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Simulation of a logistic system with Netlogo

Investigation of the performance of distribution of packages by drones compared to the standard delivery way by truck

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4 Introduction

The internationalisation of the economy is today more developed than it was ever before in the human history. The performance of an economy of a country really belongs to the level of international relations, often international commerce is even more important for than the national one. Particularly the impact of the international merchandise traffic is grown rapidly in the last twenty years and is actually one of the most complex systems in the world. Last year china has transferred for the first time goods valued at more than four trillion dollars (1). With the phenomenon of the globalisation many national companies became international players who are acting in an international net of producers, suppliers and costumers. The example of china, but also the development of other regions in Asia like India or the Asean[1] states like Singapore, Malaysia or Thailand have shown how much a national economy is able to benefit of this internationalisation and how much a worldwide selling of products throttle the economic rise of a country.

The development of the international commerce based on several facts. For producing firms it is very important to dispose of a good working distribution network. The performance of the logistic network could decide about the success of a firm. Every step during the production depends on the efficiency of the supply system, particularly the delivery of the costumers. In this last sector of the production chain there are always researches about alternative and new ways to improve the performance level.

One of the newest ideas is to realize the supply by the distribution of packages by drones instead of by trucks. Firms like ***Amazon*** (2) or the German enterprise ***Deutsche Post*** (3) investigate actually the practicability of such a distribution of their packages. The firms are actually in the stage of the development and investigate questions like ‘How it is possible to realize a save supplying by drone?’ or ‘What kind of drone is useful for this idea?’. The corporate **Amazon** hopes to be able to guarantee a supply thirty minutes after the time of order. Before this scenario could be realized across the board several problems have to be solved.

Figure 1: Amazon Pime Air (15)

The following work is a small part of the investigation to analysis the potential of the distribution by drones compared to the performance of the supplying system by trucks. The simulation should show in general which parameters are important and where the advantages or disadvantages are findable. First a small introduction into the topic is given, as well a briefly introduction in the programming languages *Netlogo* and *Python*. In the following parts the main elements of the model are described and explained. In the end you will find the results of simulations and an interpretation of validity.

[1] Asean = Association of Southeast Asian Nations (8)

5 A new age of transport systems?

The international connections and conjunctions are characterised by different dimensions (political, cultural or economical) and depend on a lot of influencing factors. One of these factors is the international transport system and logistic management. In the past different developments have influenced the structure of the logistic systems in the world. Some inventions have revolutionised the supply chain basically. These include among others the inventions of transport systems on the road (tucks), the international commerce by airplane and the utilization of containers for transporting by ship. All these modes of transport are subject of a good level of infrastructure. It is possible to distinguish between the **unphysical** and the **physical** infrastructure. The unphysical infrastructure termed for example the extension of the information technology accompanied by broadband internet connection etc. The physical infrastructure describes the 'classic' comprehension of infrastructure. It termed the expansion of roads, railways, airports, etc. There are several theories which say that an economy can be only as strong as the logistic and transport system of the country. During the whole life circle of a product the transport system is an important part to connect the several stations, like the transport from the natural resource to the factory and production place , from the factory to the large distribution centres, from there to the smaller distribution centres, than to the several shops or directly to the costumers. Even after the consumption is the transport system important to recollect the rubbish/ material to use it as a new resource at the beginning of a new life cycle. Especially the step to supply the costumers with the products is very important for the companies. A good working supplying system could be a great advantage of a company and could decide about the survival or bankruptcy of the firm. That is the reason because the logistic companies always look for new methods and ways to improve the system - means to upgrade the transport security, accelerate the transport or to satisfy to costumer request.

Figure 2: Lifecycle of product **(4)**

5.1 Transport by drones

The idea of this simulation is based on a project of ***Amazon***, called ***'Amazon Prime Air'***(2). The project investigates the possibilities to revolutionise the package distribution by sending the packages by drones. The aim is to deliver the costumer in thirty minutes. Also the German corporate 'Deutsche Post' thinks about this new way of sending. The advantages are obviously. The drone is not addicted to the actual traffic situation on the roads. It is able to fly automatically without human resources. In the whole supply system it would be possible to reduce the employment of human and to save a lot of money in this way. To supply the costumers in thirty minutes could be a great competitive advantage and makes the corporate more interesting for the costumers. In addition to these benefits there are some disadvantages respectively some points for research. Actually the range of a drone restricts the field of application. Depending on the weight of the package a drone is limited in the distance. Another question is the security question. How is it possible that the drones do not crash into each other or in another object? It has to be saved that in no way any humans are injured. Special landing places have to be signed to guarantee that nobody is hidden by a landing drone. Also the political and legal formalities have to be discussed. Actually the Federal Aviation Administration (FAA) in the United States of America has forbidden this transport way fort he moment and wants to ask the publicity about their opinion (5).

In addition also the technical side of this project is still part of several investigations. Actually the drones are able to carry a package of 2.5 kg. With such a charge they are able to move sixteen kilometres (6). These facts are not enough to realize a comprehensive distribution over a city like Turin with only one distribution centre. Either several distribution centres have to be built or the performance capability of the drones has to be improved.

Also other companies think about this way of transport. The German corporate '**Deutsche Post**' has realized in December 2013 the first successful flight and supply with a drone. Over a distance of two km the drone carried a package of one kg and reached the aim automatically (7). The drone was much faster than the transport by car. The company uses drones from type ***Quadcopter*** of the type ***MD4-1000*** (8)***,*** (9).

Figure 3: Drone of **‚Deutsche Post - DHL' (10)**

6 Netlogo and Python

This chapter should give the reader a very short introduction in the two programming languages which are used in this work. It is not the intense of this chapter to explain the languages but to give the main idea why they are used in this work. The simulation is realized with ***Netlogo*** (chapter **6.1 Netlogo**), for the evaluation and plotting the ***Python*** (chapter **6.2 Python**) library ***matplotlib*** is used. In the following you will find some several information's about these languages and some advices where you can find some more details.

6.1 Netlogo

Netlogo is an agent-based programming language witch contents an integrated modelling environment. It initially appeared 1999; today the version 5.0.5 is the actual version. ***Netlogo*** is very decent to modulate and simulate complex systems over a time period. More information's are available at ***http://ccl.northwestern.edu/netlogo/.*** It basically contents an interface area for creating a user interface with buttons, sliders and monitors and a '*code'* area for implementing the different functions of the interface elements. In chapter **7.4 The user interface** you will find an explanation of the interface of this simulation (11).

For the following **7 The model** it is necessary to understand to basic ***Netlogo*** terms: 1) **turtles** 2) **breeds**. **Turtle** is the name in ***Netlogo*** for the mobile agents and represent the basic 'class' of agents in this programming language. They are normally not presented like a real turtle (different shapes are possible). **Breeds** is a designation for a set of similar –behaviour agents, for example 'drones'. You have to define them at the beginning of the code.

6.2 Python

Python is an objective orientated programming language first published in 1991 by the *Python Software Foundation*. Actually the newest Version is 3.4.1, but in general the version 2.7.7 is used (12), (13). It is one of the most powerful programming languages, which contents several different libraries and packages for every topic. You can find more information about Python online at https://www.python.org/.

One of those libraries is the package **'matplotlib'**. This is a plotting library for Python with a very similar structure like **MATLAB**[2]. In this work **matplotlib** is used to evaluate the simulation results of **Netlogo** and to create some of the here presented plots. More information's are available at http://matplotlib.org.

For this work a small script in python is written to read the output files of **Netlogo**, to edit the data and to create the plots. The following chapter explains this script in a short way.

6.3 The python analyse and plotting script

The **Netlogo** code of this work contents to different methods to save data from the **Netlogo** simulation. On the one hand the integrated 'export' - functions of **Netlogo** are used, for example *export-world* or *export-output*. These exports create CSV - files and save them under a by the user given file path. The other method creates individual txt - files. The data is also separated by semicolons. An implemented python script opens these files (***def openFile(path)***), reads the content

[2] More information you will find at: http://www.mathworks.it/products/matlab/

and edit the content for plotting (**def readFile_NumberOfOrders(openedFile)**). The plots are realized with code based on the ***matplotlib*** library. The following part shows just a small part of these analyse script to give a you an idea about the structure. The function 'plot_NumberOfOrders' is used in chapter 9 **The Analysis of the simulation results.**

```
def openFile(path):
    data = []
    file = open(path, 'r')
    return file

def plot_NumberOfOrders(time, datatruck, datadrones):

    fig = plt.figure(facecolor='w')
    ax = fig.add_subplot(111)
    p1 = ax.plot(time, datatruck, label = 'Number of truck orders')
    p2 = ax.plot(time, datadrones, label = 'Number of truck orders')
    ax.set_ylim(0, max(max(truck), max(drones))+1)

    plt.xlabel('time')
    plt.ylabel('number')
    plt.title('Number of orders')

    plt.legend()
    plt.show()
```

For the online version of the **Netlogo** code these functions are not available.

7 The model

There are different ways to create an agent based model to simulate a real world problem. The most important part is to identify the important agents/ actors in the world and to implement their characteristic behaviour and functions. These functions should be able to reproduce the actor behaviour in a sufficient way. It is not possible and also not necessary to implement every kind of behaviour or attribute. Often you have to abstract - means you have to decide which attribute or method is relevant for the model and how detailed the implementation should be. The following part introduce into the created model. It describes the ***Netlogo*** 'world', the user interface (see chapter **7.4 The user interface**) and the different breeds of the turtles (see chapter **7.3 The actors of the simulation**). You will find an explanation about the implemented functions of the turtles and about these parts of the real world, which are not essential for this simulation. At the end of this section you should understand why it is possible to skip some attributes and why others are essential for this work.

7.1 The process to create a model

For a simulation model it is important to identify the necessary aspects of the real world problem as a base of the simulation. The process to implement such a model can be structured in several phases. At first you have to formulate the problem. You should define the aim of the simulation and a suggestion of the results. After this you have to analysis the problem in the real world. You have to find all important aspects and facts which can modify your model. This should be formulated in a text to use it as a benchmark at the end of the modelling. Based on this you create the mathematic model, means you implement all the agents and functions. At the end you should test and validate your model. The following explanations are the results of the implementation based on this guideline.

