An Agent-based Approach for Transportation Scheduling in Developing Countries

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Abstract—Developing countries can take advantage from the adoption of applications that automate the scheduling of public transportation. However, the adopted solutions must suit the peculiarities of those countries, in particular the very dynamic situation of the road and of the traffic, and also the specific management of drivers. Moreover, the solutions should have an affordable cost for this kind of countries. In this paper we present an approach to transportation scheduling based on software agents, which we developed for Buenos Aires in Argentina. The results of the application of our approach show that the scheduled departures are very close to the desired ones, respect different constraints and are produced in a short time.

Keywords—Planning, Scheduling Problems, Agent Based Model, Transportation, Developing Countries, Ant colony

I. INTRODUCTION

Planning in public transportation (generally buses in developing countries) can be defined as the activity to improve the decision-making process related to the actions to be taken on the transport system, in order to maintain the feature of accessibility and the service availability, in line with the social objectives and the collective goals. In this paper, we consider the problem of bus scheduling under company requirements in terms of costs and offered service. This problem has been faced for a lot of time, earlier manually, then following models in Operations Research [1], and recently by computer-based approaches. The typical characteristics of these types of solutions cannot be applied by the majority of companies of public transportation in developing countries, because of the cost of these solutions and of the high dynamism of the situations, such as for example the scarce state of the roads, the limited traffic regulations, the use of vehicles rather old, and others. The costs derive from both the purchase of software, the learning needs by planners, and the long waiting times to define optimal solutions. The purpose of this paper is to describe a new flexible approach in transportation planning, developed in an application applied to a real case in Argentina.

Developing countries are characterized by an extremely dynamic of environment and for the difficulty in finding reliable data. For these reasons we have focused on finding a sub-optimal solution by modeling a relaxed environment in a Multi-Agent System (MAS) and then leaving to the planners the final adjusting of the solution. We choose to use a MAS because it can be used to deal with these issues, is able to ensure cost-effectiveness, speed and flexibility. In addition, planning a transport network as a network of intelligent agents may result advantageous both for easiness of implementation of the models and for the flexibility that can ensure execution of the application. An Ant Colony Algorithm is used to optimize the allocation of vehicles and drivers at the departure times.

II. PLANNING IN TRANSPORTATION

Historically, planning was mainly related to industrial operations, and more specifically to the manufacturing sector, but today the concept of planning can be applied in different areas including broader and more diversified fields [2]. According to a report from the Department of Transportation of the University of Texas [3], during the 1960’s, almost all of the operational planning and the subsequent generation of schedules was still being done manually, but as the average age of human schedulers increased and few people desired to enter the transit scheduling career field, the research was directed toward automating the planning process. These methods, initially, tried to simulate the work of manual schedulers and were based on heuristic researches since integer linear programming models were not available to solve models of realistic size. Unfortunately, due to the cost-performance ratio of available computers and the inefficiency of the resolution’s methods, the introduction of Information Technology (IT) has not yielded the expected results. Already in 1980, in fact, it was widely thought that heuristics alone were not suitable for arriving at an optimal solution, both in term of the efficient use of resources and in the quality of service for the customers, thus inducing a change in the focus of research that was directed to producing methods that combined heuristics and mathematical programming. Due to the highly combinatorial characteristics, which make it an NP-complete problem, the dynamic nature of the problem and the wide applicability in the field of transportation, different solution methods have been developed, such as heuristics [4], set covering formulations [5], Genetic Algorithms [6], and more recently “Sharing-Sweet-and-Sour” [7], Multiple Depot Vehicle Scheduling [8], Branch-and-bound [9], multi-objective metaheuristics [10] and many others. Using these
solution methods the vehicle scheduling problem, the driver scheduling problem, or both problems simultaneously can be solved. Most of the large bus operators now rely on computers for their scheduling, with a significant improve of the productivity of scheduling staff and a more efficient operation. But these kinds of solutions cannot be applied in developing countries because a certain kind of accuracy in input data is needed to find an optimal solutions and the solutions found are often too “hard” to be applied in an environment extremely dynamic, as explained in follow.

