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T2: Extraction and Processing of Honey

Course IMS – Modelling and Simulation

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1 Introduction

This simulation study explores and compares two methods of honey extraction and processing. The first method is on-site extraction, where both the removal of full honeycombs from hives and the use of the honey extractor are performed at a single location. The second method, off-site extraction, separates these workstations to provide better conditions for the extraction process, at the cost of additional transport time between stations. Since honey extraction can only be performed a few times a year, the choice of method is critical and cannot be easily changed once the season begins, leaving little opportunity to experiment or switch approaches during the limited extraction period. Evaluation and understanding of each method's advantages and constraints are therefore essential before committing to a specific approach. Another question is when it becomes beneficial to introduce an additional beekeeper solely for transporting honey frames between stations. To model this process, a Petris net was created, and experiments were conducted using `SIMLIB` in `C++`.

1.1 Sources of Facts

The details of the honey extraction process were discussed with beekeeper Stanislav Novák[1], who has 40 years of experience in beekeeping in the Čergov Mountains of Slovakia. The consultant also provided videos of the extraction process to illustrate the procedure and to determine the duration of each task within the overall process for the model. Chosen videos are also available publically on Instagram: `@novak_med`. Another source of the facts of the process of honey harvest was a book outlining the beekeepers work [1].

2 Honey Harvesting Workflow

Honey harvesting is typically carried out at two stations: the **hive station** and the **extractor station**, with one specialized beekeeper assigned to each. The specific tasks performed at each station are described in the following sections. Additionally, a third beekeeper may be assigned to handle the transportation of honey frames between stations.

2.1 Hive Station

The beekeeper at the hive station must be highly skilled, as this work involves handling fragile hive structures and working directly with actively flying bees. This station is the starting point of the entire harvesting workflow. The beekeeper must ensure that only sufficiently capped and ripe frames are selected for extraction. His tasks are outlined below.

2.1.1 Opening Hives

The hive station consists of several beehives. The beekeeper opens the lid of each hive, removes the insulation layer, and lifts the protective net to access the honeycomb frames.

2.1.2 Removing Frames

The beekeeper removes the frames one by one, checks the amount of honey present, and shakes off the bees. Each frame is then placed into the transport, if it is available. Otherwise, the frame is temporarily placed on a stand. Once the transport becomes available, frames from the stand are loaded into it.

2.1.3 Returning Empty Frames to Hives

After the honey has been extracted and the empty frames are brought back to the hive station, the beekeeper returns them to the hives so that the bees can refill them with honey or pollen.

[1] Contact mail: `vcely.novak@gmail.com`

2.2 Extractor Station

The beekeeper at the extractor station must be proficient in operating the honey extractor and in handling all related processing steps. This includes carefully removing the protective wax layer from each frame (uncapping) and ensuring that the extraction proceeds smoothly without damaging the comb structure. His tasks are outlined below.

2.2.1 Unloading and Uncapping the Frames

When the transport brings full frames from the hive station, the beekeeper at the extractor station unloads them one by one. Each frame that is capped must be uncapped using a special uncapping fork. The amount of protective wax depends on how long the honey has ripened in the hive. After uncapping, the frame is placed directly into the honey extractor if space is available. Otherwise, it is temporarily placed on a designated shelf.

2.2.2 The Run of the Extractor

There is only one extractor at this station, and it has a limited capacity. The extraction cycle starts automatically once the required number of frames has been loaded, based on the extractor's weight sensor. After the first cycle finishes, it is possible that the honey has not been fully extracted due to its viscosity, which is influenced by the type of honey and the ambient temperature. In such cases, the extractor automatically initiates another cycle. After each completed cycle, the extracted honey is automatically drained into collection buckets.

2.2.3 Unloading the Extractor

When the extractor signals the end of the extraction cycle, the beekeeper proceeds to unload it. The emptied frames are placed into the transport box if it is available. Otherwise, they are stored on the shelf designated for empty frames.

2.2.4 Taking Out the Bucket

As mentioned in Section 2.2.2, the extracted honey flows directly into buckets. When a bucket becomes full, the beekeeper removes it and replaces it with a new, empty one. The extractor has sufficient buffer capacity to prevent overflow.

