Assessment of the taxi sector efficiency and profitability based on continuous monitoring and methodology to review fares

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ABSTRACT
The taxi sector presents many challenges to adequately serve the demand while maximising efficiency and profitability and minimising externalities. Many authors have dealt with the ‘taxi industry’ by modelling and forecasting its activity, usually using limited, incomplete or no trustable data to validate their model. The present paper tackles a different point of view. The applied methodology is based in the continuous monitoring of a sample of taxis that provide information recorded by the taximeter about their real activity. Taximeter data allows the definition of a wide series of representative and relevant Key Performance Indicators (KPIs) with which characterize the taxi activity. This paper focuses on the analysis of efficiency and profitability using KPIs. Thus, indicators firstly diagnose the system revealing its (in)efficiencies and whether or not is profitable. While studying profitability, the concept of the reasonable profit (RP) is presented to ensure welfare to the taxi driver. Indicators also represent an assessment tool to evaluate improvement measures and they constitute a powerful support for the decision making. In this sense, a methodology for the annual review of fares is developed introducing the concept of the RP. KPIs are applied in Barcelona, where they proof a demand-supply imbalance: since 2008 supply has increased significantly and demand has diminished; consequently, productivity and profitability have decreased considerably. Hence, KPIs reveal the inefficiencies of the Barcelona taxi system and demonstrate that its profitability is at risk.

Key words: taxi, taximeter, monitoring, indicators, efficiency, profitability, reasonable profit, fares.
1. INTRODUCTION
The management of a taxi fleet presents many challenges when it is time to analyse its activity and make strategic decisions especially in regulatory markets where taxi fares, fleets, work shifts and other issues are fixed (1).

To this purpose, the ‘taxi industry’ has been widely studied since Douglas (2) set the basis for the formulation to regulate fares and fleets. The optimization of fleet size and rates has been studied in different market configurations (3) using aggregated models (4, 5, 6, 7 and 8), structural models (9, 10, 11, 12 and 13), queue theory and Markov chains (14), equilibrium models (15, 16, 17, 18, 19 and 20), and simulation models (21, 22, 23, 24 and 25). However, the application of the modelling might not reproduce the real activity of the sector (26), and in addition taxi regulators do not often employ such complex models and use simpler registers.

The formulation of these models and its validation using data allows the forecasting of the taxi performance. Nevertheless, information available to study is usually limited, incomplete, and sometimes even distorted. Hence, the entire activity of the taxi driver is not reflected with trustable data, and analysis could possibly not be accurate. Common sources of data are surveys, traffic studies and other papers (4, 7, 15, 16, 17, 18, 19, 20 and 27). Taximeter data is not often used (8 and 28).

In this paper we propose the implementation of Intelligent Transport Systems (ITS) related to taximeters to continuously monitor a fleet of taxi vehicles. The taximeter records data about the activity of a sample of taxis conforming a raw data base (DB) to characterize their activity (29 and 30). This information is the basis for the definition of a series of representative and relevant KPIs that pretend to offer a detailed and faithful perspective of the sector and the taxi driver’s activity. Therefore, this paper tackles a different point of view with respect to previous literature: the focus is on monitoring instead of forecasting, and ground truth data recorded by taximeters is used.

Indicators are powerful assessment tools for taxi planners, and they are employed with two complementary goals: to diagnose and to analyse the situation of the taxi in an urban context. Although there are a wide variety of indicators, this paper focuses on those that deal with efficiency and profitability. On the one hand, productivity and occupancy ratios indicators assess the efficiency of the system (28, 31, 32 and 33) and its analysis reveals weaknesses and strengths of the daily supply–demand balance. On the other hand, KPIs are used to analyse the profitability of the taxi activity, where the concept of reasonable profit (RP) is introduced to ensure welfare to the taxi driver. In this case, the analytical application of indicators consists on the evaluation of the consequences caused to profitability by exogenous factors and the implementation of sector measures. They are finally used to support the decision making when updating taxi fares: a methodology to review rates is presented in this paper.