III. ARGENTINIAN CONTEXT

It is not so common to see the methods introduced in Section II applied in developing countries, because the relatively high cost of these programs combined with the low expected benefit of a better planning. In addition, the low drivers cost, compared with developed countries, limiting the incentive and the potential of reducing the costs. The same happens for the vehicles planning, where high working frequency of the vehicles limits the benefits expected from application of these techniques [11]. In addition to this cost limit, there is even a greater force that restricts the use of assisted planning in developing countries: many of these programs require highly accurate input of data including running times, vehicle and crew scheduling constraints such as maximum permitted working hours, or restrictions of vehicle types on certain routes. Getting these pieces of information is essential to create optimal work plans, or enough to justify the investment required, but their finding and accuracy, in these countries, is often difficult to achieve.

In this paper we analyze a case study in a real transportation company in Buenos Aires, Argentina. In this country we can find the characteristics above mentioned, especially it is possible to find a considerable use of manual planning. Also the information that may seem constant are transformed into variables with high volatility in a country like Argentina. In particular, the factors that hamper the development of the automatic planning methods are:

- The poor roads conditions, the “dynamic” driving style of the drivers and the over-exploitation of vehicles influencing the number of daily units available.
- Scarce road regulations and continuous manifestations in the streets that interrupt the viability influencing even the vehicle routing that changes almost every day.

The combination of these issues was the trigger that led to the development of the work presented in this paper. In this complex context it is clear that it is necessary to create a model that can easily adapt to different situations that occur almost daily, capable of ensuring reliable results even with incomplete or unreliable inputs. Having an optimal solution is not a priority because it may not exploit the benefits of this effort; since situations vary in a few hours, it is better to have a sub-optimal solution but in a reasonable time.

IV. DEVELOPED APPLICATION

The created application aims at achieving this goal: “The generation of a tool of automation and optimization for the integrated allocation of departures time and the respective vehicles and drivers”. Automation, to allow achieving the benefits previously mentioned such as providing more efficient schedules and reducing costs for both vehicles and operators; and integrated, aiming to a global cost reduction and not only local optimal, in order to consider aspects derived from different areas, with different objectives; it must grant, at the same time, flexibility independently of the presence or not of some inputs. With these objectives in mind the idea has been the generation of an optimization model that runs through several paths, finding various possible solutions, thus eliminating a premature convergence. Then it is important to evaluate the various solutions found to eliminate those that do not meet certain objectives. Iterating the process several times and keeping in memory what happened in the previous iterations, it will reach an acceptable solution, according to the criteria in input. To do this, it was decided to adopt a planning model based on the Ant Colony Algorithm. This algorithm is an evolutionary optimization inspired by mimicking the behavior of ant colony, proposed by Italian researcher M. Dorigo in his Ph.D. thesis and developed over the years [12]. Theory explains how the ants are able to find the optimized route to reach the food thanks to releasing pheromones tracing random street. The most covered road will have the most pheromone’s smell and will be the most attractive for the others ants too.

Based on this theory we have implemented an application that travels along various solutions, creating schedules in probabilistic way that meet the required frequencies, and choosing the vehicles to be assigned and their drivers. Once cycled several times various assignments of departure times, vehicles and drivers, the best solution in term of cost and supplied services is established. This solution is associated to the ant that has found food at a certain point and then leaves a pheromone. It iterates the process again and, starting from the second iteration, the vehicles and the drivers will always be chosen at random, but this choice will tend to follow the pheromone and thus will affect the choice as occurred previously to arrive at a solution that gave rise to the best schedule, like in ant colony algorithm. Iterating the process again for a certain number of times and then evaluating the solutions found for each created timetable, it is important to emphasize how to avoid convergences in local solutions not particularly suitable; in these iterations the left pheromone only affects a limited number of subsequent choices, evaporating with time. The best solution is chosen considering a trade-off between the adaptation and the cost of all solutions, according to some parameters defined by the user at the beginning of the application execution.

