Management and Production Engineering Review
Volume 15 • Number 1 • March 2024 • pp. 169–181
DOI: 10.24425/mper.2024.149998

The Optimal Routing of Raspberry Pickers in an Analytical and Simulation Approach

Ireneusz KACZMAR[1], Tamás BANYAI[2]

[1] *State University of Applied Sciences in Przemyśl, Institute of Technical Sciences, Poland*
[2] *University of Miskolc, Institute of Logistics, Hungary*

Received: 06 November 2023
Accepted: 24 December 2023

Abstract
The purpose of the work presented here is a comparative analysis of two methods of solving the problem of optimizing the working time and path length of operators for manual harvesting of raspberries over an area of one hectare. An analytical solution is a method of solving mathematical problems based on finding an exact formula that describes a phenomenon or process. A simulation solution is the opposite of a numerical solution, which is based on calculating an approximation using statistical methods. An analytical and simulation approach will be presented to show how to calculate the number of workers needed, the minimum working time and the length of the path taken by raspberry fruit pickers. The results obtained for the two methods are compared.

Keywords
raspberries, harvest optimization, shortest path simulation, flexsim, raspberry cultivation.

Introduction

The main objective of the presented work is a comparative analysis of two methods of solving the problem of optimizing the time and path length of operators for manual harvesting of raspberries in a field of one hectare. Analytical solution is a method of solving mathematical problems that involves finding an exact formula to describe a phenomenon or process. It is often used in mathematics, physics and other sciences where it is possible to formulate an equation that describes the phenomena under study. The simulation solution is the opposite of the analytical solution, since it is based on calculating an approximation using statistical distributions. An analytical and simulation approach will be presented to show how to calculate the number of workers needed and the length of the path taken by raspberry fruit pickers. Studies have shown that the best strategy for pickers is to move workers along an S-shaped field area. Similar results were obtained for both methods, indicating that the assumptions made are correct.

***Corresponding author**: Ireneusz Kaczmar – State University of Applied Sciences in Przemyśl, Institute of Technical Sciences Przemyśl, Poland, phone: +4816 735-51-78, e-mail: i.kaczmar@pansp.pl*

Research background

Professional raspberry fruit plantations currently show great development potential and are characterized by better and better production economics. This is because the interest in, and consumption of, soft fruit is constantly increasing (Vereecken, 2015). The awareness of consumers and their eating habits are changing, the consumption of fruit and vegetables is increasing, and consumers are paying more and more attention to organic food.

The choice of the topic is justified because the market and consumption of berry fruits show a steady growth trend. Based on published data (Faostat, 2020), it was found that the main producers of raspberries in the world in 2019 were: Russia (174 thousand tons), Mexico (129 thousand tons), Serbia (120 thousand tons), USA (103 thousand tons) and Poland (76 thousand tons). The share of Poland in global raspberry production was 9%. However, data from 2020 show that in the European Union, Poland is the leader in the raspberry production market with 51% market share, followed by Spain with 22% market share and Portugal with 12% market share of raspberry production, followed by Germany, Bulgaria, France, and the Netherlands.

Today, in large-scale industrial berry cultivation, raspberries are produced in UV-protected tunnels. The fruit is grown in pots set on heaps of soil covered with farm cloth to prevent weed growth. High yields are obtained by using seedlings of the long cane type. Long cane seedlings produce shoots from 1.5 to about 2.2 meters in length, so they require controlled conditions on the farm. As a standard, the seedlings grow in 7-liter pots on appropriate substrates, which are individually selected by the farm management. Field cultivation is also possible but pot cultivation provides better control of environmental parameters (Babik, 2002; Nowosielski, 1995; Sønsteby at al., 2009 and others).

A big problem for farms is the optimization of manual raspberry harvesting. It is difficult to plan the optimal number of employed pickers during the bush yielding period. Another important problem is to determine the optimal route for employees, so that the routes they cover are the shortest. Answers to the questions can be obtained using analytical and simulation methods. The existing methods will be presented later in this work.

Literature review

A review of scientific databases indicates a small number of publications on professional raspberry production. No publications were found describing the optimization of manual harvesting of soft fruits using computer simulation. In the most popular database of scientific works, Web of Science (WoS), 594 records were found for the phrase "production of raspberry fruit". Based on these statistics, it can be concluded that there is much to be done in this field of science. Figure 1 shows the classification of published works divided into the 10 most popular scientific categories (according to WoS) in which the authors published their works.

Figure 1 shows that the most important positions are as follows: in the first place – the category of agriculture – 63.13% of all publications, in the second place – plant science – 15.85% of publications, in the third place – food technology – 17% of publications. It should be noted that one published paper may be indexed in more than one science category, so the categories do not add up to one hundred. In other categories of science, a much smaller number of scientific papers were shown.

However, in the case of a database query for the phrase "optimization of the raspberry harvest", only 7 results were obtained (WoS). There is a large research gap in this area and the choice of topic is justified. There are three well defined research fields in the case of raspberry picking literature. The first research area focuses on optimizing, automating and robotizing berry harvesting processes for example : A Berry Picking Robot With A Hybrid Soft-Rigid Arm: Design and Task Space Control (Uppalapalti et al., 2020); Simulation of Multi-Agent Architectures for Fruit and Berry Picking Robot in Active-HDL (Kiktev et al., 2021); Route optimization in mechanized sugarcane harvesting (Santoro et l., 2017); Optimized routing on agricultural fields by minimizing maneuvering and servicing time (Spekken and Bruin, 2013); Evolutionary neighborhood discovery algorithm for agricultural routing planning in multiple fields Utamima et al, 2022); Route planning for agricultural tasks: A general approach for fleets of autonomous vehicles in site-specific herbicide applications (Conesa-Muñoz et al., 2016).

The second research area focuses on the economical impact of berry picking including legal aspects (eg. property): Property rights in conflict: wild berry-picking and the Nordic tradition of allemansrätt (La Mela, 2014); Commercial wild berry picking as a source

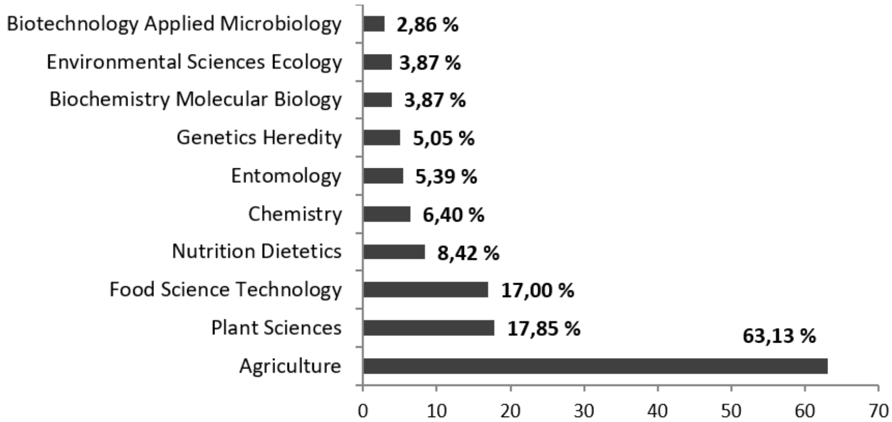

Fig. 1. Percentage of works in scientific areas for the phrase "production of raspberry fruit" in the WoS database. Source: own study

of income in northern and eastern Finland (Kangas, 2001); Changes in wild berry picking in Finland between 1997 and 2011 (Varra et al., 2013); Ruptures and acts of citizenship in the Swedish berry-picking industry (Mešić and Wikström., 2021); Factors affecting participation in wild berry picking by rural and urban dwellers (Kangas and Markkanen, 2001); Finding nineteenth-century berry spots: Recognizing and linking place names in a historical newspaper berry-picking corpus (La Mela et al., 2019).

