On Charge Point Anxiety and the Sharing Economy

Eoin Thompson*, Rodrigo Ordóñez-Hurtado*, Wynita Griggs, Jia Yuan Yu, Brian Mulkeen and Robert Shorten

***Abstract*—This paper addresses some of the issues surrounding the charging of electric vehicles (EVs) with a particular focus on charge points. We discuss the design and implementation of a charge point adapter. The key feature of the adapter is that it provides privately owned charge points with the opportunity to be rented to members of the public, resulting in additional charging opportunities for EVs. We present a number of use cases whereby the adapter is used to alleviate the demand for EV charging in an area that experiences a shortage of charge points, but where private, unused charge points are available.**

I. Introduction

The way in which we buy and sell goods and services is experiencing a profound change. We, as consumers, have begun to diverge from the concept of absolute ownership and embrace a sharing culture that is quickly becoming the focus of modern consumerism. Capitalising on unused items is the fundamental principle behind the Sharing Economy. A neglected vehicle could be rented for the weekend, a spare room leased, or an old outfit reinvented by a new owner. Forgotten, futile or fruitless, items that serve little or no purpose to their owner may still be of value to the right renter or buyer. Propelled by new advances in technology, the desire to share unused items and services has given rise to a disruptive new business paradigm – the Sharing Economy. Examples of such services include Airbnb, Uber, Blockcharge, and there are many others.

Our objective in this paper is to explore sharing economy ideas in the context of plug-in vehicles. In many countries, the adoption of plug-in vehicles has been disappointing. With a high purchase price, and doubts surrounding their range, they have not yet become a popular form of transport [1], [2]. For example, in 2015, approximately one in seven hundred cars in Europe was fully electric (FEV), which corresponds to a disappointing 0.15% of all passenger cars [3]. The sales figures for FEVs were equally unimpressive that year as a mere 1.2% of cars sold in the EU were electric [3]. However, despite these figures, there is still optimism that plug-in vehicles will become a major form of road transportation. Driven by recent concerns about air quality and extended range, the uptake of these vehicles has seen a surge in some countries: see, for example, Ireland, as depicted in Table I. In the context of Ireland, many incentives exist to promote EV ownership. For example, the Sustainable Energy Authority of Ireland is encouraging the purchase of these vehicles, by offering subsidies of up to €10,000 through a combination of grants and Vehicle Registration Tax (VRT) relief for EVs [4].

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TABLE I
Number of EVs Licensed for the First Time in Ireland [5].

Year	No. EVs Licensed	Year	No. EVs Licensed
2007	23	2012	215
2008	38	2013	72
2009	59	2014	238
2010	66	2015	497
2011	103	2016	411

Although some of the major issues associated with EV ownership are being addressed, in many countries there is still widespread dissatisfaction with the available charging infrastructure [6]. Some of the issues associated with public charge points include their scarcity and availability, in terms of their geographical spread, and in arriving at a charge point to find it already being used. Drivers are consequently reluctant to undertake long journeys in case they are unable to recharge their car. Upon reflection, this situation is absurd, as there are not only public charge points, but also private ones that can be used to charge private vehicles. Current policy in Ireland is that purchasers of plug-in vehicles (EVs) have a home charge point installed free-of-charge as part of an incentive scheme to encourage adoption of plug-in vehicles [7]. The total number of available charge points in Ireland (public plus private) therefore far exceeds the number of public charge points [8], yet insufficient public infrastructure is still cited as an impediment to the adoption of plug-in vehicles even though many charge points are potentially available to EV owners. The problem in Ireland is not one of infrastructure, but rather, access to it. More specifically, during business hours, charging spaces tend to be limited and over subscribed in work-place locations, while at the same time many nearby residents have left home for work. Consequently, an opportunity exists to monetise these unused charge points by fostering collaboration within the EV community, whereby every privately owned charge point is also made available to the public. Thus, there is an opportunity to use these vacated residential parking spaces, complete with charging points, as a charging infrastructure for workplace campuses. Similar ideas are currently emerging elsewhere; see https://chargedevs.com/newswire/swedish-initiative-lets-ev-owners-share-charging-stations-a-la-airbnb.

