Figure 6. Graphs depicting the improvement of solutions with every new generation

To show how the genetic algorithm performed, the best solution of the final generation is compared with the best solution of the initial generation in **Table 3** on the following page:

Table 3. Comparison of best initial final solutions

	Initial Solution	Final Solution
Total overtime	91.206 hours	91.296 hours
Total idle time	13 872.654 hours	13 669.592 hours
Total distance	316 843.8 km	312 328.59 km
Total deviation	142.86 minutes	140.45 minutes
Days to complete	189 days, 36 resources	189 days, 7 resources

Overtime hours increased only very slightly but idle time has decreased by 203 hours. This has allowed the servicing of all the devices to take place in 189 days, using only 7 resources on the 189th day rather than the initial 36. The graphs below show a randomly selected employees' working hours over the period of the schedules. The average length of a working day has increased from the initial solution to the final solution which means that the days for this employee are fuller i.e. there is less idle time.

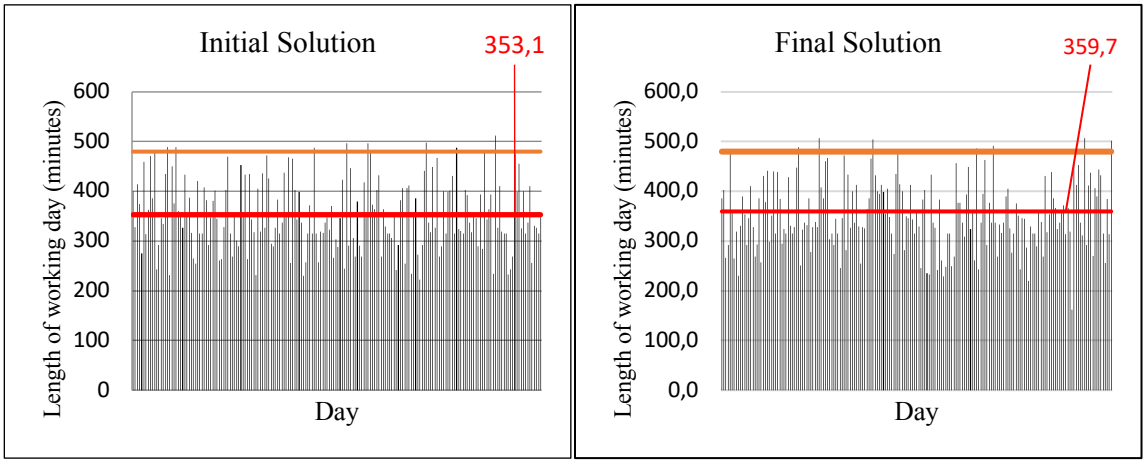

Figure 7. Comparison of working days of initial and final solutions for a particular employee

There has been a reduction in the deviations from an 8-hour working day, but there is still visibly a lot of idle time. This can be used to the company's advantage - any employee with free time on their schedule can be put "on call" for any emergencies that may occur.

Has the genetic algorithm addressed Company XYZ's issues?

The way the algorithm is built does not allow a resource to travel to location if there won't be enough time to service the devices, and so by using this algorithm, Company XYZ can automatically cut down on their overtime costs.
The algorithm produces daily schedules for each employee rather than weekly. This means that the travelling times are more accurate and the schedule is more specific. The genetic algorithm produces a solution within hours while the linear programming method that was being used took days. This means that the company can use the algorithm for more dynamic planning because it is more efficient and easier to keep up with continuous changes. If any device services pop up that were not initially planned for, the algorithm can be rerun to accommodate these devices in a more optimal way. Company XYZ can run the model it at the beginning of each week to create schedules, instead of following a static 80-week plan.

Solution Validation

The schedules produced by the genetic algorithm should be validated before the company starts implementing them. The company can put together a testing team for a week or two which follow the schedule as it is, and then report back any issues they may have had. Parameters such as travelling speed, and time in the day may have to be adjusted if employees find that they cannot manage with the given schedule. A benefit of using this algorithm is that it only

requires Python which is a free, open source programming software as well as a person with a background of coding. The code can on a continuous basis be easily be adapted and modified.

9. Proposed Implementation

The csv output file that was produced by the algorithm can be used in a number of ways. Firstly, the excel table can be filtered to show the schedule of each employee. Resource 17 for example, has the following schedule for two weeks:

Table 4. Sample schedule for an individual employee

Day	Devices	Total Time	Travel time	Service time
75	11296, 11297, 11298, 11299, 11300, 11301, 11302, 11303, 11304, 11305, 11306, 11307, 11308, 11309, 11310, 11311, 11312, 11313, 11314, 11315, 11316, 11317, 11318, 11319, 11320, 11321, 11322, 11323, 11324	431.9	20.0	411.9
76	10954, 10955, 10956, 10957	400	20.0	380
77	6121	396	80.5	315
78	3480, 3481, 3482, 3483	413	32.7	380
79	7514, 7515, 7516, 7517	399	18.4	380
80	3306	355	39.8	315
81	19914, 19915, 19916, 19917	406	25.7	380
82	5329	349	53.7	295
83	10564	315	20.0	295
84	20183	274	63.9	210

The excel table can also be filtered to show each day. Managers of Company XZY can use this to see which of their employees will servicing which devices. The table below is a sample for some of the employees on day 1.

Table 4. Sample schedule for a specific day

Resource	Devices	Total time	Travel time	Service time
13	['[12086, 12087, 12088, 12089]']	401.9	21.9	380
14	['[2428, 2429]']	424.1	64.1	360
15	['[4276]']	268.7	58.7	210
16	['[16432, 16433]']	422.8	32.8	390
17	['[13703, 13704, 13705, 13706]']	400.7	19.7	381
18	['[3946, 3947, 3948, 3949]']	438.4	58.4	380
19	['[2424]', '[17003]']	391.7	69.2	322.5
20	['[18285]']	331.5	16.5	315
21	['[19976, 19977]']	410.6	22.6	388

As mentioned in **Section 8**, the algorithm must first be put to the test to ensure that it is benefitting the company and that the schedule it has produced is verified and validated. Once the scheduling method has been implemented at the Gauteng branch and used for a period of time, users of this system can start making suggestions and improvements and get rid of bugs. Thereafter, a finalised algorithm can be adopted by other regions in the country.

10. Conclusion

Company XYZ is having trouble scheduling their staff and determining which routes its technicians should be taking in order to satisfy customer demand, while incurring minimal costs. This problem was addressed by conducting a literature review to determine what type of problem was at hand and what methods have been developed to solve similar problems. The problem can be classified as a type of Travelling Salesman problem. It was found that the Genetic Algorithm proves to be a very useful efficient method of solving these problems. Using *Python 3.6*, a genetic algorithm was built and run 100 times to create 100 generations. With each new generation, a better scheduling solution was found i.e. schedules which reduced travel distances and balanced technician workloads. And so, going back to the problem statement, has the developed solution met its objectives? *"Company XYZ requires a system which plans staffing in such a way as to balance the workloads of their employees, reduce costs and meet customer demand."* A genetic algorithm has been created [*a system which plans staffing*] which iteratively reduces solutions' deviation from an 8 hours' day of work [*balance workloads*] and total travelling distance, thereby saving on petrol, vehicle maintenance costs and overtime [*reduce costs*]. The algorithm ensures that every electrical device will get serviced [*meet customer demand*]. Before any schedule is implemented Company XYZ should go through a validation phase to ensure that assumptions made in the model are suitable. Using the genetic algorithm to create schedules could be advantageous for Company XYZ because it reduces overtime, plans daily, and finds solutions quickly.

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