The third research area focuses on the social impact of berry picking including health issues for example: Berry Plants and Berry Picking in Inuit Nunangat: Traditions in a Changing Socio-Ecological Landscape (Boulanger-Lapointe et al., 2019); Recreational wild berry picking in Finland – Reflection of a rural lifestyle (Pouta et al., 2006); Greater local recurrence occurs with "berry picking" than neck dissection in thyroid cancer (Musacchio et al., 2003).

Materials & Methods

The research was conducted on a large farm located in northern Poland, specializing in professional raspberry fruit production in tunnels. Basic quantitative parameters of the studied plantation:

- section area – 1 ha
- row length – 120 m
- number of rows – 30 rows
- number of bushes per hectare – 8400 pcs
- running meters of rows – 3600 meter
- spacing of seedlings per running meter approximate 2 – 2.5 pots

The method of arranging raspberry bushes in a single tunnel is shown in Figure 2.

A scientific approach to the optimization of the raspberry production process requires the identification and study of the influence of factors relevant to the process in a comprehensive manner. The general scheme of routes for raspberry pickers is shown in Figure 3.

Pickers move along the rows in both directions, when they reach the end of a row they can move to the next row (Figure 3). If the cart is full, they transport the fruit to the weighing point and return to the place where they finished picking raspberries. Additional parameters necessary for modeling the process, were estimated on the basis of empirical observations on the plantation and concern that pickers can only move along the rows, a unit portion of raspberries is a container containing 125 grams of raspberry fruit. The box can hold 12 containers weighing 125 grams. The capacity of the cart is 48 containers, that is 4 boxes.

Fig. 2. Realistic photo of hand harvesting raspberries using a cart

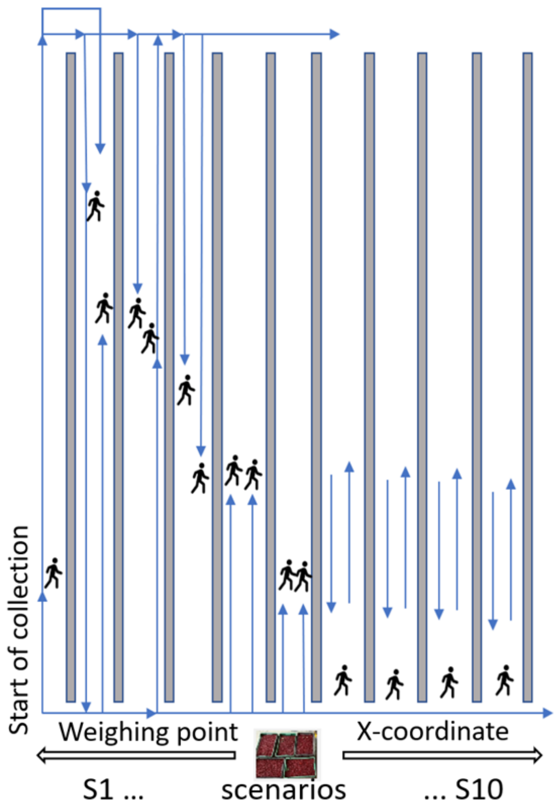

Fig. 3. Different ways for operators to move along rows of raspberry bushes

The standard team of pickers 21 workers, the area of the field under study is one hectare. At the shorter edge of the field there is a weighing point of the harvested fruit to which workers bring raspberries. The number of carts per operator is 1 cart. The time of filling a 125g container [s] was estimated on the basis of the observance of the work of pickers on the raspberry plantation. In this case, a triangular distribution with parameters: triangular (45. 90. 60) was assumed.

The average speed of the pickers in the simulation model is 0.55 m/s (3 km/h). This speed was estimated based on observations of workers in the plantation, and a normal distribution was assumed with a mean of 0.55 and a standard deviation of 0.05 m/s.

The estimated amount of fruit per hectare is the number of bushes × number of containers per bush.

In the following part of the article, a simulation and analytical method will be presented to solve the problem at hand. The results obtained by the two methods will be compared in the conclusion.

Simulation approach

A computer analysis will be conducted using optimization algorithms to find the optimal number of workers employed and the shortest path of movement for raspberry pickers. The research tool is a 3D computer model of a crop field (a set of tunnels), developed in the FlexSim General Purpose environment, and the optimizer is OptQuest. This advanced computer model was designed to simulate the processes occurring in a virtual plantation. The research method used is a simulation experiment with changing model input parameters. Input parameters such as the speed of workers and the speed of filling containers are distributed using statistical distributions, which were estimated from empirical studies in the field. An average yield of 10 containers per bush was assumed, giving a total of 1050 kg per hectare.

The optimization of the paths of the pickers is done using the Dijkstra algorithm (Javaid, 2013; Yuliani, 2021), the pseudo-code of which is presented in the following steps:

1. Set start node to have distance 0 and all other nodes to have distance infinity
2. Set priority queue Q to contain all nodes
3. While Q is not empty:
   a. Remove node u with the smallest distance from Q
   b. For each neighbour v of u:
      - Calculate the distance to v through u
      - If this distance is less than the current distance to v, update v's distance
   c. If the destination node has been visited, exit the loop
4. Return the distances to all nodes from the start node

The simulation model (Figure 4) that was designed to carry out the study is shown in the form of a block diagram. Printing the source code is not possible due to the volume of the work. The model consists of a number of modules. The first three modules (from the top) are responsible for the formation of raspberry fruit on the bushes. Subsequent elements of this block diagram perform the function of harvesting and transporting fruit to the weighing point. The point of weighing and receiving the fruit from the workers is located at the beginning of the section, from where the pickers begin their work.

Optimization of working time and mileage traveled by employees will be realized with the OptQuest optimizer, which is built into the FlexSim environment. The OptQuest optimizer was developed and is constantly being improved by OptTek Systems, which specializes in providing solutions for various industries, including manufacturing, transportation, healthcare and the military. The proposed tool uses metaheuristics and neural networks to optimize employee schedules and minimize work time. After pre-testing several scenarios for moving workers across the field surface, a rule for moving workers according to S-shape was selected. This rule was chosen because pickers cannot walk across the rows, they can only move along the rows with raspberry fruit. If they reach the end of the row they move to the next row and their route resembles the letter S.

The movements of the pickers are coded in the block diagram shown in Figure 4. Computer visualization of the harvesting process in a one-hectare field is shown in Figure 5.

