V. N. Karazin Kharkiv National University
School of Economics
Department of Economic Cybernetics
and Applied Economics

STUDYING THE POWER OUTAGES PROBLEM: SYSTEM DYNAMICS VS DISCRETE SIMULATION

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V. N. KARAZIN KHARKIN NATIONAL UNIVERSITY


Freedom square view

GOSPROM Building in Kharkiv – a unique monument of Constructivism (1925-1928), under guard of UNESCO.

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Economic Cybernetics and Applied Economics is the leading department of School of Economics at V. N. Karazin Kharkiv National University – the largest and the oldest university in eastern Ukraine, which was founded in 1804

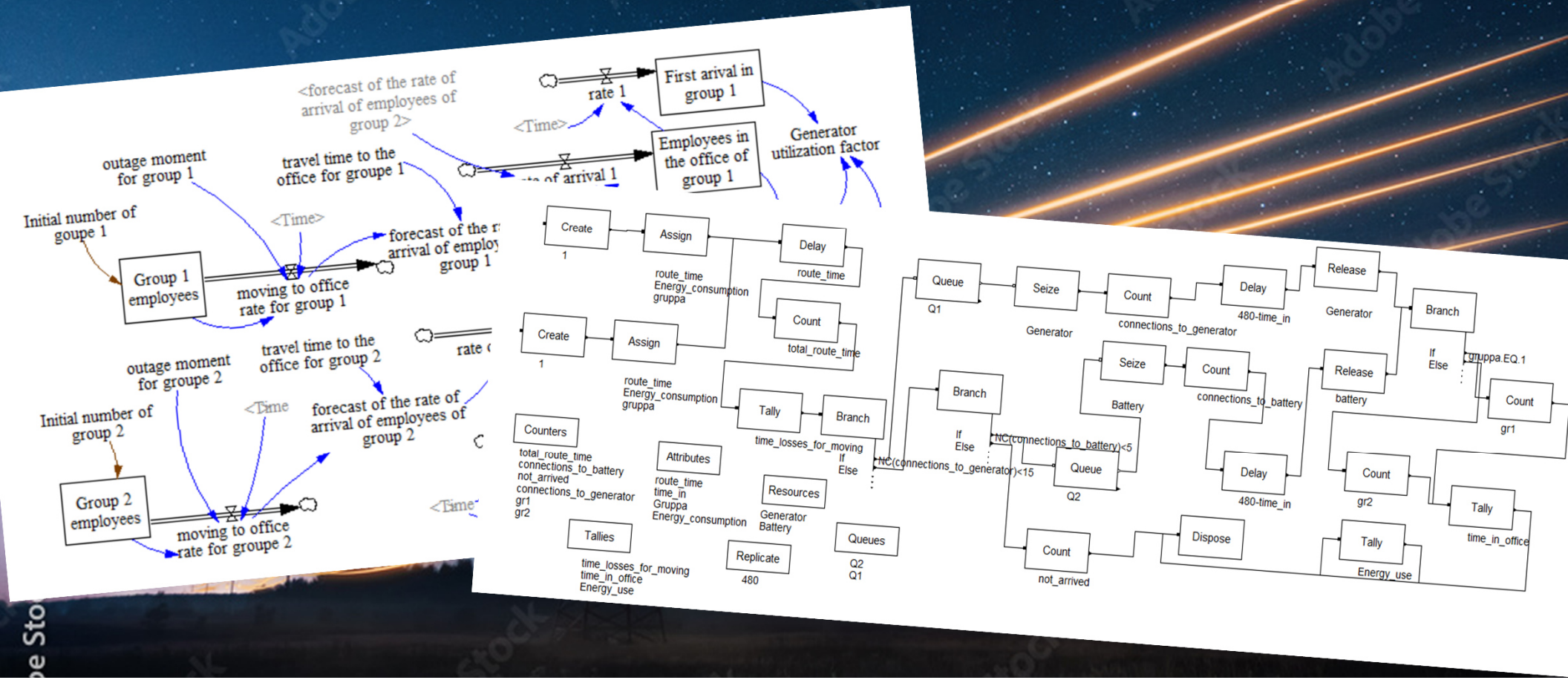
The department, which was one of the first in Ukraine to begin training in Economic Cybernetics, is currently training economists in two educational and professional programs: Economic Cybernetics (Bachelor and Master levels), Applied Economics MP and PhD EP.

