# Refugee Camp Wireless Outage Analysis

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Dedicated to migrant folks around the world.

**Abstract**

This paper addresses the gap in the literature of looking at wireless network failures in European refugee camps and the factors that may cause or even exacerbate them. After discussing the importance of connectivity for the refugees and displaced populations in general, an exploratory analysis is conducted to provide an overview of outage patterns in twelve Greek camps over the span of six months. Finally, the paper addresses three possible causes of increased outage rates - camp administration type, camp capacity status, and weather patterns. While the paper fails to confirm that any of the above factors are significant in wireless network outage patterns, it addresses limitations that future research should try to resolve.

*Keywords:* Refugee Camp; ICTD; Wi-Fi Outage

The list of those who have provided their time, guidance, and other support to this research seems to grow by the week. Here we provide an alphabetical list of those we want to acknowledge their contributions to this truly collaborative project:

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**List of Acronyms**

AP……………………………………………………………………………………………….Access Point
API…………………………………………………………………..Application Programming Interface
CSV……………………………………………………………………………..Comma-Separated Values
EU……………………………………………………………………………………………...European Union
ICT…………………………………………………….....Information and Communications Technology
ICT4D………………………………..Information and Communications Technology 4 Development
IDP…………………………………………………………………………..Internally Displaced Person
IP………………………………………………………………………………………....Internet Protocol
IRC……………………………………………………………………International Rescue Committee
MAC……………………………………………………………………………….Media Access Control
NGO…………………………………………………………………...Non-Governmental Organization
NF……………………………………………………………………………………………….Normal Form
PDF…………………………………………………………………………Portable Document Format
POC……………………………………………………………………………...….Person of Concern
SSID…………………………………………………………………………......Service Set Identifier
SQL…………………………………………………………………………..….Structured Query Language
UN……………………………………………………………………………………….....United Nations
UNHCR…………………………………………….....United Nations High Commission for Refugees
Wi-Fi……………………………………………………………………………………...Wireless Fidelity

## Introduction

In 2018, there were 68.5 million individuals throughout the globe that were forcibly displaced from their homes due to violence, environmental problems, and other causes. Of those individuals, 30 million were described as internally displaced people (IDPs) that migrate around their home country but do not leave it [30]. Another 25.4 million were described as refugees and 3.1 million as asylum seekers [30].

Individuals legally labeled as refugees[1] are people who have left their home countries because of violence or other reasons for forced migration and are no longer able to safely return [33]. What constitutes refugee status was determined by the 1951 Geneva Convention and still shapes current asylum processes today [10]. While much of the literature reviewed for this paper liberally uses the term *refugee* to describe any forced migrant, some works only refer to *refugees* as those that have explicitly identified themselves as refugees.

Once migrants flee to a different country, they may try to settle and create a life for themselves by applying for asylum, which, according to Eurostat, the official statistics office of the European Union, in Europe may be assigned to individuals who suffer "fear of being persecuted for reasons of race, religion, nationality, membership of a particular social group, or political opinion" [10]. Even under the EU's efforts to standardize the asylum process across the union in the form of Common European Asylum System (CEAS), the amount of granted asylum granted varies widely by migrant nationality with 94% recognition rate for the first instance decision among Syrians compared to 46% for Afghans as of 2017 [23], as well as by host country with 1.7% recognition for Afghans in Bulgaria compared to 97% in Italy as of 2016 [2].

The methods of entering Europe range from arrival by land or sea. Those who arrive by land, typically traveled by foot through Turkey and then into the Balkan countries. From 2013, this route, known as the Balkan route (see Figure 1), was subject to a series of closures in response to EU's slow reaction to the large influx of migrants [15, 22], leading up to the EU-Turkey deal in 2016 which would require Greece to hand over "irregular migrants" to Turkey in an effort to curb irregular crossings [13]. The closure of this path caused migration patterns to become more dangerous and erratic [1]. With popular land routes closed, most migrants now enter Europe by overcrowded and untrustworthy rafts with a reported 1.4 million people attempted these sea-based routes to cross the Mediterranean Sea between 2015 and 2017 [32].

Two of the key nations situated along the Balkan route, Serbia and Greece host many migrant people living in Europe. Serbia, being on the Balkan route, is home to 3,411 migrants living in 15 camps since September, 2018 [32]. Meanwhile, 32,194 people have settled in 34 camps across Greece since September, 2018, many of whom arrived by sea [32]. Travel to these countries is dangerous for migrants and it often separates people from their loved ones, thus communication resources have been stated as one of a migrant's more important needs

[1] This study recognizes the political, social, and legal implications of the term *refugee* and the analyses presented here focuses more widely on studying the habits and environments of those living in refugee camps, sites supported and documented by the UNHCR as places of refuge for displaced populations that may or may not be categorized as refugees.


Figure 1: Map of the Balkan route and closures as of 2016.

according to the UNHCR (United Nations High Commission for Refugees) [29]. The UNHCR's Innovations Service states [29]:

> "As exhausted, fearful refugees arrived onto Grecian shores, the very first thing some of them asked for was an Internet connection. To them, water, food and shelter could wait. Letting their loved ones know they had made it to safety could not."

Moreover, the literature on Information and Communications Technology (ICT)[2] and its usage among migrants discusses how ICTs can impact migrant lives on several different levels, including: "social inclusion and community development, economic well-being and financial inclusion, education, and health [24]."

The UNHCR and NGOs have begun Information and Communications Technology for Development (ICT4D) initiatives to meet the technology needs of migrant populations. Mercy Corps and International Rescue Committee (IRC) support the Signpost Project, a digital information dissemination platform, which provides information on a range of topics from legal and health advice to emotional counseling to people living in refugee camps [21]. Additionally, ICT4D efforts include expanding connectivity to refugee camps in the form of free Wi-Fi so individuals can access resources like Signpost as well as communicate with their loved ones around the world [21].