Our objective in this paper is to go beyond these initial ideas to both enable sharing through the design of dedicated hardware, and also to develop a suite of analytics to enable sharing of home charge points. Thus, our system will go beyond existing ones in a number of ways. First, we shall design a smart plug that connects to domestic home charge points. The smart plug has two functions: (i) to enable two (or potentially more) vehicles to be connected to a home charger at the same time, with electrical current being multiplexed between vehicles according to defined optimisation criteria; and (ii) to allow payment for charging. We also remark here on the critical differences between our device and other state-of-the-art charging solutions, such as Blockcharge (a Blockchain-based, peer-to-peer charging technology; see https://www.youtube.com/watch?v=it2X_j-DPmA). In particular: our plug is for a home 16 Amp charge point rather than a domestic 8 Amp socket; multiple cars can be connected via our plug to the charge point at the same time; multiple charging policies can be implemented (specifically, best effort algorithms can be implemented, and vehicles can be prioritised); Blockchain is not required for our system, and anyone can charge their vehicle (as opposed to only club members), and the cable is only released when payment is received; the adaptor in our case advertises a free charge point when one is available; and finally, our charge point adaptor does not block the charge point, thus eliminating some effects of miscreant behaviour. In parallel, we shall dimension the shared service based on EV demand profiles in a number of different scenarios, as well as dimensioning a buffer of charge points to protect EV owners against misbehaving charge point owners. This latter aspect is necessary to ensure a quality of service for renters by setting aside resources as contingency for events where rented charge points are unavailable.

II. Smart Plug

Our starting point in this paper is our charge point adaptor [9]. The function of this adaptor is to enable owners of a single domestic charge point to sell access to their charge point, to several EV owners simultaneously. As we have mentioned in Section I, scarcity is one of the most common problems associated with charge points. Each charge point is restricted to charging a single EV at a time and it takes several hours to achieve a significant level of charge. As a result, many drivers struggle to find suitable charging facilities outside of their homes. The most intuitive solution would be to increase the number of charge points. This is not a feasible solution due to the cost associated with building new charge points, the cost of public AC chargers can vary from $2,300 to $6,000 [10]. An alternative solution is the fast charging stations that offer a quicker charge time (30 minutes) [11], [12]. This enables the charging of more EVs over a shorter period of time. However, a 30 minute charge time can turn into hours of waiting in the face of queuing [2]. The Smart Plug, Fig. 1, is a proposed solution to the problem.

The Smart Plug enables dual access to a single charge point, allowing private sources of electricity to be monetised. While this offers a number of benefits in terms of the availability of charge points, this paper focuses on using the plug to enable the sharing of private charge points. The dual sockets give landlords (owner of the charge point) the freedom to rent their charge point to the public while still having access to a source of charge; i.e. a landlord can reserve the use of one socket for themselves while the other is used by another driver. On the other hand, the landlord can also rent out both sockets to the public and charge their car at a different time. In this section, we discuss the operation of the plug. A brief description of the hardware is given and finally we describe the testing of the plug.

A. Main hardware components

We provide a detailed description of the main hardware components of the Smart Plug, as depicted in Fig. 1.

1) Interface: The plug's interface is minimalist and consists of two push buttons (one for each socket) as input devices, and one OLED display as an output device. Each push button is used to start/stop the charging process or begin a payment for the corresponding socket, while the OLED display provides the users with the state of both sockets (i.e. availability, charging state/fee, and payment state).

