Max-Min Ant System applied to the Police Patrol Routing Problem

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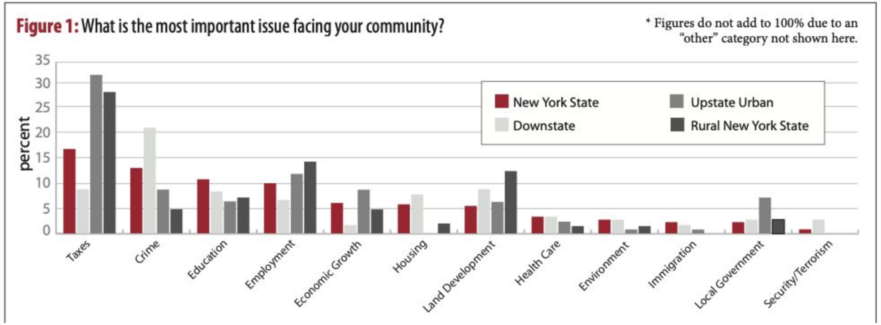
Background and Motivation (1)

- Crime remains as one of the main issues the public is concerned about. [1]
- Well documented links between crime rates and life satisfaction. [2]
- 8.5 million offences in the United Kingdom (UK) up to September 2023 [3]
- UK Government has recently given the police agencies £843 million in additional funding [4]
- The key to tackling crime rates is improving police effectiveness [5]



[1]

News story

Police to get funding boost to cut crime and keep public safe

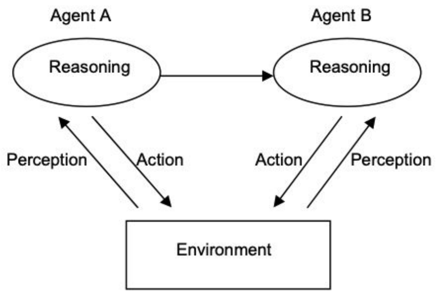
Police to receive up to £843 million next year to better protect the public, taking total to up to £18.4 billion.

From: Home Office, The Rt Hon James Cleverly MP, and The Rt Hon Chris Philp MP

Published 14 December 2023

[4]

Background and Motivation (2)



[12]

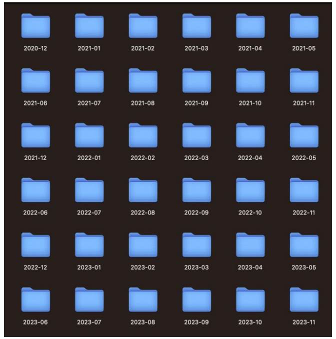
- Police patrolling has been an effective approach towards crime prevention. [6]
- Many different types of police patrolling strategies such as random patrols, problem-oriented policing, community policing, and hotspot policing. [6][7]
- Hotspot policing has been widely recognised as an effective strategy. [8]
- Hotspot policing requires an element of randomness and consistency to remain effective. [9]
- Current patrolling process leaves the planning of patrol routes to ground personnel. [10]
- Important for police patrols to be unpredictable whilst maintaining a high level of police presence.
- Development and testing of crime prevention strategies take time. [11]
- Agent Based Modelling can help with the development of crime prevention strategies. [11]

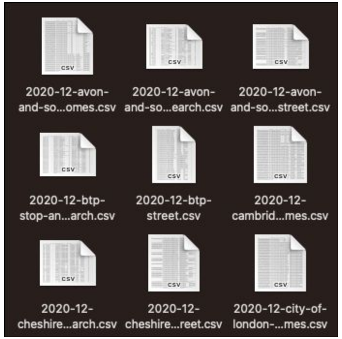
Aims and Objectives

- Create an environment that closely resembles real-world conditions.
- Apply a combination of Max-Min Ant System (MMAS) and Agent Based Modelling (ABM) to the Police Patrol Routing Problem
- Simulate the travelling time between crime hotspots
- Simulate the effects of patrol units patrolling asynchronously.
- The proposed algorithm should create police patrols that avoids repetition while maintaining a consistently high level of police presence for the City of London.