Operational measures have been widely modelled, but we believe that the monitoring can improve the diagnosis of the system in a more accurate way. Both techniques are compatible, but we want to stress that taximeters are common and economically accessible technologic equipments that might provide useful data. Data should be used confidentially and in an aggregate way for privacy concerns.

We implement the proposed methodology to the case study of Barcelona, where the taxi sector is regulated by the Metropolitan Taxi Institute (IMET), who controls fares, fleet and work shifts. Recently an important imbalance between demand and supply has been
detected. This inefficiency of the taxi system needs of a deep analysis of the activity and improvement measures to help the sector.

The paper is organized as follows. Section 2 provides the methodology employed to treat data and to obtain the indicators. Section 3 presents the results for the Barcelona case study. Section 4 analyses the results and provides a methodology for the review of fares. Section 5 summarizes the main findings and describes some possible research extensions.

### 2. METHODOLOGY

The methodology applied in this paper is based on the continuous monitoring of a sample of taxis using ITS: the taximeter records data about the taxi activity conforming a raw DB. This information is the basis for the definition of a series of representative and relevant KPIs that pretend to offer a detailed diagnosis of the taxi driver activity as well as a faithful perspective of the efficiency of the system. There is a wide variety of existing indicators describing productivity, profitability, externalities, service features and geographical trends. The present paper focuses in the two formers:

- Productivity indicators are based on the demand and the services achieved to reflect efficiency and the balance between demand and supply (occupancy rates).
- Profitability indicators economically assess the sector and the drivers with the definition of annual incomes, costs and RP. They are also useful to set new rates.

The methodology needs the definition of the daily supply curve and basic information provided by the taximeter about services provided (fare, length, duration and speed) and the previous vacant time performance (time and length spent when vacant).

#### 2.1 Data treatment

The methodology proposed in this study is used to assess indicators on both efficiency and profitability. The same criteria would be followed to obtain other indicators.

Firstly, DB is pre-treated to detect errors (invalid registers) and incidences like break times and starting workday services. To define break times, we check that the distribution of registered time between services is similar to a log-normal distribution, and we cut at the percentile 98 assuming that each taxi driver does one break per shift (34).

With resulting data, hourly mean values are obtained for each indicator and each taxi of the sample. The hour is the minimal unit of analysis and an accurate group to assure that the values of the KPIs are reasonably similar: variations between different hours of the same day are larger than between weeks or months. However, an hour is a relative short period of time and the effect of boundaries can be important as services are classified according to their finishing or starting time. If the amount of measures is large enough, this border error is balanced. Another important issue is when a taxi presents incidences or invalid registers: the activity of that taxi at that hour is not completely represented, and thus we don’t consider any register of that taxi for that hour.

Once the mean value for each taxi of the sample is obtained, a sample mean value is calculated with the values of all the taxis of the sample that provide valid data in this hour. Hence aggregating data a week type is defined for every analysed month, resulting 24 hourly means for each one of the 7 days of the week.
The definition of the indicators depends on the time scale definition (hourly, by shifts, daily, monthly or yearly). An aggregation and weighting procedure is therefore necessary. To obtain aggregated values (e.g., hourly income per day) mean hourly values are weighted using the number of taxis of the fleet operating (supply curve).

\[
\bar{X}_t = \frac{\Sigma x_i^j}{t_i} \tag{1}
\]

Where:
- \( \bar{X}_t \) Mean value of the indicator \( X \) at hour \( i \).
- \( x_i^j \) Value of the indicator \( X \) for the taxi \( j \) at hour \( i \).
- \( t_i \) Number of taxis of the sample with valid data for the indicator \( X \) at hour \( i \).

In the same way, aggregated values for the whole taxi sector (e.g., total annual revenue of the sector) are obtained through hourly sample means and the total of taxis operating at that hour. In this latter case a reduction factor is used to introduce absenteeism and vacations.

\[
\bar{X}_P = \frac{\Sigma x_i^j \cdot t_i}{\Sigma t_i} \tag{2}
\]

Where:
- \( \bar{X}_P \) Mean value of the indicator \( X \) in the period \( P \) (e.g., work shift, month or year).
- \( T_i \) Total number of taxis in service at hour \( i \) (universe of the statistic study).