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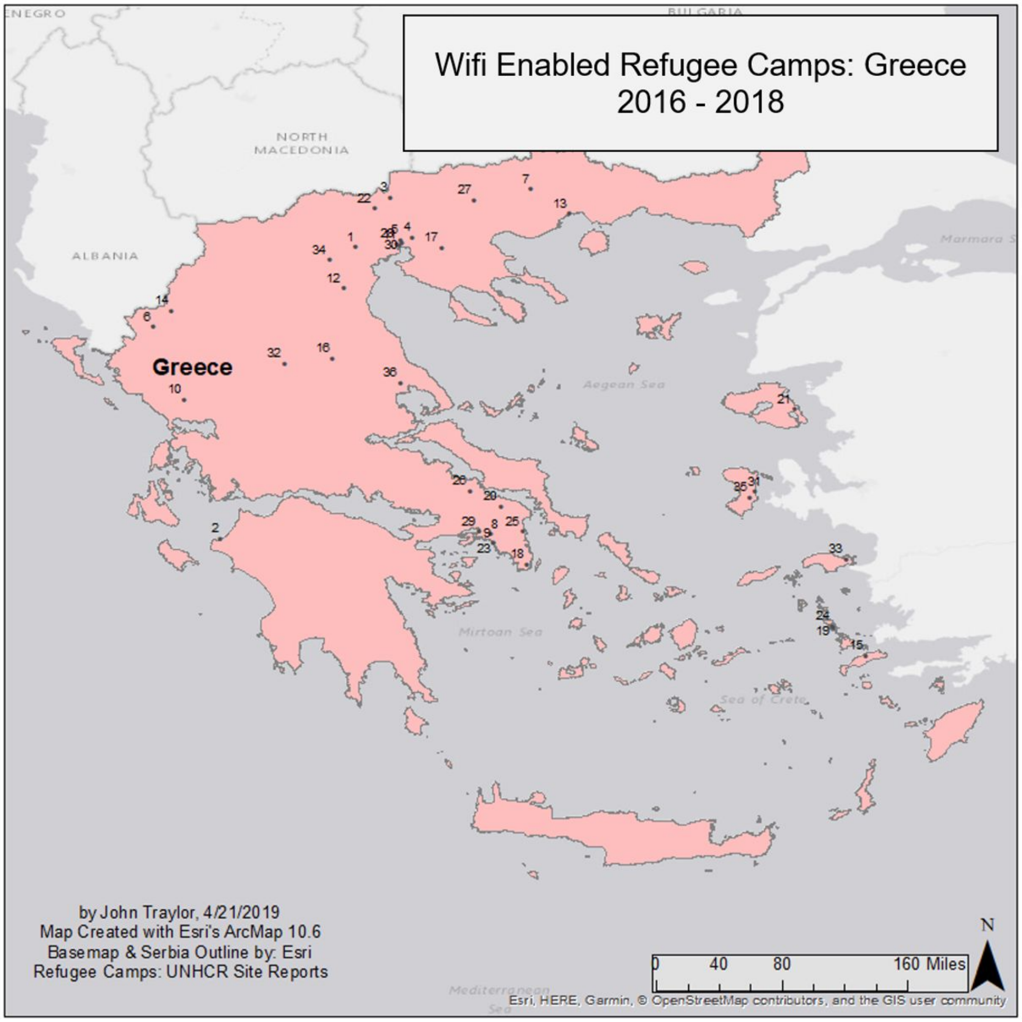
[2] Information Communications Technology (ICT): "Encompasses the hardware, software, networks, and media used to collect, store, process, transmit and present voice, data, text, images information and related services [31]."




**LEGEND:**

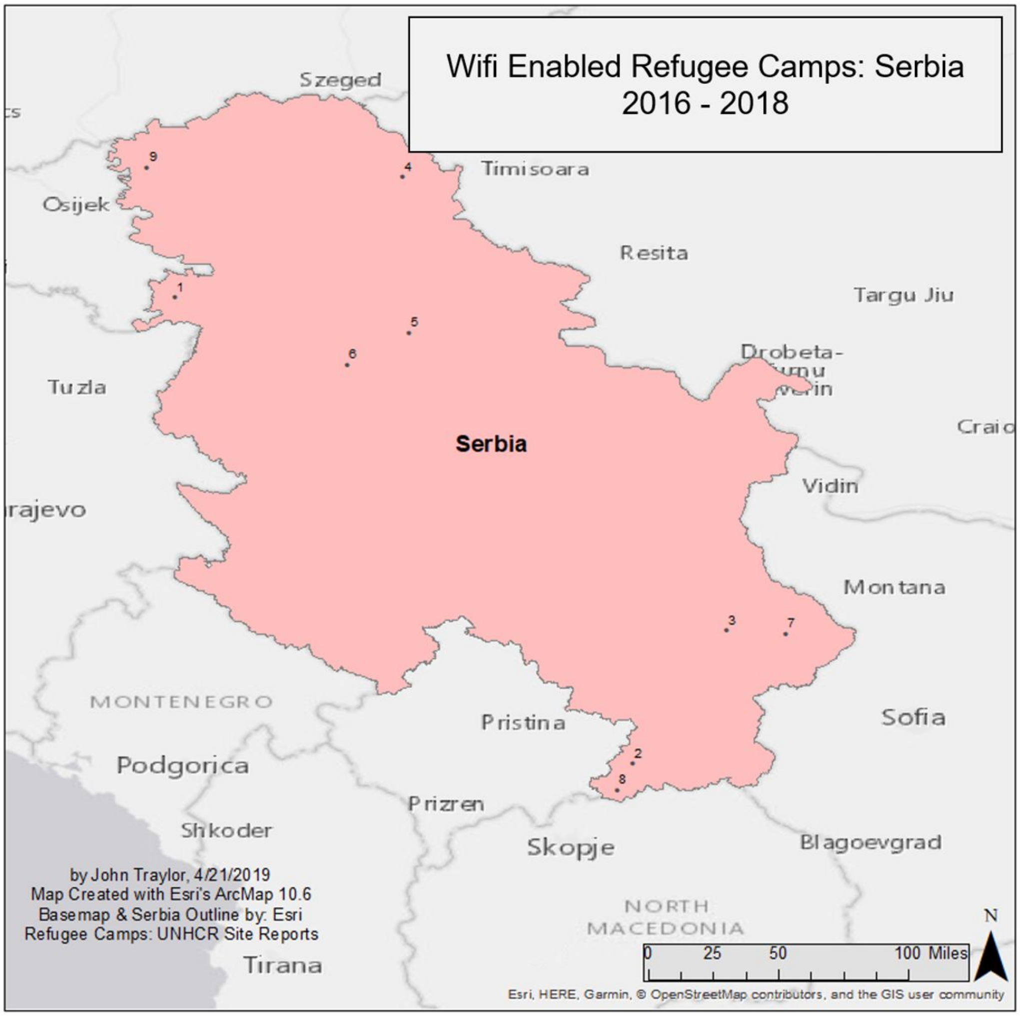
| Number | Camp Name |
|---|---|
| 1 | Alexandria |
| 2 | Andravida |
| 3 | Cherso |
| 4 | Derveni-Alexil |
| 5 | Diavata |
| 6 | Doliana |
| 7 | Drama |
| 8 | Eleonas |
| 9 | Eliniko-Hockey |
| 10 | Filipiada |
| 11 | Illiadi |
| 12 | Kato-Milia |
| 13 | Kavala |
| 14 | Konitsa |
| 15 | Kos |
| 16 | Koutsochero |
| 17 | Lagkadikia |
| 18 | Lavrio |
| 19 | Leros-Lepida |
| 20 | Malakasa |
| 21 | Moria |
| 22 | Nea-Kavala |
| 23 | Olympic Stadium |
| 24 | Pikpa-Leros |
| 25 | Rafina |
| 26 | Ritsona |
| 27 | Serres |
| 28 | Sindos-Frakapore |
| 29 | Skaramangas |
| 30 | Softex |
| 31 | Souda-Samns-Purse |
| 32 | Trikala |
| 33 | Vathi-Samos |
| 34 | Veria |
| 35 | Vial-Chios |
| 36 | Volos |

