ASSIGNMENT

AGENT NEGOTIATION TECHNIQUES FOR FORMATION FLYING

DEADLINE: NOVEMBER 15TH, 23:59

BACKGROUND

Over the past decades, formation flight has become a recognized method when considering possibilities to increase the fuel efficiency of civil aviation. Compared to other efficiency measures, such as innovative aircraft designs, formation flight requires little new technology, as implementing it would mainly be an operational change. Therefore, formation flight is an attractive potential efficiency measure, as it could be implemented by airlines without the requirement for new equipment and related investments. Xue and Hornby (2012) elaborated on grouping flights in formations in the national airspace system of the US. Considering formations up to four aircraft, they estimate that with respect to current flight plans around 600 million dollars per year can be saved on fuel.

CENTRALIZED AND DISTRIBUTED APPROACHES

Research centers around two approaches for finding formation flight partners: centralized and distributed. Centralized approaches provide solutions on a network level, indicating which flights could most beneficially be assigned to which formation. However, strong dependency on schedules as well as the computational requirements for larger problems are still limiting the potential of these methods. If the entire formation flight is planned beforehand and a fraction of the participants is delayed or otherwise unable to join, the planned routes and formations are no longer optimal. Centralized approaches do not offer a resolution for this situation.

Distributed approaches provide an en-route decision scheme designed for flexibility and en-route optimization. They provide robust solutions to form formations when schedule uncertainty is considered. However, it is very likely that the found optimum from such an approach is a local optimum and it may occur that some beneficial formation flight opportunities go by unnoticed.

BASIS MODEL

The master thesis on which this assignment is loosely based on uses a greedy algorithm and considers formation flight as an in-flight option. This way, formations are only formed when they are believed to be beneficial, based on actual in-flight data and actual flights being near the same location and ready (and willing) to cooperate. As soon as an option to save fuel is encountered by two (formations of) flights, the savings are secured by committing to the formation flight strategy (Verhagen, 2015).

In the base model used in this assignment, flights go from randomly generated origin airports to randomly generated destination airports. The origin airports are in the top left of the grid and the destination airports in the bottom right of the grid. The simulation determines the fuel savings using a distributed, greedy algorithm. In this model, all flights are always willing to cooperate with one another.

NEGOTIATION TECHNIQUES

In this assignment, we will use multiagent negotiation techniques with the aim to increase the fuel savings. The negotiation techniques that will be explored are the Contract Net Protocol (CNP) and the English, Vickrey and Japanese auction methods. Bidding is done in terms of kilograms of saved fuel. One of the functions provided in the basis model determines the total fuel savings from a potential formation. The contractor agent (in a CNP) or bidding agent (in an auction) decides on the fraction of the total fuel savings it is willing to offer to the manager agent (in a CNP) or auctioneer agent (in an auction).

In addition, a competitive environment is created in which a share of the flights are members of the alliance, while the remaining flights are independent. The goal of the alliance flights is to accomplish maximum fuel savings for the alliance. As a consequence, an alliance flight's willingness to cooperate with non-alliance flights might be lower than their willingness to cooperate with another alliance flight. Alliance flights can exchange any information among one another at all times.

A difference between the CNP and the auctions is that in the CNP a manager agent has the freedom to select the winning bid based on multiple factors, whereas in the auctions the winning bid is decided upon by the rules of the respective auction method. Furthermore, a manager agent in the CNP has the option to reject all bids, while an auctioneer agent has to abide by the auction's rules.

GOAL

The goal of this assignment is to model and analyze the concept of formation flying in a competitive environment by agent-based modelling and analysis of planning, negotiation, and de-commitment techniques.

DELIVERABLES

Each group is required to provide an archive containing both the simulation code (all files) and a report for this assignment. The part of the report for the group exercise should contain all the points highlighted in the '*IN THE REPORT*' sections of the different exercises provided below. The modeling and simulation results need to be presented as described in Lectures 2 and 3, and in document 'Presenting modeling and simulation results in the assignments' on Brightspace (Assignments section -> Support material).