Finally, to obtain aggregated values for a single taxi driver in a period of time (e.g., annual gross income), the total value of the whole sector is divided by the number of taxi drivers operating. Different taxi drivers would operate in different time windows during a day: a way to approximate a mean value for all of them is to suppose that they all contribute in the same way.

\[
\bar{X}_P^t = \frac{X_P^S}{\bar{T}_P} \tag{3}
\]

Where:
- \( X_P^S \) Total value of the indicator \( X \) for the whole sector in the period \( P \) (e.g., annual income of the sector).
- \( \alpha \) Reduction factor for absenteeism and vacations.

Statistical significance of indicators constitutes an important handicap to take into account. The disaggregation of values per hour may incur in the risk of not having enough data to consistently define a mean value. The interval estimation of a normally distributed mean (Equation 5) is an appropriate expression to evaluate the minimum number of values for achieving an acceptable precision of the indicator. That way, 5 hourly values is the minimum amount of data to assure that indicators are precise enough (34).

\[
P \left[ \mu \bar{X} \pm t_{\alpha/2,n-1} \cdot \frac{s}{\sqrt{n}} \right] = 1 - \alpha \tag{5}
\]

Where:
- \( \mu \) Population mean.
- \( \bar{X} \) Sample mean.
- \( t_{\alpha/2,n-1} \) Cumulative t-Student distribution with \( n-1 \) degrees of freedom.
2.2 KPIs for efficiency

The evaluation of the efficiency is closely related to the study of demand and productivity. Therefore, the first indicators to consider are the annual demand of taxi trips and the hourly productivity of the taxi driver (in terms of services accomplished per work hour, 33).

To determine the efficiency of the taxi activity it is helpful to relate the work production to the effort spent by the driver (31). Hence, we define the time occupancy rate as the time that the taxi vehicle is occupied by customers in one hour. To its calculation, we need to identify the average occupied time by means of the duration of fulfilled services.

Similarly, it is possible to discern between occupied and vacant mileage, detecting the length done in a service and in vacant. Mileage occupancy rate is defined as the occupied mileage over the total mileage run in one hour (32).

\[ \theta_t = \frac{\tau_{h,oc}}{60} \]  
\[ \theta_K = \frac{K_{h,oc}}{K_{h,oc} + K_{h,v}} \]

Where:
- \( \theta_t \) Time occupancy rate (min/h or %).
- \( \tau_{h,oc} \) Average occupied time per hour of service of the taxi driver (min/h).
- \( \theta_K \) Mileage occupancy rate (km/h -don’t confuse with speed units- or %).
- \( K_{h,oc} \) Average occupied mileage per hour (km/h).
- \( K_{h,v} \) Average vacant mileage per hour (km/h).

2.3 KPIs for profitability

The introduction of profitability concepts in the diagnosis of the taxi sector is an important aspect as taxi drivers seek to obtain economic profitability with their activity (35). In that way, the concept of the RP is introduced to provide a certain margin of benefits to the taxi driver to ensure his welfare. RP performs as an indicator of the profitability of the taxi driver, and it reveals whether or not the benefits obtained are enough to ensure an appropriate profit of his business activity. Therefore, it is not a cost in itself but it acts as a threshold to analyze the economic situation of the taxi market.
On the one hand, the annual gross income of the taxi driver is the main indicator in this study. It is a representative and significant parameter to describe the result of his performance and to guarantee the profitability of his regular activity. Developing Equations 3 and 4 we obtain a general formulation for the annual gross income:

$$ I_A^t = \sum_m \alpha \sum_d \frac{I_{i,d,m} T_{i,d,m} D_{d,m}}{T_m} $$  \hspace{1cm} (8)

Where:

- $I_A^t$ Total annual income of the taxi driver (€).
- $T_m$ Total number of taxi drivers in month $m$.
- $I_{i,d,m}$ Average income per hour $i$ of the day of the week $d$ in month $m$, accordingly to Equations 1 and 2 with values of the sample DB (€/h).
- $T_{i,d,m}$ Number of taxis of the fleet in service at hour $i$ of the day of the week $d$ in month $m$.
- $D_{d,m}$ Number of days of the week $d$ in month $m$.