This algorithm has been applied in a MAS, composed
of four type of agents: *allocators*, *evaluators*, *seeds* and one *mother matrix*. Conceptually, it is an application that generates a series of seeds, i.e. generates times of departures schedules randomly, under certain frequencies imposed by a mother matrix. Each seed has, in this manner, its own departure times to satisfy and it is related to a series of evaluators that in turn are related with some allocators. These allocators assign, to each departure defined in the corresponding seed, a vehicle and a driver, who will be responsible for carrying out that particular departure. Once assigned drivers and vehicles for all departures, the schedule (or diagram, as it is called by the company where the work was carried out) is considered *closed*. These created schedules are evaluated from various points of view; each allocator, in fact, passes the closed schedule to the corresponding evaluator, which is compared with the diagrams of each allocator. In this moment comes into play the Ant Colony Optimization (ACO), because the application iterates this process until each evaluator has the best diagram produced by its allocators; best diagram defined depending on certain characteristics chosen by the user. This diagram is sent to the seed, where it is weighted against the winners from other evaluators’ schedules. From this assessment a schedule is chosen and is sent to the mother matrix, where it is weighted against the winners of all the seeds and the mother matrix selects one, the *best schedule* in absolute. We remark that the application uses some parameters (alphas, betas, thetas) that affect the characteristics of the generated solutions. For example, changing the alpha parameters, it is possible to define the importance of the total cost of the schedule with respect to the assurance of the desired frequencies of the service. In our study, these parameters have been chosen *heuristically* with the company planners. Optimizations of these parameters are possible depending on the needs of the various lines in the company, or according to the user. The procedure of the model is shown in Figure 1.

![Figure 1. Flow Chart of the proposed model](image)

A. Inputs

The main idea is to provide in input the desired frequencies for each hour of the day, in a so-called mother matrix, and then the application automatically creates a number of departure times with which starting to schedule. To begin to run the application, some preliminary data are needed to enter, in order to define the specific situation:

- Number of available vehicles;
- Number of available drivers;
- Mother matrix, containing in details the frequencies of time slots, dwell time of the drivers at terminals, and travel times;
- Other information, related to the duration of the service journeys in the different hours of the day, the beginning and the end of the nightly hours, length of shifts, costs hourly of drivers etc.

The first step is the creation of a series of departures time that fulfill the frequencies present in the mother matrix. The departure times are generated in a probabilistic manner, according to a process which will be detailed in the subsection *Seeds*. Then, the evaluator applies the ACO to each of its allocators, where results are the real departure times and vehicles and drivers assigned to them. One more time, it is clear that the best schedule in absolute does not exist; being this a problem with scarce resources it is necessary to give priorities for some aspects with respect to others, e.g. it is preferable in some cases to have a schedule with a lot of overtime and use few drivers, or in other cases it is preferable to have a schedule with limited used vehicles and a lot of working hour of drivers. The parameters that give more or less importance to the different factors will be
presented in the corresponding subsection.

B. Allocator agents

The allocators are probably the most important agents in the model because their main task is to create the diagrams, whereas the function is only to evaluate this diagrams. It is important to focus once again on the amount of allocators. The greater is the number of allocators the more probable is to cross the road of the optimal solution but, at the same time, the time needed to run the application will increase. The company where this study was carried out needed an application that would give results in about 10 - 15 minutes. For this reason the number of allocator agents has been decided depending especially on the application execution time and less on the degree of optimization of the solution.

Once the application started, the departure times are processed one at a time, therefore initially the application reads from the seed the first departure time, arbitrarily defined as the first in the morning. This choice was entirely arbitrary, in fact it is possible to start trying to ensure the departures at the hours with higher frequency, considering that initially the model has access to all vehicles, and then assigns others consequently. The evaluation of these choices has been left open for future developments. For each time of departure, the allocator considers all vehicles and drivers available and chooses probabilistically who and which bus satisfied this departure. When a departure must be satisfied, the application can choose to delay the time of this departure, in order to allow the return of a vehicle in service. This delay has a cost and can change the dynamics of the schedule, but it is an opportunity that the application can choose and evaluate. The chance to choose between one or other available solutions depends on the costs of the chosen particular solution; the greater will be the cost to support the departure and the less will be the chance to support it, and therefore to choose it. The probability $P_n$ for any $n$ possible couples of vehicle/driver to be selected to satisfy a departure is expressed in Eq. 1.

$$P_n = \frac{1}{\sum_{i=1}^{n} D_i} * \frac{1}{(n-1)}$$

(1)

Where $D_i$ is the total cost that is charged in the case of the couple $i$ vehicle/driver is chosen to perform the departure, and is explicit in Eq. 2.

$$D_i = \sum_{c=1}^{5} \beta_c * \text{cost}_c$$

(2)

Where $\beta_c$ are the weights of different costs that are considered in the model:

1) **Taken cost**, is the cost for sending a vehicle in a street if it has not exited the terminal yet; it was decided to set this cost equal to the hourly cost of a driver for the number of hours of the shift.