2.2.5 Straining the Honey

The extracted honey may contain unwanted particles such as wax fragments, drowned bees, or other impurities that entered the extractor or collection buckets. For this reason, the honey must be strained before further processing or storage. The start of the straining process depends on the resources available at the station, as discussed in more detail in Section 3.

2.2.6 Cleaning the Extractor

After all hives have been processed and all empty frames have been returned, the extractor must be thoroughly cleaned. The duration of this task depends on the resources available at the station, such as water access and cleaning tools. It is also influenced by the amount of honey remaining inside the extractor that has not yet been drained into the collection buckets. This residual honey is collected separately, filtered, and used for other purposes, such as mead production or as supplemental feed for bees during winter.

2.3 Transport

As the hives and extractor stations are separate, there needs to be a way to transport the frames between the two stations. The capacity of the transport as well as the time to reach the other station is based on the method used. There can optionally be an extra beekeeper just for transport. Otherwise, the beekeeper at extractor station also takes the frames there and back. The transport leaves for the other station immediately after the capacity is full, or after a certain amount of time passes without loading any new frames.

3 Strategies of Harvesting

In this study, two strategies of honey harvesting are considered: the **on-site** strategy and the **off-site** strategy. Both approaches follow the same basic workflow, but differ primarily in the location of the extraction station and the resources available at each site.

Under the on-site strategy, both the hive station and the extractor station are located at the same place or within very close proximity. The main advantage of this setup is the minimal transport time, as frames can be moved using hand-pulled trolleys with little delay. However, the capacity of these trolleys is limited, and the beekeeper must manually transport them. Another disadvantage of the on-site strategy is the limited availability of resources in the forest environment, such as running water or sufficient electrical power. As a result, cleaning the extractor takes significantly longer than in the off-site case. Additionally, straining of the extracted honey can only begin after all hives have been processed, since the necessary equipment and space are not available at the hive station.

In the off-site strategy, the extractor station is located within a village or other inhabited area. Although the travel time between the hive station and the extractor station is significantly longer, transportation is carried out by car, allowing for a much larger transport capacity. Access to running water, pressure washers, and other tools makes extractor cleaning considerably faster and more efficient. Moreover, honey straining can begin immediately after each bucket is filled, rather than being postponed until the end of the entire extraction session. This reduces idle time and allows more continuous processing of honey.

In Section 6, these two strategies are compared in detail to determine whether switching from the currently used on-site method to the off-site method would be beneficial, or whether the advantages of the off-site approach fail to outweigh its drawbacks.

4 Model

In order to perform simulation, a model of the system was created. Petri net was used for the conceptual model, as it is the standard for queuing systems [2]. It also allows us to model the parallel work and tasks of the beekeepers on separate stations. It was created with focus on following the description of the workflow by the consultant. However, some parts were simplified, as they would have no effect on the question to be answered, as yield same slowdowns in both strategies. These include:

- The multiple layers of hive opening are merged into a single task.
- The extractor starts only when it reaches full capacity, therefore:

$$\texttt{num(frames in apiary)} \bmod \texttt{capacity(extractor)} = 0$$

- The amount of honey per extraction cycle is assumed constant.
- The percentage of fully-capped honeycombs and the number of extractor cycle repeats are based on the average from the last four years.
- Beekeepers must finish their current task before beginning another.

- Shelves and stands have infinite capacity (in reality, the capacity is always sufficient for all possible frames, as they are stored there during winter).

4.1 Concept

The Petri net is designed to accommodate both beekeepers (one at hives station, one transporting and extractor station), as well as a version with one extra beekeeper only for transport.

Each beekeeper is modeled as a facility, with each task seizing the beekeeper when the conditions are met. To track the position of the transport (hive station, extractor station, or in transit), two additional facilities are used, ensuring that the token occupies at most one facility at a time. Timed transitions use placeholders, as the exact durations may vary depending on the strategy.