Department of Economic Cybernetics and Applied Economics

Both educational programmes are based on three "whales": economics, modelling and computer technologies. This helps students in forming of a wide complex of knowledge and skills. The Department provides lectures in basic courses related to Mathematics and Computer Science, and in such professionally-oriented disciplines, as Economic Cybernetics, Operations Research, System Analysis, Economic Modelling and Simulation, Economic Dynamics, Project Management, Big Data etc.

The Department keeps up contacts with the leading higher educational and scientific institutions and organizations in Ukraine and in Europe. The main directions of scientific research: Experimental and Behavioural Economics, System Dynamics and Simulation Applications, Circular Economy and Clean Energy etc.

STUDYING THE POWER OUTAGES PROBLEM: SYSTEM DYNAMICS VS DISCRETE SIMULATION



Research background

For all the countries stability of power supply is a key point in ensuring energy security, sustainable economic life and/or survival. The lack of non-renewable energy resources is evidently affecting life not only in the countries with less developed economies, but also in the leading countries of Europe and the world, since the transition to renewable energy sources cannot provide uninterrupted energy supply always and everywhere.

In late 2022 – early 2023 Ukraine experienced a series of blackouts and outages, caused by Russian missiles attacks on Ukrainian energy infrastructure. Electricity was cut off in a number of cities for a period of several hours to 2–3 days. This has become a serious test for households and businesses, especially for those dealing in IT sphere. In order not to disrupt contract obligations, IT companies were forced to look for solutions that would minimize the losses of working time of their employees, primarily of full-time software developers.

IT industry of Ukraine

According to the results of 2023:

- foreign exchange earnings: USD 7 billion,
- taxes: UAH 36 billion.

Share of exports of computer services in 2016-2021:

- in Ukraine's GDP doubled from 1.8% to 3.5%,
- in services exports almost tripled from 13.4% to 37.8%.

Areas of application of IT technologies

Digital services

Agricultural sector

- Precision farming
- Land bank management
- Farm management system

Industry

- Artificial Intelligence (AI)
- Internet of Things (IoT)
- Big Data

E-commerce

- AR/VR/MR. Augmented reality technologies
- Big Data
- Robotization

IT in finance

- Application Programming Interface (API)
- Artificial Intelligence (AI)
- Blockchain

Military-tech

- Robotics
- Software for the military
- AR/VR

Top countries importing Ukrainian IT services (2023)

- USA – 40,26%,
- Malta – 8.8%,
- United Kingdom – 7.87%,
- Cyprus – 4.85%,
- Israel – 4.46%,
- Switzerland – 4.19%,
- Germany – 3.83%,
- Estonia – 2.26%,
- Poland – 2.20%,
- Netherlands – 1.99%.

Research goals and methodology

The purpose of the study was to analyze *Yael Acceptic* IT company's activities and develop a flexible decision support tool, which could help ensuring uninterrupted work of the IT personnel in conditions of sudden power outages. The company is a part of one of the largest groups of IT companies in Israel, Yael Group.

The key methodological approaches are two different simulation concepts, which may be used for decision support – these are System Dynamics (SD) and discrete simulation (DS) concepts. Two models are proposed for one and the same problem statement in order to compare benefits and disadvantages of both methodologies in terms of the convenience of displaying model assumptions, the possibilities of model modification and of computer experiments.

Literature review

In regard to *System Dynamics* simulation concept, historically the first SD model (a peculiar example of mega-processes simulation), reflecting global dynamics of demographics, non-renewable resources and energy supply, food production, pollution and other global processes, was presented in Jay Forrester's report to the Club of Rome back in the early 70s (Forrester, 1973). There are also studies describing classic aggregated SD models of Economy–Energy interaction (Fiddaman, 1997, Sterman, 2000).