Figure 2: A map of the UNHCR recognized refugee camps with Wi-Fi support in Greece.

The following research will focus on examining aspects of public Wi-Fi network usage of people living in refugee camps. While the literature on ICT usage spans various countries and camps, this study will focus specifically on Wi-Fi usage in refugee camps in Greece and Serbia that have installed in-house Wi-Fi networks with NGO assistance. A sample from this study illustrates the availability of these Wi-Fi networks: In September 2018, 23,102 people were exposed to free Wi-Fi networks in 20 camps in Greece and 2,378 people in 7 Serbian camps [32].

This quantitative study looks at patterns between general camp and demographic data and data from NGO-provided free Wi-Fi networks in Greek and Serbian refugee camps to address the following overarching questions and concerns:

- What types of devices (laptops, smartphones, tablets, etc.) do refugee camp residents use to connect to the internet?
- What types of applications do refugee camp residents use?
- What are the barriers to accessing Wi-Fi connectivity?




**LEGEND:**

| Number | Camp Name |
|---|---|
| 1 | Adasevci |
| 2 | Bujanovac |
| 3 | Divljana |
| 4 | Kikinda |
| 5 | Krnjaca |
| 6 | Obrenovac |
| 7 | Pirot |
| 8 | Presevo |
| 9 | Sombor |

Figure 3: A map of the UNHCR recognized refugee camps with Wi-Fi support in Serbia.

This paper begins largely as a combined effort by the three authors to answer these inquiries, not only due to a shared interest of ICT applications in a refugee camp setting, but also in part to the amount of rigorous efforts needed in the data collection and aggregation from multiple sources ranging widely in accessibility. The latter portion of this paper, however, reflects the individual efforts of each of the authors, with their respective analyses and findings on one of the three questions listed here. While collected with the short-term intentions of employing it in the analyses presented later in this paper, the resulting database and datasets are also disseminated as a contribution to future work that may be done using this resource.

**Literature Review**

The literature on Information and Communications Technologies for Development (ICT4D) spans many domains; however, this study focuses on ICT4D interventions involving access to the internet and communication technologies. An exploration of this research illustrates several key themes regarding mobile device usage among populations in refugee camps. This review synthesizes the research in two parts (a) the key roles of mobile devices and similar ICTs: (1) helping to build in-person, virtual, and learning communities; (2) providing access to news, information, and communication; and (3) giving a sense of security to migrants. Part (b) focuses on the accessibility of ICTs in refugee camps: (1) social barriers that either prevent or deter individuals from using to the internet, (2) a lack of support from NGOs and United Nations agencies to optimize connectivity, and (3) poor connectivity infrastructure at refugee camps. Moreover, this review of the literature on mobile use among refugee camp populations reveals a steady use of focus groups and small survey samples as data collection methods.

When refugees leave their homelands, they also leave their community and their support systems. This journey is challenging, and migrants often turn to ICTs and social media platforms to find new communities [8, 12]. Gillespie et al.'s [11] study shows that platforms like Facebook help guide refugees to other individuals living out experiences similar to their own, groups that support refugees, and online influencers that help refugees feel secure. Women refugees have also utilized social media platforms like WhatsApp to connect with electronic groups that support educational opportunities [7]. These learning communities foster new skills that women can use to seek a better life during their journey [7]. Despite the virtual moorings of these communities, they are integral to the livelihoods of their members and often serve as, and replace, social safety nets that have been physically left behind [11].

Creating new communities is not the only function ICTs serve for migrating populations. People on the move also use ICTs to communicate with family and friends, to share news and information over social media, and use navigation applications like Google Maps to plan routes [11]. Many migrants coming from Syria and the broader Middle East rely on Whatsapp to keep in touch with family and overcome the challenges that come with being spread across multiple countries [3]. Migrants also connect to public and private groups with names like "Smuggling into the EU" and "How to Immigrate to Europe" to connect with people that know how to make the journey [3]. ICTs provide many different kinds of news and information to people forced into migration; research illustrates how applications from navigation tools to Youtube can keep people informed about border crossing dangers, legal advice, and ways to find work.

Migrants also use their devices to connect to applications like Youtube for entertainment [28]. Youtube is also used for disseminating information and sometimes even as an educational tool to learn the foreign languages of the migrants' destinations [11]. Youtube and other applications also provide access to popular culture, music, and other forms of entertainment that are critical to people living in refugee camps. Without legal permission to seek employment, security factors that keep refugee camp populations immobile, and the infeasibility of programming meaningful activities within camps, refugees often suffer from "significant boredom" that is sometimes considered a "major concern" of camp management [28].

Perhaps one of the most important aspects of mobile phone usage among refugee populations is their ability to provide a sense of normality [28]. In fact, access to popular culture, familiar soap operas, and favorite football team matches through ICTs and the internet affords refugee populations a "sense of ontological security" which is defined as "a helpful way to understand what people do and feel in order to gain a sense of security or continuity in a world that is turbulent, insecure and constantly changing" [28]. More simply, access to familiar content can help refugee populations feel a sense of normalcy despite their often unfamiliar and uncomfortable environment. Access to these resources, most usually over ICTs, can provide this form of security and ultimately improve the mental health of people living in refugee camps.