In the computer model shown in Figure 4, a global list, which performs the function of a database storing program events, was used. The database supports the SQL language standard. In addition to the program logic, which maps the behavior of people and infrastructure, the program calculates the required indicators needed to optimize the harvesting of fruit on the plantation. The visualization of people's work is done in real time in 3D space. This allows decision makers to observe the movements of operators (Figure 5).

The designed simulation model of a raspberry field can be compared to a so-called black box, which can contain n input variables and m output variables. Optimizing a process using the simulation method entails finding the best configuration of input variables that optimize the system's response. Optimization usually involves maximizing or minimizing a selected parameter. After each simulation model is built, it should be validated, that is, its suitability for the selected application should be evaluated. The design of experiments and further data analysis can only

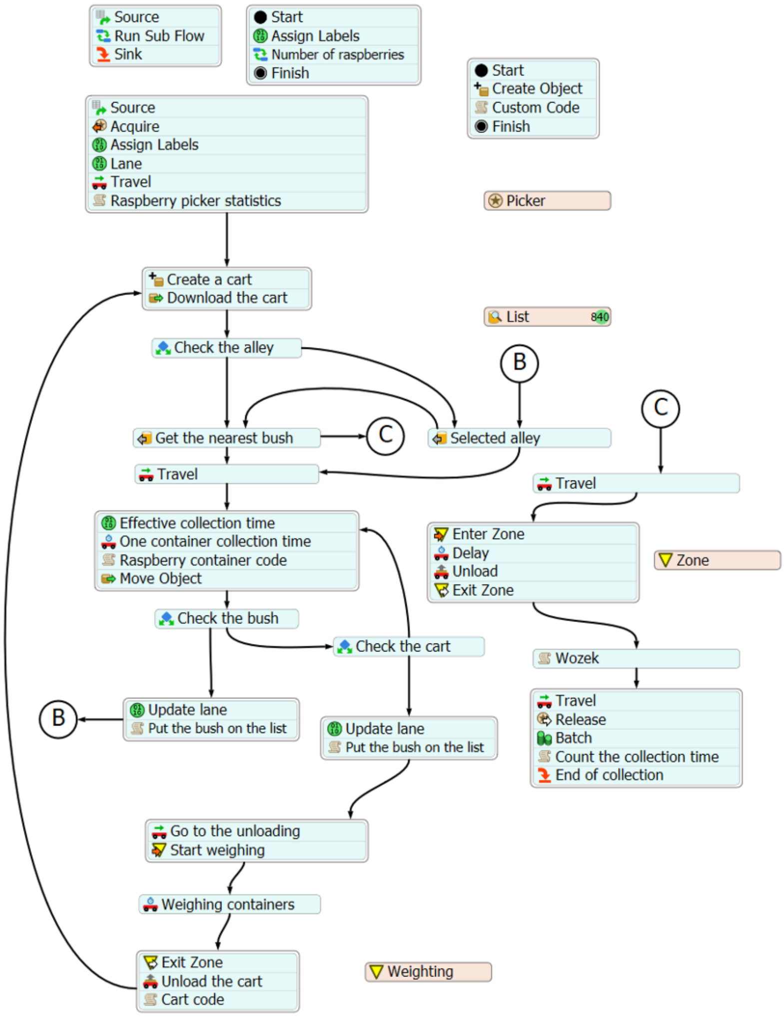

Fig. 4. Block diagram of the simulation model for manual fruit picking

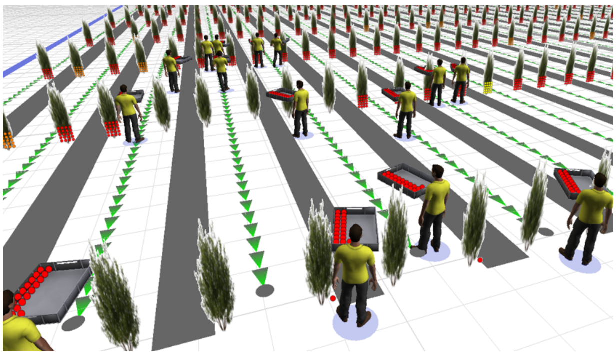

Fig. 5. Visualization of the harvesting process in computer simulation

be continued if the model is found to represent the reality correctly. The designed simulation model has been validated as it realistically replicates processes on a real raspberry plantation.

Analytical approach

The length of the optimal route can be defined depending on the geometry of the raspberry field, the specific raspberry output, and the picking capacity of raspberry pickers. In the case of a simple one-sided geometry, the optimal total length can be defined as follows:

$$L_{1S} = \sum_{j=1}^{m} \sum_{i=1}^{\frac{q \cdot l}{c}} \frac{2 \cdot i \cdot l}{r} = \sum_{j=1}^{m} \sum_{i=1}^{\frac{q \cdot l}{c}} \frac{2 \cdot i \cdot c}{q}, \tag{1}$$

where L_{1S} is the optimal length of the raspberry picking route in the case of a one-sided raspberry field with m floors, m is the number of floors of the raspberry field, q is the specific raspberry output in [kg/m], l is the length of a floor in [m], c is the upper limit of loading capacity of a raspberry picker in [kg/picking round] and r is the number of required picking rounds for one floor and

$$r = \frac{q \cdot l}{c} \tag{2}$$

In the case of a two-sided geometry, the optimal total length can be defined as follows:

$$L_{2S} = 2 \cdot \sum_{j=1}^{m} \sum_{i=1}^{\frac{q \cdot l}{2 \cdot c}} \frac{2 \cdot i \cdot l}{r} = 2 \cdot \sum_{j=1}^{m} \sum_{i=1}^{\frac{q \cdot l}{2 \cdot c}} \frac{2 \cdot i \cdot c}{q}, \tag{3}$$

where L_{2S} is the optimal length of the raspberry picking route in the case of a two-sided raspberry field with m floors. Source of presented formulas – own study.

Figure 6 shows the proportion of the optimal length of picking routes of one-sided and two-sided raspberry fields. The trend analysis based on linear, exponential and polynomial trend lines shows that the upper limit of route length reduction resulted by the two-sided picking field geometry is 50%.

The one-sided and two-sided geometry of raspberry picking fields are shown in Figure 7.

Results from the simulation approach

For a simulation run on a computer model of a one-hectare field, the average distance per operator (calculated in meters) for a process march along the raspberry fruit rows is shown in Table 1. The following is a quantitative analysis of the productivity of a team of 21 workers with an expected yield of 10 raspberry servings per bush, resulting in a total yield per hectare of 1,050 kilograms of fruit. For a single run of the model to simulate fruit harvesting, the following averaged results were obtained:

- Total number of raspberry portions [125 g] is 8400 portions
- Class I 7320 portions
- Class II 640 portions
- Waste 440 portions
- Total collection time with transport [h] 9.49
- Portion collection time per all workers [s] 546399.53
- Effective time per operator [h] 7.23

After simulating the working day of fruit harvesting for a single run of the model, data were also obtained on the distance per picker, the number of carts completed and the number of raspberry portions harvested (Table 1).