SD simulation concept is still the most popular among the researchers of energy problems. In 2018–2022 there were about 20 articles on relevant topics, published in International Conferences proceedings of the annual System Dynamics Society conferences

Literature review

The main problem spheres which were studied using SD concept are energy supply processes, including blackout problem (Agarwal, Jayendran, 2020, Dyer et al., 2021, Ivanov, 2022), energy supply and demand (Dehghan H, et al., 2021), renewable (green) energy sources effectiveness (Khoong & Bellam, 2021, Mashhadi, 2021, Merla, 2022), energy market (Sheykhha & Reinhard, 2021, Teufel F. et al., 2013) and others.

Along with SD methodology, we may note examples of research based on multi-agent and discrete simulation concepts (Negnevitsky et. al., 2014, Sony & Mariappan, 2019).

Yael Acceptic case study

Yael Acceptic (Ukraine) specializes in dedicated development teams. Within 10 years they have launched more than 60 of them. In 2019 *Yael Acceptic* became a part of a large Israeli group of companies, Yael Group. The company is engaged in sales on the B2B market. Most of the company's clients are from Israel and USA.

Projects teams include specialists in different technologies – among them: JavaScript, PHP, Java, .Net, C++, Oracle and others. Most of the developers are Middle and Senior level. In addition to programmers, a dedicated development team may also include other specialists: a tester, designer, marketer and sales manager. A specific team is being formed according to the needs of a client company. Each team must be assigned a Project Manager. In addition to the specialists employed to carry out clients' projects, the company has administrative employees.

Problem articulation

In late 2022 – early 2023 the company faced significant challenges due to power outages resulting from targeted Russian missile attacks on Ukrainian energy infrastructure. Electricity could be switched off at random moments for an indefinite duration – in the whole city or in separate quarters. In order to avoid breaches of contractual obligations to client companies, *Yael Acceptic* managers had to take prompt decisions to ensure the work of employees, primarily of developers-programmers.

Most of developers work at their homes, but under energy outage they can move to the central office, where the company has provided the opportunity to connect a certain number of laptops to a generator or to a backup battery. Both have limited capacity. One more possibility for the employees is to move to the nearest coworking centre, equipped by diesel generators and Starlink.