2) **Change shift cost**, is the cost that is necessary to spend if the application decides to change the driver of the vehicle. If one driver starts to drive one vehicle, this driver must drive the same vehicle for all the shift; this aspect will be explained in the following.

3) **Delay cost**, quantifies the cost of delaying the departures than those established in the seed, and this cost turns out to be a crucial point of the application and therefore will be covered in detail later.

4) **Overtime cost**, is the cost of each hour worked in overtime, intended as out of work shift.

5) **Idleness cost**, the time in which a driver remains on waiting for his departure but, being within his shift, is regularly paid.

The change shift cost was introduced to avoid an early change of driver before he has finished his shift; if the driver gets out of the vehicle it is for the end of the shift, and it is necessary that the application considers this aspect. For a series of union agreements, in Buenos Aires the only relief point (that is a point along a route where a driver may leave and/or take over a bus) is the depot. In this country, even, each vehicle is associated to only two drivers; this occurs for a series of reasons but specially for two important aspects: the first one is because the vehicle is like an office for a driver, that spends his own money to decorate the interior with lights, photos and other stuff; buses in Argentina are really folkloristic. The second aspect is for a kind of driving that the drivers in South America have, if one vehicle is associated to two drivers they take care of the vehicle and drive better, on the other side the company knows the responsible in case of mechanical breakdowns.

The third cost to be incurred for each departure is the delay cost; this cost plays a decisive role at the time of choice the couple vehicle/driver, since it quantifies the ability of the model to delay or not the schedules present in the seed. As mentioned above, when determining which vehicle will have to make a specific departure, it is possible to choose one of the available ones in the terminal or wait for the arrival of the vehicles already in circulation, thus delaying the expected departure. The delay should have a cost that varies depending on a departures frequencies at the same hour, e.g. delay by 10 minutes a departure at 3 a.m. with one vehicle in circulation should be cheaper than delaying of 10 minutes a departure at 8 a.m. when the vehicles start from terminal every 5 minutes. Moreover, delay cost should be of the same order of magnitude as the taken cost, because the choice of delaying will have to “compete” in the first instance with the possible departure of vehicles with drivers who have not started the shift yet.

The last factor that influences the choice of the vehicles is the pheromone; the considered costs influence, according to a certain percentage, the probability of each possible
choice, but for another percentage the choice will follow the choices made to achieve the diagram with the lowest cost in the previous iteration. When all the departures are satisfied, the schedules are considered closed, and all the schedules in output from all the allocators are evaluated in the corresponding evaluator.

C. Evaluator agents

The evaluators differ among themselves for the assignment of \( \beta \) parameters; as explained earlier, in the application it is possible to define the weights will have the five costs seen in the previous subsection. Each evaluator will have a \( \beta \) chosen probabilistically inside a definable range. These \( \beta \) determine, for example, if it will be more or less important to consider the costs of changing working shift rather than the cost of overtime when choosing between different alternatives.

Each allocator will produce in output a complete diagram, containing all relevant information in order to be assessed in the different phases of the application, e.g. obviously the departure times, the vehicles and drivers assigned to those departures, but also the cost of each departure considering overtime hours and night working hours are calculated. The evaluators have the tasks of activating allocators, evaluating the schedules that exit by the corresponding allocators considering costs and desired frequencies (this evaluation is called Assessment1), leaving the pheromone for next iterations and selecting the best of all schedules to send “upstairs”, i.e. to the corresponding seeds agents. With “leaving the pheromone”, we mean that the application saves the choices made by the allocator agent that gave rise to the lowest cost scheduling. As mentioned in the previous subsection, for every departure each allocator agent can choose these saved choices or in random manner according to a selected percentage. At each iteration of allocators, therefore, the corresponding evaluator must evaluate the schedules in outputs from allocators, and does it thanks to the assessment explained in Eq. 3.