2) Microcontroller: The operation of the plug is coordinated by an Arduino UNO microcontroller. It manages: (i) the monitoring of the plug's interface, i.e. listening for any user requests and showing the current state of the plug; (ii) the orchestration of the multiplexing of the output signals depending on both the state of the plug (i.e. number of users demanding service) and the switching rule; (iii) the calculation of the corresponding user's fee based on the power consumption estimation; (iv) the communication with a web server through the WiFi module; and (v) the processing of local payments through the NFC shield.

3) Energy meter: In the current implementation of the Smart Plug, power consumption is estimated using a current sensor and a fixed nominal value for the ac voltage from the charging station. However, as the power factor of the charging station cannot always be guaranteed to be close to 1, a future implementation of the Smart Plug will also use a voltage sensor to improve the estimation.

4) Local contact-less payment: An NFC shield is incorporated into the Smart Plug so that the users are allowed to use NFC-based digital wallets (such as Android Pay and Apple Pay). Additionally, an NFC tag with a link to a web service enabling online payment (e.g. using credit/debit cards) is also attached to the Smart Plug.

5) Internet-of-Things chip: An ESP8266 WiFi module enables the Smart Plug to connect to a web server through a WiFi access point using TCP/IP connections. This makes possible, among others: uploading periodically the state of the Smart Plug to the web server; checking online payments which are reported directly to the web server; and enabling additional online services such as searching and booking. In addition,

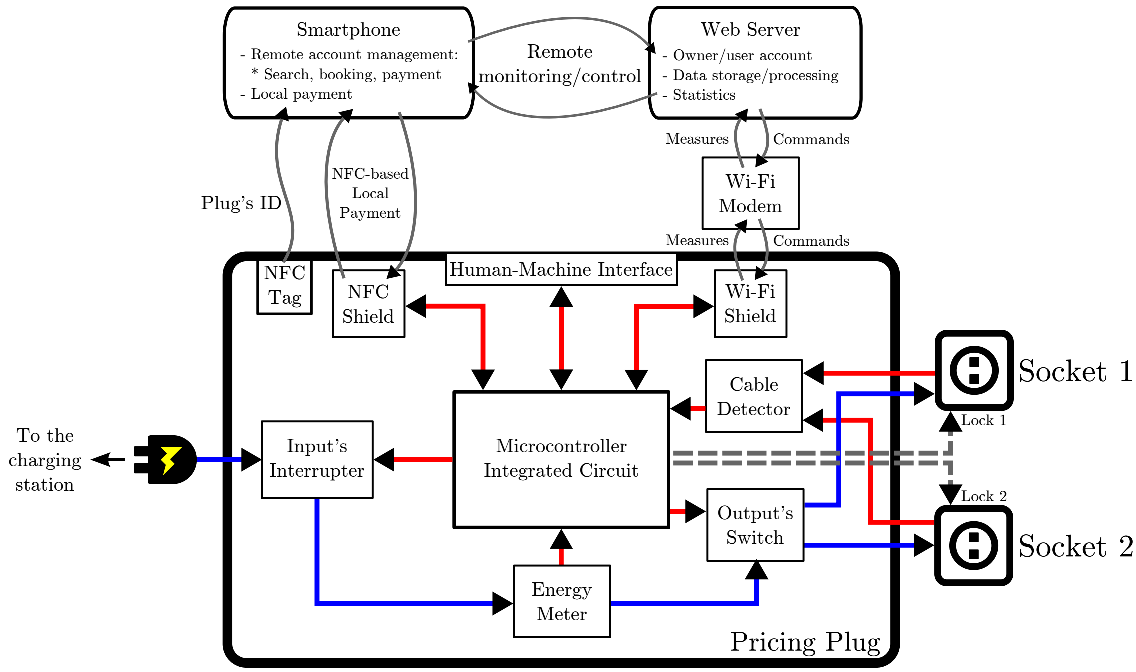

Fig. 1. Smart Plug schematic [9].

data analytics can be applied to the information saved to the web server, so both owners and users can get access to relevant statistics from the Smart Plug.