The internet presents many useful dimensions to refugee populations as described above - it affords connections to digital communities, access to news and communication, and supports the security of refugee camp populations. Despite the utility of the internet, the following synthesizes the literature on three of the key barriers that prevent refugees from accessing it: (1) social barriers that either prevent or deter individuals from using to the internet, (2) a lack of support from NGOs and UN agencies to optimize connectivity, and (3) poor connectivity infrastructure at refugee camps.

Access to the internet is prevented by several social barriers ranging from demographic to general mistrust [14, 34]. For example, young unmarried girls typically have less access to mobile phones than teenage boys [18]. Socioeconomic conditions can also bar individuals from accessing the internet. Maitland & Xu [18] found that 89% of 234 respondents living in the Jordanian Za'atari refugee camp possessed a smartphone, and 85% of these respondents own at least one SIM card. These figures could be inflated due the economic status of these respondents determined by their level of education [18]. Other studies indicate that most resource-poor refugees do not own a smartphone and many that can access a smartphone do so by sharing [11]. A particularly compelling statement about the impact of weak financial standing on refugees' ability to stay connected comes from Wall's 2017 paper [34]:

> "To afford using their cell phone, refugees used their earnings from legal or illegal jobs, their savings, which they brought from Syria, donations from relatives and strangers, and money they received from exchanging UNHCR issued coupons. Refugees faced difficult decisions in terms of what to spend precious resources on, with many opting to keep a cell phone at the expense of other needs."

Strained economic resources are a barrier to device possession, data affordability, and ultimately internet access.

For refugees that are able to connect to the internet, mistrust and danger swells around the use of ICTs despite their clear advantages. Social media platforms and other lines of communication are typically useful; however, a general sense of distrust and skepticism can arise from their use. Among refugee circles, these platforms are often used to perpetuate false rumors and conspiracy theories [34]. In addition to misleading and sometimes harmful information, refugees worry that state governments and refugee camp authorities monitor mobile phone usage [3]. Refugees reported that mobile phones could be confiscated for having foreign numbers in their call lists at checkpoints during their migration. In these cases, ICTs cause unwanted attention for the migrants as well as a loss of a valuable resource, their ability to stay connected [34]. The use of ICTs by refugees with the financial means to purchase a mobile phone, SIM card, and data is often dissuaded by the dangers surrounding their use whether it be authoritarian monitoring or false information [34].

While social factors contribute to the inaccessibility of the internet in refugee camps, they are not the only barriers. Research indicates that telecommunications infrastructure and UNHCR support for connectivity is not adequate to fulfil refugee camp needs.

An extensive study of Za'atari camp's wireless infrastructure by Schmitt et al. [26] reveals issues surrounding the digital divide among refugees caused by a lack of adequate infrastructure and support. This study indicates that individuals in the camp face a poor end-user experience "characterized by little or no signal, dropped calls or slow data speeds". These poor connectivity conditions are confirmed by Schmitt et al.'s [26] analysis of the network congestion of the three mobile service providers that support Za'atari's population, which also pinpoints the UNHCR's SIM card distribution program as a key contributor to this congestion as the program offered free SIM cards to one service provider, ultimately overcrowding its bandwidth [25, 26]. Schmitt et al. [26] recommends that the Za'atari camp management find ways to install a fixed Wi-Fi network for public use as this would likely offload some of the cellular congestion onto another network and provide a more even end-user experience. Fixed Wi-Fi networks could also allow affordable access to the more economically disadvantaged individuals.

The background research phase of this study found that much of the connectivity related literature relies on small sample sizes of usually only one camp and/or a small portion of participants [7, 11, 12, 14, 18, 19, 25-28, 34, 35]. While surveys and qualitative data on refugee ICT use provides rich detail on the experiences and lives of migrants, these methods have their weaknesses. In one study, one of these weaknesses was a bias towards the perspective of the higher educated inhabitants of the subject refugee camp: participants in the study tended to be more highly educated than the camp's general population [18]. In order to capture a broader spectrum of camps and individuals, this study has captured network-level data from 45 refugee camps in Greece and Serbia. Ideally, this data will compliment the current body of research with a large quantitative dataset.

The Wi-Fi usage portion of the dataset and analysis presented in this study is based on information gathered from networks installed to provide free public Wi-Fi networks for individual use within refugee camps. These networks were put in place with the help of several NGOs, one of which is providing access to its network dashboards for the purpose of this paper. This machine-level data captures the top client devices and web applications over a span of 12 non-consecutive months. This usage data is then overlaid with demographic data provided by the UNHCR to create a database that maps demographic, Wi-Fi infrastructure, individual usage, and client device information to specific refugee camps in Greece and Serbia. This study aims to look deeper into these issues of infrastructure, accessibility, and NGO participation in providing access to the internet. Moreover, this study aspires to open new avenues of research by expanding the study sample scope.

**Methodology**

For the purpose of analyzing and making accessible the relevant data for future analysis, monthly demographic and wireless internet (Wi-Fi) usage data is collected, organized, and warehoused in a relational database to be queried from. The goals of constructing this database is not only to abet the analyses conducted for this study, but also to make this data readily accessible for other researchers in reaching their own insights about refugee camp internet usage patterns and for entities involved in refugee camps to apply this data to improve the quality of their connectivity provisions. This section describes the notable details of these processes including the range of variables collected.

Data Collection

Data was collected from two main sources: (1) refugee camp site profiles containing demographic data from the UNHCR [32]; and (2) summary reports pulled from the dashboard of Cisco Meraki [5], the main manufacturer of networking hardware and administrative tools used in these camps, from which the Wi-Fi usage data is being derived.

The data collected spans 45 camps across Greece and Serbia during non-consecutive months from April 2016 to September 2018 (see Appendix A for the full catalog of the months and the corresponding camps that were accounted in the data collection). The monthly data of the 45 camps were selected based on their accessibility in both the Cisco Meraki dashboard and the UNHCR site profiles.

*i. Demographic data - UNHCR site profiles*

The demographic data for this inquiry was collected from unstructured PDF site profile reports from the UNHCR's data portal [32]. While the raw CSV reports for Serbian camp profiles used to create the corresponding PDFs were available, the data from the PDFs of Greek camp profiles were inputted manually due to inconsistent formatting of the PDFs. The option of using the UNHCR API[3] was also explored, but the data available was deemed not granular enough for application in this project as it did not provide any sort of monthly breakdown of demographic information for the subject refugee camps.