\[
\text{Assessment1} = \alpha_{\text{costs}} \times \text{schedule\_total\_cost} + \\
+ \alpha_{\text{frequencies}} \times \Delta_{\text{frequencies}} + \\
+ \alpha_{\text{vehicles}} \times \text{taken\_cost}
\]  \hspace{1cm} (3)

Eq. 3 can be viewed as composed of three aspects of cost:

1) **Calculation of cost**: the sum of all costs that are derived by the choices made in allocators, such as overtime, hours at night, etc.;

2) **Calculation of deviation**: compared to the frequency for time slot, is the difference between the desired frequency and the frequency in output by allocators;

3) **Calculation of work cost**: the sum of costs of drivers called to work.

After calculating Assessment1 for all schedules in output for allocators, the diagram with the lowest value of Assessment1 is considered the winner. This is time to leave a pheromone; for the next iteration the choices for selecting vehicles and drivers for each departure will not be just probabilistic, but will be influenced in some percent by the choices of the winner diagram in the previous iteration.

The evaluators will iterate the allocators for a maximum number of iterations or they stop the iterations if the winner is the same diagram for a certain number of iteration, because in this case the application cannot improve the solution. As mentioned, the last task of evaluators is to send the best schedule found to the corresponding seed agent.

D. Seed agents

The seed agents have the task of dealing with two aspects: in the first time, when the application starts, the seeds generate the departure times, after the end of the iterations of the evaluators the found solutions will be assessed.

The set of departure times that occur during the day is called seed. The creation of the seeds is the first step that the application makes; departure times will then be used for different assignments so the importance and the influence they may have in the application is clear. Starting from the indications of planners and “translating” their wills in to mathematical form, has given rise to the method of creation of the seeds described below. The times of departures are created considering individually each hour of the day, regardless of what happens in the hour before and in the hour after, because the desired frequency is defined for each hour. This is certainly a limitation of the application that does not realize that it can let two vehicles depart almost simultaneously if this happens near the end of the hour. However, this is not a problem for the planners in our case study, who think in the same way even when they are planning manually. Each hour is divided by the desired frequency, creating in this way the number of slots necessary where it will be worth choosing times of departures. Inside the first slot, the generation of departure time is chosen in a probabilistic way, according to a normal distribution of mean \( \mu \) and sigma \( \sigma \). In this manner the application has a better chance that the output occurs in the half of the slot; this is useful to encourage (but not to guarantee) the same distance of departures in the hour. Once the application has chosen the first departure time, it continues with the creation of the next, which will have an area of selection that begins at the moment of releasing of the first time and ends at the end of its predetermined slot. Within this slot a departure time will be chosen again using a normal distribution with mean equal to the half of the slot and \( \sigma \) equal to 1/n of the slot, according to the desired probability, and so on for all frequencies. Figure 2 shows graphically the manner of choice of departure times, giving an example with frequency equal to two. This approach may appear unsophisticated, but it is important to remember the context of developing countries and their typical metropolis, where the traffic conditions are not much regulated and extremely
Assessment with the lowest cost. This choice is called costs, the application chooses the winner, i.e. the schedule output from all evaluators are aggregated or not of additional to the desired characteristics. Once the various schedules in the will of the planners, being able to adapt the schedules ber, it has been seen, however, that this cost is useful to shape the single departure expressed in minutes. This additional delay in respect to desired time, this tolerance is expressed in minutes/frequency, this to give different weights to minutes depending on the frequency to be ensured in the given time. This is because it is different to have, for example, a delay of 10 minutes when it is necessary to release vehicles every 5 minutes, compared to a delay of 10 minutes when it must be let out only one vehicle in that hour. This tolerance allows to define the rigidity of the service level (departures by hour) of the application solutions. One more time, the tolerance has been defined empirically together with the transportation company. To have a satisfactory schedule for planners, a good value of this tolerance is of the same order of magnitude as the total cost. Considering all times of departures, if the difference between the scheduled and the desired departure time is greater than the tolerance, a cost is summed to that diagram; this cost is defined in Eq. 4.