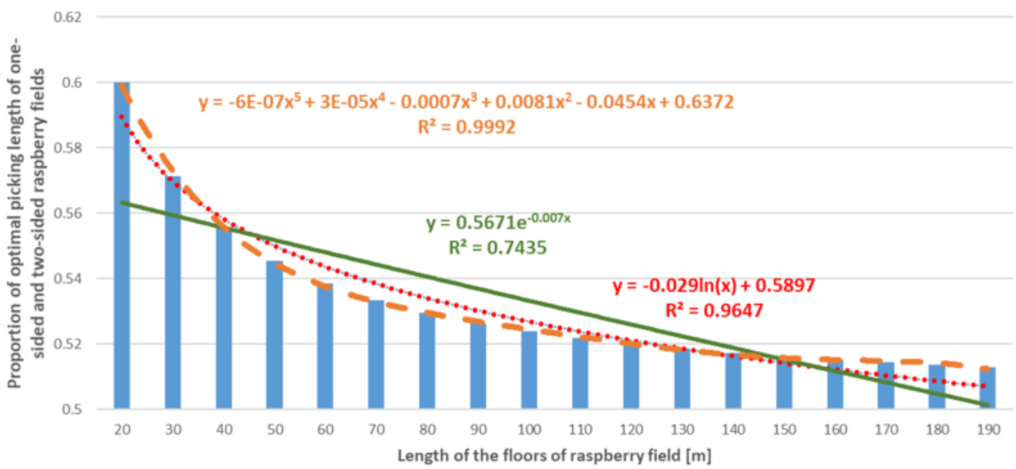

Fig. 6. The proportion of the optimal length of picking routes of one-sided and two-sided raspberry fields

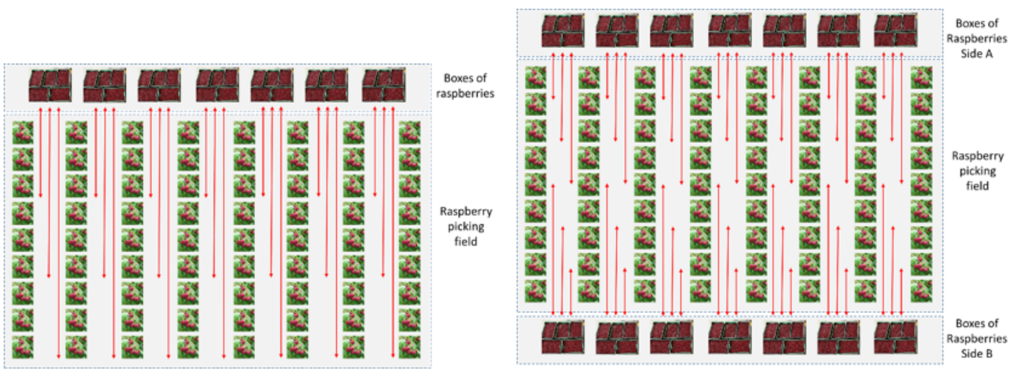

Fig. 7. The one-sided and two-sided geometry of raspberry picking fields

The share of workers' elementary activities in the fruit harvesting process, as well as their percentage yield, are shown in Figure 8.

Figure 9 shows how the total time for harvesting raspberries varies with the number of workers. A harvest of 10 to 60 workers was assumed, with the optimizer's constraints set at 10 seconds to find a single solution.

Figure 10 shows how the total working time changes depending on the location of the weighing point to which pickers bring the fruit.