Problem articulation

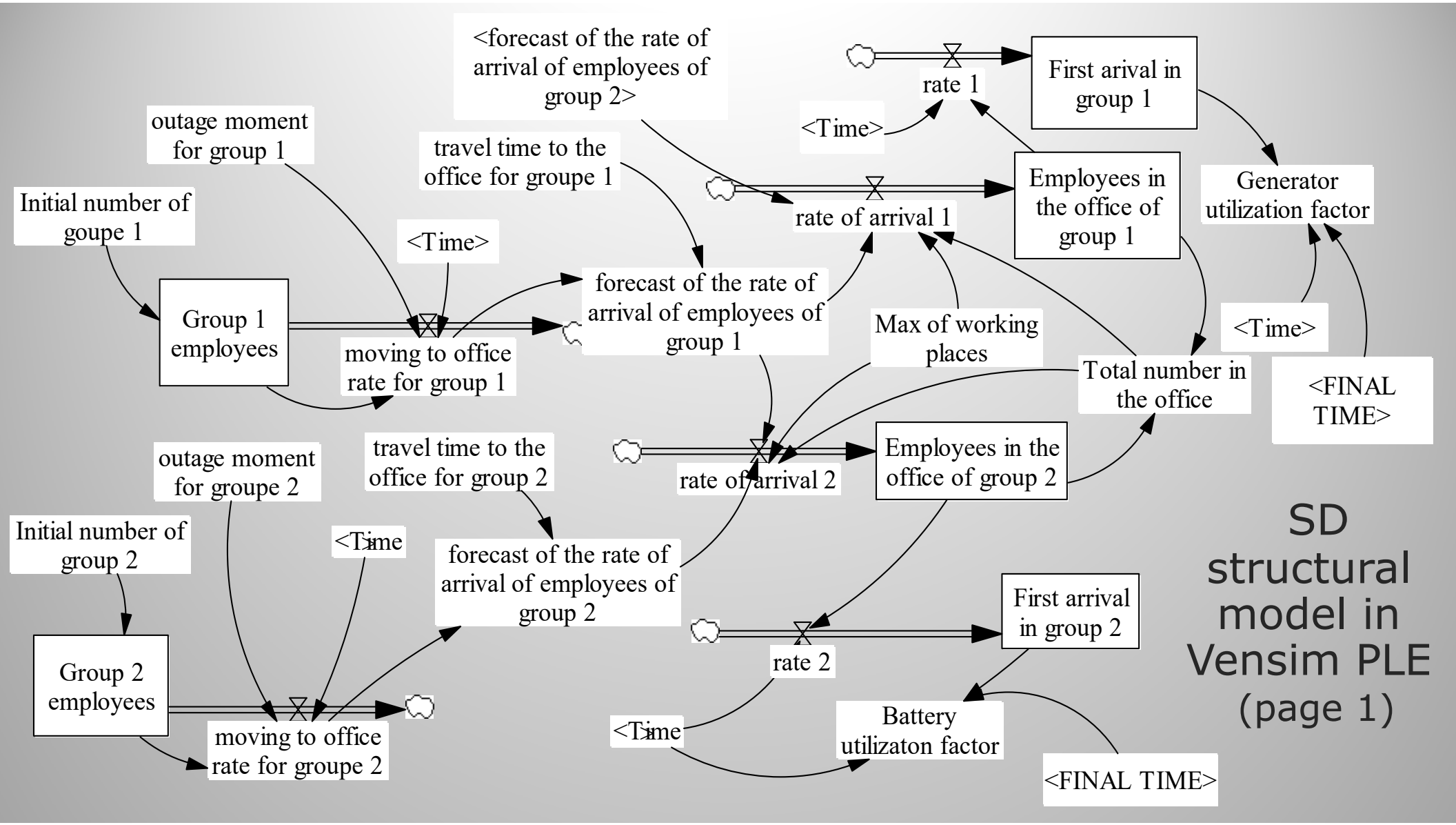
Since the task of substantiating the capacity of additional backup resources includes elements of randomness and uncertainty, we've used simulation technology as a flexible tool of formalizing and analysing the situation, taking into account various assumptions.

From the theoretical point of view, we thought it expedient to compare the effectiveness of using two fundamentally different concepts of simulation – a System Dynamics and discrete simulation ones, in relation to the same problem statement.

Though most of researches prefer SD concept in studying energy problems (including outages and blackouts), we've assumed that discrete simulation technology might be preferable for our case study.