\[
\text{Additional cost} = \frac{\text{total cost}}{\text{tolerance}} \times (\text{delay} - \text{tolerance}) \tag{4}
\]

Where total cost is the total cost of the schedule, that is the sum of costs of single departures, and delay is the delay of the single departure expressed in minutes. This additional cost to the total costs of the schedule may appear quite heavy, because quantitatively represents a considerable number, it has been seen, however, that this cost is useful to shape the will of the planners, being able to adapt the schedules to the desired characteristics. Once the various schedules in output from all evaluators are aggregated or not of additional costs, the application chooses the winner, i.e. the schedule with the lowest cost. This choice is called Assessment2, whereupon, a winner schedule will be defined as output of each seed that will be sent to the mother matrix to proceed to the last assessment, which will define the best schedule.

### E. Mother Matrix

This agent reads all input data and sends them to all other agents; once the Assessment2 is completed for all created seeds, the agent has also the task of compute the Assessment3, defining the winner diagram and printing the results at monitor so that they are available to planners. With the availability of frequencies that should be guaranteed by all schedules, the mother matrix measures the different schedules from the seeds, evaluating them with a weight called theta for the total cost of the schedule and the deviation of the frequencies stored in the mother matrix. Based on these parameters, the schedules are evaluated finding the winner. In this last evaluation, all the variations of frequency are considered in the same way, no matter they occur in time zones of high or low frequency; this assessment is defined in Eq. 5.

\[
\text{Assessment3} = \theta_{\text{frequencies}} \times \delta_{\text{frequencies}} + \theta_{\text{costs}} \times \text{schedule_total_cost} \tag{5}
\]

In Eq. 5 \(\theta_{\text{frequencies}}\) and \(\theta_{\text{costs}}\) are numbers in \([0,1]\) range and define the weight of importance of total cost and frequencies deviation, while \(\delta_{\text{frequencies}}\) is the sum of the differences for all 24 hours of the created frequencies and desired frequencies.

### V. Results

The system complexity together with the integrated approach that we have decided to use, force to define different indicators for assessing the performance of the proposed application. Defining such indicators is not an easy operation because the performance of the application is closely linked to the setting of the parameters. The more freedom is left to the application, the greater will be the difference of frequencies and departure times compared to the seed; on the contrary, the more restricted will be the constraints, the more the application will respect the imposed frequencies and timetables. In any case, we want to give the reader an idea of the indicators used during the phases of enacting of the model to understand how to set the initial variables to obtain the diagram with the desired flexibility. The application results were compared to the actual results due to the work of planners, this because of the applicative nature of our study.

1) Number of used vehicles. The application can be used to define the number of vehicles needed to “close the diagram”, guaranteeing a certain level of satisfaction, intended as guaranteed frequencies. In this case the planners can do different strategic considerations, from customers’ satisfaction to maintenance aspect for example; because they know the number of optimal vehicles needed and can be interested to improve the related aspects.
2) Respect of frequencies. This indicator relates only to the desired frequency, regardless of the results obtained from the current diagrams because this kind of information is unavailable. In Figure 3 is plotted the frequencies of a line taken as example. The graph in Figure 3 shows a frequency deviation due also to the selected settings; of course it is possible to change the stiffness of these movements. However it is recommended to try the various settings line by line and to take the one that is considered more applicable to the different real cases. It is possible to note that the application hardly increases the service frequency, in the sense of increasing the frequency of offered services in the different time slot. The chart showed leads to a few considerations on the results. The scheduling starts from the beginning of the day, then the application plans excellently the departures in the early hours, but tends to relax the solutions thus losing the peaks of requests, such as at six in the morning, where it is notable that the application cannot reach the desired service, despite following the trend in good shape. Another aspect of interest is one of the main problems in planning operations, that is the necessity to assign many departures to different drivers in the same slot of time, and an excessive availability appear in the following hours. The application fails to adequately support a strong decline of the request of departures in the final part of the day; this leads the proposed solutions to ensure more night services than required.