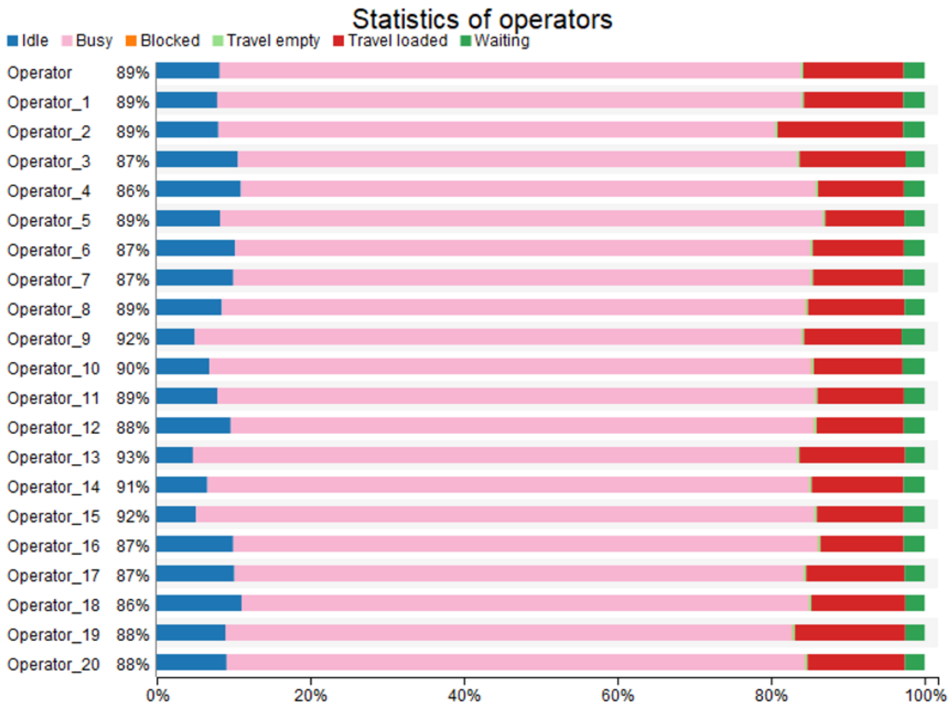

Fig. 8. Elementary activity statistics of operators' work

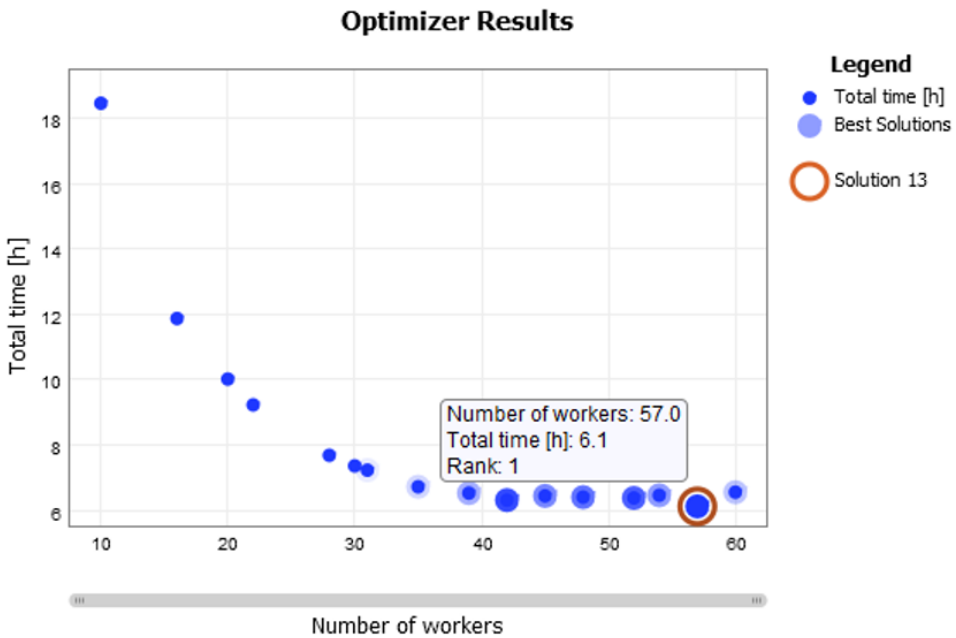

Fig. 9. Simulation of working time with different number of employees

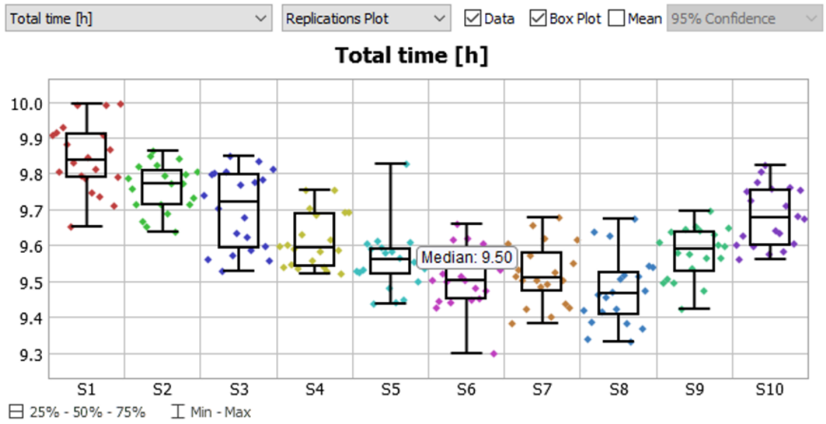

Fig. 10. Simulation of operating time with different variants of fruit weighing point setting

Table 1
The average path of arrival per raspberry picker

No.	Picker	Number of raspberry portions [125 g] collected	Number of carts com-pleted	Distance traveled [m]
1	/Operator_0	398	9	2488.98
2	/Operator_1	405	9	2459.11
3	/Operator_2	384	9	3143.3
4	/Operator_3	382	8	2675.04
5	/Operator_4	393	9	2192.7
6	/Operator_5	415	9	2123.72
7	/Operator_6	386	9	2319.21
8	/Operator_7	388	9	2323.37
9	/Operator_8	398	9	2534.54
10	/Operator_9	416	9	2403.59
11	/Operator_10	414	9	2242.16
12	/Operator_11	407	9	2187.15
13	/Operator_12	403	9	2211.61
14	/Operator_13	414	9	2637.58
15	/Operator_14	414	9	2399.84
16	/Operator_15	425	9	2172.04
17	/Operator_16	396	9	2113.58
18	/Operator_17	394	9	2444.08
19	/Operator_18	384	9	2360.51
20	/Operator_19	387	9	2751.37
21	/Operator_20	397	9	2438.85
	$\sum$	8400	188	50622.33

A diagram of the location of the weighing points is shown in Figure 3. We have a choice of 10 locations for setting the weighing point for scenarios S1, …, S10. In each successive scenario, the weighing point is shifted by 9 meters along the X axis, counting from the beginning of the coordinate system. The agricultural field is plotted on the coordinate system (Figure 3). The optimal location of the weighing point is scenario No. 6. Number of repetitions 200, confidence intervals 95%.

Result from analytical approach

Within the frame of the analytical approach, the picking process is analyzed by means of a formal calculation, where the parameters of the picking process are taken into consideration as deterministic parameters. In the analytical approach the spacing of seedlings per running meter is exactly 2.4 meters. In this case, the analytical model is simple because one trolley can be full within 20 meters, which means that 6 round is enough for an operator to pick one complete row. It means, that the required time to finish 21 rows by 21 pickers needs the following time:

$$
\begin{aligned}
T_{21} &= \sum_{i=1}^{6}\left(\tau^{\mathrm{TROLLEY}} + \frac{(i-1)\cdot 20}{v} + \frac{i\cdot 20}{v}\right) \\
&= \sum_{i=1}^{6}\left(\tau^{\mathrm{TROLLEY}} + \frac{(2i-1)\cdot 20}{v}\right) = 5.56\,h \qquad (4)
\end{aligned}
$$

where T_{21} is the required time of 21 pickers to finish 21 rows of raspberry bushes picking parallel, τ^{TROLLEY} is the required time to finish one trolley including 48 portions of 125 raspberries and v is the moving speed of pickers. Within the frame of this 5.56-hour time frame, the 21 pickers are working parallel, so the 21 rows are finished within the time frame. The simplified optimization problem in the case of this case study is to find an optimal assignment of the remaining 9 rows and their bushes to the 21 pickers.

The optimization problem in this case can be defined as a linear programming problem which can be formulated as follows:

$$x_1 \cdot a_1 + x_2 \cdot a_2 + \ldots + \\ + \left(21 - \sum_{i=1}^{n} x_i\right) \cdot a_n = r^{\text{REM}} \tag{5}$$

$$(x_1, \ldots x_n) \wedge (a_1, \ldots a_n) \in Z \tag{6}$$

$$\sum_{j=n}^{1} x_j = 0 : \quad j \to \min \tag{7}$$

where x_i is the number of pickers picking a_i trolley in the remaining part of the raspberry field, r^{REM} represents the amount of raspberry to be picked in the remaining part of the raspberry field in trolleys. In the case study, in the first part of the picking process, the 21 pickers collect 126 trolley of raspberry assuming a uniform distribution of the picking performance of pickers. In the second part of the picking process the 21 pickers must be assigned to different zones of the remaining part of the raspberry field including 9 rows of raspberry bushes. Equation (5) defines the assignment problem of raspberry pickers to the number of trolleys of raspberries to be collected in the remaining part of the field. Equation (6) defines that decision variables and number of trolleys to be collected are integer, while equation (7) defines the objective function that is minimized. The optimization objective function can be defined as an even distribution of tasks among workers, since the end of the entire harvesting process is determined by the time the last worker finishes harvesting. In our case study, in the second part of the picking process, the optimization leads to the following result: 9 pickers are assigned to collect 2 trolleys, while 12 pickers are collecting 3 trolleys in the remaining part of the raspberry field. The visual representation of the picking process can be seen in Figure 11.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Row 1	Picker 01					
Row 2	Picker 02					
Row 3	Picker 03					
Row 4	Picker 04					
Row 5	Picker 05					
Row 6	Picker 06					
Row 7	Picker 07					
Row 8	Picker 08					
Row 9	Picker 09					
Row 10	Picker 10					
Row 11	Picker 11					
Row 12	Picker 12					
Row 13	Picker 13					
Row 14	Picker 14					
Row 15	Picker 15					
Row 16	Picker 16					
Row 17	Picker 17					
Row 18	Picker 18					
Row 19	Picker 19					
Row 20	Picker 20					
Row 21	Picker 21					
Row 22	Picker 01			Picker 10		
Row 23	Picker 02			Picker 11		
Row 24	Picker 03			Picker 12		
Row 25	Picker 04			Picker 13		Picker 19
Row 26	Picker 05			Picker 14		
Row 27	Picker 06			Picker 15		Picker 20
Row 28	Picker 07			Picker 16		
Row 29	Picker 08			Picker 17		Picker 21
Row 30	Picker 09			Picker 18		

Fig. 11. Visual representation of the assignment of the pickers to rows and zones of raspberry field

Figure 12 represents the lead time of each row. The total lead time (finishing time of the picking process for the 1ha raspberry field) is the maximum of the lead times, which is 8.44 hours.