SIMULATION SET-UP

The default code with the greedy algorithm consists of 15 files. Each file includes a header providing the information regarding its goal. Inline comments are provided for additional information. It is up to you to implement the different negotiation techniques in the correct files. The standard parameter settings are listed here. Every exercise will state the parameters that are to be changed.

<u>Airport and canvas parameters:</u>

1. *n_origin_airports = 20 [-].* Number of randomly generated origin airports.
2. *n_destination_airports = 20 [-].* Number of randomly generated destination airports.
3. percentageAlliance = 40 [%]. Percentage of aircraft in simulation that are part of the alliance.
4. *width = 750 [km]*. Width of the canvas.
5. *height = 750 [km]*. Height of the canvas.
6. Boundaries of randomly generated airports:

a. *origin_airport_x: [0.01, 0.3].*
b. *origin_airport_y: [0.01, 0.3].*
c. *destination_airport_x: [0.7, 0.99].*
d. *destination_airport_y: [0.7, 0.99].*

Flight parameters:

1. *n_flights = 50 [-].* Number of aircraft/flights.
2. *departure_window = 3 [s].*
3. *speed = 0.3 [km/s].* Speed of the aircraft.
4. *communication_range = 200 [km].* Range
5. *fuel_reduction = 0.75 [-].* When flying in formation, you use 75% of your original fuel consumption.
6. *negotiation_method = 0 [-].* Set which negotiation method to use
   (0: greedy algorithm, 1: CNP, 2: English, 3: Vickrey, 4: Japanese).

Simulation parameters:

1. *n_iterations* = 1 [-]. Number of simulation runs, used in the batch runner.

PREPARATION

Run the simulation using the default code, use *'run.py'* to visualize the simulation. Observe how the agents behave and how the system as a whole performs.

DISCUSSION POINTS:

Discuss in larger groups the following topics:

- Possible performance indicators that can be useful to measure the performance of the flights and the system.
- Your expectations and thoughts regarding emergent properties of the system.

EXERCISE 1 – CONTRACT NET PROTOCOL

The purpose of this exercise is to create a CNP that will allow aircraft to form formations. Flights can act as a manager agent or as a contractor agent in a CNP. Set the negotiation method (*negotiation_method*) to 1 (CNP).

At the moment, the manager and contractor/auctioneer roles are defined in the initialization of the flight agents, this is done so that the given functions would work. However, the definition of the roles should be changed, depending on what needs to be done in a specific exercise.

DISCUSSION POINTS:

Discuss in larger groups the following topics:

- What factors could a flight consider when making the decision to act as a manager?

- What information could a manager agent ask from potential contractor agents to provide in their bids?
- What factors could a potential contractor agent consider when forming their bid?
- What factors could a manager agent take into account when evaluating the bids received from potential contractor agents?
- In what ways could a formation make the above decisions?
- In what ways could fuel savings from future formations be distributed between the two flights of the current formation?

EXERCISE 1.1 – SET UP THE INITIAL MODEL

Set up the CNP negotiation method.

IN THE REPORT:

Clearly state:

- What are the different types of agents?
- What individual goals does each type of agent have?
- Explain how you implemented the CNP process.
- What steps does each type of agent go through in the CNP?
- What factors are considered at each of those steps?
- Between which agents is communication carried out?
- What information is shared among those agents?
- What information do you consider not to be openly available?

EXERCISE 1.2 – DEFINING PERFORMANCE INDICATORS

At this point, it should be possible to run simulations with the agents that you created for the CNP. But how would one know if these operations are efficient? Useful performance indicators are required in order to analyze the results of the CNP strategies.

DISCUSSION POINTS:

Discuss in larger groups the following topics:

- Which indicators are appropriate to measure the performance of the different types of agents?
- Which indicators are appropriate to measure the performance of the whole system?
- How could these indicators be implemented?

IN THE REPORT:

- Define the performance indicators chosen and explain how they are used to evaluate the model.

EXERCISE 1.3 – DETERMINE FORMATION JOINING AND LEAVING POINT

In the model, some methods are very basic. For example, when analyzing the behavior of the model one can see that the determination of the formation joining and leaving point is not optimal.