Design, Methods, and Implementation: Data Collection

- Crime Data: data.police.uk [13]
- Distances between hotspots: Google Distance Matrix API [14]
- Police Station addresses [17]
- Converting addresses to coordinates: Google Geocoding API [15]
- City of London Borough boundaries [16]

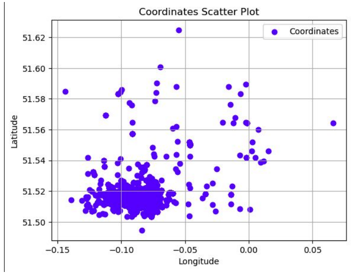




Design, Methods, and Implementation: Data Processing (1)

- Data filtering to isolate files for the City of London.
- Data filtering to extract only the latitude, longitude, and crime type headers for each crime data point.
- Each crime data point is assigned a “severity score” based on the type of crime committed.
- Data irregularities were found in the data.
  - Attempt was made to remove with z-score.
  - Irregularities were removed using the City of London boundary data. [16]
  - Boundary Data cross referenced with data from City of London Police Force. [18]

Crime Type	Score
Violence and sexual offences	5
Possession of weapons	4
Robbery	4
Burglary	3
Theft from the person	3
Criminal damage and arson	3
Drugs	2
Public order	2
Vehicle crime	2
Bicycle theft	2
Shoplifting	1
Other theft	1
Anti-social behaviour	1
Other crime	1



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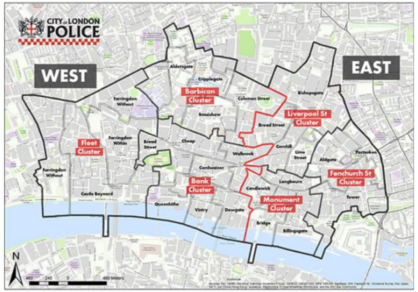

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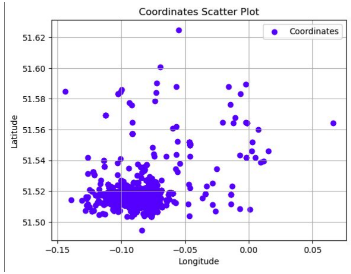


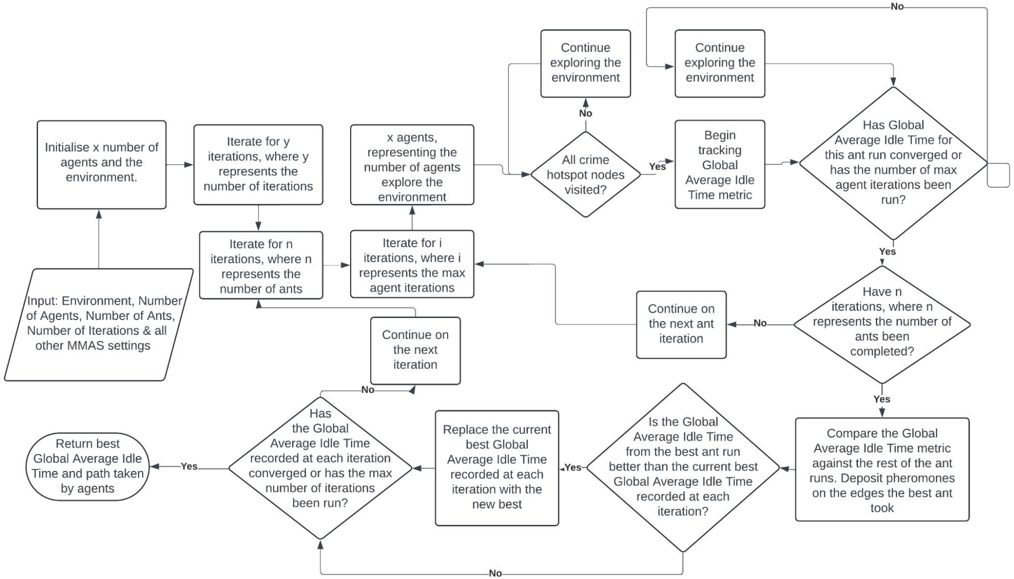
Design, Methods, and Implementation: Data Processing (2)

- The K-Means clustering algorithm is used to identify 200 clusters.
  - The clusters each have attributes:
    - Total Severity: representing the sum of the severity of each data point in the cluster
    - Data: representing the coordinates of each data point in the cluster
    - Centroid coordinates: representing the mean of all coordinates within the cluster.
  - The clusters are filtered using a threshold of 100 points to identify crime hotspots.
  - Data saved as CSV files.
- The distance between each crime hotspot is obtained using the Google Distance Matrix API. [14]
  - Due to request limits of 25 origin & destinations per request, the crime hotspot clusters have to be grouped into batches of 10 for the requests. [25]
  - Data saved as CSV files.

Design, Methods, and Implementation: Data Processing (3)

- The police station addresses are converted into coordinates using the Google Geocoding API. [15]
  - The distances between these stations and the crime hotspots are then calculated using the Google Distance Matrix API. [14]
  - Both the coordinates and the distances obtained are saved as CSV files.
- The environment is created using the data with the aid of the NetworkX library. [19]
  - A graph with nodes representing police stations & crime hotspots and edges representing the distances between them is created.