7.2 The simulation environment – the Netlogo 'world'

In ***Netlogo*** '*the world*' is the environment where the turtles or the different breeds 'live'/ act. It is possible to create your world corresponding to the real world environment. For the current model the world should represent a network of roads and buildings for the costumers. The Figure 4 shows the street grid. The white coloured patches present normal roads, the black coloured ones denote buildings. Every intersection is coloured red to demonstrate that these are parts of roads with a special meaning for the cars and the truck. The roads are only straight, curves are not implemented. That normally is not equivalent with the structure of a real city, but fortunately this used arrangement fits in a good way to the road structure of Turin. The Figure 4 shows the structure of the world without any breeds, only the patches are modified.

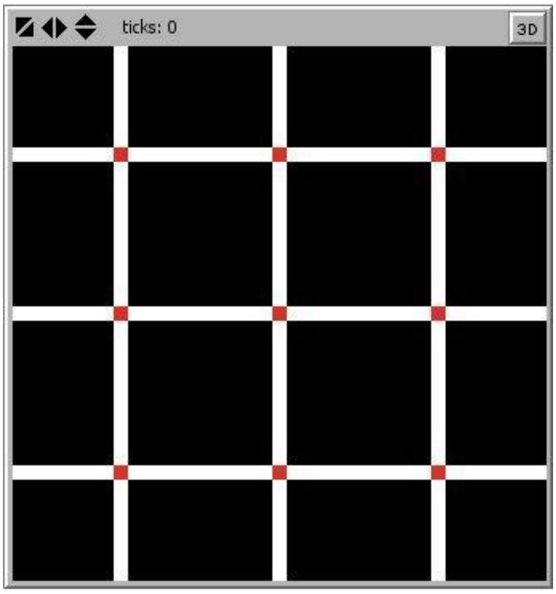

Figure 4: The empty world with the street grid and the red intersections

The World is not restricted, so for example the turtles are able to move across the right border and appear directly at the left border. This fact is not realistic as well, but simplified the modulation of the traffic in this case.

Among the different patches the environment contents three different breeds of turtles, the distribution centre (name: **distributionCenter**), the demand positions (name: **demandPositions**) and the costumers (name **costumers**). Those breeds are explained in the following chapter. The **Figure 5: The 'world' of this simulation with two hundred cars, one hundred costumers, one truck, six drones and twenty four demand centres** shows the 'world' after pressing the setup button.

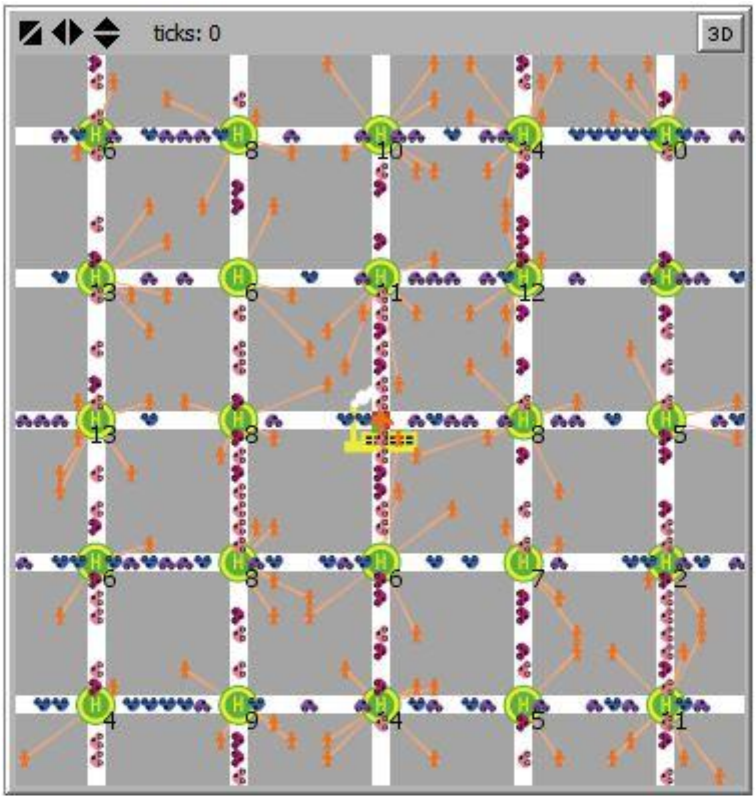

Figure 5: The 'world' of this simulation with two hundred cars, one hundred costumers, one truck, six drones and twenty four demand centres

7.3 The actors of the simulation

The model contents the different types of breeds - one the one hand the breeds which are not able to move and which are a part of the world modulation, on the other hand the moving turtles, which are the heart of the simulation.

7.3.1 The fixed actors

This model contents three different actors, in ***Netlogo*** called breeds of not moving turtles:

- the distribution centre (name: **distributionCenter**)
- the demand centres (name: **demandPositions**)
- the costumers (name **costumers**)

Those are explained in the following chapters.

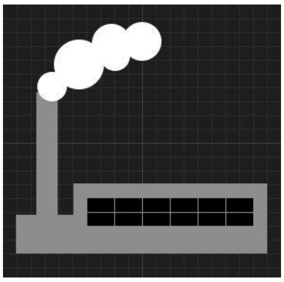

Figure 6: The distribution centre

7.3.1.1 The distribution centre

The distribution centre is always localized in the centre of the world and pictured by the **Netlogo** shape *'factory'*. It presents the starting point for the drones and the truck and should symbolise the logistic centre of the city. It is the start and ending point of the simulation. The drones return to this point after the have completed their current mission to take here a new mission. The truck is be loaded at this point and only returns when he has finished all missions - means when it is empty. The simulation will stop automatically when all packages are distributed and all vehicles are returned to the distribution centre.

The distribution centre has only one variable 'packagesTrucks', which is necessary for the initial loading of the truck at the start of the simulation.

7.3.1.2 The demand centres

Figure 7: The demand centres

The demand centres represent the places to unload the drones respectively the truck. You can take them as central ***packstations***[3], like that already exist today in Germany. In this code these centres are always located at an intersection and collect the demands of the surrounding costumers. The costumers choose the nearest demand centre for their order. In the code you find the demand centres under the name ***demandPoints***. They have three different variables.

- ***orders:*** number of all demands of all costumers which have chosen this demand centre for their order
- ***ordersTrucks:*** number of remaining orders supplied by truck
- ***ordersDrones:*** number of remaining orders supplied by drones

7.3.1.3 The costumers

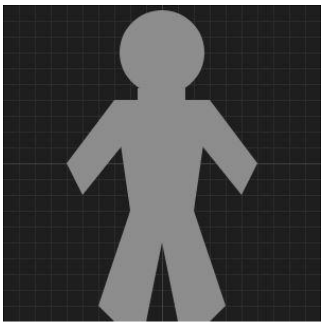

Figure 8: The costumers

The costumers are depicted by the **Netlogo** shape 'person'. Every costumer has the variable 'NumberOfCostumerOrders' which is default number from one to three. In this way it is possible to simulate that one costumer has more than one order. The costumers can not move. During the setup process they are spreaded randomly over the building patches which a random number of orders. With the function 'findNearestDemandStation' each costumer chooses his demand centre which corresponds with the nearest one. A link to the chosen demand centre is created to give the user a better visualisation. This way is the best one to describe the reality. Also in real life the costumer would choose the place where he goes to get his package. In this case he always chooses the nearest one, which will be confirmed with the most cases in the reality.

[3] See Packstations in Germany at: http://www.dhl.de/de/paket/pakete-empfangen/packstation.html

7.3.2 The moving actors

The most important actors/ breeds in this simulation are the moveable breeds. The following breeds are described in the next sections:

- the cars
- the drones
- the truck

7.3.2.1 The cars

The cars are implemented to simulate the traffic on the roads and the make the distribution of the packages by truck more realistic. The cars only can move in one direction. The direction depends on their orientation, which is chosen randomly. The current orientation is saved in the variable '**orientation**. The following table gives an overview about the possible directions.

heading	orientation / moving from to
0	from south to north
90	from west to east
180	from north to south
270	from east to west

Table 1: Orientation of the breed cars

The cars are only able to move on the white coloured patches presenting the roads. They are not able to bend at the intersections, but the have to wait at the intersection until the next patch in front of them is a free patch.

The other variable is called '**speed_Car'**, which is one in maximum. This value corresponds to the step size of the car during the next tick depending on the traffic in front of it. The speed- limit in this simulation is one (see **Figure 17: Average speed of traffic / cars**).

Figure 9: The cars

These are the implemented functions for the breed *car*

- setupCars
- putOnEmptyRoad
- setSpeedOfCar
- speedUpCar
- slowDownCar

Two functions for the setup Button, three functions which are used in every tick of the simulation.

7.3.2.2 The truck

The turtles breed *truck* is one of the main actors in this simulation. It is personated by the **Netlogo** shape 'truck'. The following list shows the implemented variables, which are self-explanatory for the most parts. For some of them you will find an explanation below.

- delaytime
- missionList

- speed_Truck
- orientation
- actuellFuelConsumption
- fueldemand
- polution
- totalpackagesNumbers
- unloading?
- initialLoadingComplet?
- Missioncompleted?
- aimXcor_Truck
- aimYcor_Truck
- aimDemandPoint
- aimDemandNumber

Figure 10: The truck

The variable ***delaytime*** represents the time for the loading and unloading procedure of the truck. At the start of the simulation all packages (sum of all demands of all costumers saved in the variable ***totalpackagesNumbers***) have to be loaded to the truck; every tick two packages are loaded. When the truck reaches a demand position which is related to its ***missionList*** he has to unload the packages, means he has to wait. The ***missionList*** is a list of small lists. Every small list contents four numbers.

index in the list	meaning
0	number of the demandPosition
1	X - coordinate of the demandPosition
2	Y - coordinate of the demandPosition
3	numberof packages, which have to be unloaded at the demandPosition

Table 2: Explanation of mission list of truck

If the variable ***Missioncompleted?*** is true the truck has distributed all packages and he will return to the distribution centre, where the simulation will end. The variables ***speed_Truck*** and ***orientation*** have the same meaning like the cars variables (see chapter **7.3.2.1 The cars**). The following list contents all implemented functions for the truck.

- setupTrucks
- OptimizeTruckList_Function
- setupMissionsForTrucks
- setupOrginazeLoadingTheTrucks
- loadTheTruck
- setTruckAction_Unloading
- setTruckAction_Moving
- turnTruck
- setTruckCorrectOnRoad
- setTruckSpeed
- setSpeedOfTruck
- speedUpTruck
- slowDownTruck

The function ***OptimizeTruckList_Function*** is the only 'report- function[4]' in this simulation and is only used when the switch ***OptimizeTruckList*** (chapter **7.4 The user interface**) is true. This function optimizes the route of the truck by ordering the **missionList**. When the user selects this option the truck do not move randomly from station to station, but rather drive to the nearest 'demandPosition'. For a more detailed work it would be interesting to implement different functions like this one to investigate the influence on the truck performance (see chapter **10 Conclusion**).