In this exercise, improve how the formation joining and leaving points are determined in the model. For this, you may consider the identified performance indicators, and consult related documents on Brightspace (in Assignment -> Support material).

DISCUSSION POINTS:

Discuss in larger groups the following topics:

- How can the joining and leaving points be better defined?
- How could these changes be implemented?

IN THE REPORT:

- Explain how the joining and leaving points are determined.
- Explain how these new definitions improved the model.

Simulate as many runs as necessary to obtain accurate results, and argue why you have chosen this number of simulations.

EXERCISE 1.4 – MODEL EVALUATION & EXPERIMENTS

Analyze the behavior of the model, the identified performance indicators, and emergent properties by sensitivity analysis. Simulate as many results as you deem necessary to obtain accurate results, and argue why you have chosen this number of simulations.

From now on the improved model from Exercise 1.3 will be used.

EXERCISE 1.4.1 – COMPARISON WITH THE GREEDY ALGORITHM

Set the negotiation technique (*negotiation_method*) to 0 (greedy) and subsequently to 1 (CNP). Use the performance indicators from Exercise 1.2, determine if the CNP has improved the system performance.

IN THE REPORT:

- Analyze and explain the improvements (and/or deterioration) of the performance of the system.

EXERCISE 1.4.2 – VARY THE COMMUNICATION RANGE

Vary the communication range of each aircraft (*communication_range*) as 50 km, 200 km, 500 km.

IN THE REPORT:

- Examine the effect of the communication range in terms of the performance of the individual agents and the overall system.

- Propose changes for all agents that would improve their respective performance when the communication range varies from 200 km to 50 km, and from 200 km to 500 km. Note that it is not necessary to implement these changes.

EXERCISE 1.4.3 – VARY THE ORIGIN- & DESTINATION AIRPORTS

Vary the positions of the origin- and destination-airports. Use the following ranges:

	Origin airport		**Destination airport**	
	(x_min, y_min)	(x_max, y_max)	(x_min, y_min)	(x_max, y_max)
1	(0, 0)	(0.1, 0.1)	(0.9, 0.9)	(1.0, 1.0)
2	(0, 0)	(0.2, 0.2)	(0.8, 0.8)	(1.0, 1.0)
3	(0, 0)	(0.3, 0.3)	(0.7, 0.7)	(1.0, 1.0)

IN THE REPORT:

- Examine the effect of the communication range in terms of the performance of the individual agents and the overall system.
- Propose changes for the flights that would improve their respective performance when the airport locations change. Note that it is not necessary to implement these changes.

EXERCISE 1.5 – DE-COMMITMENT

This is a theoretical exercise. Code implementation is only required for the bonus exercise described below.

It may occur that a flight, currently in formation, encounters another flight with which forming a formation would yield higher fuel savings. It may also happen that a destination airport closes and all flights destined for that airport are redirected to the nearest airport. As a result of such events, a flight may decide to de-commit from the formation it is currently part of in favor of another one. One way in which flights can protect themselves against de-commitment from other flights is through de-commitment penalties. These penalties can compensate the disadvantaged flight for the time and fuel spent flying to the joining point, and for missing out on fuel savings due to the formation being cancelled. Additionally, it may function as a deterrent from de-commitment.

DISCUSSION POINTS:

Discuss in larger groups the following topics:

- What factors could a potential contract agent consider when deciding upon the value of the de-commitment penalty in their bid?
- What factors could a manager agent take into account when evaluating the de-commitment penalty in bids?
- What factors could an agent consider when making the decision to de-commit or not?
- With de-commitment included, which additional indicators are appropriate to measure the performance of the model?
- What would the effect be of a fixed de-commitment penalty of 100% of the fuel savings bid? What if the de-commitment penalty would be 10%?

Develop a de-commitment strategy for the flights such that they are able to leave a formation. Adjust the agent models in order to be able to include the de-commitment penalty in their bid as a potential contractor agent, and to evaluate the de-commitment penalty in bids as a manager agent. Present the agent-based model descriptions in a mix of informal, semi-formal, and algorithmic format. Code implementation is not required.