Base model assumptions

1. All the company staff starts working at home and in case of energy outage moves to the office;
2. There are two groups of staff, differing from each other in the characteristics of the average time to get to the office (mean value and standard deviation); for each group a number of members is given;
3. Working places in the office (the number of connections to the generator and backup battery) are restricted – 15 and 5, accordingly; exceeding quantity of employees is considered not arrived;
4. If employees come to the office, they stay there til the end of the working day;
5. Moments of outages may be fixed or random; in a base model the employees of the first group are cut off from the very beginning of the working day, and those of the second group – two hours later;
6. Time step is a minute; final time – 480 (8 hours).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outage moment for groupe 2
rate of arrival 2
Employees in the office of group 2
Initial number of group 2
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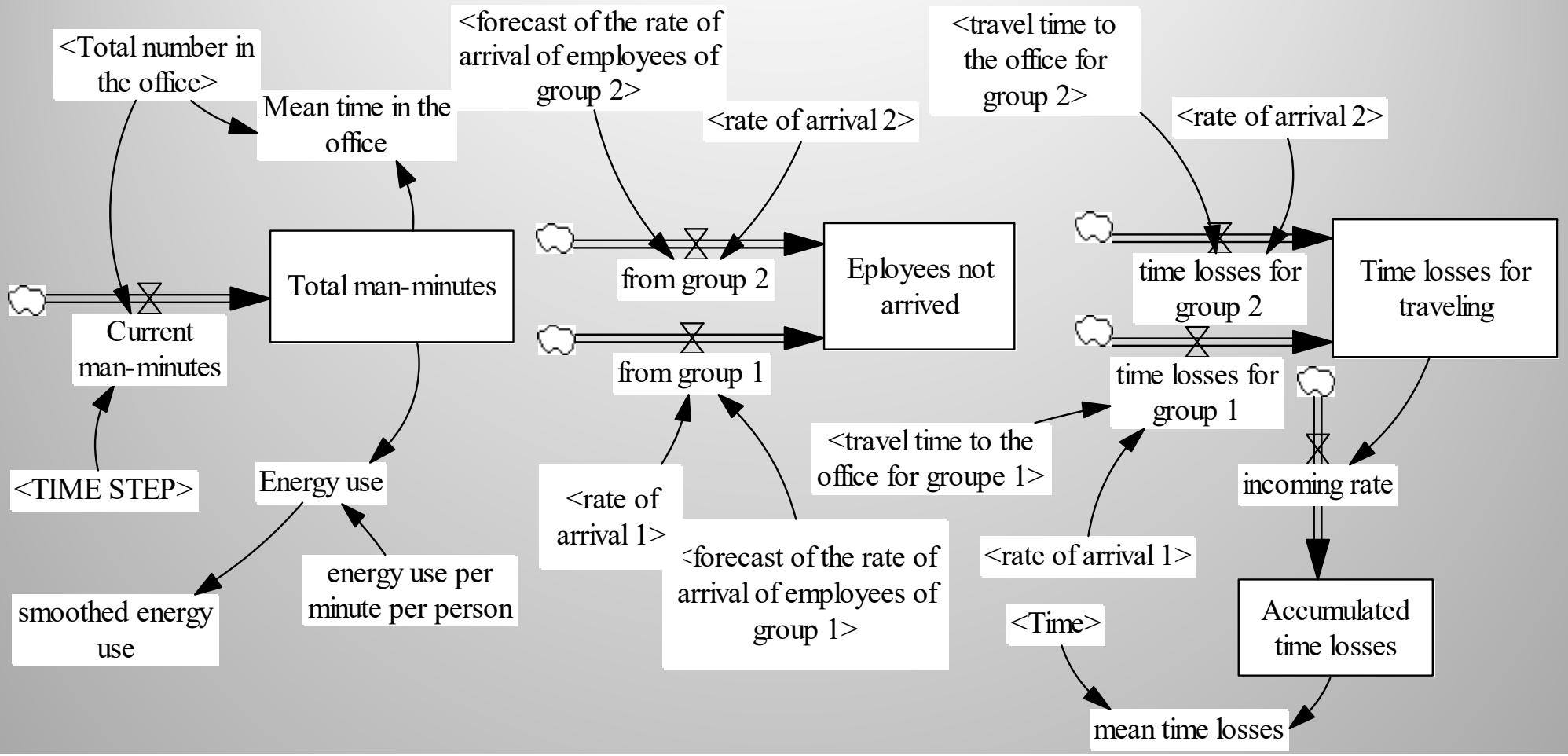
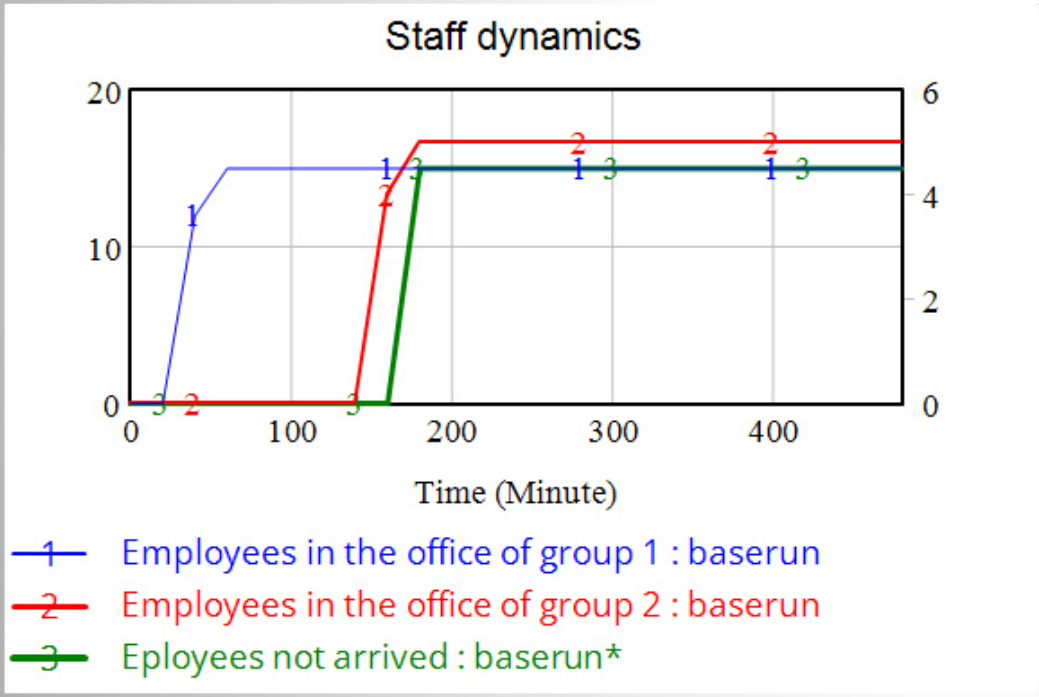
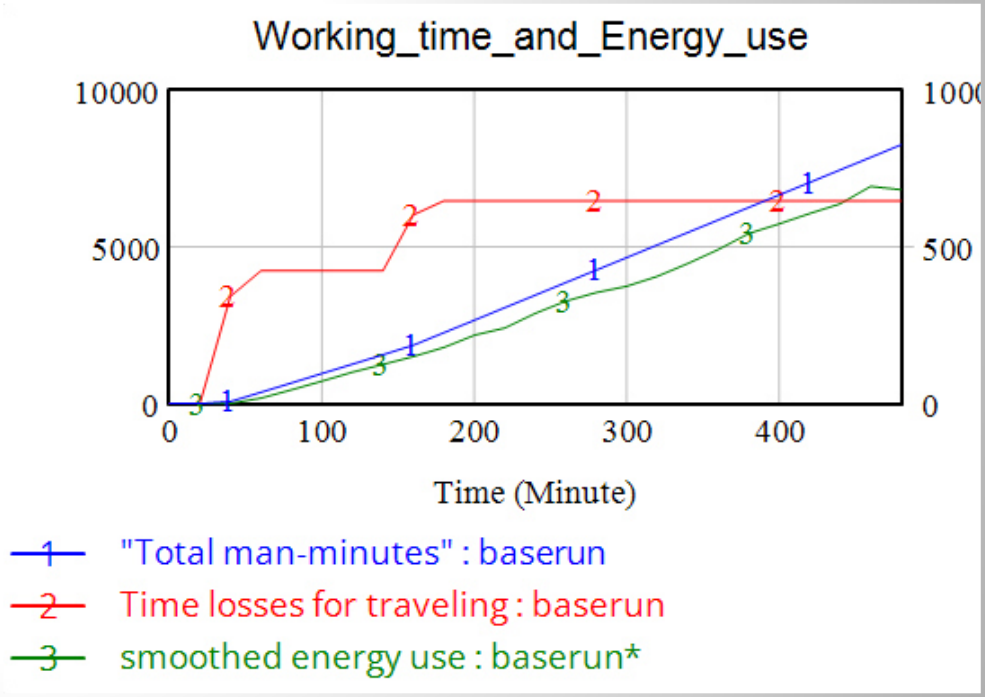
forecast of the rate of arrival of employees of group 2
First arrival in group 2
rate 2
Group 2 employees
Battery utilizaton factor
<Time>
moving to office rate for groupe 2
<FINAL TIME>
SD structural model in Vensim PLE (page 1)