The function ***turnTruck*** is used when the truck arrives an intersection. Then he always has to decide if he turns right or left or drives straight forward. The ***turnTruck*** - function changes the heading of the truck. To guarantee that the truck is always on a road (he can not drive through buildings and the cars in front of him influence his speed) the function ***setTruckCorrectOnRoad*** controls always the position of the truck and correct it if required.

The function ***setTruckAction_Unloading*** contents the truck action at the demand centres. When the truck arrives a demand centre which is part of its mission list, it starts the unloading process. At the end of this process, the truck chooses the new mission with a new demand centre. The new data is saved in 4 different variables: ***aimXcor_Truck*** contents the x - coordinate of the demand centre in the mission list, ***aimYcor_Truck*** contents the y - coordinate of the demand centre in the mission list, ***aimDemandPoint*** contains the number of the demand centre to identify it and ***aimDemandNumber*** contents the number of packages that the truck has to unload there.

7.3.2.3 The drones

The breed ***drones*** represents the other main actor in this simulation. Other than with the variables of the truck, the user can decide about the number of drones (range from one to twenty). The drones are presented by the ***Netlogo*** shape 'airplane'. They change their colour from orange (has loaded a package) to red (empty and on the way back to the distribution centre). These are the implemented variables.

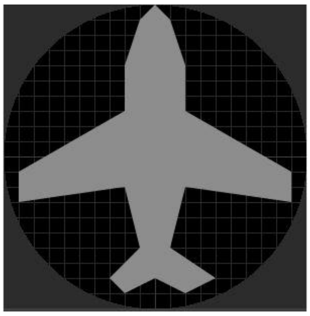

Figure 11: The drone

- missionList
- speed_Drone
- energydemand
- load?
- aimXcor
- aimYcor
- aimDemandPoint
- allMissionsComplete?

Like the truck every drone has a ***missionList*** with information about the current mission and the coordinates of the next aim. As for the truck the variables ***aimXcor***, ***aimYcor*** and ***aimDemandPoint*** content the information about the next demand centre. A declaration about the number of packages is not necessary, because every drone is only able to transport one package. If the variable

[4] See at http://ccl.northwestern.edu/netlogo/docs/dictionary.html#breedvar

allMissionsComplete? is set true, all drones return to the distribution centre. Then the simulation will stop.

These are the implemented functions for the drones, three functions for the setup procedure, one which is used for the 'go' – procedure (setDroneAction):

- setupDrones
- missionListDrones
- setupMissionsForDrones
- setDroneAction

7.4 The user interface

This chapter should give an overview about the different possibilities for the user to modify the simulation setup. It is departed in to sections, the options for changing the setting on the one hand and on the other hand the visualisation of the simulation.

7.4.1 How to change the settings

The user have available several sliders and switches to change the settings for the simulation. The button ***setup*** realise all the selected settings for the next simulation. The Button ***simulate*** starts the simulation. The following table explains all the sliders and switches.

Name	**function**
NumberOfDemandPoints_X	The user is able to modify the number of demandPositions on the x - axes
NumberOfDemandPoints_Y	the user is able to modify the number of demandPositions on the y - axes
NumberOfCostumers	the user is able to modify the number of costumers
TrafficOnOFF	if 'ON' cars will drive on the roads, if 'OFF' there will be no traffic/ no cars
NumberOfCars	the user is able to modify the number of cars on the road; minimum four, maximum two hundred cars
NumberOfDrones	the user is able to modify the number of drones; minimum one, maximum twenty drones
OptimizeTruckList	if 'ON' the truck distribute the packages by an optimized route, if 'OFF' the truck choose the next demandPosition randomly

Table 3: Content of user interface

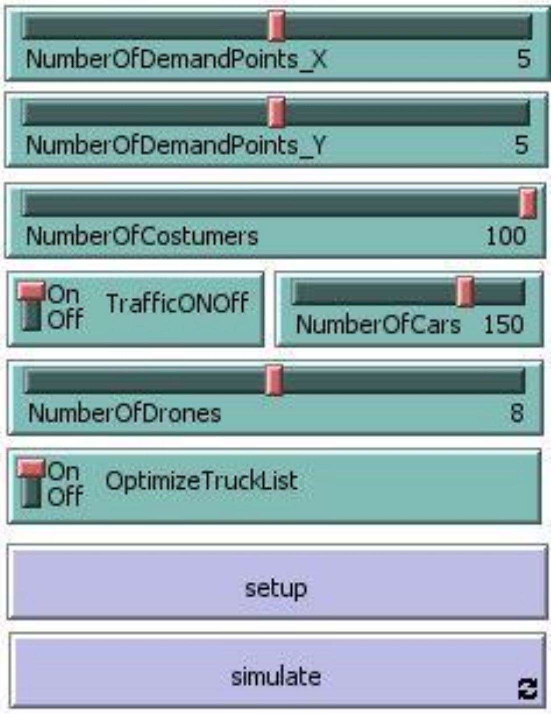

Figure 12: User interface - buttons and sliders

7.4.2 The visualisation

The visualisation contents the standard monitor of **Netlogo**. In addition there are several plots and monitors, which should help the user to understand the processes during the simulation.

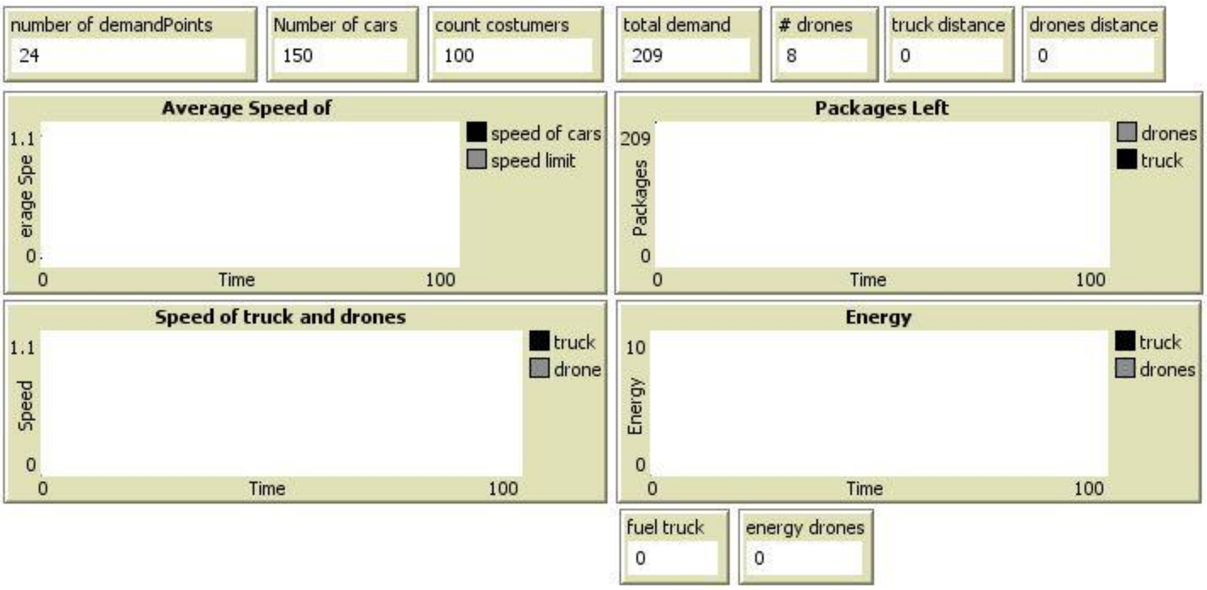

Figure 13: Visualisation - plots and monitors

The seven monitors show the settings of the current simulation. The monitor ‚total demand‘ displays the number of the sum of all costumer orders. When the user chooses one hundred costumers the minimum number of the ‚total demand‘ is hundred orders, the maximal number is three hundred orders. The monitors ‘truck distance’ and ‘drones distance’ display the sum of the travelled distance of both transportations. The monitor ‘fuel truck’ shows the fuel demand of the truck, the monitor ’energy drones’ presents the sum of the used energy of all drones. Furthermore the user has for plots. The following table explains these plots.

Name of the plot	**Explanation**
Average speed of cars	Average speed of all cars to characterize the traffic, also the speed- limit(horizontal line)
Packages Left	Number of the packages both transport systems have left, this corresponds with the number of packages the demand centres are waiting for.
Speed of truck and drones	Speed of truck and the average speed of the drones
Energy	The fuel demand of the truck and the sum of the energy demand of all drones

Table 4: Explanation of plots on the user interface

8 The simulation

This section shows the different scenarios which were simulated. You will find a small text of information about the current scenario and different tables or plots that visualise the simulation results in chapter **9 The Analysis of the simulation results**. At first the following part will give an overview about all scenarios and will describe the general setting of the simulations. From the simulations in this work the following settings are fixed: in the x - and y - dimension you will find always five ***demandPoints***; for a more detailed work it is possible to analyse the influence of a variation of the road grid.

Because several parameters are chosen randomly (for example number of packages of each costumer) every setting is simulated several times. In addition to the results of single simulations you also will find the averages of the results to formulate a generally valid statement.

8.1 Different scenarios of simulation

The different scenarios are characterised by different settings. For the traffic three different levels are investigated:

1) no traffic = number of cars: 0
2) normal traffic = number of cars: 100
3) massive traffic = number of cars: 200

For the number of costumers the following settings are simulated:

1) a few costumers = number of costumers: 20
2) normal number of costumers = number of costumers: 60
3) a lot of costumers = number of costumers: 100

The number of drones will be variegated between one and depending on the number of costumers. There will be simulations with optimized truck route and simulations without the randomly chosen route.

For each scenario you will find the setup settings and the results in two tables. The meanings of the table items are self-explanatory. The item 'average speed of traffic' should illustrate the different situations on the roads. It is the average speed of all cars over the whole time period of the simulation. An interpretation of the value you find in chapter **9 The Analysis of the simulation results.**

8.1.1 One truck and one drone

One scenario is realized by **one truck** and **one drone**. The settings of these simulations you can see in tables. There are three different levels of traffic, like it is explained above.