Design, Methods, and Implementation: Algorithm (1)



$$P_{\text{nextnode}} = \frac{\text{IT}_{\text{pnn}}^{\beta} \times \text{PL}_{\text{pnn}}^{\alpha}}{\sum_{i=1}^{n} \left(\text{IT}_i^{\beta} \times \text{PL}_i^{\alpha} \right)} \tag{4}$$

Where IT_{pnn} represents the "idle time" of a potential next node pnn, $^{\beta}$ represents beta, PL_{pnn} represents pheromone levels on the corresponding edge of the potential next node pnn, $^{\alpha}$ denotes alpha and n denotes the total number of hotspots excluding the police station nodes.

Parameter	Value
max_iterations	100
agent_max_iterations	10000
agent_min_iteration	1000
travel_speed	800
convergence_threshold	5

Parameters
num_ants
num_agents
evaporation_rate
alpha
beta
Q
tau_min
tau_max

Design, Methods, and Implementation: Algorithm (2)

- Metrics tracked:
  - Global Average Idle Time
  - Standard Deviation of each crime hotspot's idle time
  - Mean of each crime hotspot's idle time

The "idle time" of a crime hotspot ch_i at time t can be derived as:

$$\mathrm{IT}_{\mathrm{ch}_i} = t - t_{\mathrm{last\_visited}(\mathrm{ch}_i)} \tag{1}$$

where $\mathrm{IT}_{\mathrm{ch}_i}$ represents the "idle time" of a crime hotspot ch_i and $t_{\mathrm{last\_visited}(\mathrm{ch}_i)}$ represents the last time crime hotspot ch_i was visited by any police patrol unit.

The "average idle time" of hotspot ch_i is calculated as follows:

$$\mathrm{A\_IT}_{\mathrm{ch}_i} = \frac{\sum_{j=1}^{v} (t_j - t_{\mathrm{last\_visit\_before}}(t_j))}{v}$$

where $\mathrm{A\_IT}_{\mathrm{ch}_i}$ represents the "average idle time" of hotspot ch_i, v is the number of visits to hotspot ch_i, t_j represents the time of the j-th visit to hotspot ch_i, and $t_{\mathrm{last\text{-}visit\text{-}before}}(t_j)$ represents the time of the last visit to hotspot ch_i before time t_j. If j is the first visit ($j = 1$), then $t_{\mathrm{last\text{-}visit\text{-}before}}(t_1) = 0$.

The "global average idle time" of all hotspots is calculated as follows:

$$\mathrm{Global\_Average\_Idle\_Time} = \frac{\sum_{i=1}^{n} \mathrm{A\_IT}_{\mathrm{ch}_i}}{n} \tag{3}$$

where $\mathrm{A\_IT}_{\mathrm{ch}_i}$ represents the average idle time of hotspot ch_i, n is the total number of hotspots, and Global_Average_Idle_Time denotes the global idle time across all hotspots.

Design, Methods, and Implementation: Algorithm Challenges

- Challenges faced:
  - Resetting the environment, introducing pheromones on edges and tracking idle time are complex to implement on NetworkX graphs.
  - NetworkX can only creates one edge between two nodes. [20]
  - A period of low idle time before stabilisation. [21]
  - Paths taken by agents cannot be saved in a single CSV file cell. [22]
- Solutions:
  - Recreating the environment using Node & Edge classes.
  - Given that edges are given edge ids of (origin,destination), when searching for neighbouring edges to choose the next hotspot to visit, check both ways.
  - Track the idle time and number of visits only when all nodes have been visited once.
  - Split the agent path data into individual cells for each agent.

Evaluation

- Benchmark against an average of 5 runs for different number of agents.
    - Baseline method: Random Walk Algorithm
    - Ant Colony Optimisation (ACO) with ABM based off Chen et al's work. [27]

Design, Methods, and Implementation: Algorithm tuning

- Algorithm is tuned on a subset of the environment (20 Clusters)
  - Each parameter combination is ran 5 times and the average result is used for comparison.
  - Tuned for different number of agents, with 21 being the current real world scenario. [23]
  - Travel speed set to max allowable speed in the UK, 800m/min. [24]
- The ACO integrated with ABM implementation used for benchmarking is also tuned on a subset of the environment.

num_ants	evaporation_rate	alpha	beta	Q	tau_min	tau_max
10	0.1	1.0	1.0	0.1	0.1	1.0
30	0.3	2.0	2.0	0.5	0.5	5.0
50	0.5			1.0	1.0	10.0
70	0.7			1.5		
90	0.9			2.0		