SD structural model (page 2)

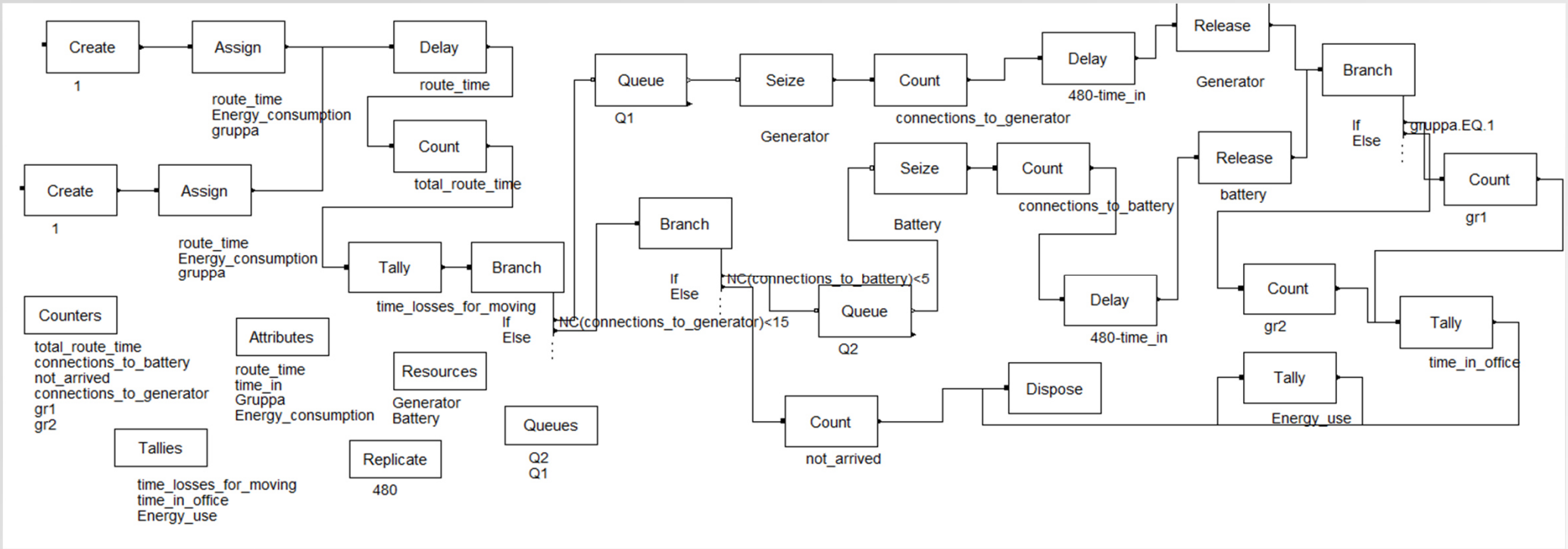


Control run results of the SD model





Discrete simulation model in Arena



Control run results of the DS model

ement	Value
Tallies	
Energy_use	Average Value: 14180.992376
Q1.WaitingTime	Average Value: 0.000000
Q2.WaitingTime	Average Value: 0.000000
time_in_office	Average Value: 412.055660
Average Value	412.055660
Standard Deviation	54.856405
Minimum Value	313.080299
Maximum Value	453.602971
Number Of Observations	20.000000
Last Recorded Value	318.100177
time_losses_for_moving	Average Value: 437.833037
Average Value	437.833037
Standard Deviation	219.265858
Minimum Value	24.000000
Maximum Value	692.738837
Number Of Observations	35.000000
Last Recorded Value	536.934121

Element	Value
Battery.NumberScheduled	Average Value: 5.000000
Battery.Utilization	Average Value: 0.667324
Average Value	0.667324
Standard Deviation	0.464628
Minimum Value	0.000000
Maximum Value	1.000000
Total Time Stats Collected	480.000000
Last Recorded Value	0.000000
Generator.NumberBusy	Average Value: 13.832365
Generator.NumberScheduled	Average Value: 15.000000
Generator.Utilization	Average Value: 0.922158
Average Value	0.922158
Standard Deviation	0.250185
Minimum Value	0.000000
Maximum Value	1.000000
Total Time Stats Collected	480.000000
Last Recorded Value	0.000000
Q1.NumberInQueue	Average Value: 0.000000
Q2.NumberInQueue	Average Value: 0.000000
CStats	
Counters	
connections_to_battery	Value: 5.000000
connections_to_generator	Value: 15.000000
gr1	Value: 15.000000
gr2	Value: 5.000000
not_arrived	Value: 15.000000
total_route_time	Value: 1276.000000