Similarly to its formatting, the content available in the site profiles was also inconsistent on the monthly basis. While the individual reports were robust in the range of information they afforded, the taxonomy and even the availability of certain sections differed from month to month. The following is a list of all data variables collected from these profiles, as well as the explanations of the inconsistencies observed during the collection process:

- *Camp type*: This was categorized as such:
    - Reception and identification center vs. temporary accommodation site for Greek camps, and

[3] http://data.unhcr.org/wiki/index.php/API_Documentation

    - Reception center vs. asylum center vs. transit center for Serbian camps.

  The label of “temporary accommodation site” varied considerably throughout the history of the site profile publication with the profiles before June 2017 using the label “temporary site” and the profiles starting from June 2018 using the label “open reception facilities”.

- *Camp administration type*: This refers to the type of institution that has taken the “the overall supervision of a camp response” and is usually a body of the host government [9]. It comprises of the following categories:
    - Military,
    - Police,
    - Local government,
    - National government - immigration ministry, and
    - National government - non-immigration ministry.

  The actual labels given for this variable varied widely and were normalized using the above categories with the information pulled from the May 2018 profile for Greek camps and March 2018 profile for Serbian camps (see Appendix B for mapping of the categories).

- *Geo-coordinates of camp*

- *Population, capacity, and capacity status*: The population statistic was present for most of the camps in all of the profiles, but this was not the case with the camp capacity. While the capacity figure was given explicitly for all months of the Serbian profiles, the Greek profiles stopped listing explicit capacity statistics starting in June 2017 which started replacing the capacity section with another section entitled “Estimated # of potential new PoCs able to reside in the vacant accommodations/spaces”.

  When this figure was over 0, a capacity figure was calculated by adding it to the population figure, but the same could not be done for a 0 figure since this implied a possibility of an over-capacity camp. Because of this, a variable of capacity status was created as a binary value for whether a camp is at or over capacity vs. not.

- *Percentage of adult males, adult females, minors (defined as being under the age 18)*

- *Percentage of majority nationalities*

*ii. Wi-Fi usage data - Cisco Meraki summary reports*

The data for Wi-Fi usage in the camps was collected from the Summary Report [5] spreadsheets downloaded from the Cisco Meraki Dashboard for the relevant camp and month combinations. The camp networks typically broadcast two SSIDs, an identifier for a local network: “#... FREE Wi-Fi” and “... RESPONDER Wi-Fi”. While the responder Wi-Fi is meant for humanitarian workers and volunteers, the free Wi-Fi is meant for the folks living in the camp. Only data from the #... FREE Wi-Fi network is taken account in the database in order to limit our sampling of data to refugee camp inhabitants and specifically exclude volunteers and humanitarian workers.

Using Python scripts for automation, the downloaded spreadsheets were converted to CSV files and the data was pulled and aggregated from the following sheets:

- *Top devices*: This sheet supplies the usage data for each *infrastructure device* - a hardware device that serves as a node for a wireless network - including the model number, the total usage in kilobytes. *Infrastructure devices* only takes into account Cisco Meraki networking equipment, not NetGear, Linksys, or other common manufacturers that could also potentially be deployed in these camps. This sheet also contains the total number of *clients* which is defined as "front-end devices (like smartphones and desktop computers) that requests services from a server" [4]. Summary Reports were only pulled for devices like access points and security appliances with priority on access points as the main component of a wireless network and no data from switches were captured.

- *Usage over time*: This sheet shows total usage and total downloads in kilobytes in four-hour intervals with timestamps marking the end of each interval.

- *Clients per day*: This sheet shows the total number of unique clients recorded each day.

- *Top clients by usage*: This sheet comprises of data from the top clients, up to 100, of each month with data on each personal device's total data sent and received in kilobytes. It also included each personal device's model, manufacturer, and operating system. Because this data from this included device-identifiable information, including MAC addresses and Android unique IDs, The data was anonymized using Python regular expressions and Pandas data manipulation libraries. Before anonymizing this device-identifiable information, a MAC address-identifying API[4] was used to add or confirm personal device manufacturer information. Lastly, although this sheet contained device-identifiable information for some clients, most did not and, without any kind of unique identifier employed, it is not possible to identify users on a month-to-month basis.

- *Top application categories*: This sheet lists the top application categories in the order of usage with the total usage in kilobytes.

While not included in the summary reports, the data regarding the client download and upload bandwidth limits (in Kbps) for each camp were also collected in January 2019 by checking the traffic shaping rules of each camp in the Cisco Meraki dashboard [5].

[4] https://macvendors.com/api

## Database Creation

The database created to store the data collected from the above sources was created using MySQL. To create this, Python scripts were used to aggregate and compile the data into CSV-formatted files which were then used to populate the database. The resulting database comprises sixteen entities with over 90,000 records in total. Figure 4 shows the entity-relationship diagram of this database.