Num of Agents
10
21
60
80

Parameter	Value
max_iterations	100
agent_max_iterations	10000
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50	0.5			1.0	1.0	10.0
70	0.7			1.5		
90	0.9			2.0		

Num of Agents
10
21
60
80

Parameter	Value
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agent_max_iterations	10000
agent_min_iteration	1000
travel_speed	800
convergence_threshold	5

Design, Methods, and Implementation: Algorithm tuning results

MMAS integrated with ABM:

Num of Agents	num_ants	evaporation_rate	alpha	beta	Q	tau_min	tau_max
10	30	0.3	2.0	2.0	0.1	0.1	10.0
21	90	0.3	2.0	2.0	0.1	0.1	10.0
60	70	0.1	2.0	2.0	0.1	0.1	10.0
80	10	0.1	1.0	1.0	0.1	0.1	1.0

ACO integrated with ABM:

Num of Agents	num_ants	evaporation_rate	alpha	beta	Q
10	70	0.5	2.0	2.0	2.0
21	90	0.9	1.0	1.0	0.5
60	10	0.1	1.0	1.0	0.1
80	10	0.1	1.0	1.0	0.1

Num of Agents
10
21
60
80

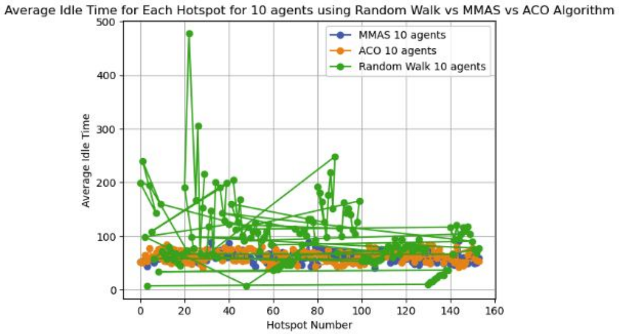
Parameter	Value
max_iterations	100
agent_max_iterations	10000
agent_min_iteration	1000
travel_speed	800
convergence_threshold	5

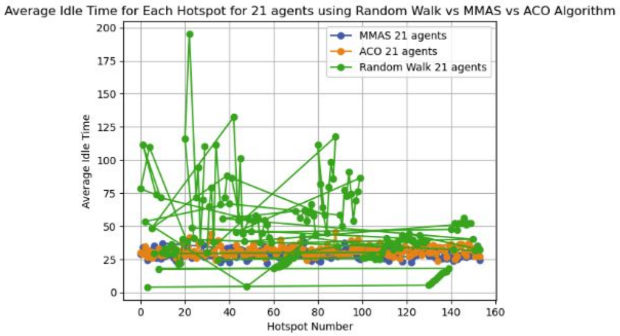
Results (1)

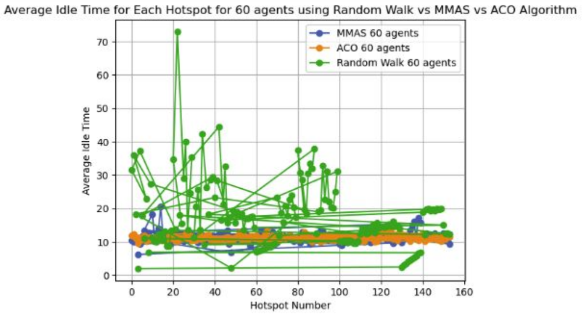
Global Average Idle Time in minutes:

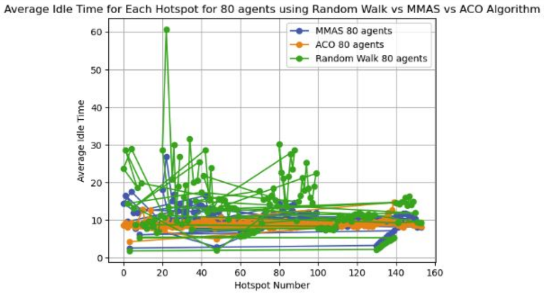
Agents	MMAS	ACO	Random Walk
10	62.05	63.29	100.77
21	29.89	31.47	48.68
60	11.39	11.24	17.62
80	9.98	9.02	13.47