The illustration of the Petri net is split across multiple figures for readability: Figures 1 and 2. The meaning of the colors used in the figures is as follows:

- **Green** – on-site strategy only
- **Blue** – transport
- **Red** – extractor beekeeper also serves as the transport beekeeper
- **Orange** – dedicated transport beekeeper

4.2 Implementation

To perform experiments from Section 6, the model was implemented in `C++` using `SIMLIB` [3] library. Strategy pattern was used in order to share the base components used by both strategies. The constants for timed transitions, capacities and counters are defined in respective namespaces.

As already mentioned, the beekeepers are modeled as facilities, using `Facility` class. Each tasks for the beekeepers use `Process` as their parent class, with defined behavior. To easily switch between modes with separate beekeeper for transport and without it, the facility for beekeeper at extractor station and transport beekeeper at extractor station are inicialized in the strategies. When there is no separate beekeeper, there is only one object for the facility of both.

`Stores` are used as well, specifically for transport – either trolley or car. Explicit queue is used for the buckets of honey waiting for straining in the on-site strategy, where the processes of straining are passivated in it, until activated in loop when all frames are returned to the hives.

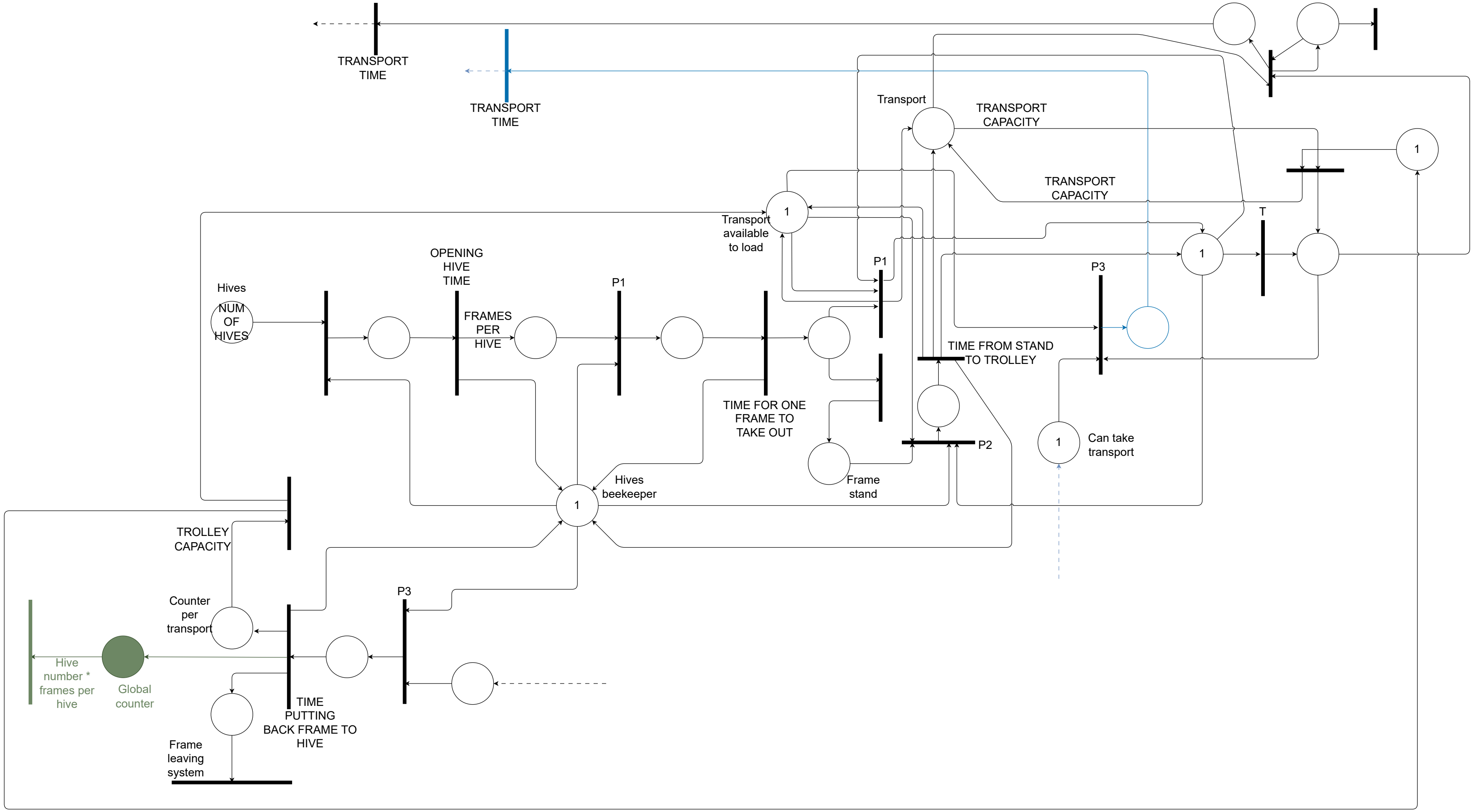

Figure 1: Petri net for hives station

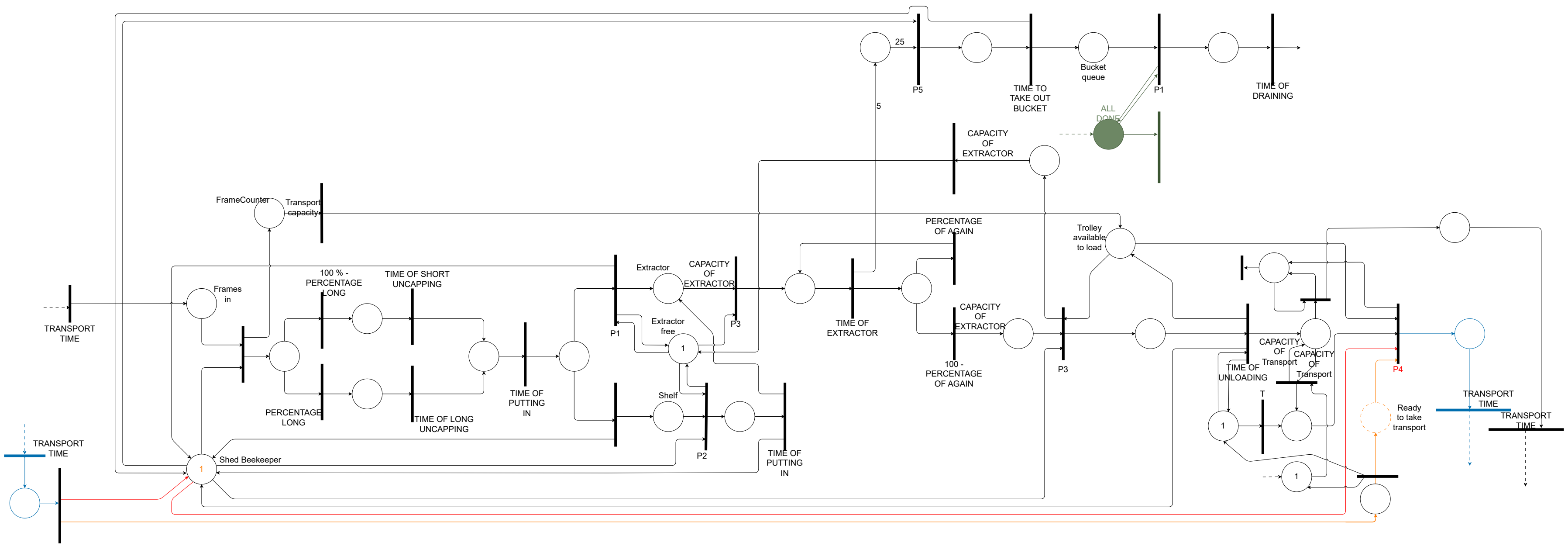

Figure 2: Petri net for extractor station

5 Running the Simulation

After compiling the project, the simulation can be executed using the resulting `simulation` binary. The program accepts several command-line parameters that control the harvesting strategy, the presence of a dedicated transport beekeeper, and the number of hives to be processed. Verbose output is optional.