8.1.1.1 Without traffic and only a few costumers

Simulation number	Number of demand centres	Number of cars	Number of costumers	Number of orders	Number of trucks	Number of drones	Route of truck optimized
1	24	0	20	39	1	1	false
2	24	0	20	50	1	1	false
3	24	0	20	43	1	1	true
4	24	0	20	45	1	1	true

Table 5: Settings for simulation without traffic, a few costumers, one truck and one drone

Simulation number	Time of drones	Time of truck	Fuel demand of truck	Energy demand of drones	Average speed of traffic	Complete distance truck	Complete distance drones
1	1141	390	1546	1140	-	290.86	1140
2	1519	388	1355.75	1518	-	291.35	1518
3	1079	375	1366.63	1078	-	290.35	1078
4	1277	319	1261.75	1276	-	233.75	1276

Table 6: Results of simulation without traffic, a few costumers, one truck and one drone

8.1.1.2 Normal traffic

Like the results of the simulation without traffic show, it is really necessary to simulate a lot of settings with only one drone to compare the both transportations. For the sake of completeness You will find two simulations with normal and massive traffic in the next chapters.

Simulation number	Number of demand centres	Number of cars	Number of costumers	Number of orders	Number of trucks	Number of drones	Route of truck optimized
5	24	100	60	119	1	1	False

Table 7: Settings for Simulation with normal traffic, normal number of costumers, one drone and one truck

Simulation number	Time of drones	Time of truck	Fuel demand of truck	Energy demand of drones	Average speed of traffic	Complete distance truck	Complete distance drones
5	774	4031	2554.21	4030	0.8389	502.65	4030

Table 8: Results for Simulation with normal traffic, normal number of costumers, one drone and one truck

8.1.1.3 Massive traffic

Simulation number	Number of demand centres	Number of cars	Number of costumers	Number of orders	Number of trucks	Number of drones	Route of truck optimized
6	24	200	60	118	1	1	true

Table 9: Settings for Simulation with massive traffic, normal number of costumers, one drone and one truck

Simulation number	Time of drones	Time of truck	Fuel demand of truck	Energy demand of drones	Average speed of traffic	Complete distance truck	Complete distance drones
6	3541	923	2450.82	3540	0.6902	432.88	3540

Table 10: Results for Simulation with normal traffic, normal number of costumers, one drone and one truck

8.1.2 One truck and a variable numbers of drones

The simulations setting above have shown the truck is always superior one drone. The comparison shows that it does not matter how much traffic is on the street. For the following settings the number of drones is varied, to find the setting where the performance of both distribution ways is equal.

8.1.2.1 Normal traffic

All the following settings use an optimized route of the truck. The numbers of drones is changed to find the optimum number.

Simulation number	Number of demand centres	Number of cars	Number of costumers	Number of orders	Number of trucks	Number of drones	Route of truck optimized
7	24	100	60	111	1	5	true
8	24	100	100	212	1	5	true
9	24	100	100	193	1	10	true

Table 11: Settings for Simulation with normal traffic, several numbers of costumers, several numbers of drones and one truck

Simulation number	Time of drones	Time of truck	Fuel demand of truck	Energy demand of drones	Average speed of traffic	Complete distance truck	Complete distance drones
7	686	694	2227.87	3482	0.8943	436.41	3482
8	1374	842	2545.57	6862	0.9030	473.64	6862
9	585	784	2524.27	5981	0.9105	426.76	5918

Table 12: Results for Simulation with normal traffic, several numbers of costumers, several numbers of drones and one truck

8.1.2.2 Massive traffic

Simulation number	Number of demand centres	Number of cars	Number of costumers	Number of orders	Number of trucks	Number of drones	Route of truck optimized
10	24	200	60	124	1	5	true
11	24	200	100	191	1	5	true
12	24	200	100	196	1	7	true

Table 13: Settings for Simulation with massive traffic, several numbers of costumers, several numbers of drones and one truck

Simulation number	Time of drones	Time of truck	Fuel demand of truck	Energy demand of drones	Average speed of traffic	Complete distance truck	Complete distance drones
10	715	911	2636.84	3588	0.7172	486.12	3588
11	1144	1108	3325.32	5740	0.6907	482.65	5740
12	879	1274	3542.54	6136	0.6930	522.46	6136

Table 14: Results for Simulation with massive traffic, several numbers of costumers, several numbers of drones and one truck

8.1.2.3 Special simulation configurations

This chapter contents different simulation setups to investigate interesting configurations. Like above you will find the settings and results of the simulation in the following tables.

Simulation number	Number of demand centres	Number of cars	Number of costumers	Number of orders	Number of trucks	Number of drones	Route of truck optimized
13	24	150	100	226	1	6	true
14	24	150	100	229	1	7	true

Table 15: Settings for simulation with different inputs

Simulation number	Time of drones	Time of truck	Fuel demand of truck	Energy demand of drones	Average speed of traffic	Complete distance truck	Complete distance drones
13	1137	983	3767.16	6852	0.7839	471.75	6852
14	983	919	2539.23	6874	0.7750	504.28	6874

Table 16: Results for simulation with different inputs

In the following chapter you will find the analysis of these simulation and some possible interpretations.

9 The Analysis of the simulation results

This chapter analyses the results of the simulation, which you can see in chapter **8 The simulation.** At first you will find some plots which present the results of the simulation.

9.1 The influence of the number of drones

The Figure 14: **Simulation number 8: number of packages** and Figure 15: **Simulation number 9: number of packages** shows two interesting facts. Both simulations use the same number of cars (one hundred). In the first simulation the transport systems have to supply 212 packages, in the second one 193. The difference is the number of drones which was doubled from five to ten. The performance of the drones gets much better. By doubling the number of drones you are able to halve to needed time of the drones.

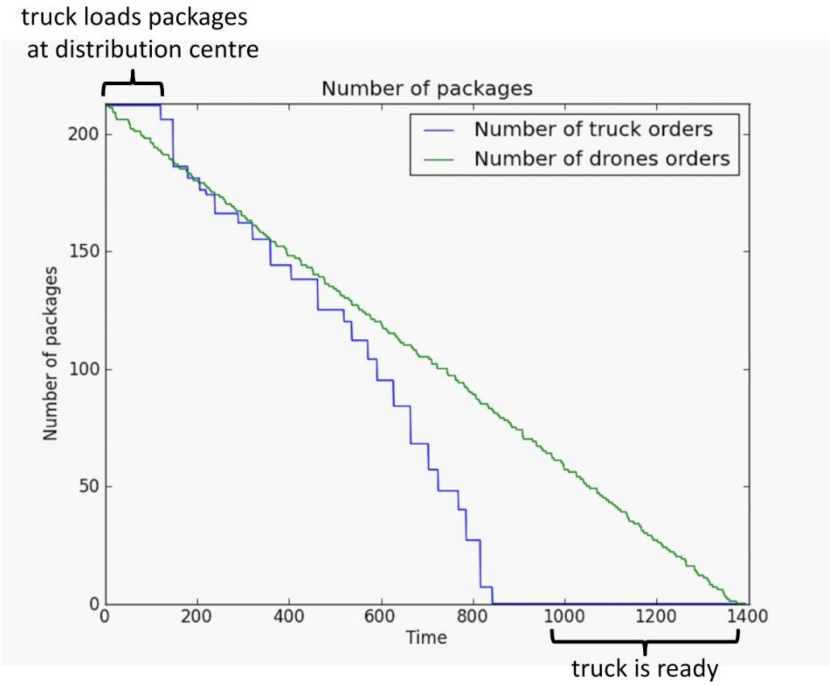

Figure 14: Simulation number 8: number of packages

The other fact is the performance oft he truck. Both figures show the delay time at the beginning oft he simulation. This is the needed time to load the truck with all packages. In the first setting the truck is able to make the time after 200 ticks and to overtake the drones. In the other setting the drone's performance is too good.

The following table shows some ratios to compare the performances.

Simulation number	Mode of transport	Needed time/ Number of packages	Needed energy / Number of packages	Needed distance / Number of packages
8	Truck	3.972	12.0074	2.248
8	Drones	6.481	32.3692	32.3692

Table 17: Analyse of simulation 8 by different ratios

You are able to see that the truck is much more efficient than the drones and that the costumers

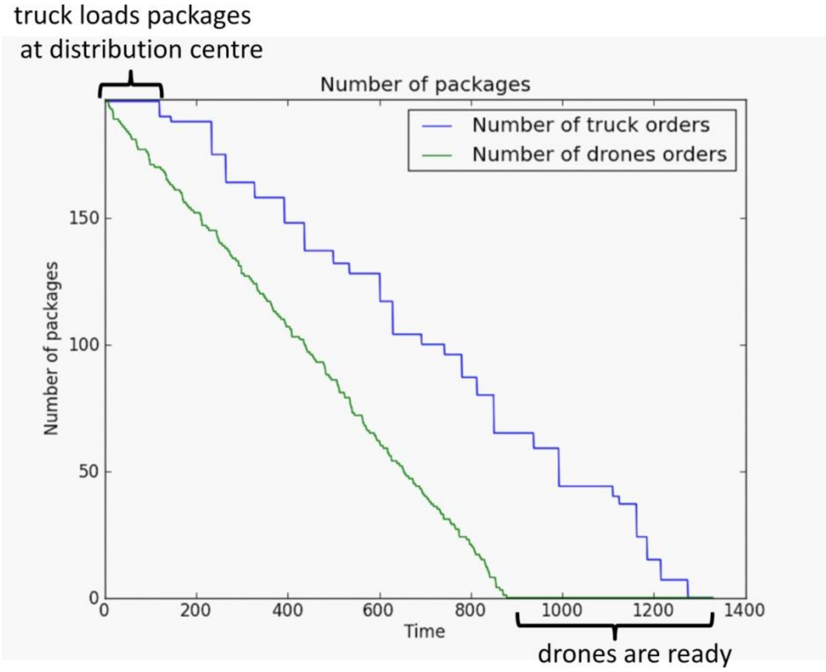

Figure 15: Simulation number 9: number of packages

In the simulation number 9 the number of drones is 10. The table shows the differences to the results of simulation number 8.