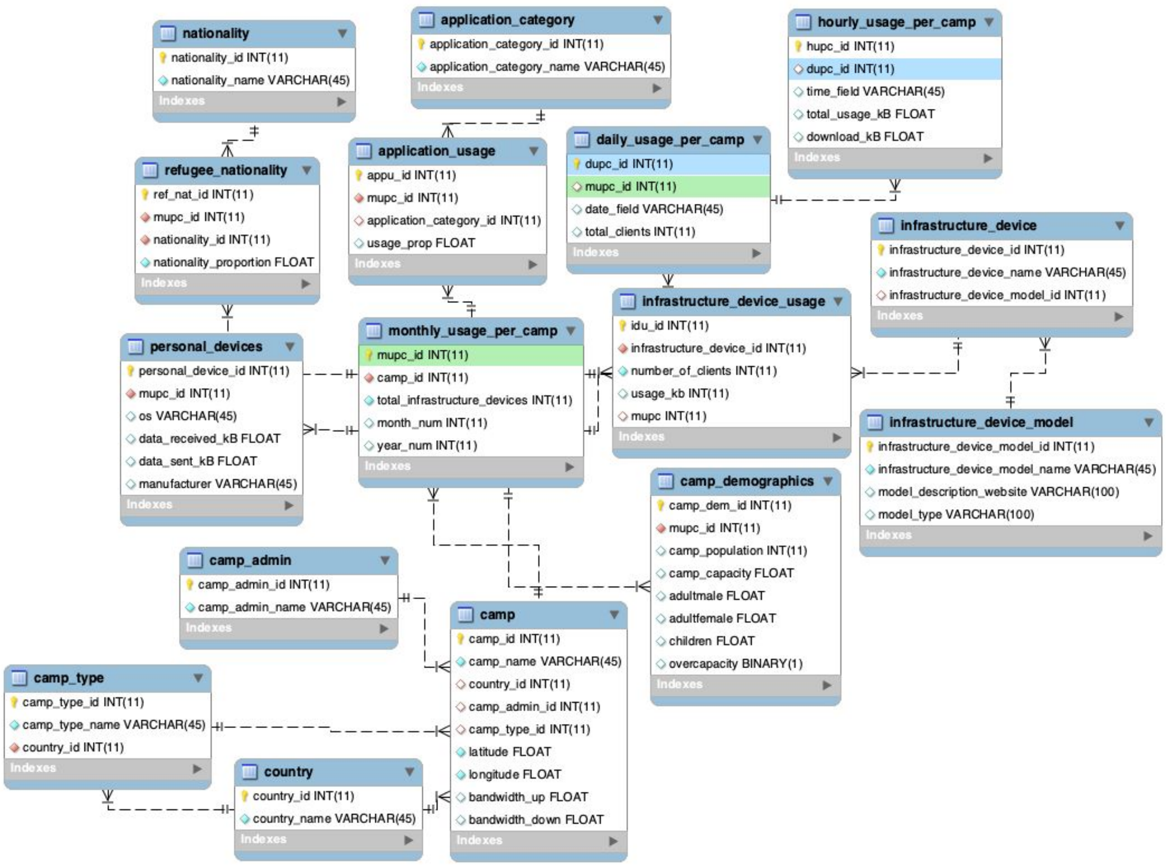



Figure 4: Entity-relationship diagram for the refugee camp database.

The design of this database is based on Codd's [6] relational model, a model for the storage of a complex array of data variables and relations that strives to portray links between different data variables and entities without compromising its type or structure and to minimize data redundancy with the concept of normalization. This model was employed specifically for this project to capture relationships between seemingly distant variables (i.e. the demographic factors of a refugee camp and its Wi-Fi usage), as well as to leverage the capacity for complex SQL queries which is widely known and taught.

Another motivation in using this model is due to its heavy emphasis on data normalization. This database consists of some data that relies on manual data entry and is vulnerable to human error. Certain categories and data types are also subject to multiple variations in terms of formatting and naming conventions including key variables such as camp names (some named differently on UNHCR site profiles and Meraki reports) and datetime variables. Normalizing even the simplest of data entities like countries or camp types were considered to be important to potentially enable mass changes in the database for the fields that are wider-reaching than others.

A premeditated measure to normalize the data before further analysis would render much cleaner datasets to manipulate. But while these reasons call for normalization, some degree of compromise is also in order. Although normalization ensures the storage and fetching of clean and well-structured data, the actual querying process could become more complicated with multiple joins and grouping statements. In addition, as Lee's 1995 study states, "higher normal forms may incur further maintenance costs, or degrade system performance, while reducing anomalies" [17].

Lee and McFadden & Hoffer [17, 20] confirm that the common practice for database design is to consider just the first three forms of normalization which served as the basis for the design of this database with some notable exceptions. The first normal form (1NF) deals with the overall structure of each table with each record of an entity possessing the same number of attributes and the principle of data atomicity remaining intact with no cell possessing an array of data. The second and third normal forms (2NF and 3NF) assert that all attributes of a record are dependent on (*functional dependency*) and are determined only by the key or the unique identifier of each record (rejection of *transitive dependency*) [16].

As noted before, however, this database does not always completely conform with the normal forms. This is the most evident with the *personal_devices* table which features the data for the top personal devices or clients of each camp by consumption. This table violates the 2NF since its keys are not actually meaningful. This is due to the fact that the original data source did not always provide unique identifiers for each device which made it impossible to track all personal devices across the different months. This table also violates 3NF by having transitive dependencies with the description and manufacturer of each device, due to time constraints in constructing a sufficient normalizing algorithm for the manufacturers. Because of these factors, this table is only useful for aggregating with the awareness that the data is not representative of all the clients in the camps and the primary keys are ultimately meaningless in identifying a unique personal device.

## Research Area #1 - Outage Analysis

After reviewing the significance of connectivity as one of the essential needs of refugees, the importance of analyzing its fragility and the factors surrounding it becomes much more evident. As the topic of immigration becomes more polarizing and the public opinion towards refugees remain somewhat lukewarm if not outright divisive, the fact remains that refugees, by the very definition of the term, are incredibly vulnerable populations that are stripped of the powers and privileges that the rest of the society take for granted due to external forces out of their control.

This analysis aims to explore the degree to which institutions might be lacking in terms of their provisions of wireless internet network and the possible factors to this scarcity with the following key questions:

1. How much Wi-Fi outage do the refugee camps experience in general?
2. Which camps suffer from the most outages?
3. What factors have an impact on the rate of outages?

**Context**

An internet outage is defined by Aceto et al. [36] as "the particular condition in which the network lies when one or multiple network elements located in a specific geographic area either do not work properly or are not reachable due to intentional or accidental events". Possible factors contributing to internet outages are numerous and can be categorized in many ways including whether it is natural (e.g. large-scale natural disaster) or anthropogenic (e.g. censorship) and whether it is accidental (e.g. maintenance) or intentional (e.g. vandalism). Cetinkaya & Sterbenz [38] lists socio-political and economic factors, malicious attacks, human errors, and environmental factors among others as possible factors of internet outages that might be particularly relevant.

The literature surrounding the potential causes of specifically wireless network outages in limited constraint areas like refugee camps, however, is sparse. From this dearth of prior research, the paper then narrows down the factors to scrutinize based on the available variables in the dataset and the external sources available, resulting in the following: (1) overcrowding of each refugee camp at a given time; (2) the type of entity in charge of a camp; and (3) weather variables including temperature, wind speed, and precipitation. The following discusses each of these factors.

a. With the influx of refugees from various crises combined with a pattern of border closings and the 4-year median duration of exile for refugees as of 2016 [39], the reality of overcrowding and refugee camps housing residents at over their capacity comes as no surprise. Overcrowding and its effects on mental health and social psyche is notable in the literature, including its tendency to increase social tensions and aggression [37]. Furthermore, overcrowding is shown to be exacerbated in refugee camps by *subjective crowding* or the perception of crowdedness which is shown to be higher among refugee camp populations and compounds the above effects [45]. Overcrowding can be a factor on the rate of wireless outages, not only due to a strain in resources, but also due to possible acts of vandalism.
b. The type of institution assigned as the administrative figure of a camp is also seen as a possible factor. Based on its organizational structure and culture, the camp administration may be vary in its motivation to respond to an outage or may even implement intentional outages to exert more control over the populace with denial of access as means to exercise power [41]. Especially as residents of refugee camps are often seen as those deprived of "right to have rights" particularly under the eyes of a foreign authority [40, 43, 44], they are vulnerable to the potential neglect and even abuse of power by these institutions playing the roles of camp administration.