Simulation results comparison: SD vs DS

In general, the main results of both models are almost perfectly consistent (SD/DS):

- The number of Group 1 staff entering the office – 15 / 15 (person);
- The number of Group 2 staff entering the office – 5 / 5 (person);
- Number of staff who did not get to the office (from group 2) – 15 /15 (person);
- Total number of man-hours of work in the office – 137,41 / 137,33;
- Average time spent in the office per employee – 6,8 / 6,87 hours;
- Electricity consumption – 14,2 / 14,2 kWh;
- Maximum loss of time to get to the office – 10,8/11,5 (man-hour)
- Average loss of time to get to the office – 9 / 7,3 (man-hour);
- Average backup generator utilization rate – 0,67 / 0,67 (Dmnl) ;
- Average generator utilization rate – 0,93 / 0,92 (Dmnl).

Testing / experimenting with models

1. Changing the number of employees in groups;
2. Simultaneous power outage in both groups;
3. Random moments of power outages in the groups;
4. Random moments of outages in the afternoon and inexpediency of going to the office if there are less than two hours of working time left.

1

Counters	
connections_to_battery	Value: 5.000000
connections_to_generator	Value: 15.000000
gr1	Value: 10.000000
gr2	Value: 10.000000
not_arrived	Value: 10.000000
total_route_time	Value: 1150.000000

2

Counters	
connections_to_battery	Value: 5.000000
connections_to_generator	Value: 15.000000
gr1	Value: 12.000000
gr2	Value: 8.000000
not_arrived	Value: 15.000000
total_route_time	Value: 1229.000000

3

Counters	
connections_to_battery	Value: 5.000000
connections_to_generator	Value: 15.000000
gr1_battery	Value: 4.000000
gr1_generator	Value: 8.000000
gr2_battery	Value: 1.000000
gr2_generator	Value: 7.000000
not_arrived	Value: 15.000000
total_route_time	Value: 1271.000000

4

Counters	
connections_to_battery	Value: 5.000000
connections_to_generator	Value: 15.000000
gr1_battery	Value: 3.000000
gr1_generator	Value: 12.000000
gr2_battery	Value: 2.000000
gr2_generator	Value: 3.000000
less_than_2_hours	Value: 4.000000
not_arrived	Value: 11.000000
total_route_time	Value: 1131.000000

Comparison of models: SD vs DS

The advantages of the SD concept are:

- the ability to track the values of all variables at any time step
- special tools for model analysis

The advantages of DS concept are the ability to:

- assign attributes to active entities (employees),
- control the characteristics of resources utilization,
- provide automatic processing of statistics,
- track results depending on the entities' belonging to a certain group,
- quickly adapt the model to new conditions.

SD vs DS

No less important in comparing both concepts are the ease of adaptation and carrying out computer experiments.

The main adaptation options based on real conditions may include:

- greater number of groups – it’s no problem for both concepts;
- changing the moment of energy outages, including the possibility of random turn-offs (DS has certain preferences);
- taking into account the probability that not all employees will go to the office – (DS has preferences);
- taking into account the condition of the impracticality of going to the office, if there are less than 2 hours left before the end of the working day – much easier to realize using DS concept;
- changing resources capacities – DS concept has real advantages over SD one.

Conclusion

In our case study we see that both concepts are applicable for the formalization of the basic problem statement and provide plausible results. Although the main results of SD and DS models almost perfectly match each other, there's a significant difference in the effectiveness of these concepts in relation to the case study in question.

The main technical advantages of DS concept are the possibilities of assigning attributes to active entities (employees), to control resources utilization indicators and to use automatic processing of statistic data generated during the model run. "Personalization" of model entities through attributes allows (among other things) to trace the results depending on whether the entity belongs to a specific group.

Simulation model could be used in real time conditions to justify management decisions related to minimizing the total losses of the working time.

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