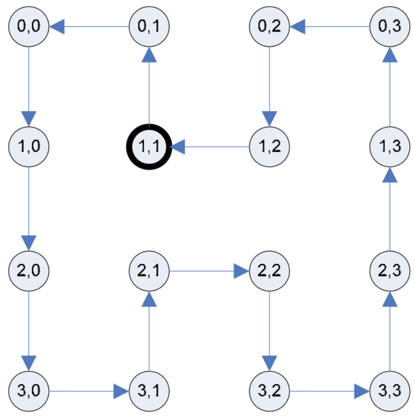
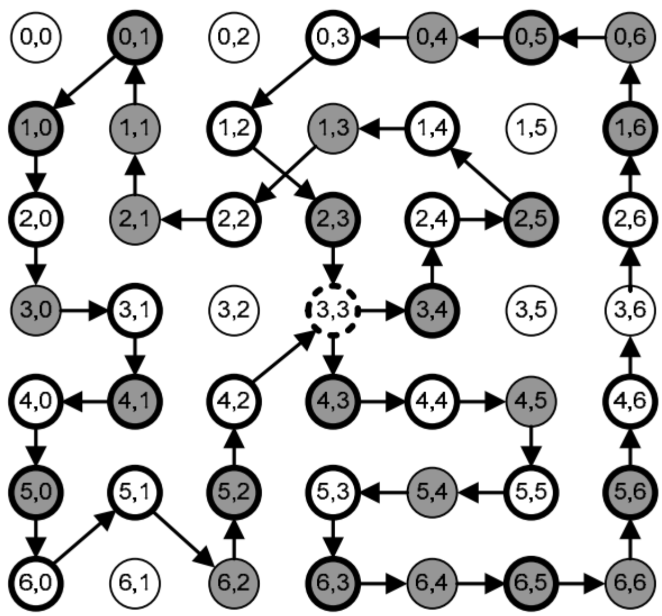
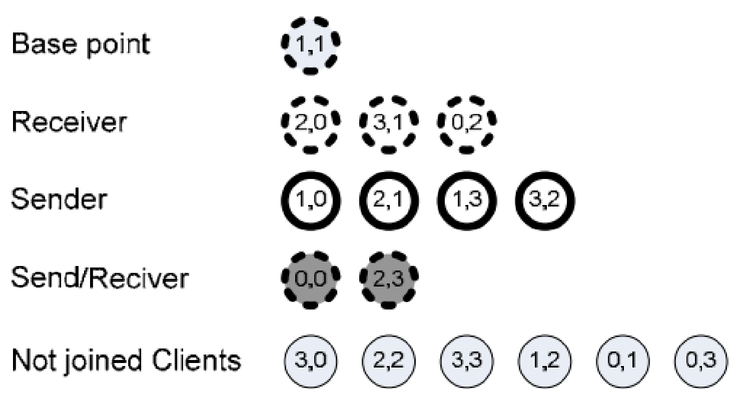
Article notes should be on separate sheets

KEEP THIS BLANK AND USE AS A TEMPLATE

Source Title	
Source citation (APA Format)	
Original URL	
Source type	
Keywords	
Summary of key points (include methodology)	
Research Question/Problem/ Need	
Important Figures	
Notes	
Cited references to follow up on	
Follow up Questions	

Article #1 Notes: A Multi Vehicle Routing Algorithm for Package Delivery

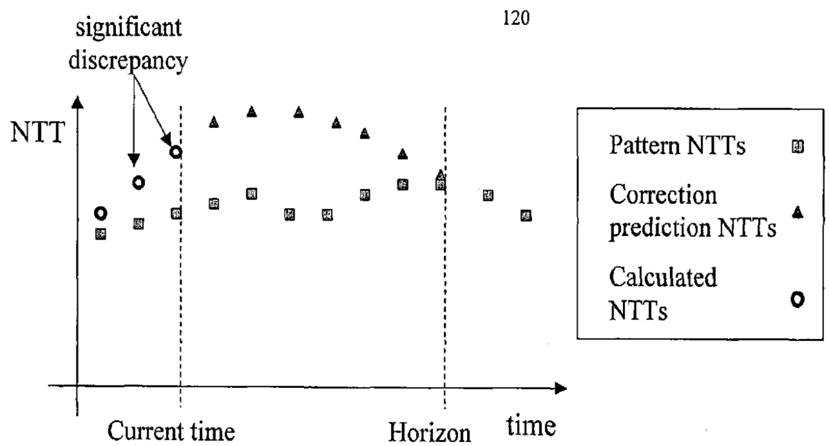
Source Title	A Multi Vehicle Routing Algorithm for Package Delivery
Source citation (APA Format)	Kim, T., Song, C., Lee, W., & Ryou, J. (2006, June 12). A Multi Vehicle Routing Algorithm for Package Delivery. Retrieved September 3, 2020, from https://pdfs.semanticscholar.org/9b77/3ad70581edd0286da5d6d00d431bb9a4c092.pdf
Original URL	https://pdfs.semanticscholar.org/9b77/3ad70581edd0286da5d6d00d431bb9a4c092.pdf
Source type	Short paper
Keywords	Algorithm, Packages, Multi Vehicle, Routing
Summary of key points (include methodology)	This article will describe an algorithm used to find the optimal route for the delivery of packages through multiple vehicles. There is a **base station** where the packages are loaded, and collection and drop off opportunities at every house. The complexity in the algorithm comes from the multiple functions it serves – to drop off packages and to collect them to ship. To be efficient, the algorithm should be able to synchronize truckloads of outgoing packages arriving at the base station, so as to avoid unnecessary trips. The mathematics involved in the problem increases according to the number of houses or customers to visit. The article will provide a method to create this algorithm, though it may not be fully laid out.
Research Question/Problem/ Need	The need for an algorithm that efficiently collects and distributes packages between many houses and a base station with multiple vehicles

Important Figures	  
Notes	The math used is too advanced for me, so I will focus on learning the

	set theory used in order to understand how this algorithmic approach works. The maximum number of stops the algorithm used is 49, which should be more than enough for my algorithm. The routings for the delivery of packages and the pickup of packages are actually very similar in difficulty to the routings for a combined route. As seen in the first figure above, the points of interest are labeled with a coordinate system, with the optimal route being traced out with arrows. The second figure is the final tracing of a route after the algorithm has been applied to a complex case. The last figure shows how the points are labeled. The article leaves off by saying that this algorithm can definitely be improved upon and that it is just a baseline, though it does effectively solve the initial problem.
Cited references to follow up on	Wee-Kit Ho, Andrew Lim and Wee-Chong Oon, 'Maximizing Paper Spread Examination Timetabling Using a Vehicle Routing Methods', Tools with Artificial Intelligence, Proceedings of the 13th International Conference on,
Follow up Questions	Can this algorithm be applied to something simpler such as collecting garbage? What constraints does the algorithm have? Can it be used in most neighborhoods? What rules or algorithms are delivery/garbage people already using? Is it just decided by the driver or are more complex calculations taking place? How easy/difficult would it be to implement novel machinery?

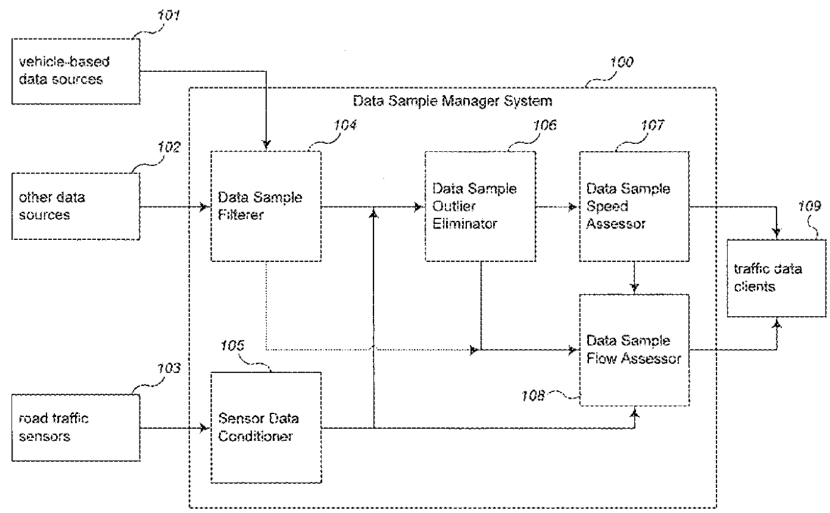
Patent #1 Notes: Modeling Vehicular Traffic Data

US20190156661A1	
Source Title	METHOD AND SYSTEM FOR MODELING AND PROCESSING VEHICULAR TRAFFIC DATA AND INFORMATION AND APPLYING THEREOF
Source citation (APA Format)	Feldman, I., Trinker, H., Meltzer, G., Eshpar, K. S., & Lotem, H. H. (2019). *U.S. Patent No. US20190156661A1*. Washington, DC: U.S. Patent and Trademark Office.
Original URL	https://patents.google.com/patent/US20190156661A1/en?q=traffic+data&oq=traffic+data
Source type	Patent
Keywords	Traffic, modeling, network
Summary of key points (include methodology)	The patent is for a system that takes a spatial representation of a road network and breaks it down into simpler groups of roads. It then can calculate the “Mean normalized travel time (NTT)” for each subgroup and then create a more detailed model of the entire road network with the current traffic situation included. The researchers calculated the NTTs, then compared those with the NTTs found by pattern analysis. They observed that the calculated NTTs were a lot longer than the pattern-found ones, so then they were able to correct that discrepancy and get the NTTS back down to a more accurate time.
Research Question/Problem/ Need	How can a road network be modeled with accurate traffic information?

Important Figures	
Notes	The patent is very long and it will be impossible to extract 100% of the information, so just focus on the most important parts.
Cited references to follow up on	N/A
Follow up Questions	Why were the NTTs calculated so much higher? What will that mean for my algorithm? What should I do to compensate?

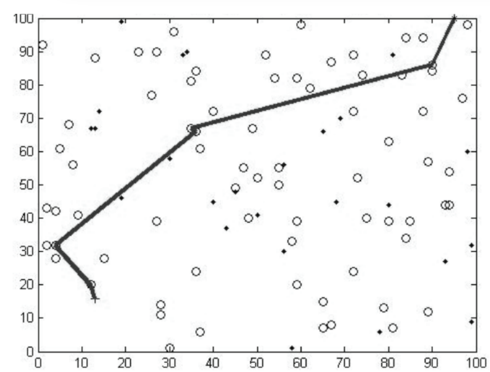
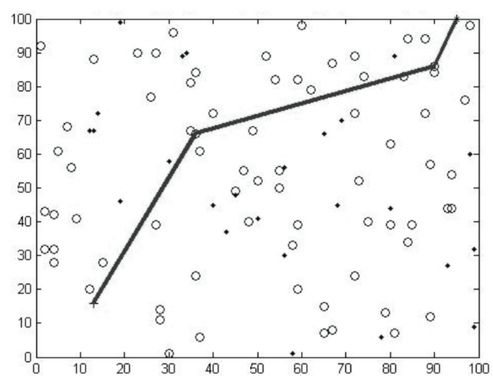
Patent #2 Notes: Filtering Road Traffic Condition

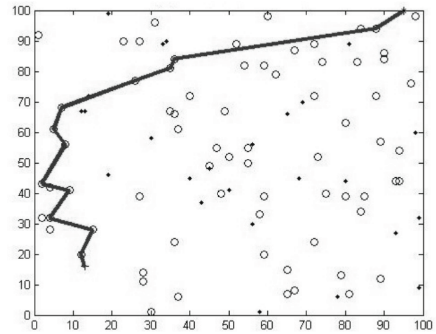
US10403130B2	
Source Title	Filtering road traffic condition data obtained from mobile data sources
Source citation (APA Format)	Chapman, C. H., Barker, A., Downs, O. B., Burns, M. A., JR., & Love, S. R. (2019). *U.S. Patent No. US10403130B2*. Washington, DC: U.S. Patent and Trademark Office.
Original URL	https://patents.google.com/patent/US10403130B2/en?q=road+traffic&oq=road+traffic+
Source type	Patent
Keywords	Filter, Traffic, Road, Condition
Summary of key points (include methodology)	The patent describes techniques used to assess the amount of road traffic. These techniques include information taken from the actual cars or the road, mobile data sources (such as smartphones) inside the car, and sensors placed near to or inside the roads. The patent describes how all of this information could be processed, and how it can identify some of the data that would make the assessment inaccurate. The inventors wish to remove the data that would create an unrealistic or impossible representation of the actual road and traffic conditions.
Research Question/Problem/ Need	How can the amount of traffic on roads be measured through a network of devices?

Important Figures	
Notes	I should organize my project with a flowchart similar to this one, since it makes the complex methodology a lot easier to understand.
Cited references to follow up on	U.S. application Ser. No. 13/194,822 U.S. application Ser. No. 11/444,998
Follow up Questions	How can this be implemented in mobile devices and how would it most effectively be distributed to the public?