5.1 Command-Line Interface

The general usage pattern is:

```
./simulation <on|off> [true|false] [-v] [hives]
```

The meaning of the arguments is as follows:

- `on` – runs the on-site extraction strategy. This mode requires an additional boolean argument specifying whether a dedicated transport beekeeper is present:
  - `true` – transport is handled by a separate beekeeper,
  - `false` – the extractor-side beekeeper also performs transport.
- `off` – runs the off-site extraction strategy. No additional boolean argument is required.
- `-v` – optional flag enabling verbose mode. When enabled, the program prints diagnostic information such as the number of hives being processed and details of the simulation flow to the standard error.
- `hives` – optional integer specifying the number of hives to open. If omitted, the default value from `BaseConstants` is used.

5.2 Examples

On-site strategy without a dedicated transport beekeeper:

```
./simulation on false
```

On-site strategy with a dedicated transport beekeeper, verbose mode, 30 hives:

```
./simulation on true -v 30
```

Off-site strategy with default hive count:

```
./simulation off
```

Off-site strategy with verbose output and 40 hives:

```
./simulation off -v 40
```

5.3 Output

Upon execution, the simulation initializes the selected strategy, prints optional verbose information (if enabled), and runs the model until all frames are processed and returned to the hives. The simulation outputs total completion time and, when compiled with statistics enabled, reports facility and queue metrics for further analysis.

6 Experiments

Using the program described in Section 4.2, multiple experiments were performed. They are described in further detail below. After preliminary testing, the total simulation time horizon was set to **10 hours** for on-site strategy and **11 hours** for off-site strategy, where one unit of simulation time corresponds to one real second.

6.1 Model Validation Experiment

To validate the model, the configuration was set to reflect the current on-site strategy used by the consultant. The main parameters were:

- **Hives:** 40
- **Frames per hive:** 5
- **Extractor capacity:** 5
- **Trolley capacity:** 10
- **Separate beekeeper for transport:** no

The simulation was executed 100 times and consistently concluded with all frames returned to the hives and all buckets strained. The average completion time was approximately **8 hours and 20 minutes**, which matches the range provided by the consultant (8–8.5 hours). The model is therefore considered valid for further experiments.

6.2 On vs Off-site Strategies Experiment

Our primary focus regarding this experiment was to confirm a long-asked question in the Čergov Mountains beekeeping community. The question is as follows. Is it more time efficient to have the extractor station at home, where a beekeeper has better access to cleaning facilities? Or is it better to have it next to the hive station, typically located in a forest, where you only have access to limited cleaning facilities.

- **Hives:** variable for each run (1–40)
- **Frames per hive:** 5
- **Extractor capacity:** 5
- **Trolley capacity:** 10