Results (2): Average idle time for each hotspot

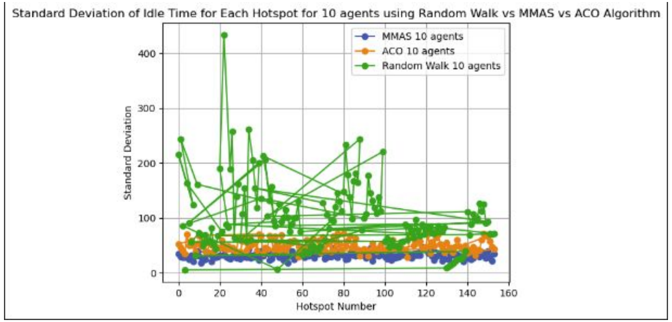


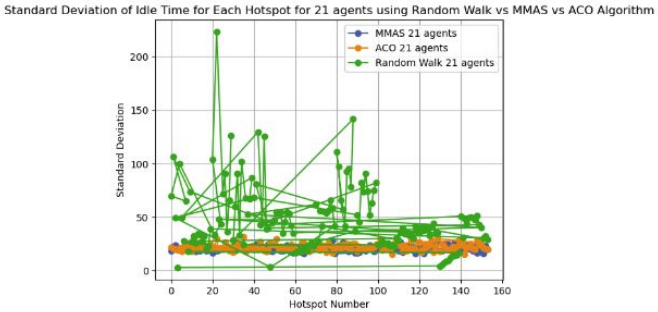


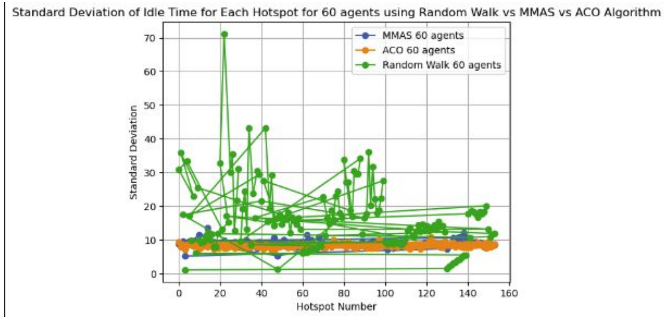


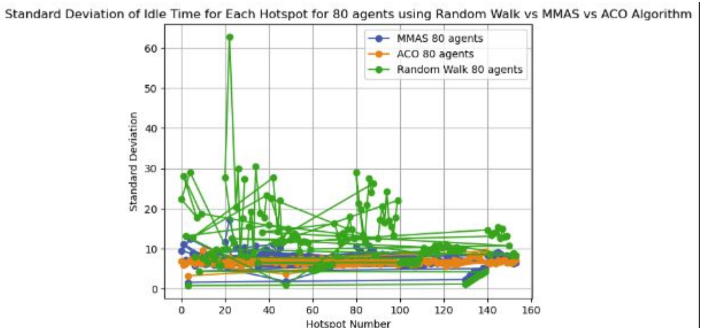


Results (3): Standard Deviation of idle time for each hotspot

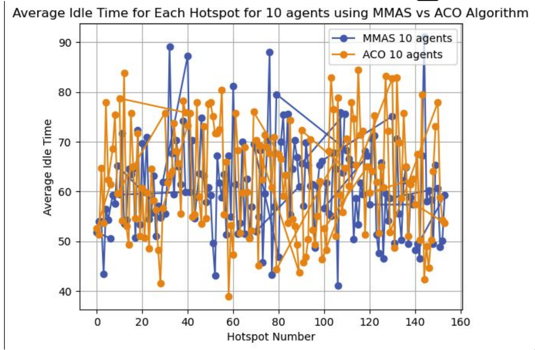


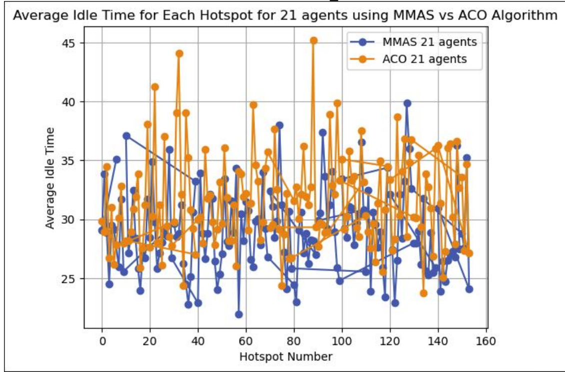


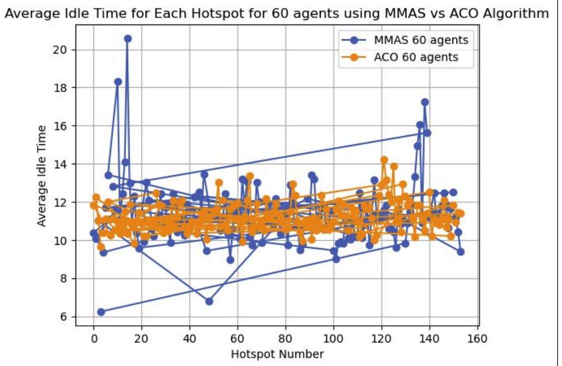