Simulation number	Mode of transport	Needed time/ Number of packages	Needed energy / Number of packages	Needed distance / Number of packages
9	Truck	4.062	13.079	2.2111
9	Drones	3.03	30.9896	30.9896

Table 18: Analyse of simulation 9 by different ratios

9.2 The influence of the current traffic situation

One parameter which influences the performance of the truck is the traffic situation on the roads. Like it is described in chapter ***8.1 Different scenarios of simulation*** three different levels are simulated. These tree levels of traffic are able to be interpreted in the following way:

- ***No traffic:*** the truck works on a quite day/ time, for example on Sunday
- ***A little bit traffic:*** normal traffic situation on the roads, for example working day at midday
- ***A lot of traffic:*** the roads are full with cars, for example working day at rush hour

The effect of the traffic on the performance of the truck shows the simulation number 11 and number 12. They have the same settings like the simulations number 8 and 9, but have a doubled number of traffic. Now the truck needs for the same number of orders (circa 193) 490 ticks more (784 -> 1274). This is a rise about 62.5 % With this traffic situation only five drones are necessary to be as fast as the truck.

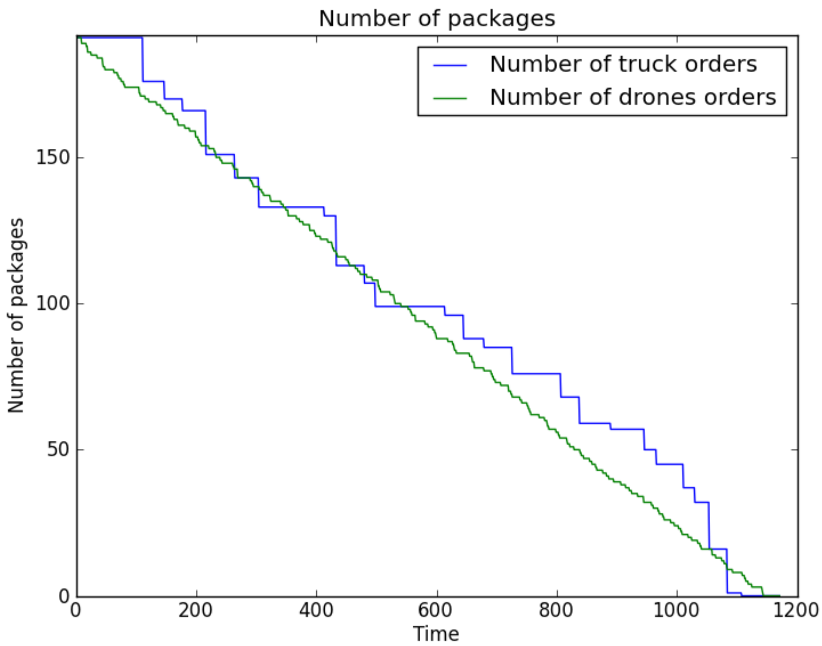

Figure 16: Simulation number 11 – number of packages

To analyse the necessary time to distribute all packages the following variables and parameters are good qualified.

- Number of cars on the roads
- Average speed of all cars during the simulation period
- Needed time of truck to distribute all
- Distance of truck

Number of cars	**0**	**50**[5]	**100**	**150**	**200**
All average speeds of cars	0 0 0 0	0.9992 0.9908 0.9837	0.8389, 0.8943, 0.9030, 0.9105,	0.7839, 0.7750 0.7678	0.6902, 0.7172, 0.6907, 0.6930
average	**0**	**0.9912**	**0.8867**	**0.7756**	**0.6978**

Table 19: Average speed of traffic

The **Table 19: Average speed of traffic** and the **Figure 17: Average speed of traffic / cars** show the average speed oft he cars.

[5] Determined by extra simulations

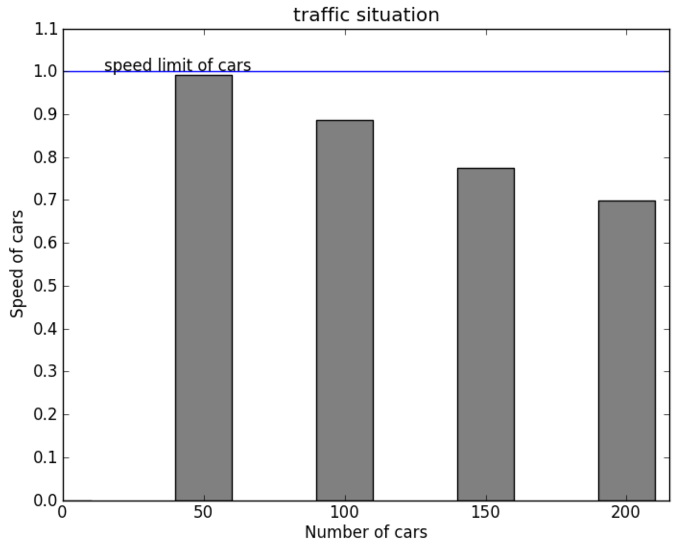

Figure 17: Average speed of traffic / cars

It is obviously that with an increasing number of cars the average speed oft he traffic falls. The cars have to stop more often, as well the truck has to. The time to distribute all packages with a truck is influenced in this way. If you double the numbers of cars from 100 cars to 200 cars, the needed time to realize the complete supply increases about circa 55%. In this way the traffic has an influence on the comparison of drones and truck. With more traffic the time for distribution by truck increases, means the performance of the truck gets worse, this influences automatically the performance of the drones – their performance get better, although they are not directly correlated to the traffic.

9.3 The influence of an optimized route for the truck

The model gives the user the possibility to optimize the route of the truck with one function. With the optimized route the truck does not choose its next aim randomly, it drives always to the next nearest demand centre. The influence of this function is investigated in simulations number 1 to 4 without traffic. Like you can see it is possible to reduce the needed time from 390 to 319, to reduce the fuel demand from 1546 to 1261.75 and to reduce the travelled distance from 290.86 to 233.75 although the number of demands increase from 39 to 45 (all dates from simulation 1 and simulation 4). This is significant improvement which would save a lot of money for the company. It has to be commented that the success of the function of optimizing depends on the distribution of the costumers and demand centres. This effect is analysed in the chapter **9.4 The influence of the random distribution of the costumers.** This way to optimize the route is a very basic solution, other algorisms, which are optimized for those problems would return even a better solution and would increase the level of the performance of the truck.

9.4 The influence of the random distribution of the costumers

To analyse this influence it is possible to show at the simulations number 14 in the next figure. It is a setting of a simulation in which both ways of transportations are equal. The demand of fuel for the truck is 2539.23 for 229 packages. If you compare these values with the results of the simulation number 13, you will see that the truck has a fuel demand of 3767.16 for 226 packages. This huge difference is only explainable by a completely different distribution of the costumers and the demand centres over the world.

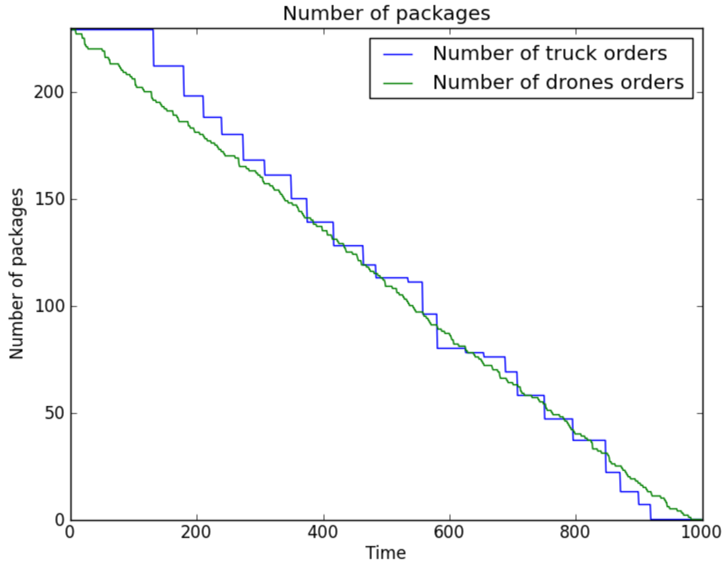

Figure 18: Simulation number 14 – number of packages

9.5 Costs and pollution

The analysis has shown that the performances of both ways to distribute the packages depend on several influences and parameters. Each system has its own advantages and disadvantages. Another influence to evaluate the different transport systems has the costs of transport and the pollution of the environment. The truck has costs for the fuel, the driver and the truck itself. The demand of fuel for the truck is correlated to the speed of the truck, to make the consumption more realistic. The drones need for example electrical energy, a controller at the distribution centre and the money to buy the drones.

It is outside the scope of this work to compare all the costs with each other. The simulations show that the truck in most cases consumes less fuel than the drones consume electrical energy. On the one hand this effect is explainable with the implemented way of energy consumption of the drones (every step the energy demand of the drones rises by one), on the other side with frequency the drones have to go to the several demand positions. To make both values comparable to each other, both values should be brought to a common denominator in another investigation. It is possible to calculate the costs to produce the electrical energy for the drones in a normal power plant using gas, carbon or renewable energy sources and compare these costs with the current prize for gasoline.

The same procedure is thinkable for the values of environmental pollution. Both values should be made comparable with primary energy factors to assess the different energy sources and ways of pollution (for drones the energy production creates the pollution, the truck creates the pollution itself). At the end the investing in the drones only will pay off, if the technology is a convenient and reliable and on the other hand the customer is willing to pay more for a faster delivery.

Another point to investigate is the costs for the society to implement a new distribution system with drones. The infrastructure for the transport system based on trucks already exists and is also used by normal vehicles – so it is part of common property. For the solution by drones a new infrastructure is necessary. There will be costs for new distribution centres or for special landing areas for the drones. Furthermore you should think about facts like noise annoyance and changes of townscape. These changes should be calculated and considered.

9.6 The look at another paper

This work contents an agent based simulation of a logistic problem with the programming language **Netlogo**. During the research for this work and the implementation of the model to simulate it became clear that the implementation of a logistic problem with all relevant parameters is one of the most complex exercises for modelling. The paper '***Simulation and Implementation of Logistic Systems based on Agent Technology'*** (14) thematizes the problems to implement the complexity of a logistic problem with the mainstream software engineering paradigms. The authors introduce into the different and important characteristics of a logistic problem, like the *high complexity* or the *number of decision* makers (page 2 in (14)), which are the reason why those real world problems are so difficult to solve with algorithms. Furthermore they explain the attributes of individual agents and multi-agent systems (MAS) (from page 4 to page 9). The paper illustrates that normally for simulation like that multi-agent systems (MAS) are necessary and introduce in a new concept to allow a seamless transition between simulation and operation models of multi agent systems. The authors declare that you normally can find gab between simulation and realty. This gab normally results from the divide between the development and the simulation phase. The authors elucidate a method and tool to reduce this gab for a better development of the agent's behaviour and relationships between each other. This would improve the performance of the simulation and the model becomes more realistic. Also the performance of this simulation could be increased by more detailed implemented agents.