Article #2 Notes: Evaluation Function Effectiveness in Wireless Sensor Network Routing using A-star Algorithm

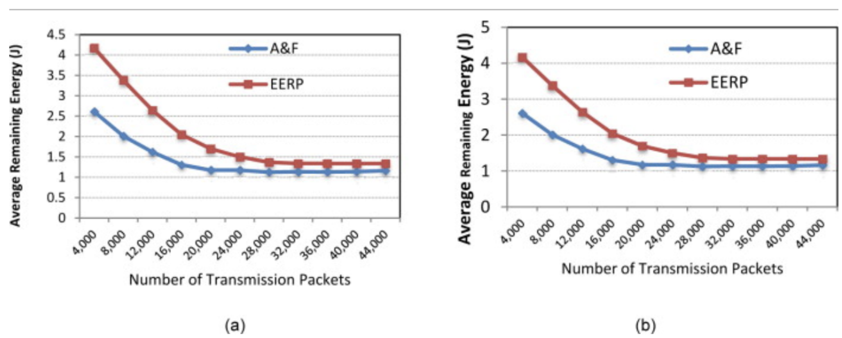
Source Title	Evaluation Function Effectiveness in Wireless Sensor Network Routing using A-star Algorithm
Source citation (APA Format)	R. Septiana, I. Soesanti and N. A. Setiawan, "Evaluation function effectiveness in Wireless Sensor Network routing using A-star algorithm," *2016 4th International Conference on Cyber and IT Service Management*, Bandung, 2016, pp. 1-5. doi: 10.1109/CITSM.2016.7577519
Original URL	https://ieeexplore-ieee-org.ezpxy-web-p-u01.wpi.edu/stamp/stamp.jsp?tp=&arnumber=7577519
Source type	Scientific Article
Keywords	A-Star, Wireless Sensor Network WSN, heuristic, Djikstra, RSSI, Pathfinding
Summary of key points (include methodology)	This article details an application of the A-Star search algorithm in the field of wireless routing. The Wireless Sensor Network (WSN) is a system that determines the optimal oath and manages energy consuming saving when data is transmitted wirelessly. It accomplishes such a feat by using a form of Artificial Intelligence known as path-finding methods. In the paper they look to improve on this network by introducing a pathfinding algorithm known as A-Star into the network. The function works by using some function f(n), which is the sum of two parts. The first part, known as g(n), is a cost-evaluation function that will calculate the "cost" between two points, or nodes, in the system. This "cost" can mean many things, but in this case it would be the physical distance between two points in the system, as well as the energy needed to connect the points. The other part of the function f(n) is what is known as h(n), or a heuristic value. This value is interesting in that it is more of a guess. This "guess" estimates the total cost from any target node to the destination node. As f(n) is the sum of g(n) and h(n), the values of the function with the lowest totals are what the algorithm will prefer. So, from any start node, the algorithm will choose the nodes around it that a) take the least effort to get to, and b) are the closest to the end. RSSI what this "cost" is known as officially, and LQI is what is known as a Link Quality Indicator. This LQI ensures that the path

	taken is not only safe to take but also efficient, and it is also factored into the evaluation of f(n). The researchers decided on adding in more heuristic values to their calculation of the function, and wanted to see the improvement it made on the algorithm. In testing, the improved WSN was able to significantly reduce the energy consumed, though it did take longer to make the calculations. In the end it was a tradeoff between time and efficiency, and in the end the researchers decided that the improvement in energy consumption was worth the negligible amount of extra time.
Research Question/Problem/ Need	How can the Wireless Sensor Network (WSN) be improved to be more efficient?
Important Figures	 Fig. 2. Path formed using two heuristic functions  Fig. 3. Path formed using three heuristic functions

	 Fig. 1. Path formed using the initial A-star The first figure shows the first improvement made to the A-Star algorithm with a second heuristic function. The second figure is a second improvement, which turned out to be the best solution. The third figure shows what the original A-Star algorithm was able to come up with.
Notes	● A-Star is an improvement of *Djikstra's Shortest Path* algorithm, as the latter only considers g(n). ● In terms of routing, energy efficiency is more important than time taken in some cases, as energy cost (in currency) can be reduced by a large amount in a large scale. ● It is not too complicated to calculate all the values in the A-Star evaluation, as the only operations used are addition and division. The harder part is finding all the individual parts that make up the final sum.
Cited references to follow up on	K. Khan, G. Konar, and N. Chakraborty, “Modification of FloydWarshall’s Algorithm for Shortest Path Routing in Wireless Sensor Networks,” presented at the Annual IEEE India Conference (INDICON), 2014. K. S. Shivaprakasha and M. Kulkarni, “Energy Efficient Shortest Path Routing Protocol for Wireless Sensor Networks,” 2011, pp. 333–337. [10] C. R. Rigi, S. B. Sasi, and A. Antony, “Energy Efficient Shortest Path Routing in WSN Using Two point Crossover and External Mutation.”
Follow up Questions	● How can this information be applied to the routing of trucks? ● How can this model be simplified without sacrificing much efficiency? ● What other values could “cost” represent?

Article #3 Notes: An Energy Efficient Routing Protocol for Wireless Sensor Networks using A-star Algorithm

Source Title	An Energy Efficient Routing Protocol for Wireless Sensor Networks using A-star Algorithm
Source citation (APA Format)	Ghaffari, A. (2014). An Energy Efficient Routing Protocol for Wireless Sensor Networks using A-star Algorithm. *Journal of Applied Research and Technology*, *12*(4). https://doi.org/10.1016/S1665-6423(14)70097-5
Original URL	https://www-sciencedirect-com.ezpxy-web-p-u01.wpi.edu/science/article/pii/S1665642314700975
Source type	Scientific Article
Keywords	A-star, Fuzzy Logic, Residual Energy, EERP, A&F, Buffer Occupancy
Summary of key points (include methodology)	In the WSN, prolonged network lifetime is seen to be a critical issue. This paper details the EERP, or Energy-Efficient Routing Protocol that can potentially help with this. The researchers utilize the A-Star algorithm, which will improve the network lifetime by directing the data packets across the shortest path possible. Maximum residual energy is what is used as a metric for the A-Star algorithm Residual energy is essentially the energy left over after a hop is made. A “hop” is simply the movement from one node to the next. The algorithm wishes to minimize the number of hops taken in an WSN. Micro-electro-mechanical systems (MEMS) are on the forefront of routing, and it is clear that they require WSN. WSNs can be applied to many broad fields, including environmental monitoring and battlefield applications. As the name implies, the routing is wireless, so energy can be somewhat scarce. Hence it is essential that as much energy is preserved as possible in any given WSN. An energy hole problem is when energy is quickly lost and destroyed, mainly due to a poor management system. The main issue with most WSNs is that they choose to minimize total energy consumption, while suffering non-uniform energy drainage. There are 4 parameters that were taken into account for the design: 1) energy consumption and balancing, 2) load balancing, 3) the selection of the shortest path, and 4) reducing

<table>
<tr><td></td><td>packet retransmission. Retransmission is inefficient since it doesn’t accomplish anything for the overall system to send data packets to places they already have been or don’t need to be. The researchers used MATLAB for their procedure and compared their new EERP to the standard A&F procedure. It was found that their system lost significantly less energy. They achieved this by utilizing what is known as an energy threshold value. This is essentially the minimum amount of leftover energy that they specified would be required for a successful hop. Any potential hops that had less residual energy than this threshold were not considered, so overall energy saving was increased.</td></tr>
<tr><td>Research Question/Problem/ Need</td><td>How can the energy consumption of a WSN be improved to have a longer lifetime?</td></tr>
<tr><td>Important Figures</td><td>


It can be seen that the researcher’s EERP model saved significantly more energy than the standard A&F method.</td></tr>
<tr><td>Notes</td><td>

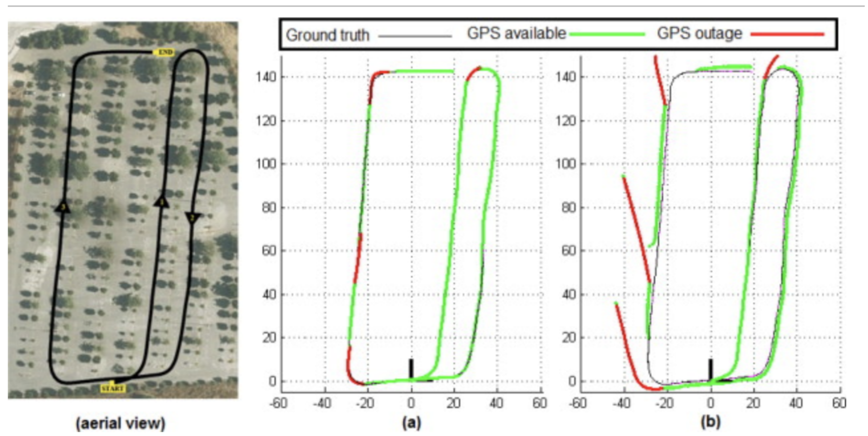
- In a way, energy consumption in wireless networks can be compared to traffic in road systems.
- It is possible that a certain road can be <u>avoided</u> by a truck if it causes too much traffic, similar to the energy threshold value.
- From what I can gather, it seems that added on complexities to the A-star algorithm only improves it. Thus the A-star algorithm is a great base algorithm to use for my project
- It is important to note that with every added complexity, the difficulty of creating the algorithm will substantially increase. Therefore I believe that the right complexities must be chosen for my project in order to increase effectiveness and feasibility.

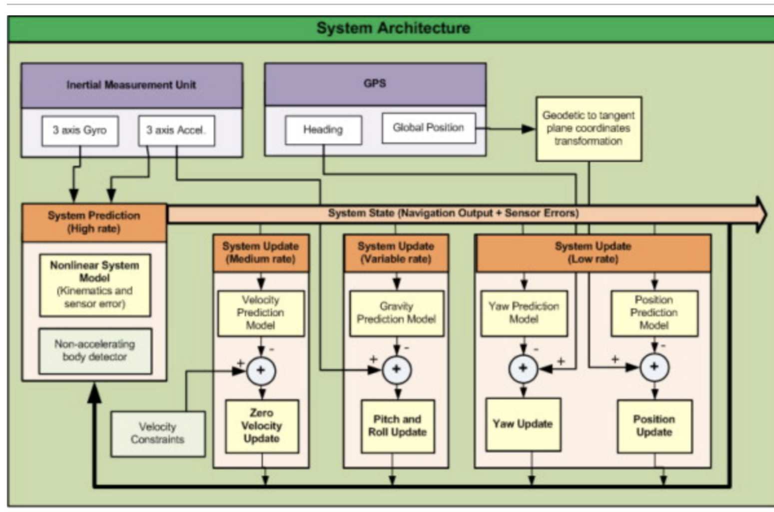
</td></tr>
<tr><td>Cited references to follow up on</td><td>M. Adam, S., & Hassan, R. (2013). Delay aware Reactive Routing Protocols for QoS in MANETs: a Review. Journal of Applied Research and Technology, 11(6). https://doi.org/10.1016/S1665-6423(13)71590-6</td></tr>
</table>

	I. S. AlShawi, L. Yan, W. Pan and B. Luo, "Lifetime Enhancement in Wireless Sensor Networks Using Fuzzy Approach and A-Star Algorithm," in *IEEE Sensors Journal*, vol. 12, no. 10, pp. 3010-3018, Oct. 2012.
Follow up Questions	● How can I get the A-Star algorithm (or a variation of it) to run on my computer? ● How can I create a similar system to the EERP, but for traffic? ● Why is energy consumption less important than energy saved?

Article #4 Notes: A GPS-aided inertial navigation system in direct configuration

Source Title	A GPS-aided inertial navigation system in direct configuration
Source citation (APA Format)	Munguía, R. (2014). A GPS-aided Inertial Navigation System in Direct Configuration. *Journal of Applied Research and Technology*, *12*(4). https://doi.org/10.1016/S1665-6423(14)70096-3
Original URL	https://www-sciencedirect-com.ezpxy-web-p-u01.wpi.edu/science/article/pii/S1665642314700963
Source type	Scientific Article
Keywords	Inertial Navigation, Sensor Fusion, State Estimation
Summary of key points (include methodology)	This article looks to find a way to estimate the kinematic state of a vehicle by using inertial and GPS measurements. The application of this work would be for real-time guidance and navigation tasks. The system is based on what is known as an Extended Kalman Filtering (EKF) approach. With this approach the estimated variables and parameters are: 1) Attitude and bias-compensated rotational speed of the vehicle, 2) position, velocity and bias-compensated acceleration of the vehicle and 3) bias of gyroscopes and accelerometers. The results from the experiments of the summary show that the method they have proposed can be successful with low-cost sensors. In this paper autonomous navigation is discussed, and "autonomous" in this case refers to the system being able to estimate the kinematic state of the vehicle without human assistance. Inertial Navigation System, or INS is the current standard system and what this paper will be adding on to. INS uses accelerometers to measure inertia and gyroscope to measure rotation. Using these two bits of data, the INS can estimate the position and orientation of the vehicle. While INS can be accurate, it is usually only accurate for a short period of time, and this is especially true when low-cost sensors are used. The paper decides to supplement this with the use of GPS, or Global Position System. While INS can deliver information substantially quicker than GPS, the GPS is more sustainable, so a combination of both sensors is used to exploit the benefits of both systems. The combination of the interior sensors with GPS is usually classified as either Loosely

<table>
<tr><td></td><td>coupled, tightly coupled, or ultra-tightly coupled. In the actual model, gyroscopes are measuring vector arrows in each direction. The combination of this 3-axis gyroscope with a 3-axis accelerometer and 3-axis magnetometer is what is considered. The system can be updated periodically through three separate methods: 1) Updates by means of dynamical constraints, 2) Updates by means of the observation of the gravity vectors, 3) Updates by means of GPS measurements.</td></tr>
<tr><td>Research Question/Problem/ Need</td><td>How can the kinematic state of a vehicle be estimated from a distance with as little error as possible?</td></tr>
<tr><td>Important Figures</td><td>




The first diagram shows the path taken by a tested vehicle, while each of the other two figures next to it display the times when the GPS dropped off.

The last diagram is an overall flowchart for the whole system.</td></tr>
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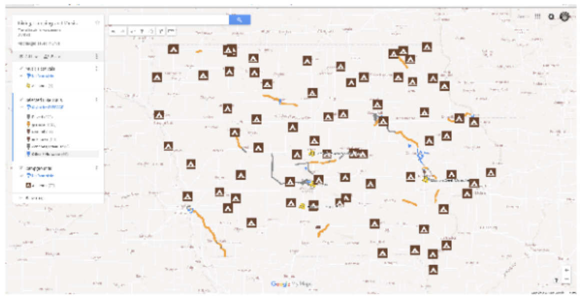
Notes	• In a suburban town, low-cost sensors would be essential. • System bias can be represented by using a matrix. • GPS outage is an issue that pops up in navigation quite often. It is important to try to reduce the time that the GPS is unavailable, as real-time updates should be very important to the overall system • The mathematics in this article is far above my comprehension level, so what should be most important to me as of now is the general idea behind all of it.
Cited references to follow up on	E. J. Ohlmeyer, "Analysis of an Ultra-Tightly Coupled GPS/INS System in Jamming," *2006 IEEE/ION Position, Location, And Navigation Symposium*, Coronado, CA, 2006, pp. 44-53. doi: 10.1109/PLANS.2006.1650586 I. Skog, P. Handel, J. Nilsson and J. Rantakokko, "Zero-Velocity Detection—An Algorithm Evaluation," in *IEEE Transactions on Biomedical Engineering*, vol. 57, no. 11, pp. 2657-2666, Nov. 2010. doi: 10.1109/TBME.2010.2060723
Follow up Questions	• Could/should garbage trucks be controlled autonomously? ○ How would this be possible? Would people lose their jobs, or would new opportunities open up for them? • This article describes a very complex way of implementing its system for measuring kinematics. How can this model be simplified to and how can the data from a model similar to this be helpful in my overall project? • Could it be possible to track the speed of all the cars travelling and compare them to the speed limit? As traffic slows down cars, should the average speed limit of all the cars determine the amount of traffic?