6) Electronic cable locks: Two electronic locking solenoids are used for each socket to secure the charging cables once the charging process has begun, and only will be released after a successful payment. This offers advantages to both the Smart Plug's owner and to the user, as the locking system prevents users from leaving without paying, and also prevents the theft of the owner's charging cable.

B. Smart-plug operation

The Smart Plug enables dual charging of two EVs and can be used with a Type2, 16A charging cable. To begin charging, the charging cable of the car is inserted into one of the sockets. Once inserted correctly, the display will show a message notifying the user that the cable is connected to the corresponding socket. Once the connection has been confirmed, the user can initiate the charging process by pushing the corresponding button. As the charging process begins, the cable is locked to the socket. This prevents users unplugging other cars mid-charge and also provides a security measure to the landlord of the charge point. When there are two cars using the plug, the charge is distributed by switching back and forth between the two sockets. The charging process can be stopped by pushing the button for a second time. The display will notify the user that the charging process has stopped and will prompt the user for payment. Payment can be made via the NFC Shield (RFID) or online through a web server. Once payment has been accepted, the cable is released from the socket.

C. Testing

The Smart Plug was tested on the University College Dublin campus in Belfield, Dublin 4. The two cars used during the test were a Nissan Leaf and a Volkswagen Golf GTE. Both cars were observed to charge using the plug, and the charging process was monitored using the OLED display; in both cases, the correct state and fee were displayed. Finally, a local NFC payment was successfully emulated using a test NFC card to release the charging cables.

D. Charging policies

There are also a number of different charging policies that could be implemented, i.e. different ways in which the Smart Plug distributes its charge. For example, the Smart Plug could be programmed to detect the battery level of each vehicle. Priority could be given to the vehicle that has a shorter charging time; by charging this vehicle first, the owner does not have an unnecessarily long charge time.

The Smart Plug could take a user's journey into consideration. A predefined start and end point could be used by the Smart Plug to estimate the amount of charge required by the vehicle to complete the journey. For example, a user could upload their home address to the Smart Plug and request that the charge point allocate enough charge that would allow them to drive home.

The driving habits of an EV owner have a significant influence over the amount of battery used when driving, and an efficient driver can preserve their battery whereas some drivers may drain their battery unnecessarily. A user could upload their driving profile to the Smart Plug, which would enable the Smart Plug to determine a more accurate estimate of the amount of charge required to complete a journey.

Regarding the renting of privately owned charge points, a pay-as-you-go policy could be incorporated which would allow users to make a payment before arriving at the Smart Plug. For example, a user could pay a given fee and the Smart Plug could distribute charge in proportion to this payment.

Other policies could involve users specifying their own cut-off time, and the Smart Plug could charge a vehicle for a given period and then stop distributing charge. The Smart Plug could also be programmed to reward those who carpool; this concept has been adopted by many companies, for example Intel in Lexilip, Kildare, Ireland, reward employees who carpool with preferred parking. Thus, the Smart Plug could give charging priority to those who carpool. The implementation of these policies requires further development of the software (programming the Arduino).

III. Use Case – Design of Sharing Systems

In the previous section, we described the design and capabilities of the Smart Plug. The purpose of the plug is to enable the public sharing of privately owned charge points. We now present a use-case whereby the plug is used to rent private charge points to the public. We consider two areas that offer the same resource while experiencing a complementary supply and demand, i.e. one area has an excess of charge points while the other suffers from a shortage. We consider three different example locations that experience a shortfall of charge points: a University Campus, a Hospital, and a Stadium.