   The interaction between the camp administration type and overcrowding will also be analyzed as a way to see whether a certain type is better at responding to the needs of way too many than the other possibly due to lack of proper training and a generally poor infrastructure.

c. Finally, this analysis will look at weather and its possible impact on the rate of wireless outages. Much of the notable long-term internet outages in Aceto et al.'s [36] review were due to extreme weather conditions. Although these "notable" outages were often months-long and caused by more extreme weather conditions than those observed in the sample here, high winds and storms may have some negative impact on infrastructure devices especially if not properly mounted and maintained.

## Methodology

### Sample

This analysis explores data from 12 Greek camps during the period of February 1st, 2018 to July 31st, 2018 as this happens to be the longest streak of consecutive months, as well as some of the most recent, in the database.

Data from 9 Serbian camps during the period of January 1st, 2018 to March 31st, 2018 were also briefly examined, but no significant outage was observed. This may be due to many possible factors including differences in camp operations with Greece being under EU asylum policy and Serbia having its own or location differences. The reason for this observation is out of scope for this paper and, while it is recommended for the future research to dive deeper into this matter, this phenomenon will not be explored and the data from the Serbian camps will not be included hereafter.

The source dataset does pose considerable limitations. It comprises usage data over 4-hour intervals, which leads to a high likelihood of lower observed downtime than actual. Because of this, this analysis is only taking into account significant outages that last at least four hours. In addition, this dataset looks at usage across the entirety of a camp network, regardless of the number of access points and other infrastructure devices. Therefore, this analysis will inevitably completely disregard partial outages. Finally, some of the outages observed might be due to electricity outages (Maitland, 2015) which is outside of Aceto et al.'s [36] definition of an internet outage. Since the power log for each camp is not available, these outages will be considered in the analysis as well.

### Data Aggregation and Collection

The percentages of uptime and downtime for a given month are selected as the primary measure of the rate of outages with repair and recovery methods not being taken into account. While mean length of uptime and downtime (MUT and MDT), as well as mean time to recovery and failure (MTTR and MTTF), are recommended measures of network failures (Cholda et al., 2013; Shen et al., 1999), the wide time intervals in the source data leads to some deal of inaccuracy and the data is not deemed granular enough to employ these measures. In addition, for the analysis of the effects of camp administration type and overcrowding, the data was aggregated by month and by day for analysis of weather effects.

The historical weather data was scraped from the Weather Underground[5]. Since this historical weather database only stores data for cities and airports, the nearest airport to each camp was found using the geo-coordinates. The scraping of daily weather data was performed using the Selenium web driver library for Python.

**Results**

Summary Statistics

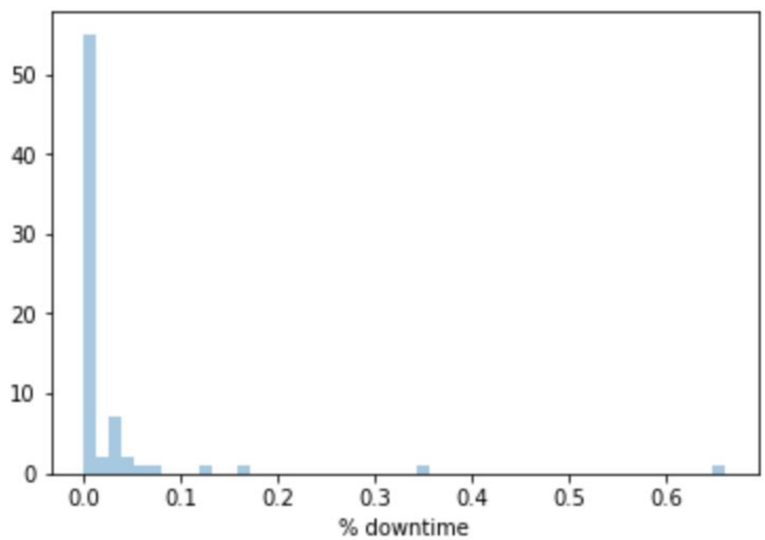



Figure 4: Histogram (n=72) of % downtime for each month across the twelve camps.

The observed mean monthly downtime for the camps in the dataset (n=72) is 2.606%. The spread of the distribution is, however, much more interesting with the standard deviation of 8.984%. Figure 4 shows the distribution of monthly rate of downtime. This distribution certainly does not look normal and resembles a poisson distribution for rare events which is more or less expected considering that an outage is indeed supposed to be rather unlikely and has been also observed in prior system outage and failure analyses [42, 46]. It also shows an outlier of 66.129% which comes from Vathi-Samos camp (see Figure 5), which experienced a long outage for most of May and is contributing to the big standard deviation figure.

Figure 6 and Appendix C displays the ranking of the twelve camps by total percentage of downtime. Vathi-Samos camp is in the lead, due to its big outages in April and May of 2018 with 13.889% downtime over the six-month period, compared to 0.009% downtime for Diavata and Eleonas.