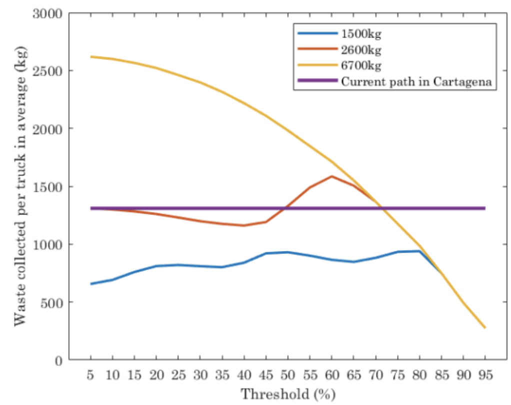
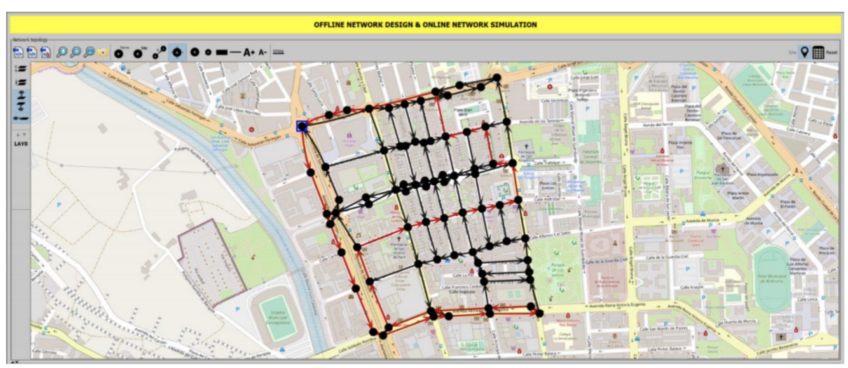
Article #5 Notes: Importing Data into Google Web Maps

Source Title	Importing Data into Google Web Maps
Source citation (APA Format)	Dunn, Austin; Hanson, Bailey A.; and Seeger, Christopher J., "Importing Data into Google Web Maps" (2016). Extension and Outreach Publications. 187. http://lib.dr.iastate.edu/extension_pubs/187
Original URL	https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1146&context=extension_pubs
Source type	Article / Informational Guide
Keywords	Google Maps, importing, downloading
Summary of key points (include methodology)	This short paper details some very important instructions on how to import important data into Google Maps. In their example, they were able to import the locations of many locations of music festivals. The type of file that they demonstrated first was known as an KML file, which is commonly used for internet-based maps and applications. The other kind of file that they detailed was known as an GPX, or GPS Exchange Format, which is the data format commonly used by GPS devices to store routes, tracks, adn waypoints. In both methods the article instructs to add a new layer on top of the google maps layer with the new data. The colors of just about everything can be adjusted.
Research Question/Problem/ Need	How can data from an external source be imported to Google Maps?

Important Figures	 The final product of the instructors' work can be seen here, with all the local music festivals mapped out.
Notes	● These instructions detail how to IMPORT data into google maps, but not EXPORT it. Perhaps I should consider importing data into google maps and working in that space rather than trying to bring it somewhere else? ● This could be very important for the presentation of my product, since these tools allow for the maps and data to be manipulated to show whatever I want in whatever color I want, so I can use the very powerful base of Google maps without having to make my own modeling environment ● This is just a potential way to solve this problem, and many more approaches should be considered. ● It is very good that the data imported can be easily updated and changed, since I feel that the data will constantly be changing in my project, if not instantaneously (?) ●
Cited references to follow up on	No references cited in this article. :(Perhaps I could look at more material from Iowa State University.
Follow up Questions	● What data would I import into Google Maps? Would it be the location of every garbage can, or should a basic outline of the path the algorithm takes be displayed over the map? ● Would it be possible to somehow import coordinates to Google Maps? What if some algorithm I make spits out coordinates, rather than these detailed map locations with descriptions? ● Can this version of Google Maps with the data imported be ported to a mobile device, such as a smartphone, for easier use by the end user?

Article #6 Notes: Optimal Path Planning for Selective Waste Collection in Smart Cities

Source Title	Optimal Path Planning for Selective Waste Collection in Smart Cities
Source citation (APA Format)	Bueno-Delgado, María-Victoria, et al. "Optimal Path Planning for Selective Waste Collection in Smart Cities." *Sensors (Basel)*, vol. 19, no. 9, 2019, p. 1973., doi:10.3390/s19091973.
Original URL	https://www.mdpi.com/1424-8220/19/9/1973/htm
Source type	Scientific Article
Keywords	Waste collection, path optimization, Net2Plan, software platform, smart city, smart container, open-source
Summary of key points (include methodology)	Smart cities aim to optimize their waste collection, as many results from waste collected can be seen as very impactful to the cities. These include environmental, economic, and social impacts. This article proposed an optimal path planning algorithm that will enable cities to stay as sustainable as possible by minimizing the environmental impact of CO2 emissions and acoustic damage, as well as the socioeconomic impact, which ties into the number of trucks used and fuel consumption. Net2Plan is the planning tool of choice for these researchers. The algorithm solves what is known as an Integer Linear Programming (ILP) program. With a lot of information at hand, the ILP is able to calculate the optimal number of trucks the city should use, while also finding the path they should follow to collect the waste bins. Aside from the Net2Plan that the researchers use, they use JOM, which is known as the Java Optimization

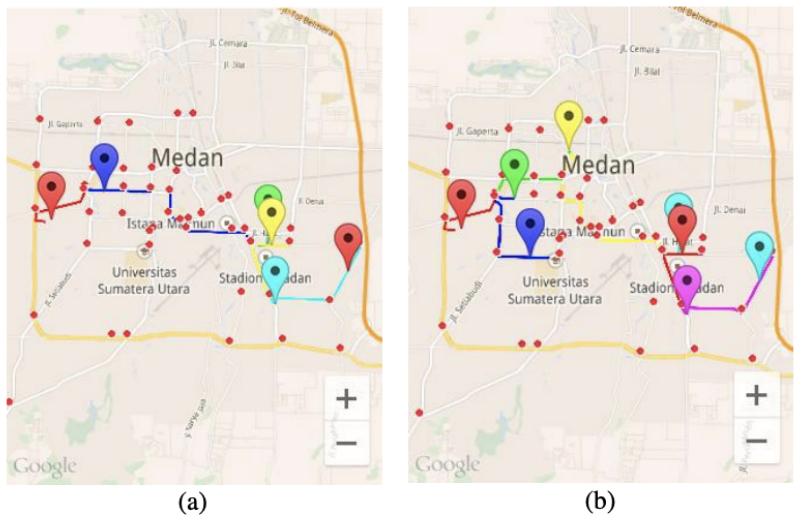
	Modeler, which is also open-source and free. This is a Java library that can be used to model optimization problems. Many variables are defined for the algorithm, and they are explicitly defined. In the end, with all of the aforementioned criteria in mind, the algorithm takes small calculations based around all the parameters and finds an optimal route. The researchers were successful in creating this algorithm that works very effectively.
Research Question/Problem/ Need	How can waste collection be optimized for cities that wish to reduce carbon emission, traffic jams, and socioeconomic problems?
Important Figures	 **Figure 4.** Average waste collected per truck (different truck capacity) for the optimal path given by ILP and the real behavior of truck routes in Cartagena.  **Figure 3.** Snapshot of Net2Plan-GIS after integer linear programming (ILP) execution in the scenario under study in Cartagena city, setting threshold of waste level in containers to 85%. Optimal path route in red color.
Notes	• Net2Plan may be something to consider, since it is open-source and easily-accessible. As my project seems to follow a model that is similar to this paper, perhaps it is a wise choice to choose this platform. • CRUCIAL: Net2Plan can import city layouts directly to the algorithm from GIS, or geographical information system

	databases.
	• The algorithm here is focusing on cities, which have many different factors than a common suburb. Cities usually follow a somewhat
	• grid-like pattern, while suburbs do not follow that pattern in the slightest. It is definitely a challenge to adapt an algorithm like this for a suburb, so perhaps the algorithm has to be entirely rethought.
	• The main problems that cities are trying to solve are air pollution, jammed traffic, waste management, and sustainability.
	• The ILP relies on city layout information given by the GIS, which includes information of roads and location of waste containers in the streets.
	    ○ ILP also considers the number of trucks available and what their capacity is
	    ○ It also considers the fill level threshold and capacity of the contained that are collected.
	• As I am most literate in JAVA, it is promising that these researchers decided to also use a JAVA library to solve their problem.
	• All of the work from the researchers is available for FREE online, so that is something that I can definitely reference

Cited references to follow up on	Karadimas, N.V.; Papatzelou, K.; Loumos, V.G. Genetic Algorithms for Municipal Solid Waste Collection and Routing Optimization. In Artificial Intelligence and Innovations 2007: From Theory to Applications; AIAI 2007. IFIP International Federation for Information Processing, Springer: Boston, MA, USA; Volume 247. Akhtar, M.; Hannan, M.A.; Begum, R.A.; Basri, H.; Scavino, E. Backtracking search algorithm in CVRP models for efficient solid waste collection and route optimization. Waste Manag. 2017, 61, 117–128.
Follow up Questions	• Is this the best possible platform for me so far? It seems like it has all that I need, but would it count as a proper project to simply adapt this algorithm for my purposes? I would say for now that it would be a good idea to reference this work as a baseline for my work, so that I will not be as lost. • If all the factors are ignored except for the effect on traffic, how would the calculated optimal route change? How big of an impact do these other factors have on the overall calculation?

Article #7 Notes: Standalone Mobile Application for Shipping Services Based on Geographic Information System and A-Star Algorithm

Source Title	Standalone Mobile Application for Shipping Services Based on Geographic Information System and A-Star Algorithm
Source citation (APA Format)	D Gunawan *et al* 2018 *J. Phys.: Conf. Ser.* 978 012122
Original URL	https://iopscience-iop-org.ezpxy-web-p-u01.wpi.edu/article/10.1088/1742-6596/978/1/012122/pdf
Source type	Scientific Article
Keywords	GIS, SOM, PBS, shipping, A-Star
Summary of key points (include methodology)	This article focuses on the delivery of goods to customers. The goal of the paper is to detail a standalone mobile application that can help assist the deliverers of the goods. It utilizes GIS, which is Geographic Information System, as well as A-Star. The designers wish for the final design to be able to be used offline, so that any driver using the application won't have to worry about the connection being stable from their phones. However, they also detail a version of the app that uses LBS, or Location-Based Services. Though A-Star is the main algorithm that the researchers use, they also mention that they can use a clustering algorithm in addition to a self-organizing map (SOM) to achieve the same result. Loosely coupled design is used in this case, which in this case specifically means that the offline model can be replaced with the online model for initial testing. As a lot of food delivery occurs in rural areas, it makes sense that an offline model is developed. As for methodology, the researchers need to use Global Positioning System, or GPS, as well as Google Maps. They place nodes at each of the junctions between roads, and they record these nodes' coordinates either with Google Maps' manual coordinate-gathering system, or quickly with GPS. The coordinates have to be exact to many decimal points, since in the grand scheme of the earth the distance between nodes is very small. The researchers then take the standard g(n), h(n), and f(n) values by using strictly euclidean distance. This is very interesting since it almost completely disregards every other variable that can be involved in the problem. Nonetheless, A-Star and used and the shortest path is found and

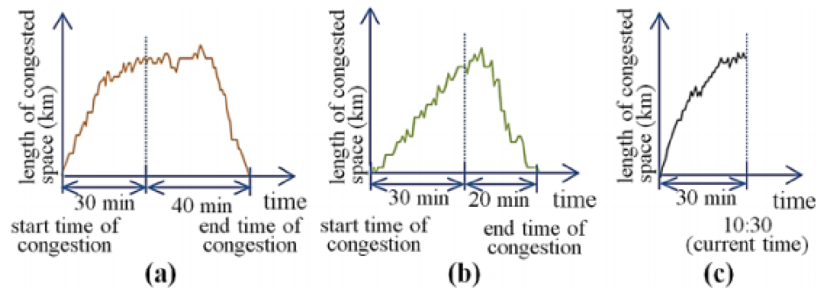
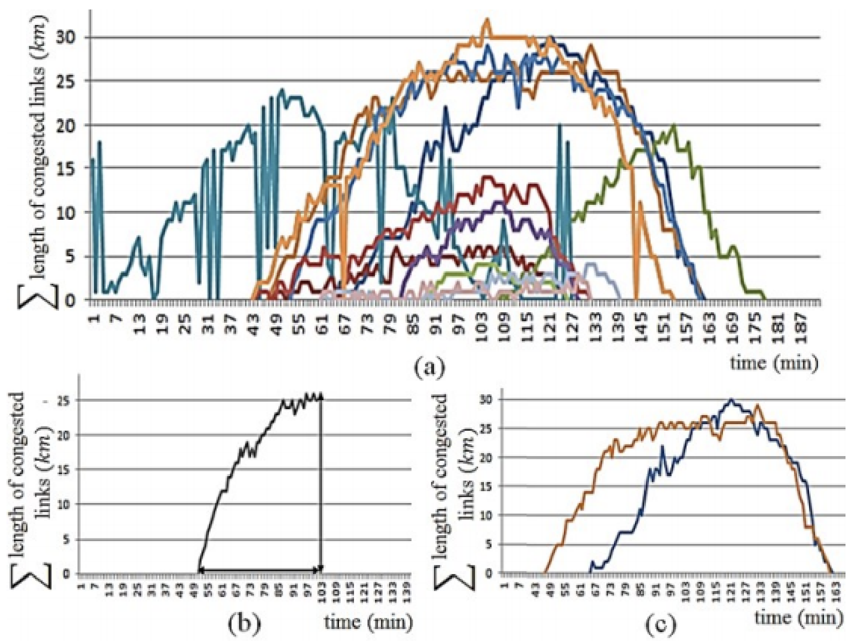
	ported to a smaller, more portable app. The researchers nicely present their findings visually through google maps. In their results they show that their smartphones are able to process the algorithm, as long as their hardware meets the minimum requirements.
Research Question/Problem/ Need	How can the routes of delivery trucks be optimized to reduce travel time?
Important Figures	 **Figure 4.** The visualization of shortest path result
Notes	● The article discussed multiple similar approaches to get to the same solution, which is a very good idea for me to consider because I need to have not only backup plans, but also many strategies to attach the same problem ● CRITICAL: The researchers choose to avoid any occurrence of obstacles in their approach, so this is different from the type of model that I will be producing. It's good however to see how a more simple algorithm works. ● It is important to note that if coordinates are being used in my project, they have to be specific to 10+ decimal places, to make sure that the scale of the earth is being accounted for. ● How can my algorithm be ported in such a way to be useful to an end user? Is this even a question that I should consider for now ● Once again, this article shows that algorithms similar to A-Star can run and not demand too much of their hardware, as some very old and low-level android phones were used effectively in this paper.