A typical day on a University Campus sees staff and students compete for the charge points on a *first-come, first-served* basis. A hospital faces similar competition from patients and staff. Inevitably, the charge points are used to their full capacity and users must search elsewhere to charge their vehicle. Stadiums host a number of events such as concerts and sports games. Many people drive to these events and wish to charge their car while attending the concert/game. However, these events attract thousands of supporters, resulting in a shortage of charge points. In each of these situations, we have a potential charge-point gradient; namely, artificial charge point congestion, in close proximity to an oversupply of charging opportunities. Specifically, apartment residents or housing estate residents may be home to a number of EV owners, each with their own personal charge point [7], but which are unused for long periods during the day. For example, a charge point is left vacated during business hours while the landlord is at work, resulting in an unused resource. This is a situation that, using our Smart Plug, can be exploited by following and developing some of the ideas in [13]. Specifically, a sharing scheme is proposed whereby the landlords allow car owners to use their charge point while they are away. A specific time period is contracted, during which the landlord agrees to vacate their charge point, allowing car owners from the university, hospital or stadium to charge their car. As in [13], the charge points offered by the university, hospital and stadium are considered as premium charge points as they experience a high demand. The charge points offered by the apartment residents are considered as secondary charge points as they are neglected during this time. The apartment residents are assumed to be located closely to the area with the premium charge points so that it is not an inconvenience to access. Mathematically, our objective is to formulate a system that assures a **high level of *Quality of Service (QoS)*** to members of the public wanting to rent a charge point in a geographical region, their preference being to particularly rent in the area that experiences the high demand and thus the charge point shortfall, but where they will also settle for renting nearby. We wish to formulate this QoS problem in a manner that makes the probability of not being able to access a premium charge point be bounded below some threshold.

A. Dimensioning – stadium use-case

Our sharing scheme sees the landlords of the secondary charge points renting them to the public. A problem may arise, however, if a landlord 'misbehaves'; for example, if their car is parked in their driveway, this may impede the renting EV owner's access to the charge point. We propose that a number of premium charge points (i.e. at the university, hospital or stadium) are left in reserve, only to be used by EV owners that have been unexpectedly left without a secondary charge point. This approach differs to the recent work of [13] as it considers the point of view of the renter rather than the landlord. Furthermore, [13] considers parking spaces and not charge points. In this section, we determine the number of premium charge points to be left in reserve so that a certain QoS to the renter is assured. The dimensioning is applied to the stadium example in particular. The following notation will be used: $N =$ number of premium charge points available; $M =$ number of secondary charge points available; $Q =$ number of reserved premium charge points.

Each charge slot is split into a rental window $[0, W]$. Depending on the setting, there may be several charge slots per day. The landlord agrees to make at least one socket in the charge point available during the interval $[0, W]$ while the EV owners agree to charge their car during this interval only. We let the index $i = 1, 2, ..., M$ denote both the landlords of the secondary charge points and the guest EVs. Each landlord is assigned a non-negative random variable T_i which represents the time that the landlord returns and demands sole, private access to his/her charge point(s) again. A non-negative random variable A_i is assigned to each charge point which represents the departure time of each EV owner. We assume that T_i are independent and identically distributed (similarly for A_i) and that these are mutually independent, and all distributions are assumed to have densities as well [13].

The following event is defined for each secondary charge point [13]: $E_i \triangleq \{T_i \in [0, W]\} \cap \{T_i < A_i\}$. This event represents a landlord returning earlier than agreed, in which case the EV owner from the stadium is left without a charge point.

1) Dimensioning formula: Let F_T denote the probability distribution of T_1 and F_A denote the probability distribution of A_1. Then $P(E_1) = \int_{t=0}^{W} (F_A(W) - F_A(t)) dF_T(t) + F_T(W)(1 - F_A(W))$.

This formula characterises the probability of a landlord returning early in terms of the probability distributions F_T and F_A [13]. As a corollary, the following is an expression for the probability that the reserved spaces are not sufficient [13]:

$$P(M, Q) = \sum_{k=Q}^{M} \binom{M}{k} P(E_1)^k (1 - P(E_1))^{M-k}.$$

B. Parking data with example

In this section, the dimensioning is applied to a **university** and a **stadium**. By estimating the distributions F_T and F_A, the required number of charge points to be left in reserve to achieve a quality of service target can be determined.