Figure 13 shows the Gantt-diagram for 1st type pickers picking a full row and Zone1-Zone 3 in a second row (for pickers ID01-09). In their picking process the finishing time is 8.28 hours.

Figure 14 shows the Gant-diagram for 2^{nd} type pickers picking a full row and Zone4-Zone 6 in a second row (for pickers ID10-12). In their picking process the finishing time is 8.44 hours.

Figure 15 shows the Gant-diagram for 3^{rd} type pickers picking a full row and Zone4-Zone 5 in a second row (for pickers ID13-18). In their picking process the finishing time is 7.46 hours.

Figure 16 shows the Gant-diagram for 4^{th} type pickers picking a full row and Zone6 in a second a third row (for pickers ID19-21). In their picking process the finishing time is 7.52 hours.

Summary and conclusions

During the implementation of this project, it was noted that the chaotic movement of workers between rows of fruit resulted in large losses of labor time. Coordinating and selecting the right number of pickers to work in the field is a key element in optimizing production costs. To improve labor productivity, both the simulation and analytical approaches proved correct, as similar results were obtained.

With an assumed yield of 1050 kg per hectare, different results were obtained for the analytical and simulation approaches. The analytical approach yields a maximum lead time of 8.44 hours (Figure 12). The simulation approach with optimal weighting point set-

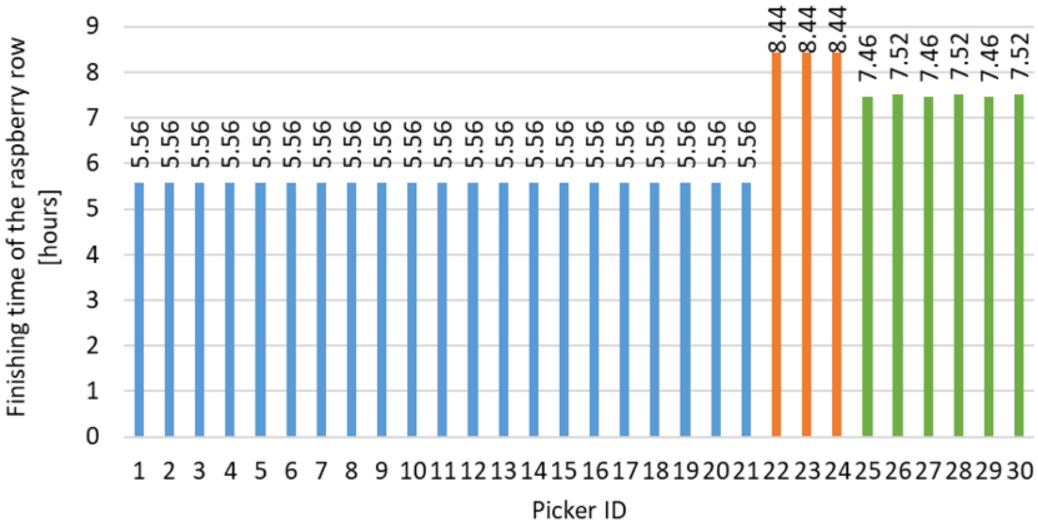

Fig. 12. Distribution of finishing time of raspberry rows

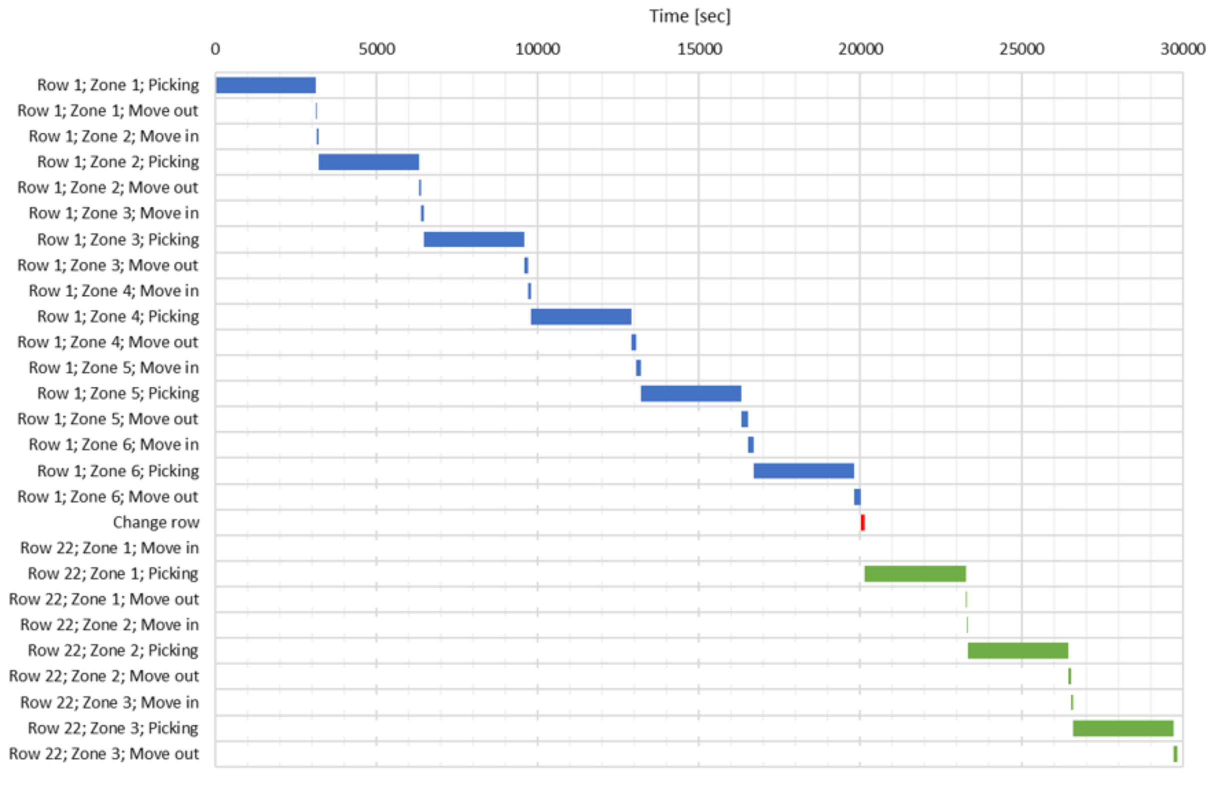

Fig. 13. Gant-diagram for 1^{st} type pickers picking a full row and Zone1-Zone 3 in a second row (for pickers ID01-09)

ting yields a statistically calculated confidence interval as a median of 9.5 hours (Figure 10). Figure 9 shows how total raspberry harvesting time depends on the number of workers employed. Combinatorial method, OptQuest optimizer. The number of available workers was assumed to range from 10 to 60. The shortest harvesting time (6.1 hours) was obtained for 57 workers. It was found that increasing the number of workers beyond 21 does not pay off because it does not dramatically reduce the total harvesting time. The optimal number of workers in a group is 21 pickers per hectare. With this number of workers, the total harvesting time