This work has shown that an agent based simulation with autonomous actors is very suitable for logistic application; also the authors of this paper come to this conclusion. But they note that usually '*simulation systems and logistic control applications rely on different kinds of agents execution platforms'* (page 16, page 17, chapter 'Conclusion' in (14)). They suppose a possibility to close this gab with a special tool. This problem is not the aim of the simulation in this work, but shows the embarrassments to realize a realistic model for a logistic transport system.

10 Conclusion and resume

The present work and simulation have shown that deliveries to customers with drones can be a real alternative to the normal delivery solution. Not without reason companies as **Amazon** or **Deutsche Post** check currently this kind of service and hope that they will have significant competitive advantages. Especially their speed, flexibility and independence of the current traffic situation on the road makes the supply per drone really interesting for the companies and can even be understood as a possible beginning of a new era in the transport system. The supply by drones can relieve the traffic situation on the roads and also realize a better and faster support of the costumers. In this context it is necessary to be mentioned that this technology is still in the early stages, and some time is needed until the here simulated scenario can be realized in the real world, but the results of the simulation have shown the potential.

In this work some assumptions and simplifications have been taken for the development of the simulation model, which has been described above. These conditions were necessary to implement the model, but restrict also the validity of the simulation results. Therefore, it must be mentioned that the present model has to be understood as an entry-level model, with which you can compare these two modes of transport, to make a big statement about pros and cons, but which is not able to identify exactly the better transport system. Therefore in the following part possible expansion and extension of this model are given. Some possible approaches to the improvement of this simulation are briefly characterized. By using this work as a starting point for different investigations these facts should be considered.

A possible point for improving the simulation is a more detailed elaboration of the ‘world’. It is for example possible to implement a real grid of streets and houses. Furthermore the implementation of several distribution centres and demand places could be interesting, as well as an improved simulation of traffic (traffic lights, etc.). These changes would create a more realistic setup for the simulation and would influence the performances of both systems.

The simulation of the drones could be improved at several parts. Other works could think about the risk of collision, the injury of humans, the real track of the flight or the risk to fall hazard. Furthermore some functions for a specified energy demand or times for reloading the drones could be implemented.

To make it more realistically the implemented delivery by truck could be extended with more methods to optimize route planning, like, for example, the travelling salesman problem. Also a more detailed implementations the fuel consumption of the truck and the resulting pollution and costs would increase the validity of this model. With these extensions the model could answer the question like: “Is it possible to realize a supply thirty minutes after ordering?”, “how much costs this transport the company” or “is this technology a realistic alternative to the transport systems by trucks?”. It would be clear, if the potential of drones like you are able to see in this simulation is enough to convince a company the change their logic management. All in all this implemented model is able to be a good starting point for future investigations and to new thoughts about this new, very interesting development in the logistic sector.

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12 Appendix

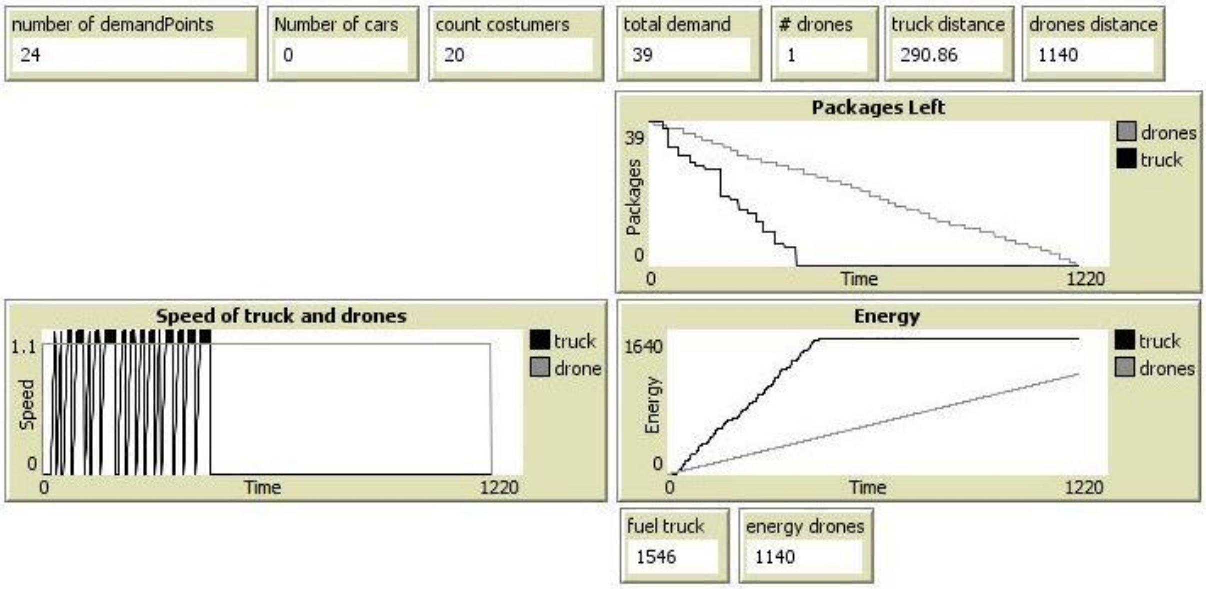


Figure 19: Simulation results number 1

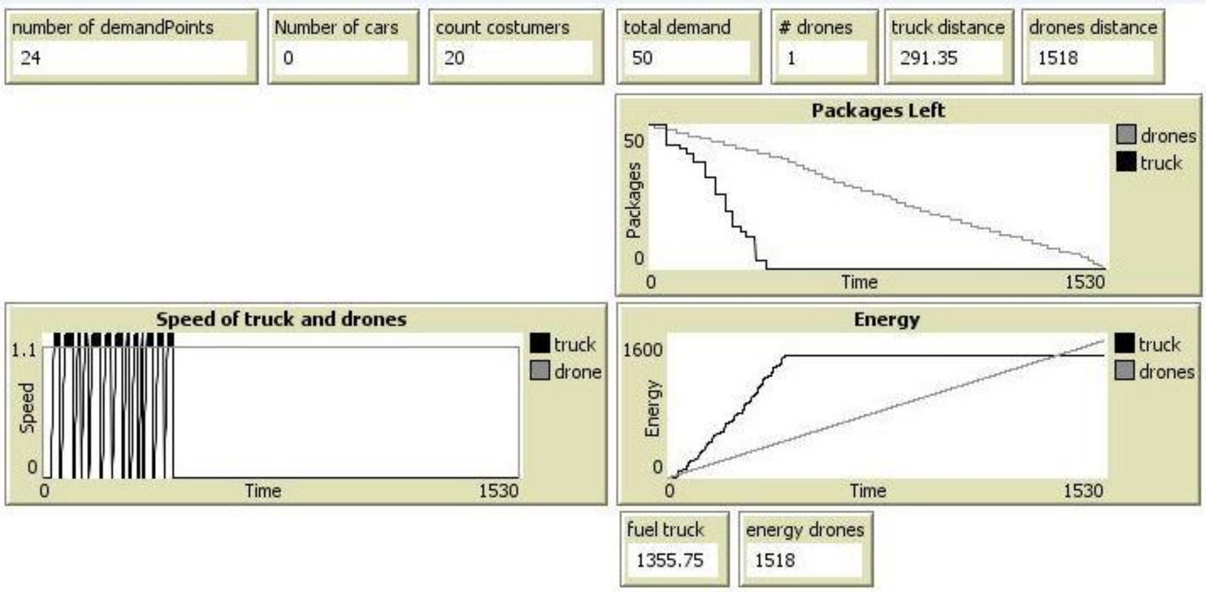


Figure 20: Simulation results number 2

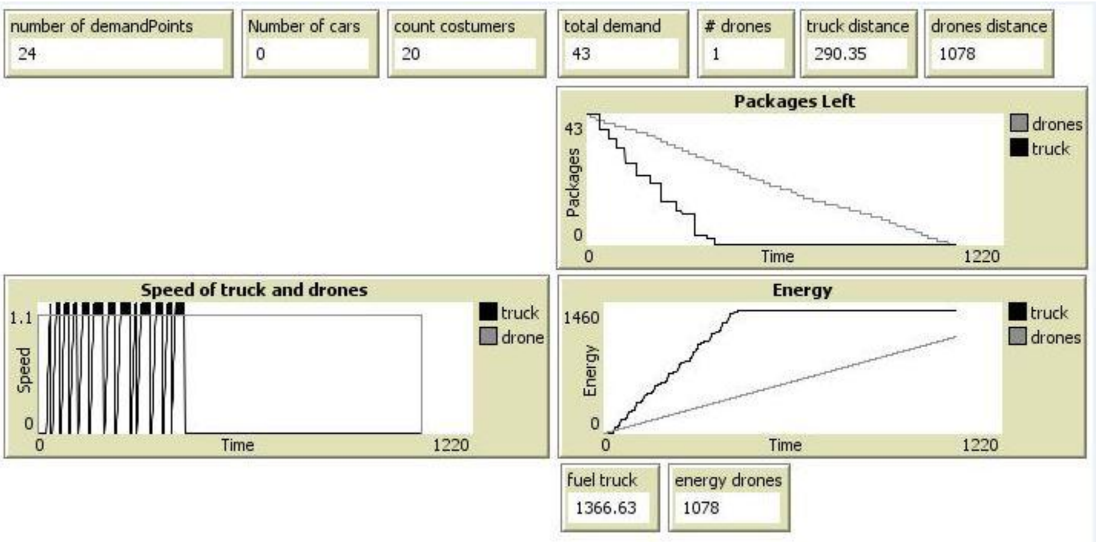
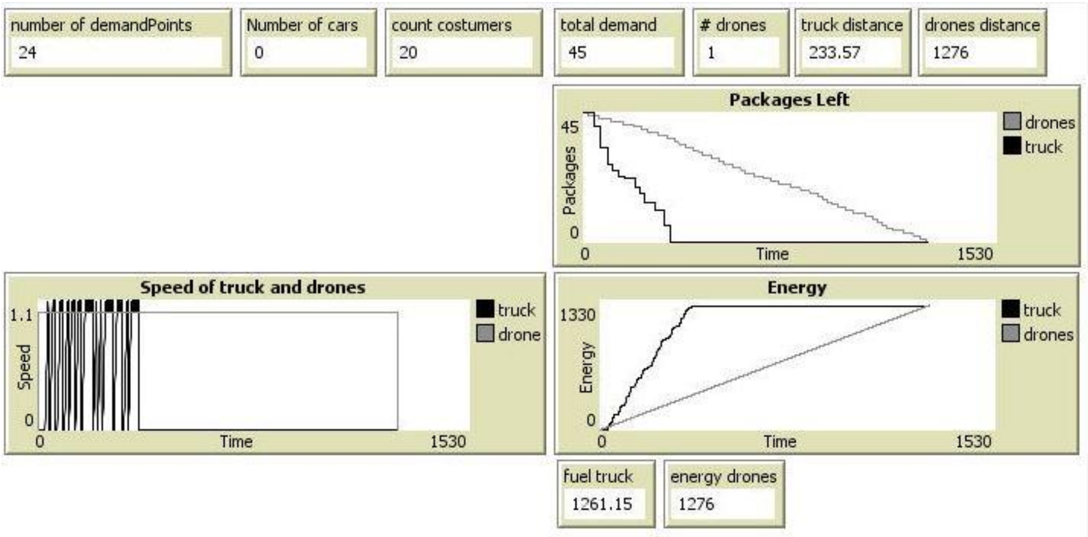