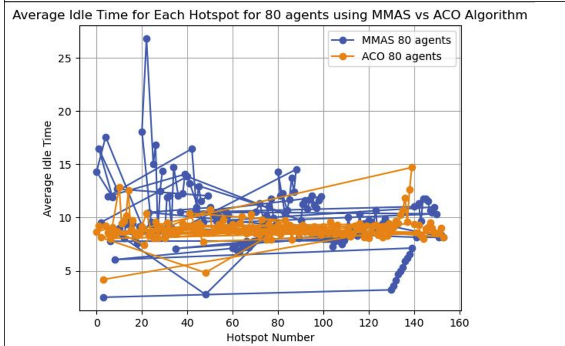


Results (4): Average idle time for each hotspot (ACO & MMAS)









Results (1)

Global Average Idle Time in minutes:

Agents	MMAS	ACO	Random Walk
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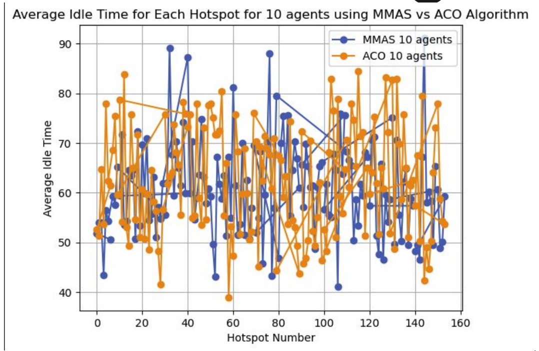
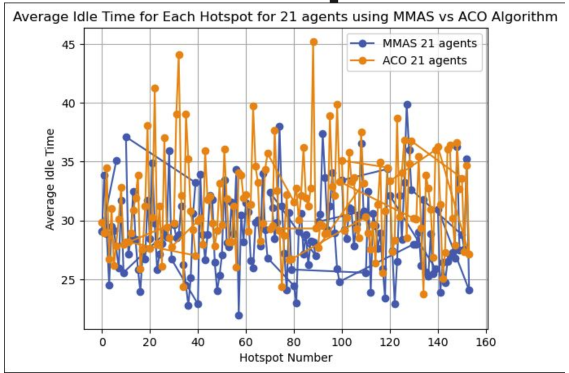
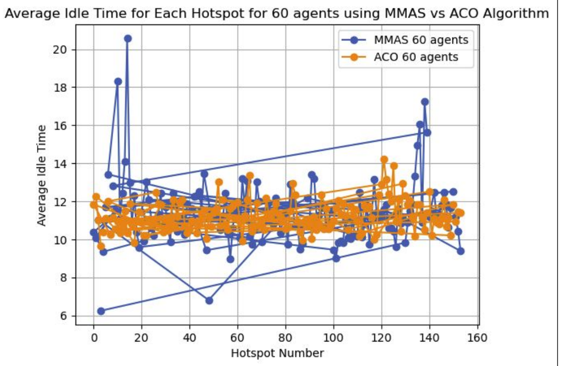
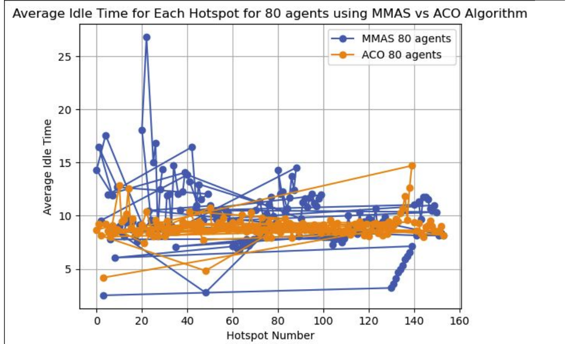
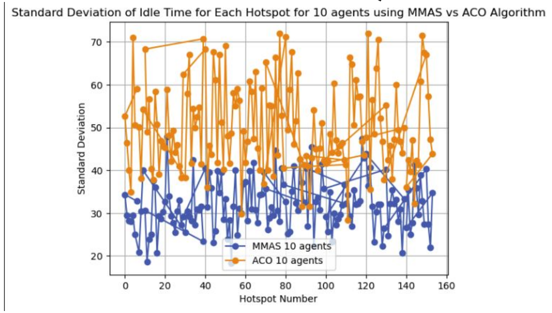