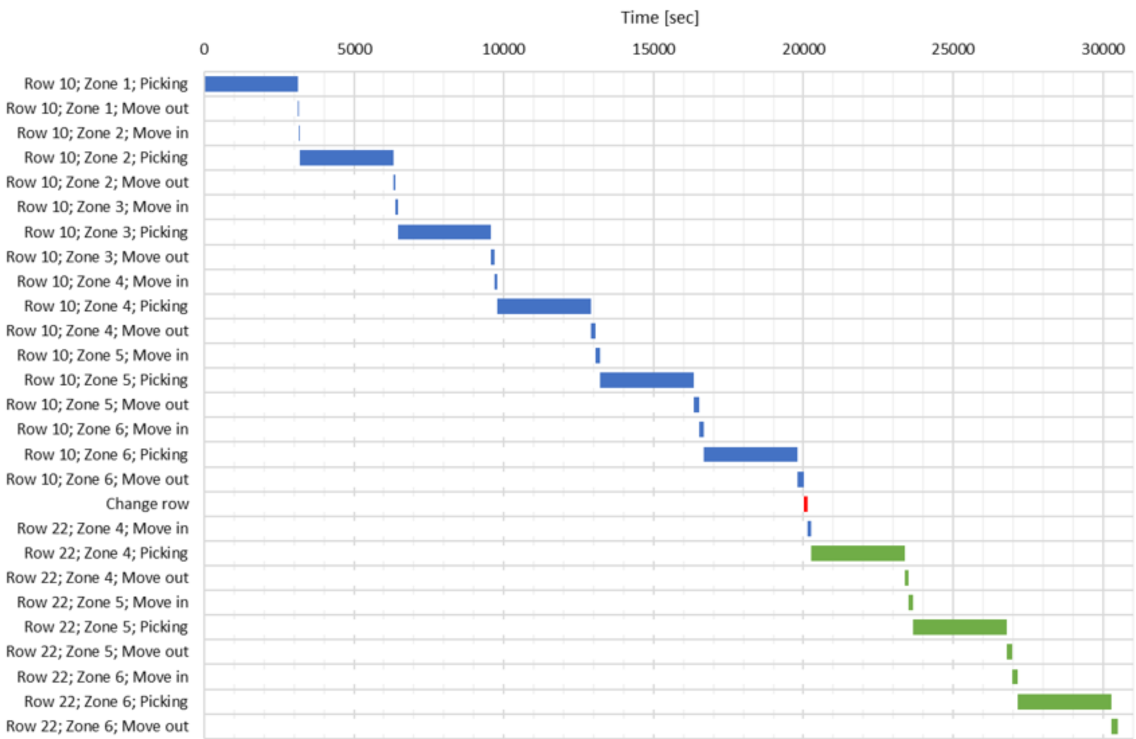

Fig. 14. Gant-diagram for 2^{nd} type pickers picking a full row and Zone4-Zone 6 in a second row (for pickers ID10-12)

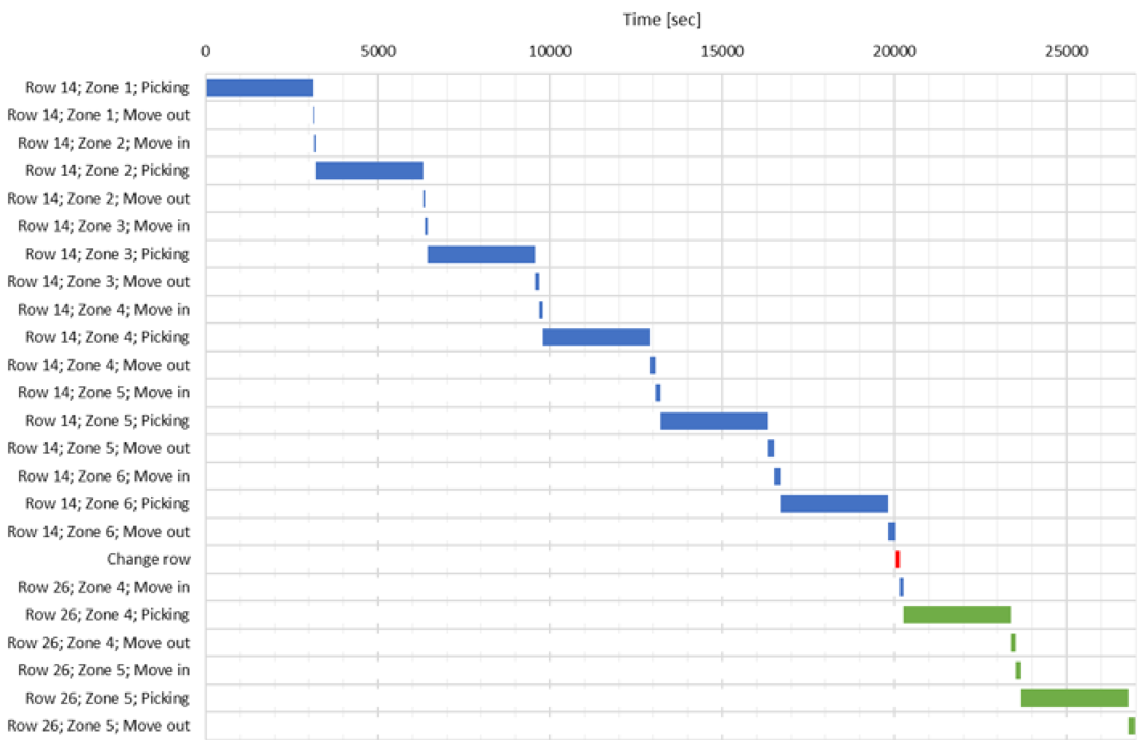

Fig. 15. Gant-diagram for 3^{rd} type pickers picking a full row and Zone4-Zone 5 in a second row (for pickers ID13-18)