Cited references to follow up on	Siregar B, Gunawan D, Andayani U, Lubis E S and Fahmi F 2017 Food Delivery System with the Utilization of Vehicle Using Geographical Information System (GIS) and A Star Algorithm J. Phys. Conf. Ser. 801 1 p 12038 Gunawan D, Amalia A and Charisma I 2017 Clustering Articles in Bahasa Indonesia Using SelfOrganizing Map 2017 Int. Conf. on Electrical Engineering and Informatics
Follow up Questions	● How much of a difference does assuming no obstacles make on the final product? Why did these researchers take this approach? Does it have anything to do with the hardware limitations? ● Why did the researchers choose A-Star over a clustering algorithm? It seems like A-Star is chosen by many researchers, but it is difficult to pin-point exactly why this is ● What alternatives are there to Google Maps? Is there another web-based map service that can be used with an algorithm?

Article #8 Notes: Congestion Pattern Model for Prediction Short-Term Traffic Decongestion Times

Source Title	Congestion Pattern Model for Prediction Short-Term Traffic Decongestion Times

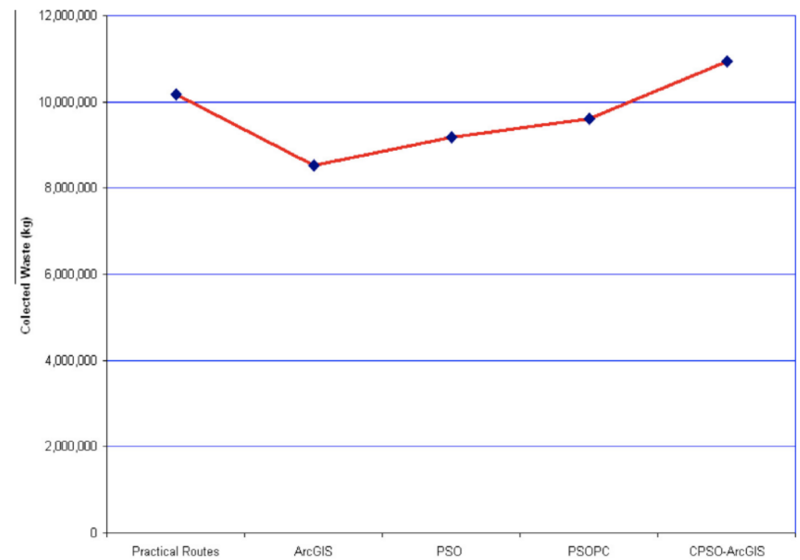
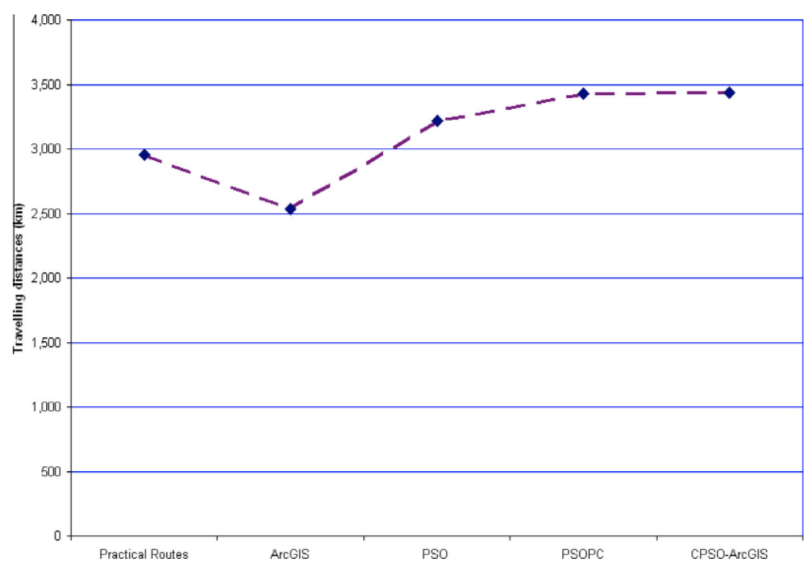
Source citation (APA Format)	K. Lee, B. Hong, D. Jeong and J. Lee, "Congestion pattern model for predicting short-term traffic decongestion times," 17th International IEEE Conference on Intelligent Transportation Systems (ITSC), Qingdao, 2014, pp. 2828-2833, doi: 10.1109/ITSC.2014.6958143.
Original URL	https://ieeexplore-ieee-org.ezpxy-web-p-u01.wpi.edu/document/6958143
Source type	Scientific Article
Keywords	Decongestion, Traffic, STCP, ITS
Summary of key points (include methodology)	This article describes how patterns in big traffic data can help to predict when traffic will ease up, and patterns and methods to analyze the patterns are discussed in this paper. They propose a new method of representing traffic that involves what is known as branched spatiotemporal changes. Another method that they use involves comparing and finding similarities between multiple patterns, based on historical patterns. If a historical pattern can be matched closely enough to a current pattern, it can be assumed that the traffic will also ease in a similar way to the historical example. An Intelligent Transportation System (ITS) can be used to display the current amount of traffic by using historical traffic data in tandem with the current traffic data. Congestion can be quantified as a graph that compares time to the length of congested space. So, if a historical graph is similar to a current graph, the missing part of the current graph can be predicted by simply matching it with the historical graph. Of course, it is more complicated than that, but at a basic level it is easy to understand. Many elements are involved in the most complex example of a traffic prediction model, including the Head node, Linked node, Spatiotemporal chain, Spatial outgoing chain, Spatial incoming chain, Temporal outgoing chain, and Temporal incoming chain. Similar to A-star, these elements all work together in trying to come up with a solution to the problem.
Research Question/Problem/ Need	How can the timing of traffic easing up be predicted based on current traffic data?

Important Figures	 Figure 1. Example of analyzing current and past traffic congestion: (a) a past congestion pattern, (b) another past congestion pattern, (c) current congestion pattern  Figure 5. (a) Historical congestion pattern, (b) Current congestion pattern, (c) Similar congestion patterns
Notes	● It seems that the first method provided in the article is much easier to follow than the second one, but nonetheless the first method is very interesting and useful to me, since it provides a way to predict traffic, rather than constantly collecting data about it. ● Branched spatiotemporal chains are similar to A-star, as they have nodes and look for changes between nodes. However, it gets much, much more complicated and it's near-impossible to follow. ● A small amount of pseudo-code is provided, and it is very

	useful to see the process that the researchers are following. The code looks somewhat like Python. ● Many historical graphs can be compared at once in order to find the graph that best resembles the current graph ● Traffic can be QUANTIFIED, as length of congestion per time unit. THIS IS VERY IMPORTANT
Cited references to follow up on	P. Pongpaibool, P. Tangamchit and K. Noodwong, “Evaluation of Road Traffic Congestion Using Fuzzy Techniques,” TENCON 2007-2007 IEEE Region 10 Conference, 2007. F. Maier, R. Braun, F. Busch and P. Mathias, “Pattern-based short-term prediction of urban congestion propagation and automatic response,” Traffic Engineering & Control, pp. 227-231, 2008.
Follow up Questions	● As traffic graphs somewhat resemble some of the formulaic graphs that I know of, is there any way to tell a computer to fit a line to the graphs in order to predict when the traffic will lighten up? For example, mapping an upside-down parabola onto a traffic graph, and solving for y = 0. ● If traffic can be graphic in this matter, what other variables in my problem can be graphed and analyzed? ● Is it possible to create a database for some historical data to use to compare to in my algorithm? If so, how effective would this be?

Article #9 Notes: Optimizing Municipal Solid Waste collection using Chaotic Particle Swarm Optimization in GIS based environments: A case study at Danang city, Vietnam

Source Title	Optimizing Municipal Solid Waste collection using Chaotic Particle Swarm Optimization in GIS based environments: A case study a Danang city, Vietnam
Source citation (APA Format)	Son, Le Hoang. "Optimizing Municipal Solid Waste Collection Using Chaotic Particle Swarm Optimization in GIS Based Environments: A Case Study at Danang City, Vietnam." *Expert Systems with Applications*, vol. 41, no. 18, 2014, pp. 8062–8074., doi:10.1016/j.eswa.2014.07.020.
Original URL	https://www-sciencedirect-com.ezpxy-web-p-u01.wpi.edu/science/article/pii/S0957417414004187
Source type	Scientific Article
Keywords	ArcGIS, Chaotic Particle Swarm Optimization, Vehicle routing model, Heuristic algorithms, Municipal Solid Waste Collection
Summary of key points (include methodology)	Municipal Solid Waste, or MSW, is an increasing problem in the world, and it is contributing heavily to climate change and global warming. This article wishes to help collect MSW at Danang City, which has a very large quantity of MSW. They set out to create a system to route a vehicle for MSW collection, and then used a hybrid combination between Chaotic Particle Swarm Optimization and ArcGIS. They found that this hybrid method was more effective at collecting MSW than the current standards used by the city. A vehicle routing, or VR model is proposed. There are three primary "gather sites" for MCW, and those sites are streets, markets, and hotels & restaurants. Similarly, there are three types of vehicles that collect: Tricycles, fork-lifts, and hook-lifts. Each type of vehicle has its own weight capacity and constraints. The researchers defined all their terms/variables and their explanations. What makes this article unique is it has to consider the capacities of all of the vehicles that it used in routing to the collection site. The data was recorded in "moves," and the states of the vehicles were constantly recorded. As

	a vehicle filled up, they had to be routed back to empty their supplies. As stated before, this system of Combining Satellite navigation and Swarm Optimization was more effective than the standard methods already available for MSW collection.
Research Question/Problem/ Need	How can MSW be more effectively gathered in cities with high rates of waste?
Important Figures	 **Fig. 3.** The total collected waste quantities of algorithms (kg).  **Fig. 4.** The total traveling distances of algorithms (km).
Notes	● This is extremely useful to me, since this paper takes into

	consideration the capacity of the vehicle that is collecting the trash. If I wanted to downsize the current garbage truck, I would have to also consider the new capacities. ● This article once again shows that many factors are needed in any sort of routing algorithm ○ A new discovery is the consideration of capacity ● It is useful to store data in long ArrayLists or sequences, as key information tends to be defined indefinitely. ArrayLists have a dynamic size, so they could fit the criteria needed for these problems. ● This solution involves lots of summations of terms, which comes into play since the individual capacities need to be summed to find the total capacity of all the vehicles.
Cited references to follow up on	S. Wang, G. H. Huang, Y. Yao, Y. L. Xie, J. L. Zhen. (2017) An inexact fuzzy bi-level programming model for energy–traffic system planning under uncertainty: a case study of Urumqi city, China. *Engineering Optimization* 49:8, pages 1441-1461. Ye Xu, Guohe Huang, Jianjie Li. (2016) An enhanced fuzzy robust optimization model for regional solid waste management under uncertainty. *Engineering Optimization* 48:11, pages 1869-1886. Y. P. Li, G. H. Huang, X. S. Qin, S. L. Nie. (2008) IFTCP: An Integrated Method for Petroleum Waste Management under Uncertainty. *Petroleum Science and Technology* 26:7-8, pages 912-936.
Follow up Questions	● What other criteria / variables do I need to consider for my algorithm that I haven't already? ● If the truck sizes cannot be changed for whatever reason, what can be done to increase the capacity of them or reduce their load? ● What negative effects do suburban garbage trucks have on the environment? (need more details) ●

Article #10 Notes: Short-Term Traffic Flow Forecasting by Selecting Appropriate Predictions Based on pattern Matching

Source Title	Short-Term Traffic Flow Forecasting by Selecting Appropriate Predictions Based on Pattern Matching
Source citation (APA Format)	D. Ma, B. Sheng, S. Jin, X. Ma and P. Gao, "Short-Term Traffic Flow Forecasting by Selecting Appropriate Predictions Based on Pattern Matching," in IEEE Access, vol. 6, pp. 75629-75638, 2018, doi: 10.1109/ACCESS.2018.2879055.
Original URL	https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8528330
Source type	Scientific Article
Keywords	Short-term traffic flow, forecasting, pattern matching, CNNs-LSTM
Summary of key points (include methodology)	In traffic management, predicting short-term traffic flow is one of the most important components. In the method which is known as data driven, historical data is used to train a predicting system to accurately predict short-term traffic. However, on days that do not follow the expected traffic betters, the prediction of traffic is hurt significantly. Traffic is not completely predictable, so relying on past data always has its risk. This paper proposes a more advanced method, which will use pattern matching to make its predictions. Instead of just clumping all of the historical data together, this method splits it up into groups based on their patterns. It achieves this by using clustering algorithms. Next, a smart predictor is trained in a meticulous matter with each group, one at a time. The group that appears to be the most similar to the target day is chosen first, and the others follow in rank from most similar to least similar. This way the predictor is most prepared for days that resemble the target day, and therefore the predictor will work on any given day.
Research Question/Problem/ Need	How can traffic be predicted in the short term without changing the overall cost of the system?