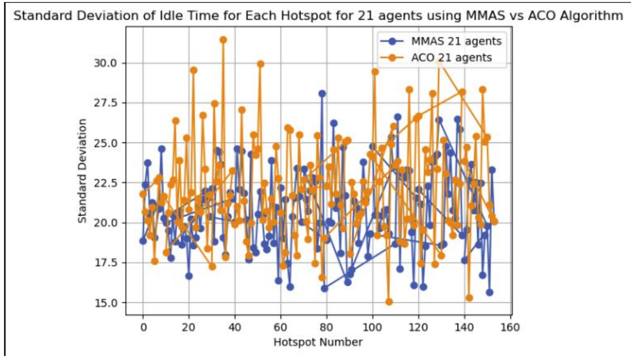


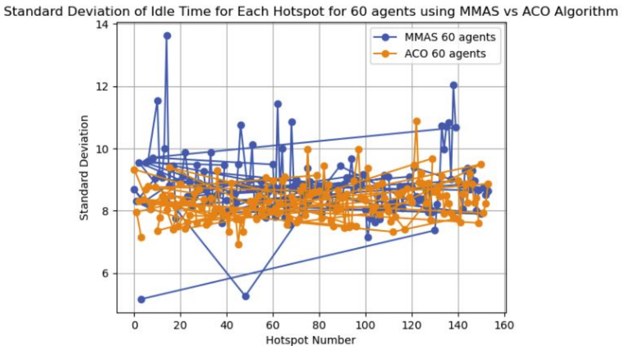


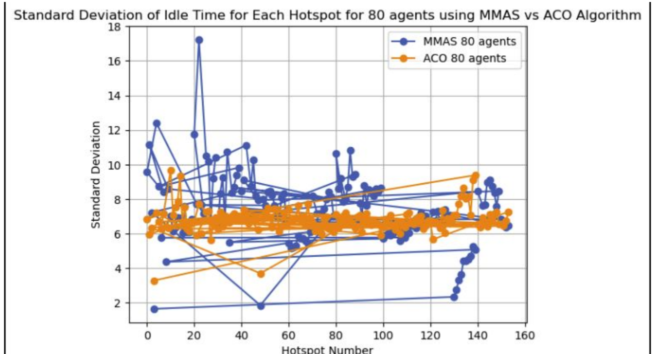


Results (5): Standard deviation of idle time for each hotspot (ACO & MMAS)

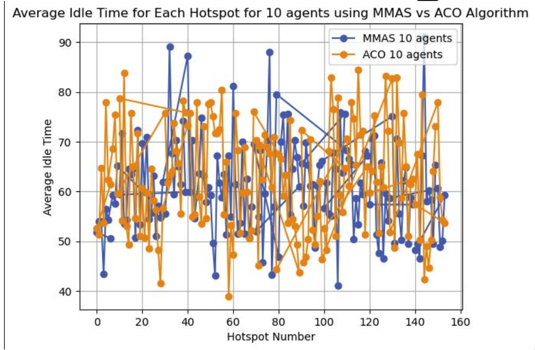


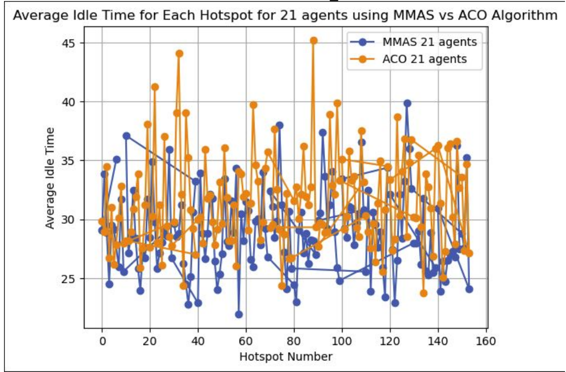


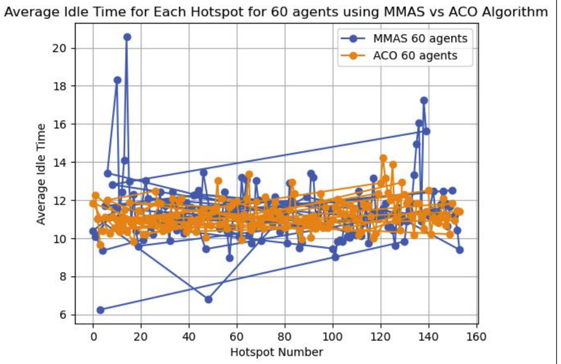


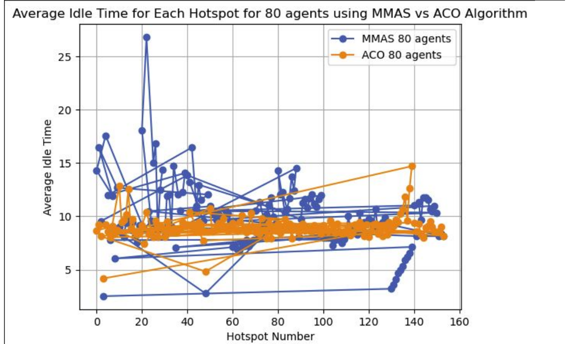


Results (4): Average idle time for each hotspot (ACO & MMAS)