IN THE REPORT:

- Explain how the value of the de-commitment penalty is decided upon by a potential contractor agent.
- Explain how the de-commitment penalty is evaluated as part of the bid by a manager agent.
- Explain how an agent makes the decision to de-commit from a formation or not.
- Define the new performance indicators chosen and explain how they would be used to evaluate the model.
- Predict how the performance of the system will improve and/or deteriorate.

Bonus exercise (+ 1 point): implement and evaluate your de-commitment algorithm.

EXERCISE 2 – AUCTIONS

The purpose of this exercise is to use auctions that will allow aircraft to form formations. The auctions considered are the English, Vickrey and Japanese auction methods. The purpose of this exercise is to compare the performance of the system for the different auction methods. Set the negotiation technique (*negotiation_method*) to 3-5 (English, Vickrey, Japanese).

DISCUSSION POINTS:

Discuss in larger groups the following topics:

- What factors could a flight consider when making the decision to act as an auctioneer?
- What factors could a potential bidding agent consider when making the decision to reply to the auctioneer agent with a bid?
- What factors could a bidding agent consider in its bidding strategy?
- In what ways could a formation make the above decisions? The two flights might not have the same goals.
- Which indicators are appropriate to measure the performance of the flights, and the system for the five auction methods?
- How could these indicators be implemented?

Carry out the necessary number of simulation runs for each auction method. Use the relevant performance indicators from Exercise 1.2, and the newly identified ones in this exercise, to compare the performance of flights and the system for the three auction methods.

IN THE REPORT:

Clearly state:

- What are the different types of agents in each auction method?
- Explain how you implemented the auction methods.
- What steps does each type of agent go through in the different auction methods?
- What factors are considered at each of those steps?
- Between which agents is communication carried out?
- What information is shared among those agents?
- What information do you consider not to be openly available?
- Explain the strategy used for deciding to be an auctioneer in each auction method.
- Explain the bidding strategy used in each auction method.
- Define the new performance indicators chosen and explain how they are used to evaluate the model.
- Analyze and explain the differences in the system for the different auction methods.

APPENDIX – CODE EXPLANATION

This section explains the operational concept of the default code, as well as the general code structure.

A. OPERATIONAL CONCEPT

A flight is defined by a unique ID, an origin, a destination, and is randomly assigned to an airport. The flights are defined as agents, which are Mesa objects. Furthermore, a departure time is specified, which is a random time within the *departure_window* (chosen uniformly).

At each step of the flight, an agent can opt to start its negotiation algorithm. The following methods are already included in the model and are at your disposal for creating your negotiation functions. Also, you are allowed to change any function as you like, as long as you clearly explain why and how you have done this in your report. When in doubt, use Monday's practical sessions or MS Teams to discuss this. The workings of all the functions is extensively documented in the comments in the code.

- Add_to_formation
- Start_formation
- Find_bidding_candidate
- Calc_middle_point
- Distance_to_destination
- Is_destination_open
- Calc_speed_to_joining_point
- Find_new_destination
- Make_bid
- Do_move
- do_CNP

Each step of the model, all agents are called upon twice by the model. First, their "step" functions are called, in which the negotiations are performed. Subsequently, their "advance" function is called, in which the flight actually moves. This two-staged approach avoids agents moving before all negotiations are finished.

B. CODE STRUCTURE

The code contains 15 files which are divided over three levels. The first level contains the files to run the model. Then in the second level, in the file 'Formation Flying', one can find the files that create and visualize the model. On the third level there are on the hand the agent definition in the 'Agents' file. On the other hand, there are the files that define the negotiation methods in the 'Negotiation' file.

- *run.py*
- *batchrunner.py*
- File - Formation Flying:
    - *model.py*
    - *parameters.py*
    - *metrics.py*
    - *server.py*
    - *simplecontinuousmodule.py*
    - *simple_continuous_canvas.js*
    - File - Agents:
        - *flight.py*
        - *airports.py*
    - File - Negotiations:
        - *greedy.py*
        - *CNP.py*
        - *english.py*
        - *vickrey.py*
        - *japanese.py*

B.1 – RUNNING THE MODEL

RUN.PY

Run the model and get a visual simulation run on the server. This can be a bit slow, but is very useful while coding to see what happens.