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<td>Important Figures</td>
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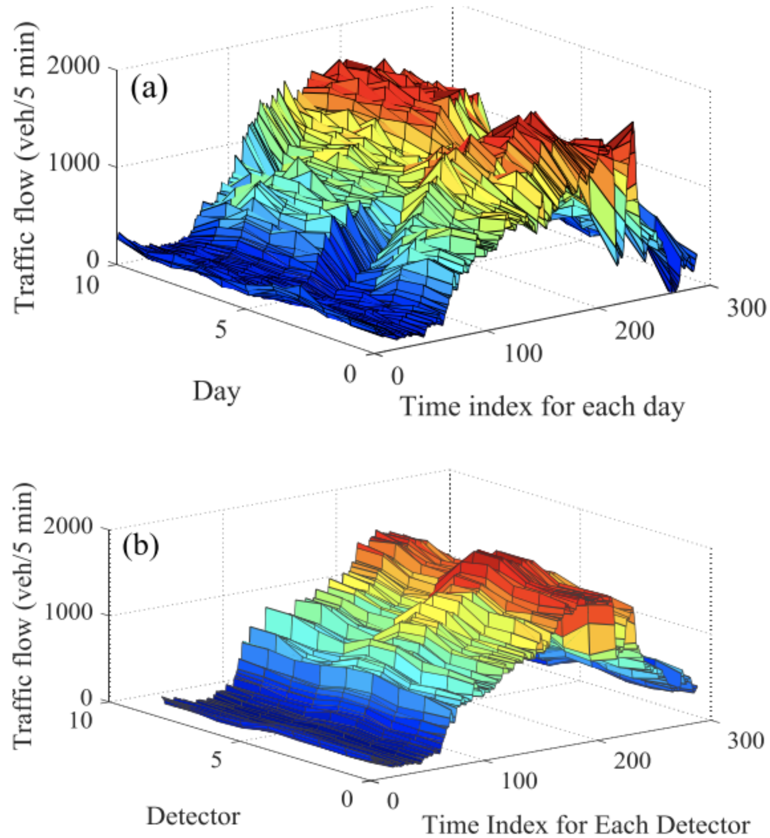

FIGURE 5. Traffic flow data in the test set :(a) Temporal pattern and (b) Spatial pattern.

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- Though at the premise this strategy seems simple enough, it actually involves a lot of tricky math that I would need to learn.
- In the clustering algorithm for the historical data,
    - The average of all of the euclidean distances between each historical traffic graph and the target daily graph is taken, and the historical graphs with the least distance are taken to be the closest, so they are put into a category that labels them as such.
- The algorithm runs on a loop, and therefore values must be updated at every iteration.
- Long-Short-Term models are used in this solution
    - This is something common that I have found in multiple papers
- A case study was conducted with one years' worth of data, and the average error was shown to be about 7.66%, which is lower than average error values.

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<td>Cited references to</td>
<td>W.-C. Hong, "Traffic flow forecasting by seasonal SVR with chaotic</td>
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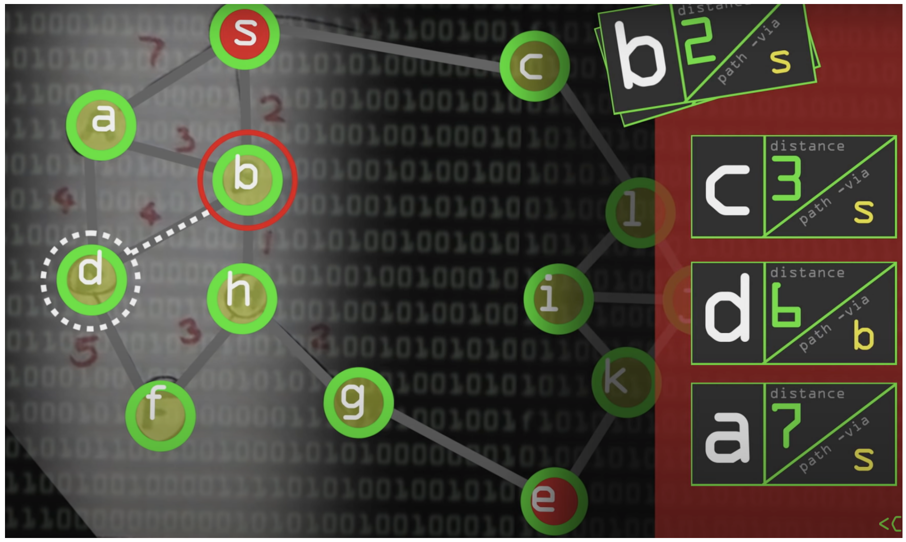
follow up on	simulated annealing algorithm,'' Neurocomputing, vol. 74, nos. 12–13, pp. 2096–2107, 2011. D. Ma, X. Luo, W. Li, S. Jin, W. Guo, and D. Wang, ''Traffic demand estimation for lane groups at signal-controlled intersections using travel times from video-imaging detectors,'' IET Intell. Transp. Syst., vol. 11, no. 4, pp. 222–229, May 2017
Follow up Questions	● How exactly does the LTST model work? This is something that I need to research more of. ● How large would a database of historical data need to be in order to be effective? Is this a static constant (some amount of gB, tB, etc.), or would this requirement change over time? ● As these deep learning algorithms are very smart and complex, can they be taught to learn other parameters that might be beneficial to the system as a whole?

Article #11 Notes: Dijkstra's Algorithm - Computerphile

Source Title	Dijkstra’s Algorithm - Computerphile
Source citation (APA Format)	Pound, M. [Computerphile]. (2017, January 4). Dijkstra’s Algorithm - Computerphile [Video]. YouTube. https://www.youtube.com/watch?v=GazC3A4OQTE
Original URL	• https://www.youtube.com/watch?v=GazC3A4OQTE
Source type	Informational Youtube Video
Keywords	Dijkstra’s, Shortest Path, SATNAV, GPS, Node
Summary of key points (include methodology)	Pathfinding algorithms are used in places such as google maps or satellite navigation. The problem arose when the question of finding the shortest path to some point was considered. The question also appears in network routing problems, where it is asked what the best way to route packets is. Dijkstra’s can be improved upon in many different algorithms, including A-Star, making Dijkstra’s a baseline algorithm of sorts. The cost between two nodes can represent many things, including distance, time, difficulty of travel, and so on. An analogy of roads is the simplest to work with for an example. Any Dijkstra’s problem will have one starting point and one ending point (or node). Between each node is a cost, represented as strictly integers. In most Dijkstra implementations, a smaller cost is always better. On smaller graphs, a brute force approach should be just as effective as Dijkstra’s, but in larger problems the algorithm becomes more necessary for solving the problems. Dijkstra’s algorithm is essentially a brute force approach but with a more sensible and logical order of checking paths (lowest to highest cost). In order to perform Dijkstra’s, we need all of the cost values between each of the nodes. At the start point, the cost is 0 and every other point has a cost of infinity before they are known. A priority queue is then made to order each point in terms of lowest cost to highest cost. Once each point is “visited,” their cost value is assigned and they can join the priority queue in the correct position.
Research Question/Problem/ Need	How does Dijkstra’s Algorithm work and how can it be used in practical applications?

Important Figures	 This figure shows a graph of all the nodes and the priority queue that is being used to order these nodes from lowest cost to highest cost.
Notes	● Dijkstra's algorithm is easy to follow and makes logical sense, almost thinking like a human would think. However, it is necessary to understand how this algorithm can be made into code. ○ I believe that if this algorithm were to be implemented in JAVA it would need a class architecture to construct every single node on the map, with data fields assigning things like position, cost, etc. ● Dijkstra's isn't the most effective algorithm, but it is a great baseline algorithm to build any subsequent algorithms off of, so it is important for research. ● A priority queue is a structure that I have not worked with at all, so I should do more research into what exactly it is.
Cited references to follow up on	*None*
Follow up Questions	● How difficult is it to improve this algorithm and turn it into A-Star? ● Can this algorithm be used practically in my project at all? Or does A-Star outdo it in every way? ● What are the comparative runtimes between the two algorithms, and how significant is the difference? ●

Article #12 Notes: Finding shortest paths on real road networks: the case for A

Source Title	Finding shortest paths on real road networks: the case for A*
Source citation (APA Format)	Zeng, C. (2009). Finding shortest paths on real road networks: the case for A. International Journal of Geographical Information Science : IJGIS, 23(4), 531–543. https://doi.org/10.1080/13658810801949850
Original URL	https://wpi.primo.exlibrisgroup.com/discovery/fulldisplay?docid=cdi_crossref_primary_10_1080_13658810801949850&context=PC&vid=01WPI_INST:Default&lang=en&search_scope=MyInst_and_CI&adaptor=Primo%20Central&tab=Everything&query=any,contains,%20finding%20shortest%20paths%20on%20real%20road%20networks&sortby=rank&mode=basic
Source type	Scientific Research Article
Keywords	Shortest path algorithms; A* algorithm; Transportation networks
Summary of key points (include methodology)	In network modeling, one of the most basic problems is finding the shortest path from an origin to a destination. Though there were many attempts to make an algorithm to solve this problem, Dijkstra's stood out for being very efficient, and it is agreed upon that implementations of his algorithm is the best at solving one-to-one routing problems. In the paper, the researchers show how the algorithm can be improved with GIS-sourced data. A* differs from previous implementations in that it uses an estimated cost of "path-completion." The paper tests many versions of Dijstra's, including Djikstra's algorithm with k-array heap, Dijkstra's algorithm with double-level buckets, A* algorithm with double buckets, and A* algorithm with approximate buckets. All of the programs are made to read network data from an ASCII file. They then changed the files around to include a little bit of geographical information from the GIS database. Then, the researchers tested their programs with two different parts of California: Los Angeles and Santa Barbara. They randomly selected 500 pairs of points, with each pair consisting of an origin and destination node. They tested all seven algorithms 500 times with all of these pairs of nodes, and recorded the average performance for each tested algorithm. It was found that A-Star outperforms Dijlstra's algorithm and a class of SPAs (Shortest-path algorithms) known as the Gallo-Pallottino class. Thus, A* was

concluded to be the best performing and most efficient SPA available.

Research Question/Problem/ Need

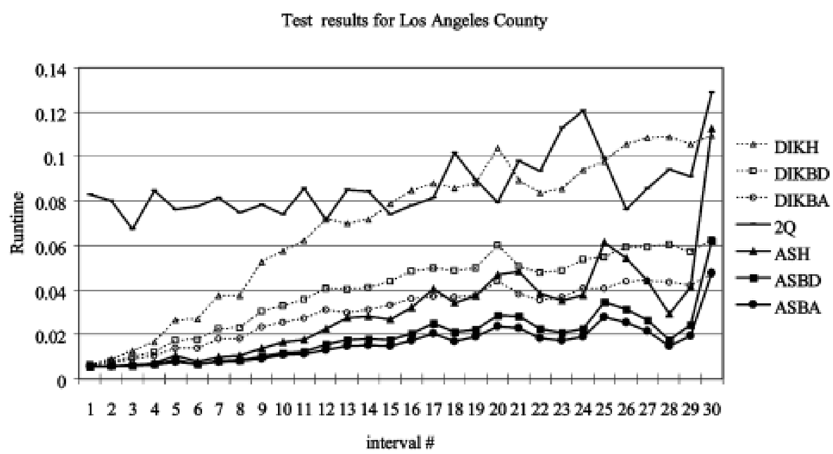
How do the different versions of Dijkstra’s Algorithm compare? Which is the fastest / most efficient?

Important Figures

Table 1. Algorithms Tested

Class	Abbreviation	Description
Dijkstra	DIKH	Dijkstra’s algorithm with k-array heap
	DIKBD	Dijkstra’s algorithm with double-level buckets
	DIKBA	Dijkstra’s algorithm with approximate buckets
Graph Growth	Two-Q	Pallottino’s algorithm with two queues
	ASH	A* algorithm with k-array heap
A*	ASBD	A* algorithm with double buckets
	ASBA	A* algorithm with approximate buckets

This table lists all of the algorithms tested, which are different variations of Dijkstra’s Algorithm



This table shows the runtime of the 500 test cases for all of algorithms using Los Angeles as an environment. A* with random buckets showed the lowest trend of runtimes, making it the clear winner. Also, A* variations beat out the other algorithms in general.