On the other hand, costs are usually divided in direct and indirect costs. Direct costs are those resulting from the provision of the service (fuel and maintenance) and are mostly expressed in terms of the mileage (€/km). Indirect costs are independent from the activity of the taxi driver (net salary, social security, amortizations, insurances, etc.) and they can be

**FIGURE 1 Qualitative assessment of the economic status of the sector.**
expressed as cost per hour in service (€/h). In this paper we compute costs in an aggregate way as we are interested in the annual profitability.

\[ C_A^t = \left[ (K_A^t \cdot \mu \cdot \tau_f) + (K_A^t \cdot \tau_m + c_m) \right] + C_I \]  \hspace{1cm} (9)

Where:
- \( C_A^t \): Total annual costs of a taxi driver (€).
- \( K_A^t \): Total annual mileage (km).
- \( \mu \): Fuel consumption (l/km).
- \( \tau_f \): Fuel fare (€/l).
- \( \tau_m \): Maintenance costs per kilometre (considering repair frequencies) (€/km).
- \( c_m \): Other maintenance costs (cleaning and taximeter maintenance) (€).
- \( C_I \): Indirect costs: net salary, social security, amortizations, insurances, taxes, parking, administration, annual inspections, company and dispatching centre affiliation fees, and other costs (€).

Finally, the margin of RP is the main contribution of this methodology to the assessment of the taxi profitability. Its value can be arbitrary set to ensure a fixed benefit. However, it is desirable to establish some mechanisms in order to relate the RP (expectation of benefits of the taxi sector) to the general/regional economic context of the taxi system. Thus, to its calculation we introduce socioeconomic indicators (such as the percentage of benefit of a small or medium enterprise -SME- over its net asset) and some asset of the taxi driver (e.g., taxi license).

\[ RP = \varepsilon \cdot \beta \]  \hspace{1cm} (10)

Where:
- \( RP \): Margin of reasonable profit (€).
- \( \varepsilon \): Considered taxi driver’s assets (€).
- \( \beta \): Percentage representing socioeconomic indicators (%).

3. CASE STUDY: BARCELONA

Taxi services are regulated by the IMET in the Barcelona Metropolitan Area (AMB), a 475 km² area that involves 28 cities and has nearly 3 million inhabitants. The IMET manages taxi supply, fares structure, its annual revision and other policy issues.

The license is the title that officially allows the operation of the service to its owner, and it is intrinsically associated to one vehicle. Currently there are 10,523 vehicles (licenses) in the AMB, and this number has been frozen since 2005 in order to control the supply. Licenses belong to self-employed (9,977 licenses, 94.8 %) or to taxi companies (546, 5.2 %). On the other hand, taxi drivers need the so-called credential to provide the taxi service. The current 13,297 active credentials mostly belong to license owners that drive their taxi (9,514, 71.5 %), but many others are obtained by professional drivers with no own vehicle license (3,729, 28.5 %). These are salaried drivers, whose number has increased importantly in the recent years as credentials are not fixed: in 2012 there were 1,641 more salaried than in 2008 (78.6 % increase) and 2,757 more than in 2005 (283.6 %). Owners take profit of fixed costs by hiring salaried drivers and maintaining the vehicle in service for more hours (double and triple shifts). This is a minor but noticeable part of the sector: 7,863 taxis (74.7 %) are driven by their self-employed owner and 2,660 (25.3 %) by two or more salaried drivers. Nowadays, there are in average almost 5,500 taxis in service per hour during a day shift of a workday (7,300 in the peak hour), and about 1,250 in the night shift; in a weekend day there is less
supply (3,150 and 1,450 taxis per hour in average in day and night shifts). This represents an average increase of 27.1 % in the supply with respect 2008. The purpose of this Section is to determine whether or not the taxi is really (in)efficient and profitable in a city like Barcelona.