3) Quantity of vehicles for every time. Figure 4 shows the number of vehicles on the street for each hour, the availability of vehicles in the terminal and the desired frequencies. The results of this indicator are important because they show how the application slightly late to get the operating limits of the vehicles, in the middle of the day it is able to respect all the departures, exploiting also the entire fleet if necessary. Another aspect of interest is one of the main problems in planning operations, that is the necessity to assign many departures to different drivers in the same slot of time, and an excessive availability appear in the following hours. The application fails to adequately support a strong decline of the request of departures in the final part of the day; this leads the proposed solutions to ensure more night services than required.

4) Working time. According to the application’s results, it emerges that the average of the working time of drivers is 523 minutes plus/minus 36 minutes, depending on the complexity of the line. Comparing with the planners, we found that these results are similar to those that the planners supplying today in manual manner; in fact, the application’s results have a variation from the average working time manually scheduled of the 2%. These data are not official, but represent the average working day of the drivers according to the experience of the planners.

5) Profiteer time. Before considering this indicator, it is important pay attention to an important factor in assessing the quality of a schedule. It is defined as the number of the base turns, the number of departures that a driver can achieve without going to overtime. For example, if a round of service lasts 74 minutes, including wait’s minutes, a driver can ensure at the maximum 6 turns without going to overtime, as shown in Eq. 6

\[
\frac{480 \text{ minutes}}{74 \text{ minutes}} = 6 \text{ turns without overtime} \quad (6)
\]

These 6 turns in a shift multiplied by the required time to traverse a turn (74 minutes in the example) are the time really worked by the driver. The difference between this time and the duration of the shift (480 minutes in the example) produce a quantity of time in a shift that are called, in our application, profiteer time. According to our experience, in developing countries, it is preferable to minimize this profiteer time at the expense of the additional payment for overtime. This happens because it is always possible to find a solution with the drivers by paying them, the variables costs are low and it is rooted the idea that it is better to departure one vehicle more than one less. An objective for the application is, therefore, to minimize the profiteer time, for this reason a good indicator of a diagram is a low number of it. Figure 5 shows the average of time profiteer, represented in minutes, for three lines analyzed taken as an example, plotting the difference of the profiteer time obtained with the application and that resulting from the charts currently in use. According to Figure 5, the application is able to reduce the mean profiteer time; for the first line, the simplest, the reduction is 8% only, but as the lines become more complex the application is able to...
improve the work of planners almost 20% of minutes for any driver.

6) Execution time. With an Intel® Core™ i5 CPU M 560 2.67 GHz 2.66 GHz and RAM 4 GB the average time of execution is 16 minutes. This time is definitely a good base to work on, since nowadays one or two planners are used full time with the only task of closing schedules, which could use the application to have more time to improve other aspects.

VI. CONCLUSIONS

This work does not aim to be considered as a point of arrival, but as a starting point for the creation of models for planning in transportation where the environments are extremely dynamic and especially useful in developing countries. Based on the results presented in the previous section, we can provide some recommendations. Despite not having defined metrics and thresholds for determining compliance with the objectives, the first important conclusion is that our approach can improve the current situation in the company. The benefits of the automated system are the provision of more efficient schedules, reduction of staff requirements for conducting scheduling processes, the reduction of costs for both vehicles and operators, and, most important, able to provision of enhanced flexibility and dynamism in the scheduling process. This is reflected both in the results presented and by the feeling that we had by planners with which we worked in teams throughout the duration of the project, on account of all the factors described in the previous sections. The recommendation of the project is to implement the tool and free up the time of the planners, so to involve them in a continuous improvement of the application itself. As for all technological developments, the use of the model by qualified personnel with the necessary know-how of the tasks would lead to improvements in terms of changing parameters and objectives. It is hard to expect that the study of a few months is better than the daily work of years of experience of the planners. This is encouraging since this process of continuous and iterative improvement, will lead to combining the power of automatic calculation of the model with the planning experience of the employees. This combination will be the key for the creation of a tool that not only reduces the working times, but that has the capacity to adapt more dynamically to unexpected events.

In the future the application must be able to understand the areas of scheduling, maintenance and days of rest, in order to integrate all the activities of the operational planning. With regard to this integration, it is necessary to consider that one of the pillars for the improvement will be, undoubtedly, good communication between the different departments of the transportation company.

ACKNOWLEDGMENT

The idea and the development of the application were done by Continente Siete (www.continentesiete.com).

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