1) Estimating F_T: The distribution F_T represents a landlord breaching the contract by not vacating their charge point. There are many reasons why a landlord may not vacate their charge point. For example, the landlord has taken a sick day and so has stayed home, blocking access to the charge point. The distribution F_T can be represented by the number of sick days of NHS staff in England over the period from April 2009 to February 2014. The average sickness rate is used to estimate the probability of T_i, taken to be 0.042, and assume that T_i is taken to be 0.958 otherwise [13].

2) Estimating F_A – synthetic data: The distribution F_A represents a car owner overstaying. An accurate estimate could be obtained with access to data regarding charge point usage in a university campus, hospital and stadium. This data is not readily available. Instead, we construct synthetic data by estimating the duration of a parking event (how long the vehicles stayed in the car park) for a university and a stadium.

The university chosen was University College Dublin, Stillorgan Road, Belfield, Dublin 4. The following information was considered when constructing the data. The capacity of parking offered by UCD is 4000 [14]. A typical working day commences at 9:00 a.m. which is also when the first lectures of each day commence. At this time, the car parks on campus are usually full. This remains the case until 3:00 p.m., when the majority of students have finished lectures for the day and leave campus. By 6:00 p.m., the majority of lectures have finished for the day, students and staff leave campus with the exception of those working late or taking part in extracurricular activities. The number of cars parked on campus therefore experiences a significant drop after 7:00 p.m., as depicted in Fig. 2.

The stadium chosen was Croke Park, Jones' Road, Drumcondra, Dublin 3. Croke Park offers a number of parking facilities to those attending concerts or sporting events. Q-Park is an off-street car park operator that offers parking to those attending events at Croke Park. Located on Marlborough Street, the capacity of the car park is 567 spaces. The parking data was constructed to emulate the distribution of parking during the 2016 All Ireland football final. This day consists of two games, a minor and senior final. The minor final commences at 1:15 p.m. and the senior final commences at 3:30 p.m. Each game lasts 70 minutes with a 15 minute break at half time (Fig. 3).

C. Results

The results of the dimensioning are illustrated in Figs. 4-7. The interval [0,W] is chosen by defining a percentage of the parking population as 'overstayers'. In this paper, we choose W to simulate the fact that 10% and 20% of drivers overstay, i.e. we choose W such that $P(A_i > W) = 0.1$ and 0.2. Of course, access to more particular data would provide a more accurate value for this interval. The number of charge points left in reserve are varied for a fixed value of M and the probability $P(M, Q)$ is determined.

The probability of the Q reserved spaces being insufficient is seen to approach zero exponentially. The results show that a quality of service target can be achieved by reserving a number of the premium charge points. It can be observed that a larger number of premium charge points are required when the number of users that overstay is increased.

IV. Conclusion

In this paper, we presented a charge point adapter and discussed a sharing scheme whereby the adapter is used to rent privately owned charge points to the public. We presented a number of use cases for the plug and performed dimensioning on one of those use cases to ensure a quality of service target for all users. Based on this work, the authors are currently working towards implementing simultaneous charging to the plug, which allows two cars to charge at the same time, rather than switching between them. The dimensioning can be improved by obtaining more accurate data regarding charge point usage, in particular how long users stay at charge points and what percentage are likely to overstay once their charge slot has expired. By improving our models of F_T and F_A, we can obtain a more realistic value for $[0, W]$.

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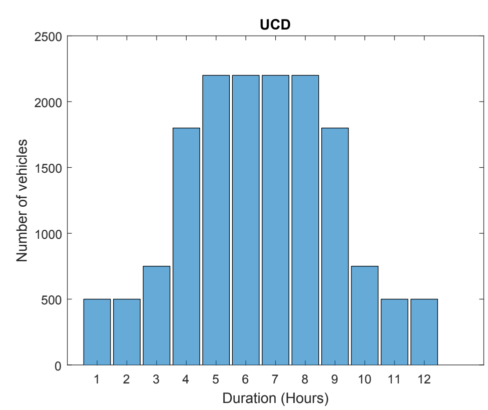

Fig. 2. UCD parking duration.