3.1 Available data
Data available for the study comes from a sample of vehicles within the AMB taxi fleet whose taximeters record all the necessary fields to characterize the activity of the taxi driver. The amount of available data varies due to budget restrictions, but as an average we have information of 30 taxi vehicles (out of 10,500) and about 180,000 registers per year (Figure 2a). Although the sample is not too large, data provided is large enough to adequately define every hour of every day of the year.

3.2 Diagnosis of efficiency
The first indicator of efficiency is the productivity, which is directly related to the demand of the service and the number of services performed in a certain time. From Figure 2b we can state that it has been an 8.3 % decrease in the Barcelona taxi demand between 2008 and 2012; accordingly to this loss and the increase in supply, the taxi driver’s hourly productivity has experienced a 15.6 % drop since 2008.

As a result, the taxi driver spends more time without customer and its occupancy rates decrease. The taxi driver spends about 60 % of an hour with no client, that is, without revenues (Figure 2c). Moreover, the time occupancy rate has experienced a 16.5 % reduction in the period 2008-2012. Similarly, mileage occupancy rates have decreased 9,8 % (Figure 2d), although its values are slightly above the 50 % (as taxi drivers may reduce the speed or take advantage of stands when in vacant).

The reduction in productivity merged with the observed in both occupancy rates is a relevant indicator that the Barcelona taxi system is less efficient every time.

3.3 Diagnosis of profitability
The income per hour and the total annual income might be the most significant indicators of the taxi’s performance. It is much related to productivity, but it adds the value of the service and the possibility to study the profitability of the profession. Working with time scales, a taxi driver can identify the most and the fewest profitable work shifts (Figure 2e for the year 2012).

For the cost computation, we use a confidential study provided by the IMET and other sources (interviews, publications) to determine unit prices of parameters in Equation 9. We introduce all the particularities of the cost study of the Barcelona taxi system: bank loans to purchase the vehicle and the license, taxes and salary depending on the annual takings, etc. It is also necessary to determine the annual mileage (Figure 2f) to calculate the direct costs, which approximately represent 10-20 % of total costs.