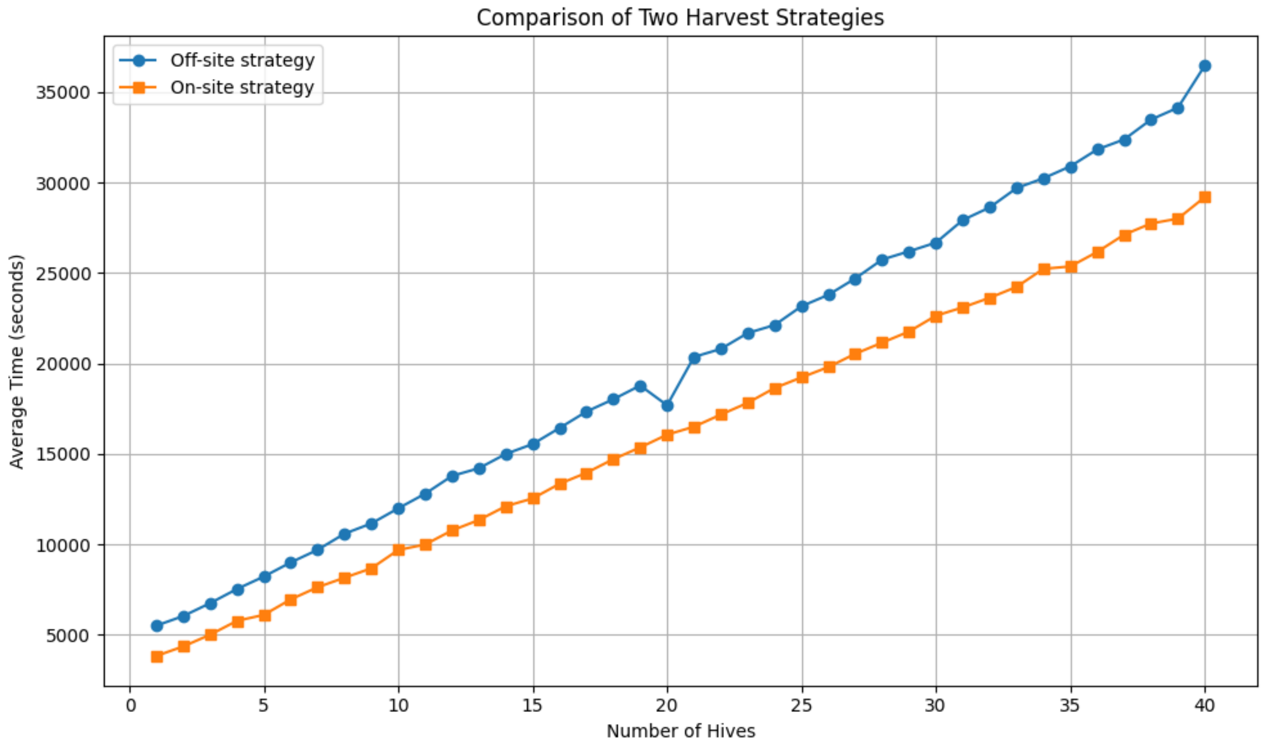

Figure 3: Comparison of total harvest time on and off site

6.3 Separate Beekeeper for Transport Experiment

This experiment focuses on determining when it becomes beneficial to add an extra beekeeper solely for transport. According to the consultant, the threshold for a significant benefit is **20 minutes**. The maximal number of hives was chosen to be 40, as it is the number of hives the consultant has on his apiary. The simulation was executed with the following parameters:

- **Hives:** variable for each run (1–40)
- **Frames per hive:** 5
- **Extractor capacity:** 5
- **Trolley capacity:** 10
- **Separate beekeeper for transport:** yes/no

From the plotted results shown in Figure 4, it can be observed that for harvests of 22 or more hives, it is consistently beneficial to assign an additional beekeeper to handle transport.