Notes

- All of these algorithms assume non-negative lengths
- Very interestingly, the programs that the researchers testing got all of their data form an ASCII file, which has the data fields (variables) for nodes, arcs, and arc lengths.
- GIS data stands for Geographical Information System
- The researchers ONLY worked with integers, using a multiplication factor of 1000 and truncation
- Log Angeles contains 195,223 nodes and 532,178 arcs
- Random selection of start and end nodes is used in legitimate

	research. ◦ Should the points be perimeter? Or just random in general?
Cited references to follow up on	ERTL, G., 1998, Shortest path calculation in large road networks. OR Spektrum, 20, pp. 15–20. ZHAN, F.B. and NOON, C.E., 2000, A comparison between label-setting and label-correcting algorithms for computing one-to-one shortest paths. Journal of Geographic information and decision analysis, 4, pp. 1–13.
Follow up Questions	• As described, there are many versions of the A* algorithm. How can they be implemented, and how much of an improvement do they make? • What are the applications of the other implementations? Are they just completely useless at this point? •

Article #13 Notes: The investigation of a class of capacitated arc routing problems: the collection of garbage in developing countries

Source Title	The investigation of a class of capacitated arc routing problems: the collection of garbage in developing countries
Source citation (APA Format)	Amponsah, S. (2004). The investigation of a class of capacitated arc routing problems: the collection of garbage in developing countries. Waste Management (Elmsford), 24(7), 711–721. https://doi.org/10.1016/j.wasman.2004.01.008
Original URL	https://wpi.primo.exlibrisgroup.com/discovery/fulldisplay?docid=cdi_crossref_primary_10_1016_j_wasman_2004_01_008&context=PC&vid=01WPI_INST:Default&lang=en&search_scope=MyInst_and_CI&adaptor=Primo%20Central&tab=Everything&query=any,contains,problems%20with%20garbage%20collection&offset=0
Source type	Scientific Research Article
Keywords	Garbage Collection, heuristics, arc routing, environment
Summary of key points (include methodology)	Collection, transport, and disposal of waste is an overlooked service in many developing countries, mainly due to the hot weather. The paper looks at cities in Ghana, which is a hot place that doesn't have many resources available to it. The waste that is generated from the area has some ingredients that could be toxic. Multiple trucks are currently used for collection, and the researchers look to construct a heuristic that can help route each of these vehicles. The algorithm they design not only tries to minimize the cost (time or distance), but also tries to minimize the time that uncollected waste stays on the roads, since that waste may harm the community. There is a large inconvenience in the community due to the smell of the waste, so the longer the waste stays out on the roads, the worse the smell will be. In one strategy the trucks would branch out to all of the connecting

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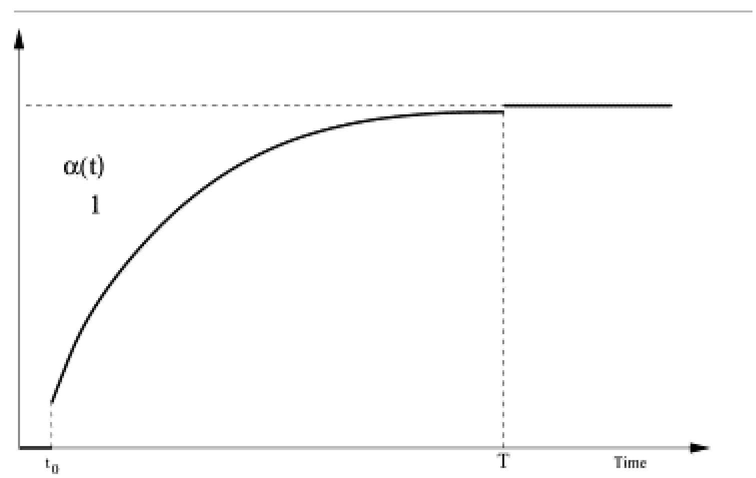
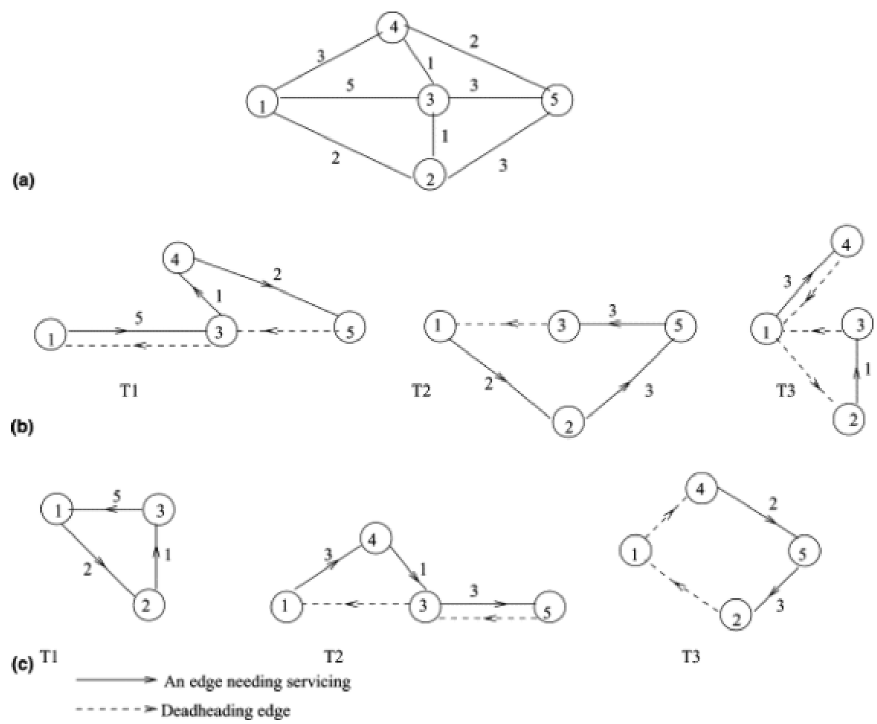
<tr><td></td><td>nodes and evaluate them for dead ends and then find the costs of all connecting nodes. The algorithm then maximizes the cost and chooses to service the road that needs the most attention.</td></tr>
<tr><td>Research Question/Problem/ Need</td><td>How can garbage collection in developing countries with hot weather be improved with an algorithm?</td></tr>
<tr><td>Important Figures</td><td>

This graph shows how the smell of waste can change over time, with a maximum score of 1 being the flatline, or worst possible smell. The graph’s nature is somewhat logarithmic.

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	These figures show the difference possible paths that a truck could take from node 1, with the solid edges representing the places that need immediate servicing.
Notes	● While this article talks about using a “constructive heuristic” that takes into account environment, perhaps a constructive heuristic can be made that takes into account traffic instead. (Just a thought) ● This algorithm works similarly to A*, except it **maximizes** the cost to choose the next path, rather than minimizing, since the goal is to give the most attention to roads that are difficult to travel and thus will have more uncollected garbage. ○ This approach can be adapted for traffic, if an algorithm could choose to route a truck where traffic flow as a cost is **maximizes** (essentially meaning that the roads visited would have the least back-ups) ● An interesting strategy used in this paper is the assessment of the current load of the truck, which is something that I have not considered at this point. ○ In my project, it seems that this will hopefully not be a problem, though it is definitely something to keep in mind.
Cited references to follow up on	M. Dror (Ed.), Arc Routing: Theory, Solutions and Applications, Kluwer Academic Publishers, Dordrecht (2000), pp. 277-326 Public waste collection: a case study Belgian Journal of Operations Research Statistics and Computer Science, 31 (1991), pp. 5-15
Follow up Questions	● This algorithm uses a lot of the sigmoid function, which essentially can compress a value town to a range between 0 and 1. Why is this necessary? Is it something that should be considered for my project? ● This problem was solved for a country with limited resources. What improvements could be made with more resources?

Article #14 Notes: Net2Plan: An Open Source Network Planning Tool for Bridging the Gap between Academia and Industry

Source Title	Net2Plan: An Open Source Network Planning Tool for Bridging the Gap between Academia and Industry
Source citation (APA Format)	Pavon-Marino, I. (2015). Net2plan: an open source network planning tool for bridging the gap between academia and industry. IEEE Network, 29(5), 90–96. https://doi.org/10.1109/MNET.2015.7293311
Original URL	https://wpi.primo.exlibrisgroup.com/discovery/fulldisplay?docid=cdi_gale_infotracacademiconefile_A438666552&context=PC&vid=01WPI_INST:Default&lang=en&search_scope=MyInst_and_CI&adaptor=Primo%20Central&tab=Everything&query=any,contains,net2plan&offset=0
Source type	Scientific Article
Keywords	Net2Plan, Routing, Traffic, Open-source
Summary of key points (include methodology)	As of recent, a lot of network planning research and development has been done, which is a good thing. However, it is difficult for network creators to demonstrate the effectiveness of their results on their networks. This is partially due to a lack of planning tool for software which is powerful enough to use. However, an open-source tool known as Net2Plan has been released that may potentially solve these problems. Net2Plan uses an open-repository of network planning resources that are available to everyone. It is based on Java, and can be licensed and downloaded for free. The program benefits from being offline, meaning that it can run without an internet connection. The program also includes traffic matrix generation, which can be used to estimate, predict, and measure traffic. A benefit of the program is easy peer review capability, as you can upload your project to the cloud and have lots of other users test your algorithm with a consistent software.
Research	How does Net2Plan help developers implement their routing

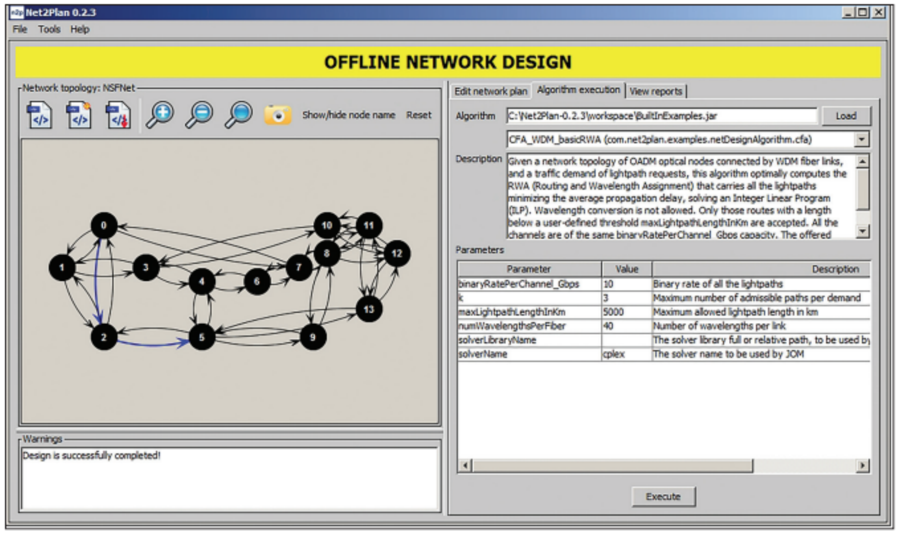
<table>
<tr><td>Question/Problem/ Need</td><td>algorithms into the real world?</td></tr>
<tr><td>Important Figures</td><td>


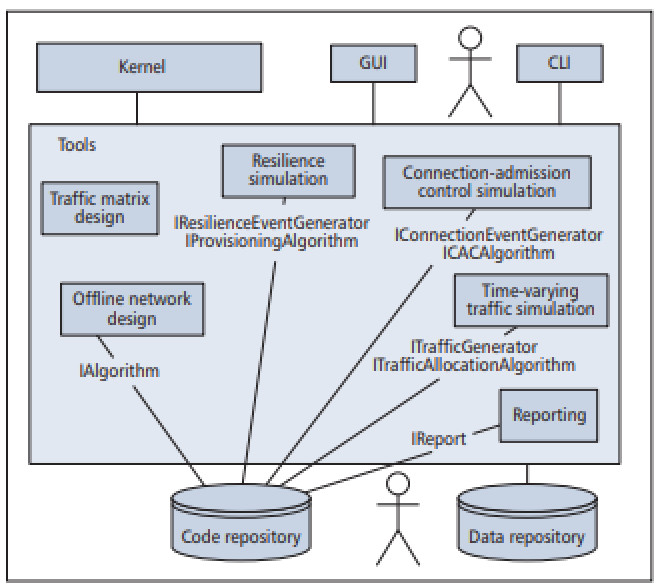
Figure 2. Offline network design tool.
This figure shows how the program can run offline, with the nodes and arcs being easily displayed to the user.


Figure 1. Architecture of Net2Plan.
This figure shows all of the features and the architecture that is included with the software. It can be seen with the stick figures where the user interacts and where the backend development occurs.
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<tr><td>Notes</td><td>

This is the first time I have heard of a traffic matrix
Net2Plan displays really helpful visuals, which could be something that supplements the visuals that I have at the

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	moment. ● Net2Plan can output a lot of statistics and data easily, which could be helpful for proving any results that I think I have ● The software uses an energy efficient analysis based on NCU (network controller unit)
Cited references to follow up on	Net2Plan — The Open-Source Network Planner; http://www.net2plan. com/ [last accessed: April 2014].
Follow up Questions	● How easy would it be to copy in my JAVA code that I have already made? (Net2Plan seems to be written in JAVA) ● Could this be licensed for a student? If so, what are the steps that need to be taken? ● Would this program be able to take advantage of the Google Maps API?

Article #15 Notes: Backtracking search algorithm in CVRP models for efficient solid waste collection and route optimization

Source Title	Backtracking search algorithm in CVRP models for efficient solid waste collection and route optimization
Source citation (APA Format)	Akhtar, H. (2017). Backtracking search algorithm in CVRP models for efficient solid waste collection and route optimization. Waste Management (Elmsford), 61, 117–128. https://doi.org/10.1016/j.wasman.2017.01.022
Original URL	https://wpi.primo.exlibrisgroup.com/discovery/fulldisplay?docid=cdi_proquest_miscellaneous_1865532856&context=PC&vid=01WPI_INST:Default&lang=en&search_scope=MyInst_and_CI&adaptor=Primo%20Central&tab=Everything&query=any,contains,Backtracking%20search%20algorithm%20in%20CVRP%20models%20for%20efficient%20solid%20waste%20collection%20and%20route%20optimization.%20Waste%20Manag&sortby=rank&mode=basic
Source type	Scientific Research Article
Keywords	Waste collection, CSRP model, BSA (Backtracking Search Algorithm)
Summary of key points (include methodology)	By optimizing waste collection, the budget needed for waste collection and the effect on the environment can be reduced by shortening the route distance. This paper describes a modified Backtracking Search Algorithm, also known as BSA. A CVRP is what is known as a capacitated vehicle routing problem. The paper looks at minimizing the sum of the waste collection route distances. It uses a threshold waste level (TWL) of the waste bins that it uses in order to minimize the number of bins that are emptied. The paper also uses a scheduling model to test the applicability of the algorithm, comparing it with the conventional systems used by measuring travel distance, waste collected, emissions, costs, fuel consumption, etc. With this algorithm, the researchers were able to increase waste collection efficiency by 37%, while also reducing emissions, costs, and consumptions by around 48%.
Research Question/Problem/	How can a BSA be used to improve the system of waste collection by reducing the time and increasing efficiency?