With regard to the RP, we consider the license price as the asset value to take into account (Equation 10) as the taxi driver has to do an important investment to obtain the title to legally exploit the service. Besides, to introduce the general/regional economic context we want to relate the expectation of benefits to those of a SME. In this sense, as a socioeconomic indicator we use the percentage of benefit of a SME over its net asset.
FIGURE 2  Results: (a) Available data; (b) Productivity and annual demand; (c) Time occupancy rate; (d) Mileage occupancy rate; (e) Average hourly income and costs by day (2012); (f) Annual mileage; (g) Annual profitability; (h) Annual purchasing power and margin over RP.
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<tr>
<td>CPI *</td>
<td>%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9.5</td>
<td>6.4</td>
<td>3.8</td>
<td>-</td>
</tr>
<tr>
<td>Annual Incomes (1)</td>
<td>€</td>
<td>42,967</td>
<td>43,553</td>
<td>45,414</td>
<td>45,571</td>
<td>47,521</td>
<td>47,151</td>
<td>47,697</td>
<td>45,571</td>
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<tr>
<td>Annual variation</td>
<td>%</td>
<td>-</td>
<td>1.4</td>
<td>4.3</td>
<td>0.3</td>
<td>-</td>
<td>-0.8</td>
<td>1.2</td>
<td>-4.5</td>
</tr>
<tr>
<td>Costs (a)</td>
<td>€</td>
<td>19,231</td>
<td>20,145</td>
<td>21,942</td>
<td>22,276</td>
<td>21,057</td>
<td>21,435</td>
<td>22,776</td>
<td>22,276</td>
</tr>
<tr>
<td>Net salary (b)</td>
<td>€</td>
<td>16,945</td>
<td>17,393</td>
<td>18,073</td>
<td>18,759</td>
<td>18,555</td>
<td>18,507</td>
<td>18,759</td>
<td>18,759</td>
</tr>
<tr>
<td>Annual Costs (2)= (a)+(b)</td>
<td>€</td>
<td>36,175</td>
<td>37,539</td>
<td>40,014</td>
<td>41,035</td>
<td>39,612</td>
<td>39,941</td>
<td>41,535</td>
<td>41,035</td>
</tr>
<tr>
<td>Annual benefit (purchasing power) (3)= (1)-(2)</td>
<td>€</td>
<td>6,792</td>
<td>6,015</td>
<td>5,399</td>
<td>4,536</td>
<td>7,909</td>
<td>7,210</td>
<td>6,162</td>
<td>4,536</td>
</tr>
<tr>
<td>Annual variation</td>
<td>%</td>
<td>-</td>
<td>-11.4</td>
<td>-10.2</td>
<td>-16.0</td>
<td>-</td>
<td>-8.8</td>
<td>-14.5</td>
<td>-26.4</td>
</tr>
<tr>
<td>Reasonable profit, RP (c)</td>
<td>€</td>
<td>6,484</td>
<td>4,970</td>
<td>4,065</td>
<td>3,763</td>
<td>7,100</td>
<td>5,288</td>
<td>4,219</td>
<td>3,763</td>
</tr>
<tr>
<td>Costs + RP (4)=(2)+(c)</td>
<td>€</td>
<td>42,660</td>
<td>42,509</td>
<td>44,079</td>
<td>44,798</td>
<td>46,712</td>
<td>45,230</td>
<td>45,754</td>
<td>44,798</td>
</tr>
<tr>
<td>Annual variation</td>
<td>%</td>
<td>-</td>
<td>-0.4</td>
<td>3.7</td>
<td>1.6</td>
<td>-</td>
<td>-3.2</td>
<td>1.2</td>
<td>-2.1</td>
</tr>
<tr>
<td>Margin over RP (5)=(1)-(4)</td>
<td>€</td>
<td>307</td>
<td>1,044</td>
<td>1,335</td>
<td>773</td>
<td>808</td>
<td>1,921</td>
<td>1,943</td>
<td>773</td>
</tr>
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* Annual CPI variation is considered from December year i (2009, 2010 and 2011) to December 2012, and changes in prices level are refered to the region of Barcelona. For the annual income, CPI is considered quarterly.
We analyze the data for the period 2009-2012 in Figure 2g and Table 1 (not enough data for costs was available for 2008) to study the profitability for a self-employed taxi driver. We introduce the Consumer Prices Index (CPI) to consider the changes in the price level in Barcelona, thus we compute incomes, costs and RP with and without inflation. Although incomes increase yearly favoured by the increase in tariffs, the purchasing power (annual benefit considering inflation) of the taxi driver decreases: the taxi driver covers costs but the margin is lower each year (Figure 2h). On the other hand, the value of the RP diminishes year after year as a consequence of the financial crisis as most SMEs decrease their benefit. Therefore, taxi drivers achieve this margin of RP even though their real benefit (incomes-costs) decreases significantly (-3,373 €, -42.6 %) as shown in Figure 2h.

4. ANALYSIS OF RESULTS

This section deals with another important issue: the ability of indicators to become a powerful analytical assessment tool for taxi planners. Based on the case study, we want to stress how indicators are worthy to detect weaknesses and strengths of the sector, to evaluate the implementation of measures and the effect of exogenous factors, and to support decision making.

4.1. Data treatment methodology

The study presented in this paper tackles a different point of view with respect to prior literature. On the one hand, previous studies are based on the modelling and forecasting of the taxi activity, and data from surveys or other studies is used to validate. On the other hand, the proposed methodology focuses on the monitoring of a subset of vehicles and uses taximeter data to diagnose the sector. This analysis that we propose is thus based on more accurate information of the real activity of a sample of taxis. Furthermore, this methodology is based on an economically affordable and widely used technology, so it is feasible to adapt it in any other location.

The definition of indicators with taximeter data depends on the successful realization of a trip. This can be a disadvantage in a context of lack of supply where unsatisfied demand wouldn’t be counted, and therefore not all the real (or potential) demand would be considered.