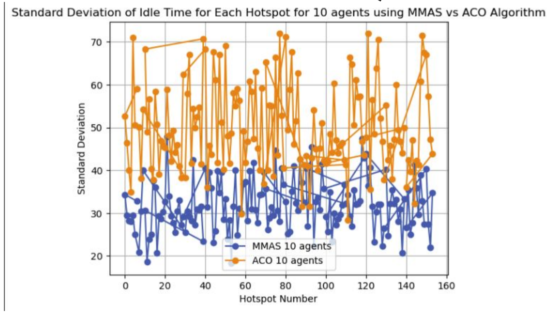


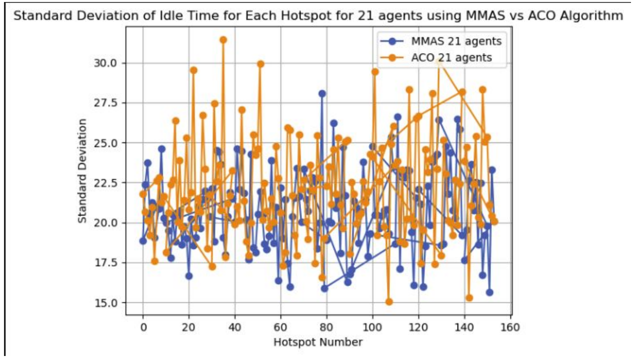


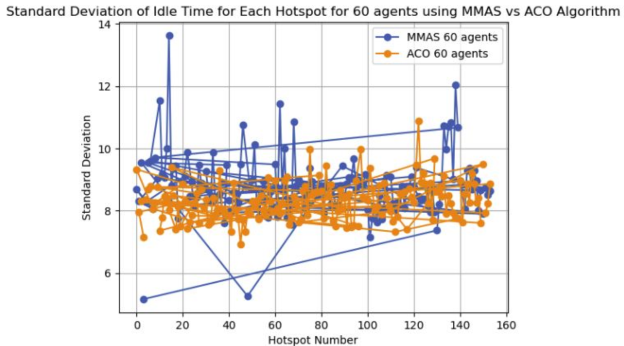


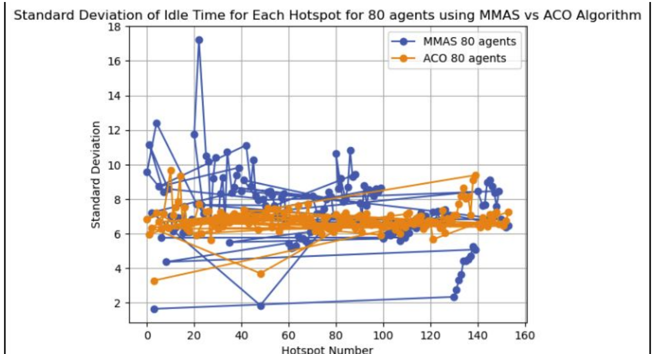


Results (5): Standard deviation of idle time for each hotspot (ACO & MMAS)









Code Demonstration

Conclusion: Project Outcomes

- All the aims for environment creation were met.
- All the aims for the algorithm were met.
- The results indicate that the proposed algorithm performs better than the random walk baseline and similar to the ACO variant.
    - The proposed algorithm is however, less stable and has frequent sharp spikes in standard deviation and hotspot “average idle time”

Conclusion: Limitations

- The simulation does not replicate the process of finding the shortest path between crime hotspots, rather it relies on the Google Distance Matrix API to find the shortest route between crime hotspots.
- Each hotspot is treated equally, rather than prioritising hotspots with more crime or severe crimes.

Conclusion: Future work

- Using data from Ordnance Survey (OS) to construct an environment that allows specific roads to be explored to find the best path between hotspots.
- Each hotspot will have a different rate of increase for their idle time corresponding to the total severity it has.
- Further studies into the cause of frequent spikes in the “average idle time” and standard deviation of idle time when using MMAS should be attempted.

References (1)

[1] Robin M. Blakely. “Community Issues in New York State: What’s Important?” In: Rural New York Minute, Cornell University Issue Number 7 (July 2007). (accessed: 05.03.2024).

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