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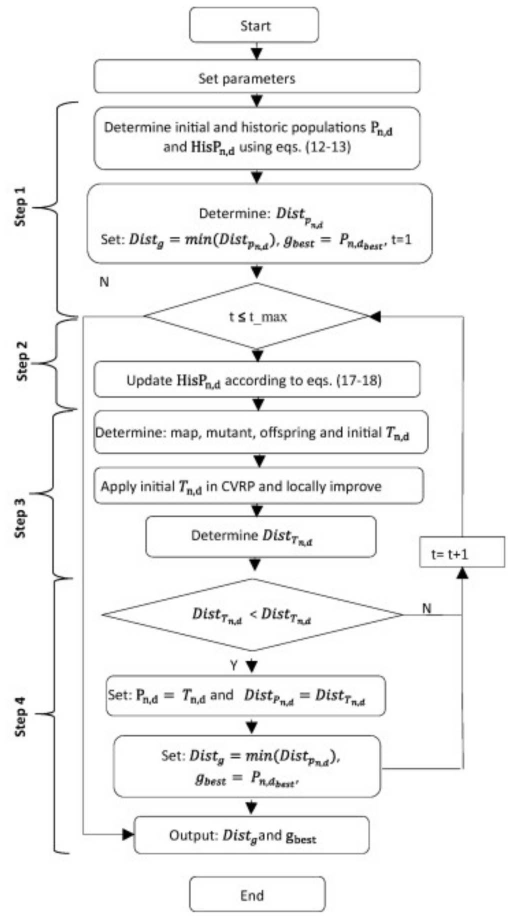
<tr><td>Important Figures</td><td>

This flowchart shows the process that BSA takes, with a lot of initial calculations and use of historic data.</td></tr>
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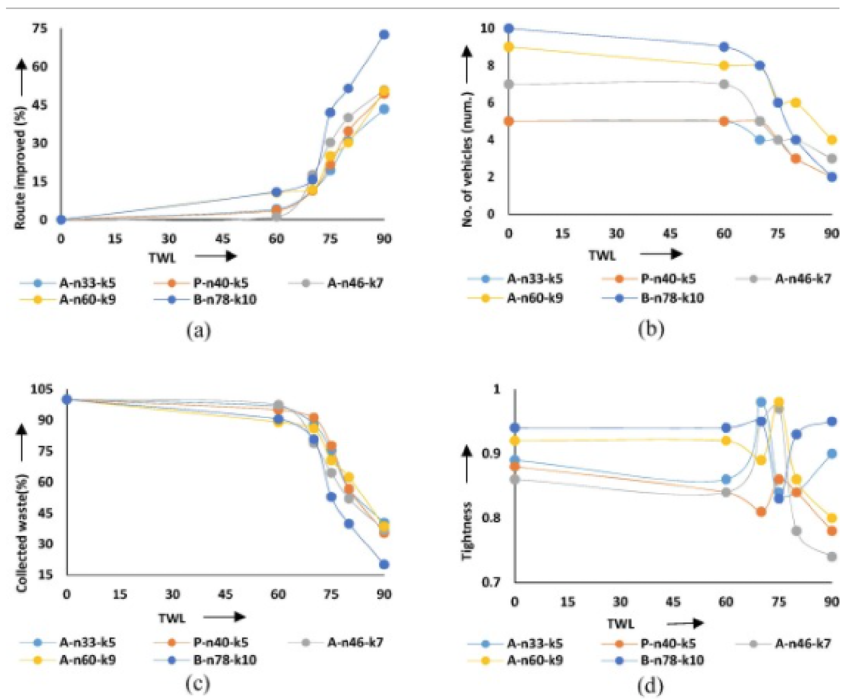
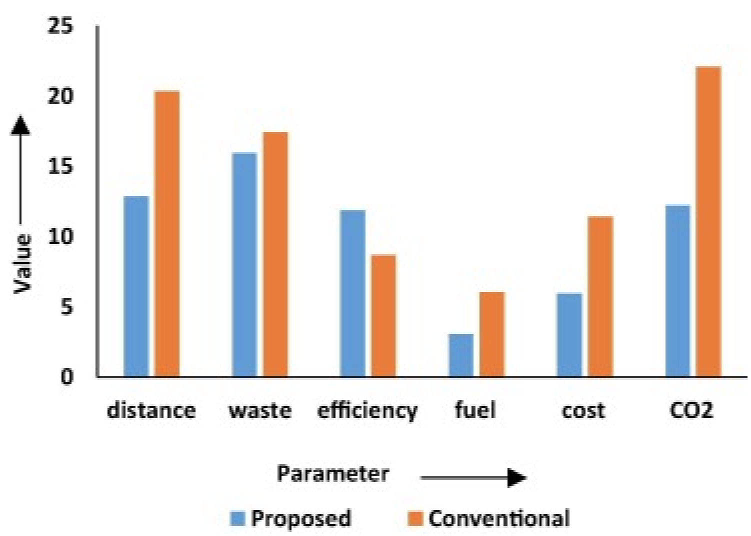


These graphs show how the algorithm improves over a few tests 4 parameters: route improvement, waste collection, vehicle number, and tightness.


A clear improvement in all parameters is shown here with the proposed algorithm versus the conventional method.
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BSA uses a lot of historical data,which I am not sure is available to me at the moment.

They use initial population, historic population, fitness value, global best, and best population .

Every iteration of the algorithm has to set up a lot of initial

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	parameters, which contrasts my current method of random selection. ● **Decision variables** are a new concept I learned from this paper. They're essentially booleans that evaluate to either 1 or 0 and are used in equations. This is useful because a value of 0 in any multiplication would automatically make the entire product 0. ● BSAs are a more complicated algorithm than SPA, but perhaps a simplified combination of the two would be effective. ● A **flowchart** would be a very good way to present my algorithm to make it more understandable
Cited references to follow up on	M. Faccio, A. Persona, G. Zanin Waste collection multi objective model with real time traceability data Waste Manage., 31 (2011), pp. 2391-2405 M.A. Hannan, M.A.Al. Mamun, A. Hussain, H. Basri, R.A. Begum A review on technologies and their usage in solid waste monitoring and management systems: issues and challenges Waste Manage., 43 (2015), pp. 509-523
Follow up Questions	● This article has a conventional method for waste collection noted. Could I use this data? If not, where could I find similar data? ● What other factors of waste collection could be improved? Would it be better for me to show improvement or traffic, or should I use these factors? ● How fast is the computation time of the BSA?

Article #16 Notes: Waste collection multi objective model with real time traceability data

Source Title	Waste collection multi objective model with real time traceability data
Source citation (APA Format)	Faccio, P. (2011). Waste collection multi objective model with real time traceability data. Waste Management (Elmsford), 31(12), 2391–2405. https://doi.org/10.1016/j.wasman.2011.07.005
Original URL	https://wpi.primo.exlibrisgroup.com/discovery/fulldisplay?docid=cdi_proquest_miscellaneous_900637093&context=PC&vid=01WPI_INST:Default&lang=en&search_scope=MyInst_and_CI&adaptor=Primo%20Central&tab=Everything&query=any,contains,Waste%20collection%20multi%20objective%20model%20with%20real%20time%20traceability%20data&offset=0
Source type	Scientific Research Article
Keywords	Model, traceability data, waste collection, real-time
Summary of key points (include methodology)	This paper talks about volumetric sensors, RFID (radio frequency identification), GPRS (general packet radio services) and GPS (global positioning system), All of these technologies can be used to collect real-time data, which is essential in a routing model. The general concept is knowing the real time state of each and every waste bin and then using an algorithm to decide which bin should be emptied and which should not, thus optimizing the distance travelled, the vehicles needed, and the environmental impact. The testing is done on an Italian city with about 100,000 inhabitants. The approach should reduce noise, reduce investment costs for a fleet of vehicles, reduce operational costs, and eliminate unnecessary stops. The algorithm must take static input from both the bin and the vehicle, while also taking real-time input from both of them. Then, that data will be processed and the route will be determined. After a step on the route is taken and waste is collected, the algorithm will take more real time data and repeat the cycle, until the route is finished.
Research Question/Problem/ Need	How can real-time data collection form vehicles and waste bins improve and optimize waste collection?

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<td>Important Figures</td>
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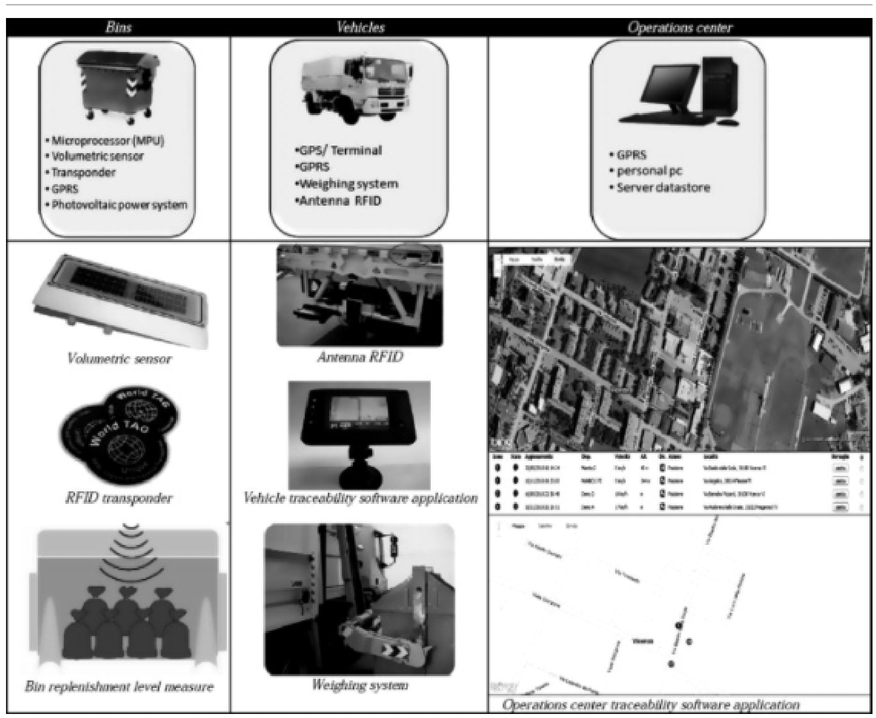
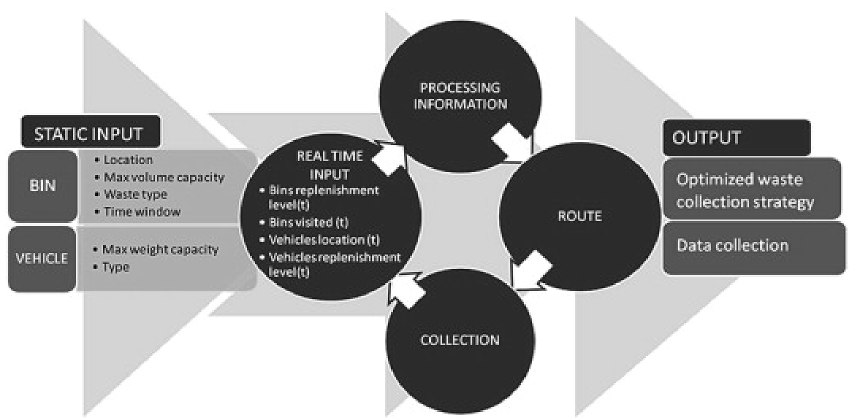


This figure shows all of the necessary components for this program, including the microprocessor, RFID, and volumetric sensor.



This flowchart shows the easy-to-follow steps that the algorithm takes, with the static the real time data collection included.
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<td>Notes</td>
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- Reduction of noise is not a factor that I have considered before
- This algorithm requires a lot of technology that I obviously do not have access to, like the volumetric sensors and RFIDs. However, these could potentially be simulated and data can be randomized.
- The pseudocode for this algorithm is much easier to follow

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</table>

	than others I have researched, and this could potentially be due to the fact that it uses a lot of independent technologies ● This paper describes economic feasibility, which is a really important thing to consider if any technologies are brought into a system. Perhaps I could use theoretical cost estimations, like this paper does
Cited references to follow up on	B.G. Wilson, B.W. Baetz, F.L. Hall Reduction of queuing delays at waste management facilities Civil Engineering and Environmental Systems, 19 (4) (2002), pp. 311-331 A.G. Qureshi, E. Taniguchi, T. Yamada An exact solution approach for vehicle routing and scheduling problems with soft time windows Transportation Research Part E, 45 (2009), pp. 960-977
Follow up Questions	● Does this paper not assume that every garbage can will be full? What is the exact need for the exact volume of waste? Is the algorithm taking into account the exact amount of waste, or just if the can is full or empty? ● What is the need for both the GIS and GPS data? Does it merely just improve accuracy, or is there an inherent need for both? ● Why is there a risk of an oversized bin? Is there a defined capacity that the trucks can hold?

Article #17 Notes: Improved route planning and scheduling of waste collection and transport

Source Title	Improved route planning and scheduling of waste collection and transport
Source citation (APA Format)	NUORTIO, K. (2006). Improved route planning and scheduling of waste collection and transport. Expert Systems with Applications, 30(2), 223–232. https://doi.org/10.1016/j.eswa.2005.07.009
Original URL	https://wpi.primo.exlibrisgroup.com/discovery/fulldisplay?docid=cdi_gale_infotracacademiconefile_A197522933&context=PC&vid=01WPI_INST:Default&lang=en&search_scope=MyInst_and_CI&adaptor=Primo%20Central&tab=Everything&query=any,contains,Improved%20route%20planning%20and%20scheduling%20of%20waste%20collection%20and%20transport&offset=0
Source type	Scientific Research Article
Keywords	Metaheuristic, waste collection, expenditure, variable neighborhood thresholding
Summary of key points (include methodology)	Located in Finland, these researchers try to solve the expense problems of municipal waste collection. They preface the article by saying that waste collection is one of the most difficult problems to solve, since it is highly visible to the public and is fragile and sensitive to big changes being made. Despite this, the paper looks to optimize vehicle routes and schedules of collecting solid waste in Finland. The way they accomplish this is by creating a guided variable neighborhood thresholding metaheuristic. They outline serverl approach that can work to speed up the process of waste collection as well as minimize memory usage. There are a few files and pieces of data that they work with, including information on bins, facilities, vehicles, stop points, rules, and a distance matrix. In terms of bins, the researchers have access to a file that contains the X and Y coordinates of each bin as well as the mass and volume of the waste, service time, and interval of collection. They also have a file that contains information on what vehicles are available to be used, along with their Vehicle IDs. By using historical data, the researchers have access to the historical stop points made by the vehicles, which is essentially where the vehicle is stopped for loading or unloading. They also have the maximum daily and weekly working hours, days, and planning periods, as well as creating a distance matrix of all of the shortest distances between the stop points. In their conceptual model, the program must first parse all of the input data and decide what it wishes to optimize. The default setting is optimizing the total distance travelled, but there is also total time or total cost optimization.