FIGURE 3 Different points of view for the analysis of the taxi sector.
**4.2 Analysis of efficiency**

The imbalance between demand and supply has caused a decrease in the productivity and the efficiency of the taxi driver activity during the last years: in this section we want to analyse weaknesses and strengths of the taxi activity.

Figures 4a, 4b and 4c compare the hourly distribution in a work day of the main indicators of efficiency (productivity and occupancy rates) and profitability (incomes). All of them follow a similar pattern with two peak periods (8h-10h and 22h-0h) and two off-peak periods (16h-19h and 2h-3h). That is, hourly indicators are showing the weaknesses of the daily activity (less efficiency between 16h and 19h) and the strengths, where the supply better meets demand (22h-0h). Therefore, managers should act to improve the efficiency of the taxi activity specially during the afternoon, and also should take advantage of the peak time. In this sense, it would be interesting to study an optimal supply defined by different work shifts that appropriately serve the demand.

**FIGURE 4** Analysis of efficiency and profitability in Barcelona 2012: (a) Hourly occupancy rates vs. productivity in a work day; (b) Hourly occupancy rates vs. income; (c) Hourly income vs. productivity; (d) Sensitivity analysis of annual profitability towards a reduction on vacant mileage.

**4.3 Analysis of profitability**

In this section we analyse how indicators respond to the effect of sector measures (reduction on annual mileage) and changes in exogenous factors (increase on the fuel price). We then propose a methodology for the annual review of rates based on the achievement of the RP.
359 4.3.1 Sensitivity analysis of the taxi profitability
360 The profitability of the taxi is intrinsically related to some parameters that directly affect
361 incomes and costs (Equations 8 and 9). Changes in driver’s activity or in exogenous costs
362 may modify economic expectations.
363 First, we are interested in analysing the effects of a reduction on the annual mileage in
364 the taxi profitability: the promotion of stands could reduce vacant mileage, which could also
365 significantly contribute to the reduction of externalities. Assuming constant demand
366 (passengers go to a stand to find their taxi) and that occupied mileage remains constant (as it
367 depends on demand), the reduction of total mileage comes from a different behaviour of the
368 taxi driver when empty. By reducing mileage we reduce direct costs (fuel consumption and
369 maintenance, Equation 9) and taxes (in Barcelona some taxes are defined as a function of
370 mileage). In Figure 4d a sensitivity analysis of the profitability towards a reduction on vacant
371 mileage is presented studying the cases of a 5, 10, 25, 50 and 90 % of reduction with respect
372 to the current situation (22,720 km in vacant, 47.3 % of total annual mileage). With a little
373 decrease on mileage a significant improvement on the margin of benefits is satisfied, which
374 points out the advantages for the taxi driver to reduce speed or movement when there is no
375 customer aboard. Contrary, increases of 23.4 % (5,323 km) and 137.5 % (31,243 km) on the
376 annual vacant mileage would imply neither achieving the RP nor covering costs, respectively.
377 On the other hand, an increase in fuel fares gets directly translated into an increase of
378 costs (Equation 9). The fuel price is a strong constraint for mobility in non-producer
379 countries, especially for a taxi driver who runs about 45,000 km/year (Figure 2f). We want to
380 determine the threshold for the price of fuel in which taxi drivers wouldn’t achieve the RP. In
381 the profitability study presented in 3.3, it was considered an annual average price of 137.7
382 c€/l for 2012. Keeping the annual mileage constant, for 155.8 c€/l (13.2 % increase) the taxi
383 driver wouldn’t achieve the RP; for 246.0 c€/l (78.7 % increase) the taxi driver would only
384 cover costs; and prices of fuel above this limit would cause a deficient status of the sector.
385
386 4.3.2 Methodology for the annual review of taxi fares
387 Taxi fares are reviewed annually in order to introduce inflation and to ensure the welfare and
388 the purchasing power of the taxi professional. This annual review of taxi fares is related to
389 the concept of the RP: projected incomes should provide a healthy status of the sector, that is,
390 ensure that they will cover costs and the margin of RP (Figure 1). Following the scheme in
391 Figure 5, the proposed procedure consists on using data from previous (i-1) and present (i)
392 years to determine the projection (year i+1) of incremental needs of incomes for the taxi to
393 achieve the RP.
394 Once the percentage of increase of the taxi fares is determined, a new procedure starts
395 to translate this augmentation into the fare structure of the service. This time, the goal is to
396 estimate the total revenue in the projection year (i+1) that a taxi driver would obtain under
397 certain conditions of rate increments. Comparing this estimated income with the one
398 calculated previously we are able to determine whether or not the suggested new fares are
399 adequate. Thus, an iteration process is applied in which the resulting rates depend on the fare
400 structure and composition. To estimate the effect of the fare increase over a trip it is
401 necessary to have a classification (or estimation) of services performed according to length
402 and duration. Then we could estimate the total revenue.
403 A similar methodology to update fares is already being applied in Barcelona, but
404 further research can consider studying the impact of this procedure.
FIGURE 5 Methodology for the annual review of fares introducing the RP.
5. CONCLUSIONS