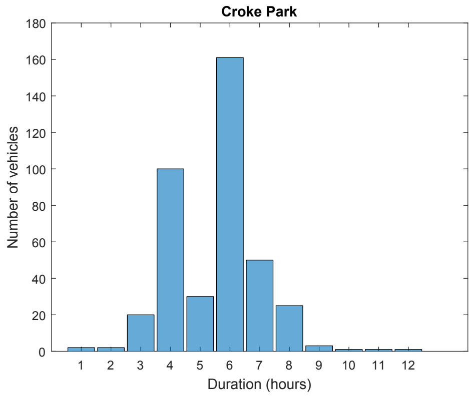

Fig. 3. Croke Park parking duration.

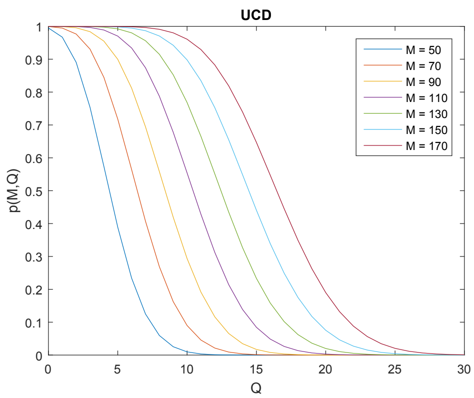

Fig. 4. Probability of Q reserved spaces are insufficient, 10% Overstay.

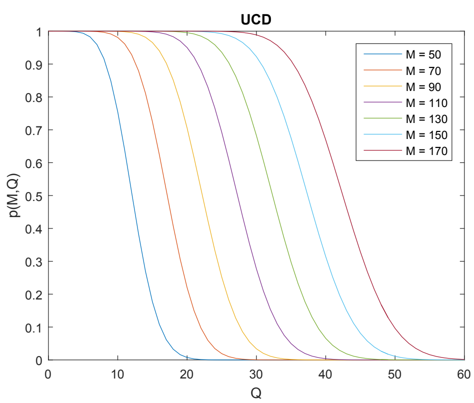

Fig. 5. Probability of Q reserved spaces are insufficient, 20% Overstay.

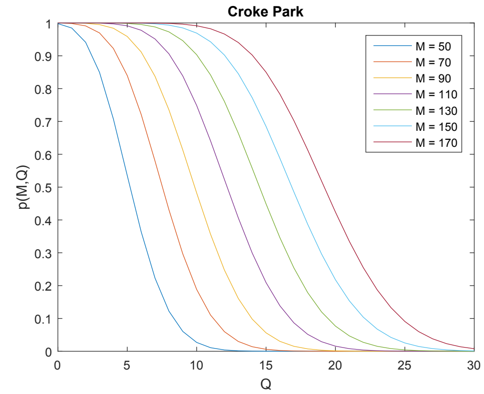

Fig. 6. Probability of Q reserved spaces are insufficient, 10% Overstay.

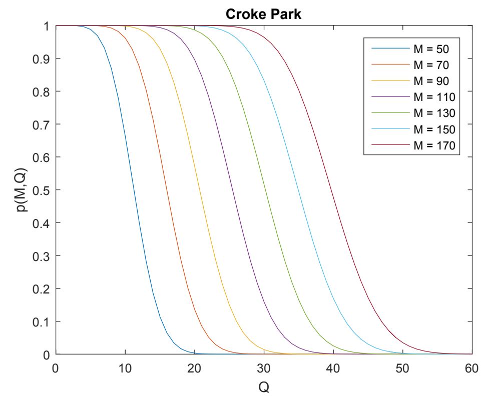

Fig. 7. Probability of Q reserved spaces are insufficient, 20% Overstay.

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