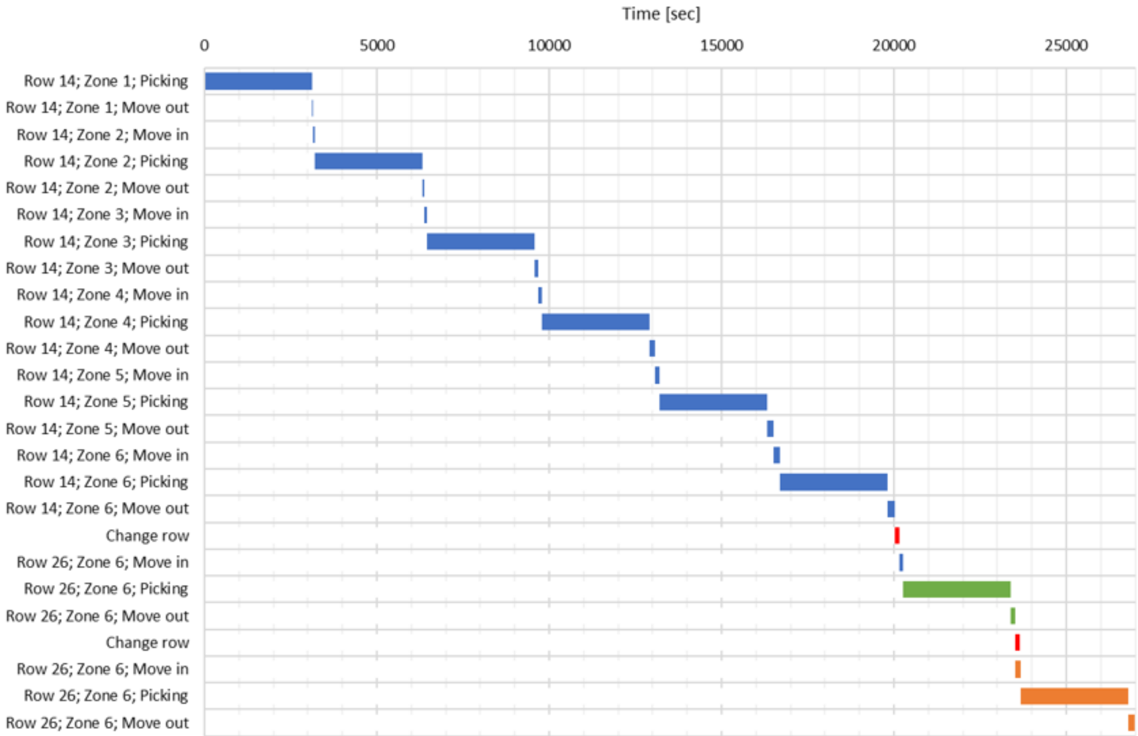

Fig. 16. Gant-diagram for 4st type pickers picking a full row and Zone6 in a second and third row (for pickers ID19-21)

is 9.49 hours, and the effective working time per operator/collector is 7.23 hours. The run-time analysis shows that the results based on deterministic parameters of the harvesting process differ by about one hour compared to the results obtained from the simulation model in which stochastic parameters were included.

For the shortest route problem, analytical formulas (1), (2), (3) were developed, and the dependencies of workers' path lengths between one and two-sided fruit harvesting were shown. The results that were obtained for the simulation method (Dijkstra's Algorithm) are shown in Table 1. The data in Table 1 are for a single run of the simulation model for a working day. The statistics of workers' elementary activities are presented in Figure 8. One potential direction for future research is to apply the developed analytical and simulation design methods to other areas of agriculture.

References

Babik, I. (2002). Effect of pot size and fertigation on the growth of vegetable seedlings and crop yield in the field (in Polish). *Problem Books of Progress in Agricultural Sciences*, 485, 15–28.

Boulanger-Lapointe, N., Gérin-Lajoie, J., Siegwart Collier, L., Desrosiers, S., Spiech, C., Henry, G.H.R.,

Conesa-Muñoz, J., Bengochea-Guevara, J.M., Andujar, D., & Ribeiro, A. (2016). Route planning for agricultural tasks: A general approach for fleets of autonomous vehicles in site-specific herbicide applications. *Computers and Electronics in Agriculture*, 127, 204–220.

Faostat 2020, https://data.un.org/Data.aspx?d=FAO&f=itemCode%3A547.

Hermanutz, L., Lévesque, E., Cuerrier, A. (2019). Berry Plants and Berry Picking in Inuit Nunangat: Traditions in a Changing Socio-Ecological Landscape. *Human Ecology*, 47(1), 81–93. DOI: 10.1007/s10745-018-0044-5.

Javaid, A. (2013). Understanding Dijkstra's algorithm. Available at SSRN 2340905.

Kangas, K. (2001). Commercial wild berry picking as a source of income in northern and eastern Finland. *Journal of Forest Economics*, 7(1), 53–68.

Kangas, K., Markkanen, P. (2001). Factors affecting participation in wild berry picking by rural and urban dwellers. *Silva Fennica*, 35(4), 487-495. DOI: 10.14214/sf.582.

Kiktev, N., Didyk, A., Antonevych, M. (2021). Simulation of Multi-Agent Architectures for Fruit and Berry Picking Robot in Active-HDL. *2020 IEEE International Conference on Problems of Infocom-*

munications Science and Technology, PIC S and T 2020 – Proceedings, 9467936, 635–640. DOI: 10.1109/PICST51311.2020.9467936.

La Mela, M. (2014). Property rights in conflict: wild berry-picking and the Nordic tradition of allemansrätt. *Scandinavian Economic History Review*, 62(3), 266–289. DOI: 10.1080/03585522.2013.876928.

La Mela, M.L., Tamper, M., Kettunen, K. (2019). Finding nineteenth-century berry spots: Recognizing and linking place names in a historical newspaper berry-picking corpus. *CEUR Workshop Proceedings*, 2364, 295–307.

Musacchio, M.J., Kim, A.W., Vijungco, J.D., Prinz, R.A. (2003). Greater local recurrence occurs with "berry picking" than neck dissection in thyroid cancer. *American Surgeon*, 69(3), 191–196.

Mešić, N., Wikström, E. (2021). Ruptures and acts of citizenship in the Swedish berry-picking industry. *Journal of Rural Studies*, 88, 518–526. DOI: 10.1016/j.jrurstud.2021.04.011.

Nowosielski, O. (1995). A field friendly crop (in Polish). Modern agriculture. *Science, advice, practice* 2(11), 12–13.

Pouta, E., Sievänen, T., Neuvonen, M. (2006). Recreational wild berry picking in Finland – Reflection of a rural lifestyle. *Society and Natural Resources*, 19(4), 285–304. DOI: 10.1080/08941920500519156.

Santoro, E., Soler, E. M., & Cherri, A. C. (2017). Route optimization in mechanized sugarcane harvesting. *Computers and Electronics in Agriculture*, 141, 140–146.

Sønsteby, A., et al. (2009). Production of high yielding red raspberry long canes in a Northern climate. *Scientia Horticulturae,* 121.3 2009: 289–297.

Spekken, M., & de Bruin, S. (2013). Optimized routing on agricultural fields by minimizing maneuvering and servicing time. *Precision agriculture*, 14, 224–244.

Uppalapati, N.K., Walt, B.T., Havens, A.J., Mahdian, A., Chowdhary, G., Krishnan, G. (2020). A Berry Picking Robot With A Hybrid Soft-Rigid Arm: Design and Task Space Control. *Robotics: Science and Systems*, 2020. DOI: 10.15607/RSS.2020.XVI.027.

Utamima, A., Reiners, T., & Ansaripoor, A. H. (2022). Evolutionary neighborhood discovery algorithm for agricultural routing planning in multiple fields. *Annals of Operations Research*, 316(2), 955–977.

Yuliani, S. Y. (2021). Dijkstra's algorithm to find shortest path of tourist destination in Bandung. *Turkish Journal of Computer and Mathematics Education* (TURCOMAT), 12(8), 1163–1168.

Vaara, M., Saastamoinen, O., Turtiainen, M. (2013). Changes in wild berry picking in Finland between 1997 and 2011. *Scandinavian Journal of Forest Research*, 28(6), 586–595. DOI: 10.1080/02827581.2013.786123.

Vereecken, C. (2015). Fruit and vegetable consumption trends among adolescents from 2002 to 2010 in 33 countries. *The European Journal of Public Health 25.suppl_2*: 16–19.