BATCHRUNNER.PY

Run the model without visualization. This is much quicker and can be used to produce and analyze results.

B.2 – CREATING THE MODEL

MODEL.PY (ALL EXERCISES)

Here the actual model is defined, it considers agent creation, placement and scheduling.

Defines the model class: 'FormationFlying',
which includes the following unique functions: make_agents, make_airports.

PARAMETERS.PY (ALL EXERCISES)

In this file, one can change the parameters as stated by the exercises. Clarifications of the model parameters can be found in this document in 'Simulation Set Up' or in the script itself.

METRICS.PY (ALL EXERCISES)

The DataCollector module calls basic pre-defined functions to calculate and store simple data statistics and metrics. You can define more sophisticated data analysis functions and metrics for your exercises.

B.3 – VISUALIZE THE MODEL

SERVER.PY (EXERCISE 1.2 & 2)

Run the model and get a visual simulation run on the server. If additional charts are needed, or to change variable parameters of the server, this file needs to be modified.

Includes the function: 'boid_draw'.

SIMPLECONTINUOUSMODULE.PY (OWN CHOICE)

This file contains the drawing of the canvas for the visualization. It uses 'simple_continuous_canvas.js' .

Defines the class: 'SimpleCanvas', which includes the 'render' function.

SIMPLE_CONTINUOUS_CANVAS.JS

This is a standard java script which can be used when creating a simple and continuous canvas. Nothing needs to be changed in this script.

B.4 – AGENTS IN THE MODEL

AIRPORTS.PY

Here the airport agents are defined. The airports are randomly positioned within a specified part of the model.

Defines the agent class: 'Airport'.

FLIGHTS.PY (EXERCISE 1.3 & 1.5 (bonus))

In this file, the Flight-styleagent is defined. Flights have a communication_range that defines the radius in which they look for their neighbors to negotiate with. They negotiate to form a formation to save their fuel.

The defined negotiation methods will be used here. In this file, the implementation of Exercise 1.3 can be performed.

Defines the agent class: 'Flight', which includes the following unique functions: calc_distance, calculate_potential_fuelsavings, add_to_formation, start_formation, find_bidding_candidate, make_bid, find_new_destination, calc_middle_point, distance_to_destination, do_move, is_destination_open, calc_speed_to_joining_point

B.5 – NEGOTIATIONS METHODS

Different negotiation methods can be implemented. In the parameter file, one can set 'negotiation_method' which defines which method will be used. The base model only includes the greedy algorithm.

GREEDY.PY

In the greedy algorithm, an agent accepts any bid which improves its fuelsavings.

CNP.PY (EXERCISE 1.4)

Add own CNP function.

ENGLISH.PY (EXERCISE 2)

Add own English function.

VICKREY.PY (EXERCISE 2)

Add own Vickrey function.

JAPANESE.PY (EXERCISE 2)

Add own Japanese function.

C. SUGGESTED TIMELINE

In the table below a timeline is suggested for finishing the assignment, this is not binding. We suggest to not wait with writing the report until the last week, as you work in pairs some work can be done in parallel.

Suggested deadline	Exercises:
29 Sept	1.1 - set up an initial model for CNP 1.2 - define PIs
4 Oct	1.3 - define joining and leaving
11 Oct	1.4 - sensitivity analysis 1.5 - decommitment
8 Nov	2 - auctions (3x)

REFERENCES

Xue, M., &. Hornby, G. (2012). An analysis of the potential savings from using formation flight in the NAS. *AIAA Guidance, Navigation, and Control Conference*, 1-12.

Verhagen, C.M.A. (2015). *Formation flight in civil aviation* (Master's thesis). Retrieved from https://repository.tudelft.nl/view/ir/uuid:44cc6034-e974-4306-a540-9195a48322f8?