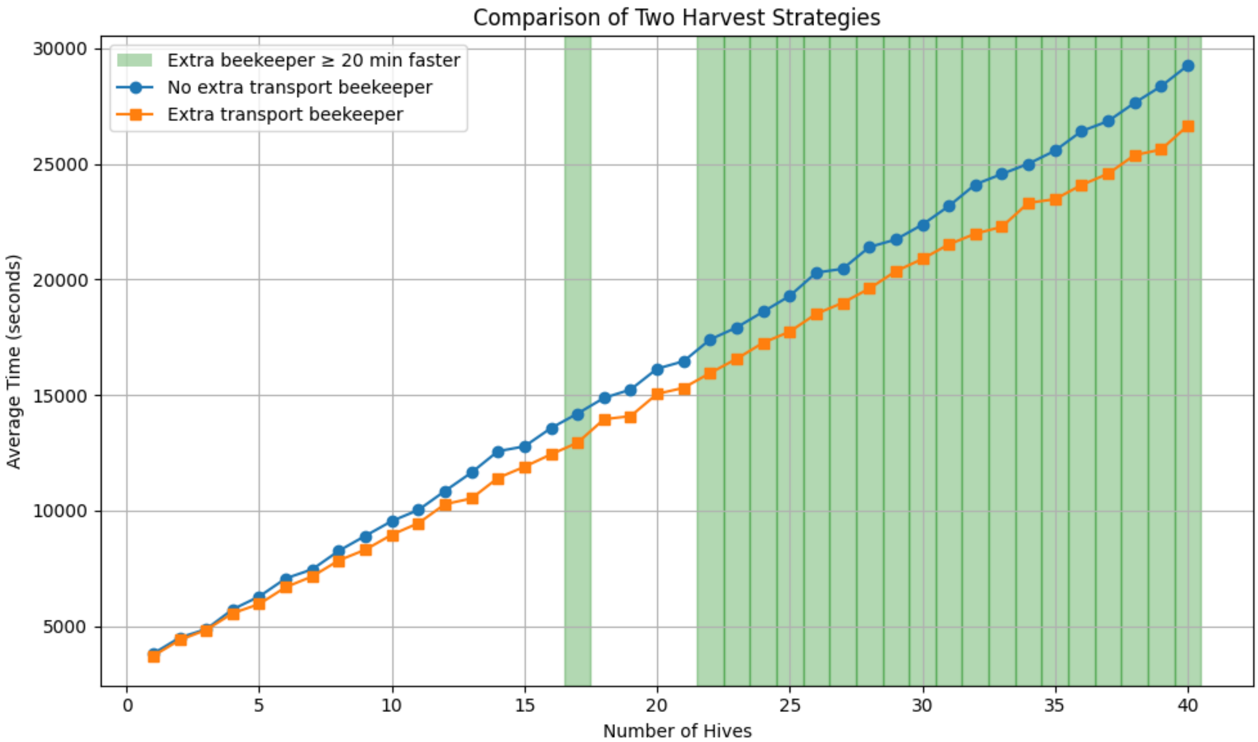

Figure 4: Comparison of total harvest time with and without an extra transport beekeeper

6.3.1 Utilization Experiment

To better understand how the introduction of a dedicated transport beekeeper influences system performance, we conducted a utilization-focused experiment. The goal was to compare the workload distribution between the hives-side beekeeper and the extractor-side beekeeper, as well as to observe changes in queue behavior. Table 1 summarizes the key facility and queue metrics for both scenarios.

Table 1: Comparison of Facility and Queue Statistics With and Without Transport Beekeeper

	Without Transport Beekeeper		**With Transport Beekeeper**	
Metric	**Hives**	**Extractor**	**Hives**	**Extractor**
Facility statistics				
Number of requests	630	659	630	612
Average utilization	0.394376	0.829123	0.393708	0.448467
Queue statistics				
Incoming	599	652	603	564
Outcoming	599	652	603	564
Maximal length	44	16	46	15
Average length	5.17632	3.4041	5.66331	1.73091
Minimal time	0	0	0	0
Maximal time	6908.4	578.089	7406.3	490.189
Average time	311.097	187.956	338.108	110.484
Standard deviation	975.313	156.863	1080.1	117.489

From the results, it is evident that introducing an additional transport beekeeper significantly reduces the load on the extractor-side operator, lowering both average queue length and waiting time. However, the hives-side beekeeper shows only marginal changes in utilization, indicating that this part of the workflow remains the primary bottleneck in both setups. Overall, the dedicated transport beekeeper improves flow uniformity and reduces congestion at the extractor, but does not fully eliminate delays caused upstream at the hives.

7 Conclusion

This study explored multiple approaches to honey extraction and harvesting. The entire process and tasks were modeled using a Petri net and simulated with the `SIMLIB` library. Simulation results indicate that, even though the off-site strategy allows for significantly shorter cleaning times and enables straining of the extracted honey immediately after bucket removal, the additional transport time still slows down the overall process, even when using a large-capacity vehicle.

For the on-site strategy, it was demonstrated that when harvesting from more than 22 hives, it is beneficial to assign an additional beekeeper specifically for transporting full and empty frames between stations. This additional resource effectively reduces overall completion time and improves workflow efficiency for larger apiaries.

References

1. CHADWICK, F.; ALTON, S.; TENNANT, E.S.; FITZMAURICE, B.; EARL, J.; PETRUSOVÁ, H. *Velká kniha včelaření*. Knižní klub, 2018. Universum (Knižní klub). ISBN 9788024262413.
2. *Modelování a simulace – prezentace k předmětu* [`https://www.fit.vut.cz/person/peringer/public/IMS/prednasky/IMS.pdf`]. 2025. [visited on 2025-12-05].
3. PERINGER, Petr. *SIMLIB* [`https://www.fit.vut.cz/person/peringer/public/SIMLIB/`]. 2025. [visited on 2025-12-05].