Figure 21: Simulation results number 3



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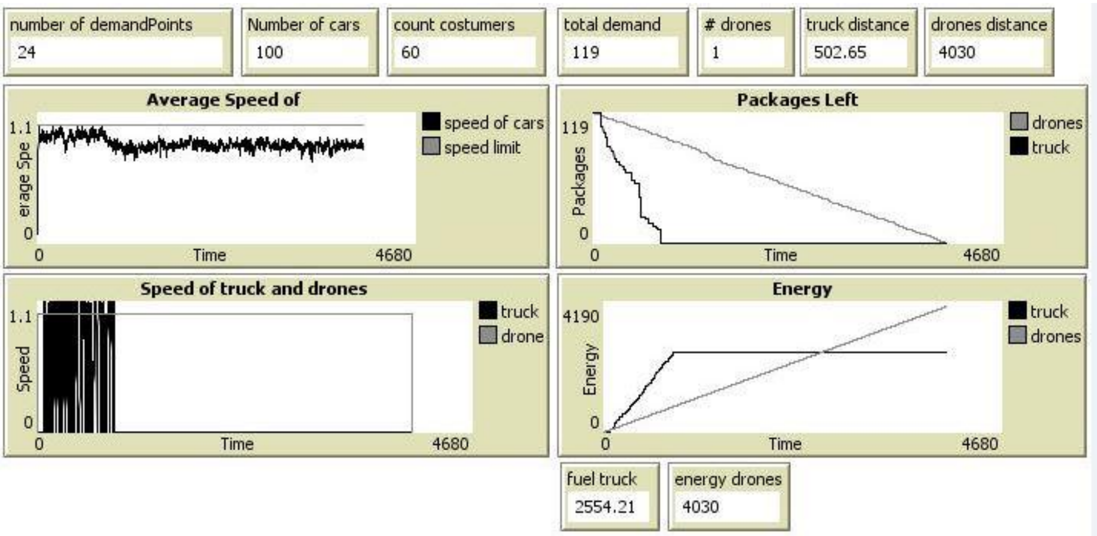

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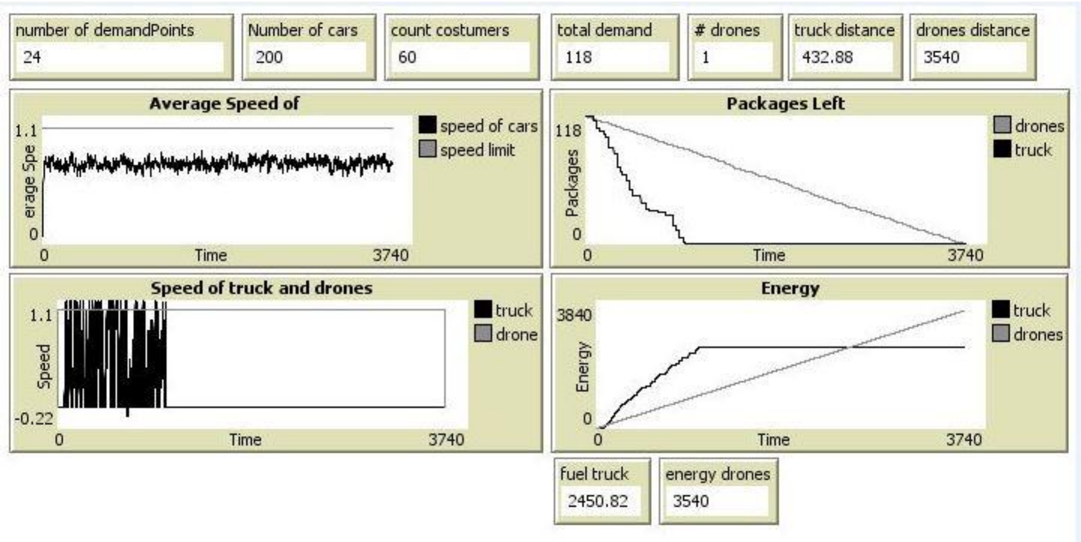
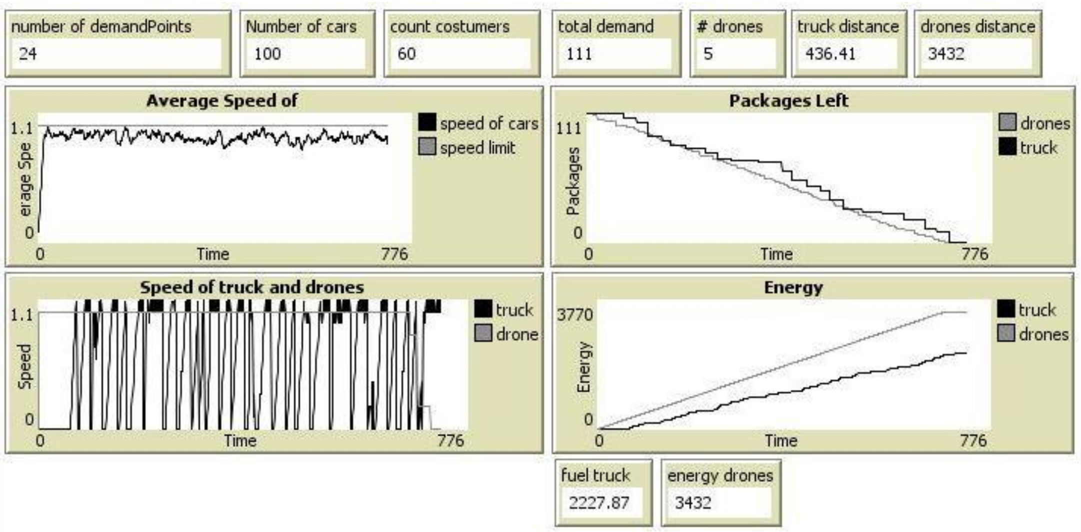


Figure 24: Simulation results number 6



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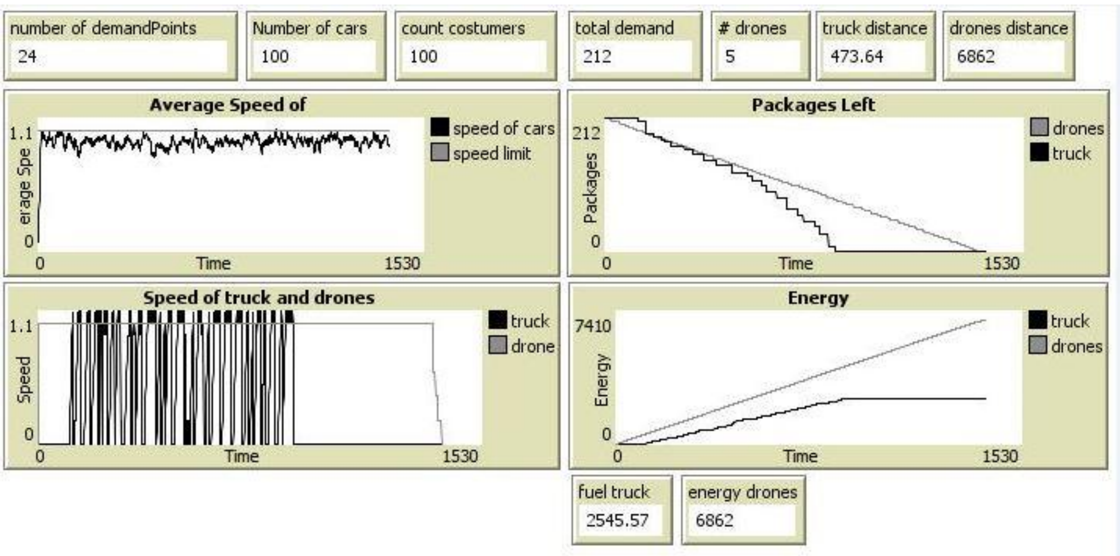