In this paper a methodology to analyse the taxi system is presented based on the continuous monitoring of a fleet of taxi vehicles with the implementation of ITS related to taximeters, an affordable and widely applied technology. The use of ground truth data registered by taximeters offers the possibility to achieve more accuracy in the diagnosis of the activity of the sector, revealing its strengths and weaknesses. Nevertheless, although an important amount of data can be provided by a few taxis, it is essential to ensure statistical significance with an adequate sample as taxi drivers may present many differences in their behaviour.

Monitoring a taxi sample allows the definition of a wide series of representative and relevant KPIs to characterize the real activity of taxis in an urban context. This paper focuses on the analysis of efficiency and profitability using KPIs. The former analyses the supply-demand balance; the latter is used to economically assess the taxi activity and to set a methodology for reviewing rates. The concept of RP is introduced as a threshold to ensure profitability and provide welfare to the taxi driver.

Indicators are applied in Barcelona in order to evaluate their effectiveness when achieving their main objectives. Firstly, they diagnose the sector and reveal the inefficiency of the Barcelona taxi system with an imbalance between demand and supply: an increase on the supply (78.6% more hired drivers employed in double shifts and an average of 27.1% more vehicle hailing each hour since 2008) is not corresponded by the demand (decrease of 8.3%, 5.1 million services, in the same period). Consequently, a 15.6% fallen in the productivity (trips/h) is detected, as well as a decrease in time and mileage occupancy rates (-16.4% and -9.8%, respectively). This imbalance affects the profitability: the annual margin of benefit of the taxi driver has experienced a 42.6% (3,373 €) drop since 2009 diminishing their purchase power (although they have yearly covered costs and the RP). Indicators are also used to reveal weaknesses and strengths in the daily taxi efficiency and to evaluate economic consequences of measures (reduction on mileage) and feasible scenarios (increase on fuel price). Finally, indicators support the decision making with the development of a methodology for the annual fare review, in which the concept of RP is introduced.

Therefore, indicators show their potential for the Barcelona taxi sector as a diagnosing and assessment tool and as a support for the decision making (with an important application on the review of taxi fares). In future tasks it would be interesting to apply the methodology in different urban contexts to empower the validation of the model, but at present we don’t have the necessary information for other cities.

Future research lines can focus first on determining the optimal taxi fleet to correct the supply-demand imbalances, considering the RP to establish profitable work shifts. Taxi planners and companies can take advantage of ITS and indicators to undertake improvement measures to increase productivity and profitability of their fleet. A control centre could manage the sector in an efficient way by an in real time monitoring. Similarly, dispatching centres and smartphones applications may offer better and more accurate results with the use of KPIs. Another work line is to assess the implementation of more dynamic fare structures (e.g., with supplements when demand is inelastic). KPIs may also be used to calculate externalities introduced by the taxi sector, and to help sizing the layout of an efficient taxi stand network by means of GPS data. Taxis can be used to provide traffic information as floating vehicles (29) to facilitate synergies with the traffic management.
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