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<td>Then, the program uses seven well-known heuristics to guide the function and optimize for the specified parameters. Their routing algorithm runs differently than an SPA in that it relies on heuristics to solve the routing problems. First they use a “seed container,” which is just the bin that is closest to wherever the truck hub is. Then, they add the remaining waste containers with their distance minimization function with respect to all of their input parameters. There is a rerouting and recalculation process every single bin to ensure the most optimal solution.</td>
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<tr>
<td>Research Question/Problem/ Need</td>
<td>How can the cost and time taken of garbage collection be optimized?</td>
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<tr>
<td>Important Figures</td>
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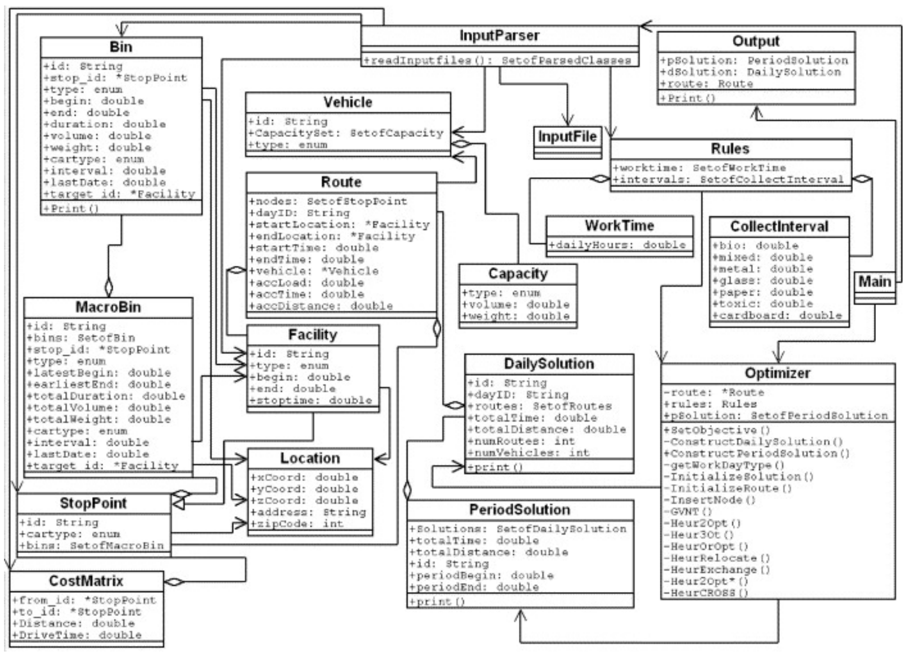
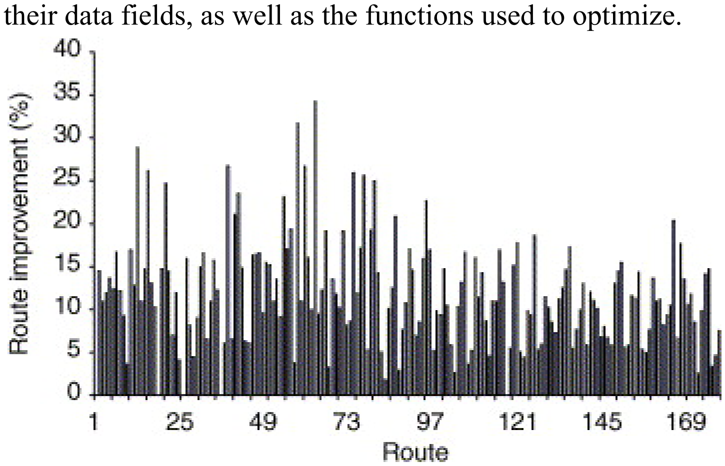


This shows each part of the conceptual design, including the input files and their data fields, as well as the functions used to optimize.



This graph shows the percent improvement of each route in terms of distance when routed using the program. Each route has clear improvement, if not significant.</td>
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Notes	● Route recalculation based on real-time collection data is an interesting concept, since it would allow for even more precise and meaningful routing. However, this is hard in a simulated environment unless everything is randomized ● Another interesting concept brought up in this article is the rules document that has all of the working hour requirements. This information can be taken from my town or simply guessed at to ensure that the routing will align with whatever standards it needs to meet ● Something I can try to implement is routing based off of the cans themselves rather than the entire road as a whole, since a truck only needs to visit where there is garbage to collect ● Using multiple heuristics is already an idea that I have been considering, so it is good to see that this is being used in a paper of this quality.
Cited references to follow up on	Dror, M. (Ed.). (2012). *Arc routing: theory, solutions and applications*. Springer Science & Business Media. Dueck, G., & Scheuer, T. (1990). Threshold accepting: a general purpose optimization algorithm appearing superior to simulated annealing. *Journal of computational physics*, *90*(1), 161-175.
Follow up Questions	● How is historical data collected for stopping points? Is it done manually, or with something like RFIDs? ● Why is CPU and RAM usage important? Aren't computers powerful enough as they are to handle this strain? Is this program designed to run on low-powered machines? ● What is the purpose of the “seed” garbage can? Can the program not start from anywhere or is this determined to always be the best way to start? ● Which heuristics used had the biggest impact on the overall output of the program? Are any of them extraneous or should they all be included?

Article #18 Notes: GIS technology for vehicle routing and scheduling in solid waste collection systems

Source Title	GIS technology for vehicle routing and scheduling in solid waste collection systems
Source citation (APA Format)	Chang, L. (1997). GIS Technology for Vehicle Routing and Scheduling in Solid Waste Collection Systems. Journal of Environmental Engineering, 123(9), 901–910. https://doi.org/10.1061/(ASCE)0733-9372(1997)123:9(901)
Original URL	https://wpi.primo.exlibrisgroup.com/discovery/fulldisplay?docid=cdi_gale_infotracacademiconefile_A20032724&context=PC&vid=01WPI_INST:Default&lang=en&search_scope=MyInst_and_CI&adaptor=Primo%20Central&tab=Everything&query=any,contains,GIS%20technology%20for%20vehicle%20routing%20and%20scheduling%20in%20solid%20waste%20collection%20systems
Source type	Scientific Research ARticle
Keywords	Management, GIS, waste collection, engineering, civil, mixed-integer
Summary of key points (include methodology)	This paper revolves around the GIS, also known as Graphic Information System, which is the baseline for many hardware and software engineering problems that have to do with routing. In this paper, the researchers use a mixed-integer programming model to try to optimize the collection of solid waste in municipal services in Taiwan. They also program what is known as a "decision maker," which analyzes potential options for a truck to take based on the GIS and other factors. The basis of the problem is in the large amount of variation between different environments that need waste to be collected. Because of this variation, it is impossible to plan one system of collecting that works for every single environment. The paper states that the cost of waste collection makes up a large amount of the total caste of municipal solid waste management, so it follows that the optimization of such a service will greatly lower the overall cost of the service. The paper identifies three main objects that can be considered for collection: Minimization of total distance, minimization of collection costs, and minimization of total collection time. There is a fleet of trucks that must be used in this problem, so multiple routes have to be considered at once. The article uses summations of costs and simply minimizes them to find the best route. So, in a sense, the researchers are using a brute force method in combination with minimization functions in order to determine the most effective route. Along with this, the researchers use complex topological data of the environment that they are terraining to adjust the parameters and

<table>
<tr><td></td><td>data output, since Taiwan can be a difficult landscape to traverse. In all, there is promise in using GIS as a basis for routing since it can gather many scenarios at once and determine the best one based on objective data, something that couldn’t be done before without extensive legwork to simulate real-life environments.</td></tr>
<tr><td>Research Question/Problem/ Need</td><td>How can the GIS system be used to improve municipal solid waste collection in real-life areas?</td></tr>
<tr><td>Important Figures</td><td>

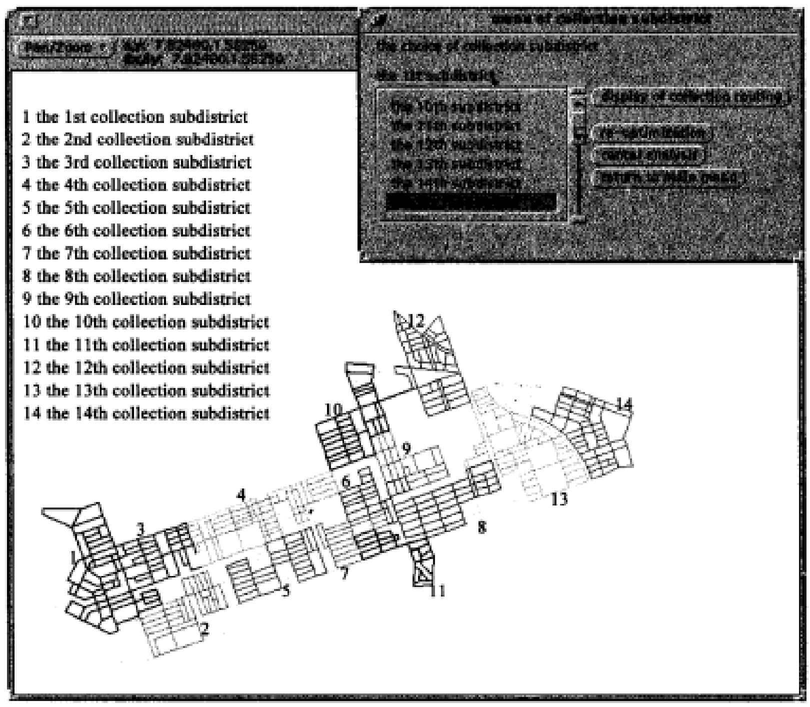

FIG. 6. Modified Waste Collection Network in Lin-Ya District of Kaohsiung City

This graphic depicts how the routing is shown visually, with a lines of varying darkness shown over a realistic map.</td></tr>
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TABLE 3. Evaluation of Efficiency of Collection Service in Lin-Ya District

Scenario (1)	Attribute (2)	Subdistrict 1 (3)	2 (4)	3 (5)	4 (6)	5 (7)	6 (8)	7 (9)	8 (10)	9 (11)	10 (12)	11 (13)	12 (14)	13 (15)	14 (16)	Total (17)	Average (18)
Current condition	Service frequency of collection vehicle	3	3	3	4	4	4	4	4	4	3	4	4	3	4	51	3.6
	Accumulated collection distance (m)	4,816	5,523	3,813	8,080	5,370	5,062	6,190	5,808	444	6,155	3,353	6,157	8,782	6,978	80,528	5,752
	Total collection time (min)	126	132	103	128	101	120	98	114	98	160	100	122	107	120	1,629	116
	Total collection points	88	185	71	161	112	152	150	104	78	173	153	134	100	127	1,788	125
Proposed management scenario	Service frequency of collection vehicle	2	2	2	3	3	2	4	4	4	3	3	3	4	3	42	3
	Accumulated collection distance (m)	3,090	4,021	2,589	4,081	3,393	3,433	4,538	3,746	2,578	3,903	2,394	3,877	5,088	4,445	51,176	3,655
	Total collection time (min)	68	87	59	144	93	67	106	165	154	116	93	83	161	124	1,521	109
	Total collection points	32	34	31	58	41	48	46	42	34	45	27	50	72	57	617	44
	Efficiency of capacity utilization (%)	72	88	91	87	89	97	72	80	77	77	67	62	94	79	1,132	80
	Average walking distance from collection point (m)[a]	54	57	41	43	43	36	44	45	42	45	42	40	41	39	602	43
Modified management scenario	Service frequency of collection vehicle	3	3	3	3	3	3	3	3	3	3	3	3	3	3	42	3
	Accumulated collection distance (m)	5,177	3,687	3,916	4,965	4,244	3,312	2,331	2,922	2,056	3,904	2,395	3,878	3,943	4,446	51,176	3,655
	Total collection time (min)	115	102	106	130	85	118	73	132	121	116	93	83	123	124	1,521	109
	Total collection points	51	37	51	69	46	44	25	35	25	45	27	50	55	57	617	44
	Efficiency of capacity utilization (%)	79	85	90	90	80	86	62	89	81	77	67	62	93	79	1,120	80
	Average walking distance from collection point (m)[a]	39	36	31	34	41	36	29	43	41	45	42	40	34	39	530	38

[a]Average walking distance = total length of arc/(2 × the number of arc in the network).

The overall results of the program, showing the different factors that are compared with the original plan versus the proposed and modified solutions.

Notes

- If the three main objectives of this program are cost, distance, and time, then traffic impact must be something that has not been considered.
    - Considering this however, it may be that the distance and time measurements inherently include traffic, since heavier traffic causes more time to be taken over the same distance.
    - Nevertheless, the only thing considered in this paper is distance and time for the truck itself, and not any of the surrounding vehicles.
- Since this program considered multiple routes at once just like my program, I could say that each route represents a different truck in one fleet rather than the same truck over multiple days.
- Collection points is a data field that I have not seen used before, and it seems to fluctuate greatly over different variations of the program.
- Another field that GIS can measure is average walking distance from the truck to the garbage can. This is something that I can not implement easily in my program. But it is something that I can consider in any future extensions.

Cited references to follow up on

Hromadka, T. V., Whitley, R. J., Harryman, R. R., and Braksator, M. J. (1992). "Application of a graphics database-management system: computerized master plan of drainage." Computer techniques in environmental studies TV, P. Zannetti, ed., Computational Mechanics Inc., Portsmouth, England, 805-817.

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Follow up Questions	- How can GIS be used in combination with Google maps to simulate real-life environments? - How can the GIS be accessed? Can it be accessed from any computer or any person? - Is a fleet of vehicles something to consider? How would this change my project as a whole and how would it change the cost, hours, and wages? - Do these programs have to be varied from country to country with different laws on waste collection? If so, how difficult would it be to implement?