Figure 26: Simulation results number 8

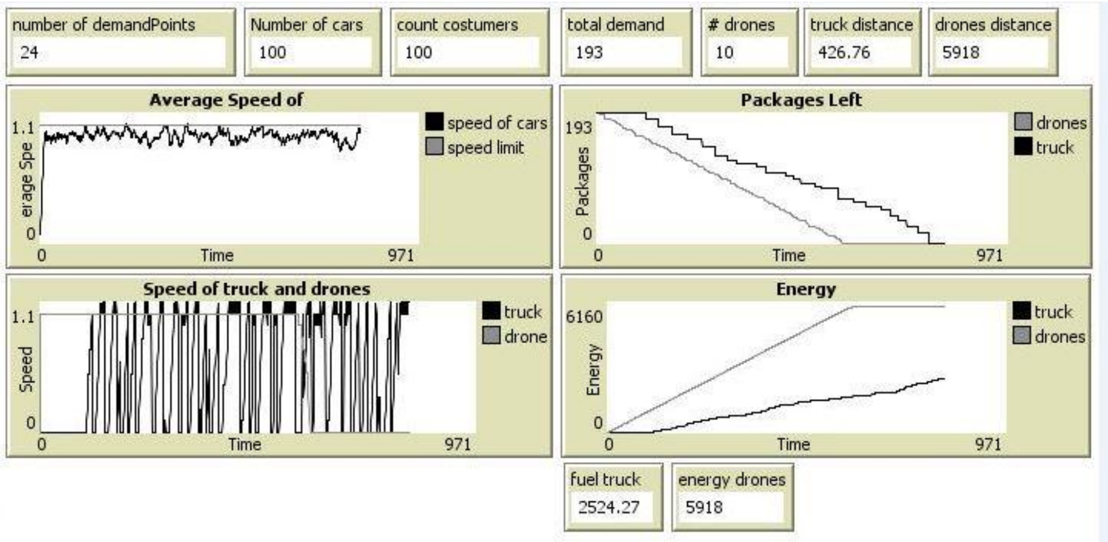


Figure 27: Simulation results number 9

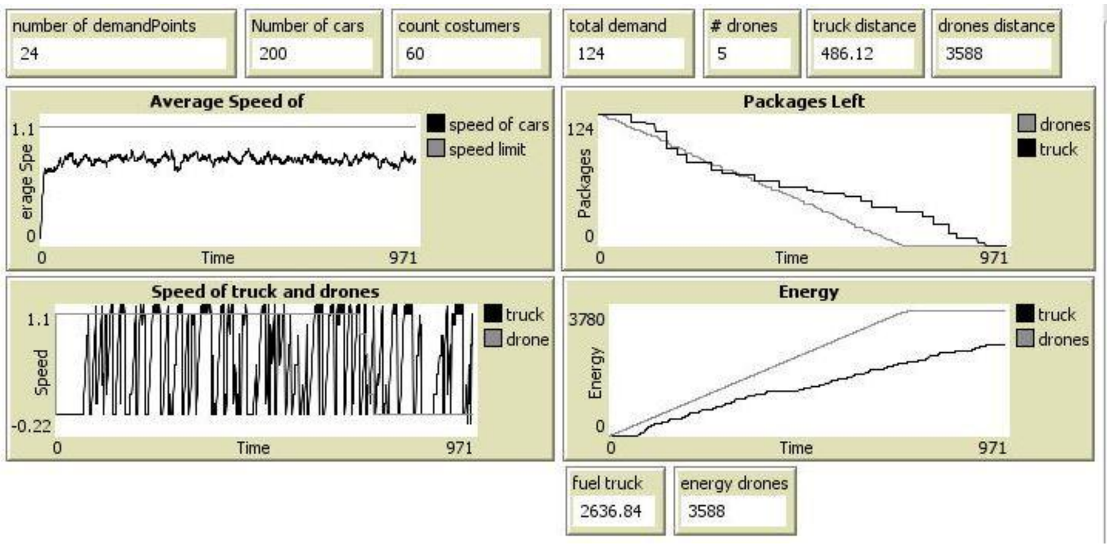


Figure 28: Simulation results number 10

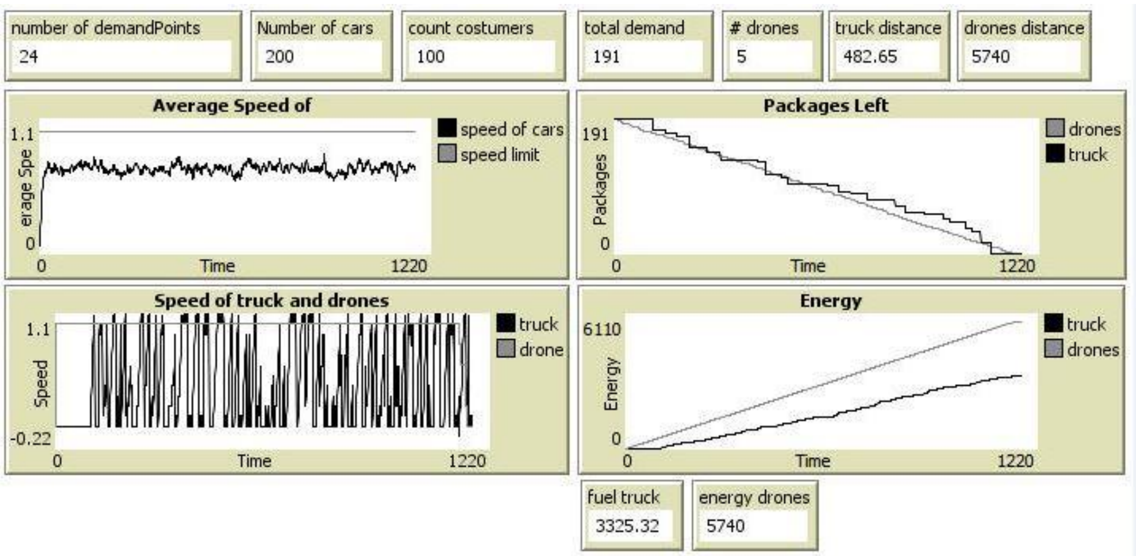
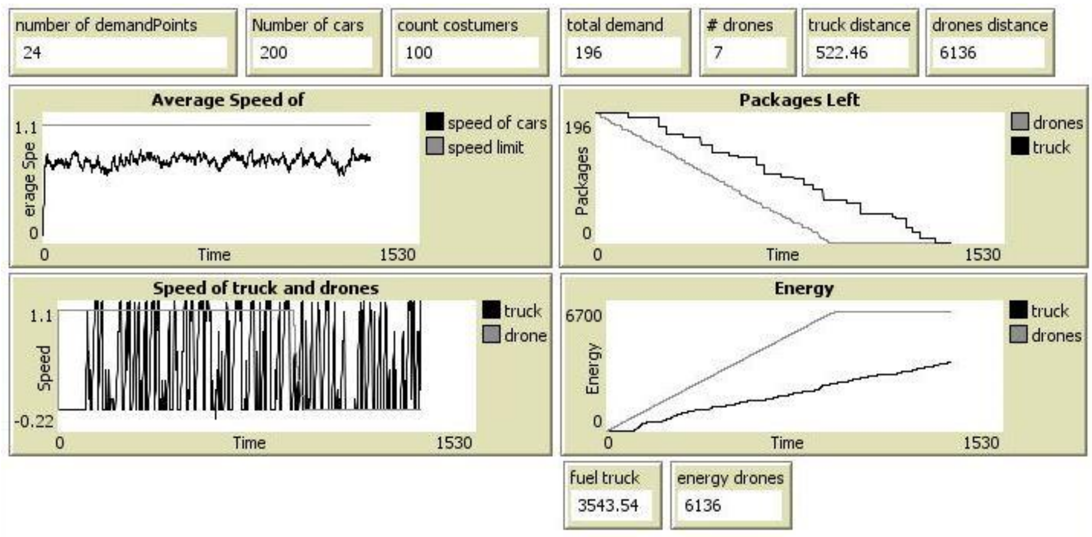


Figure 29: Simulation results number 11



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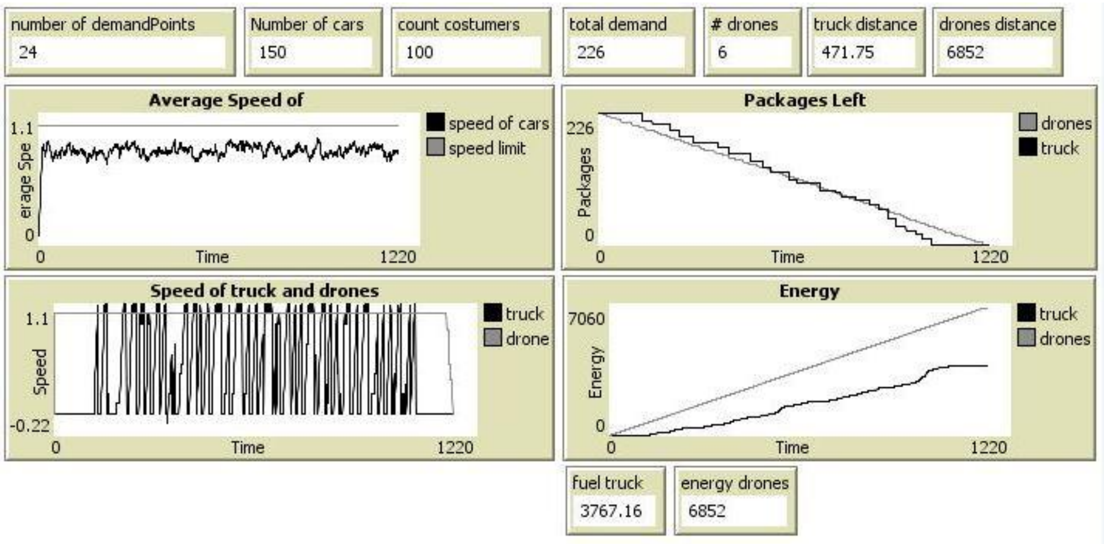

Figure 31: Simulation results number 13

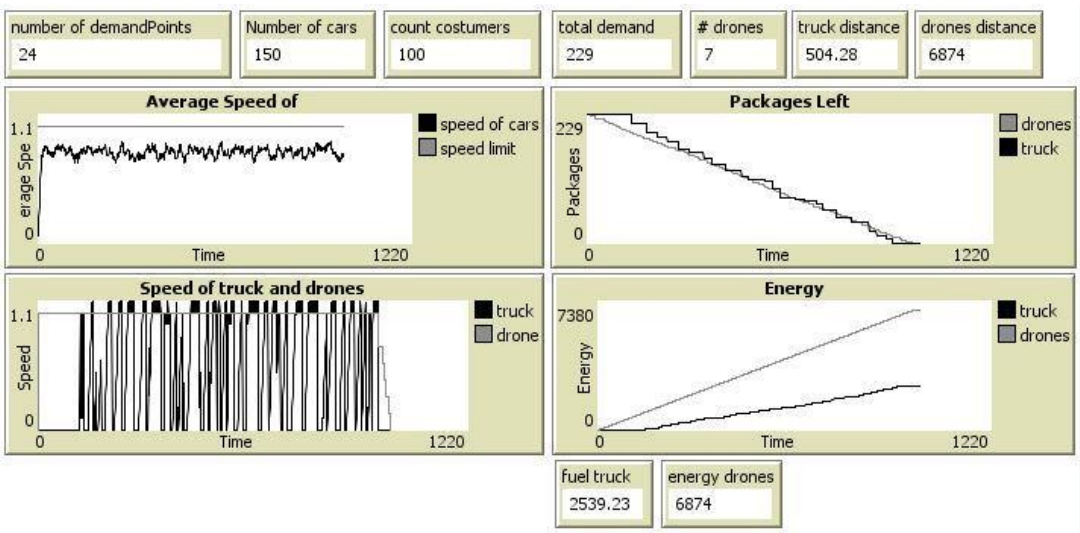

Figure 32: Simulation results number 14