[5] https://www.wunderground.com/

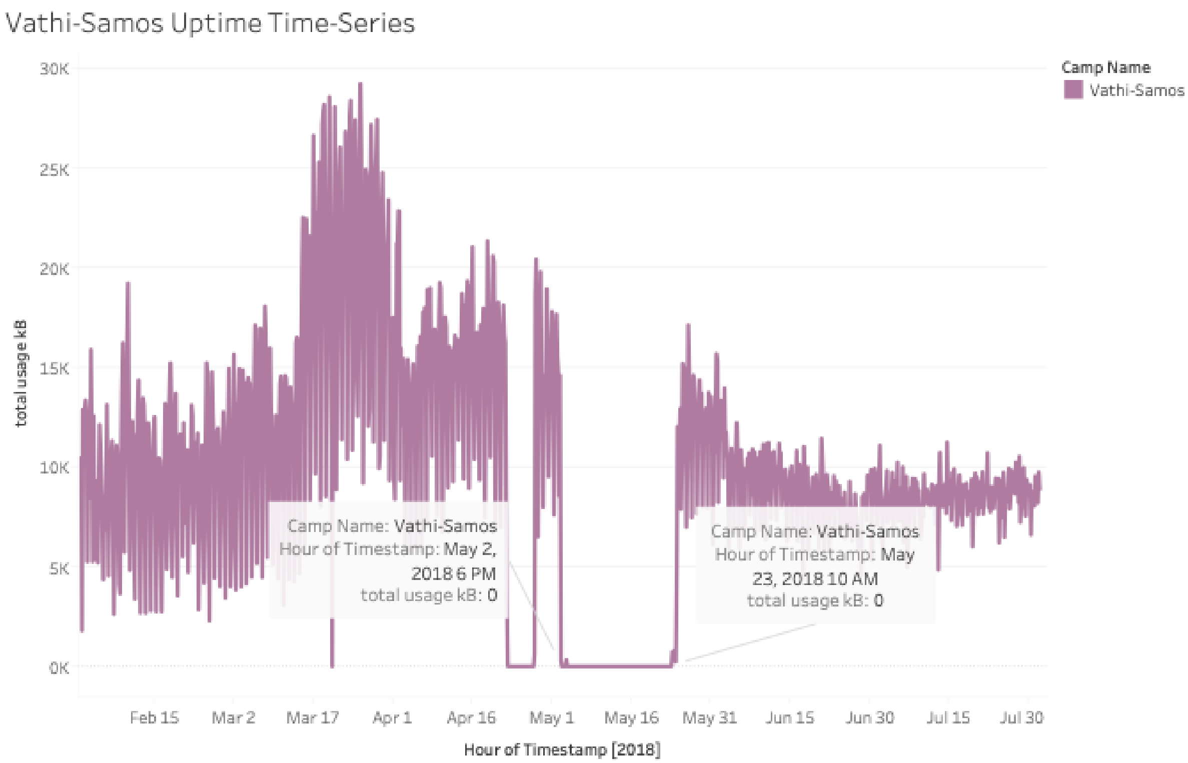



Figure 5: Time-series of Vathi-Samos camp's total usage (kB) by time. Annotations indicate the start and end time that occurred in May 2018.

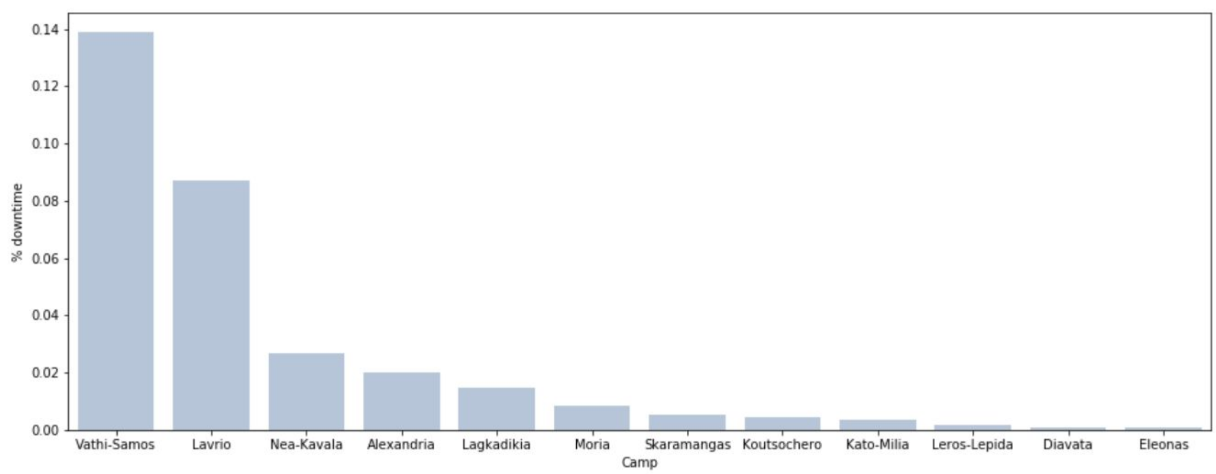



Figure 6: Bar chart with the rate of outages measured as % downtime for each camp.

Figures 7 and 8 show the breakdown of frequency of camp administration type and capacity status in camps over the months. This sample contains twice as much military-run camps (8) as camps administered by national government entities. Another important thing to note is that over 70% of camps are over capacity.

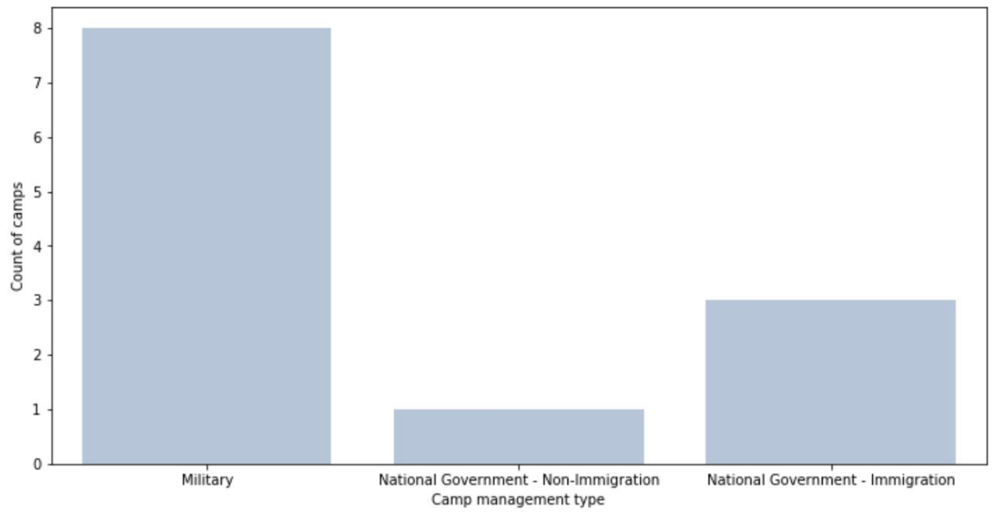



Figure 7: Bar chart with the number of camps belonging to certain camp administration type.

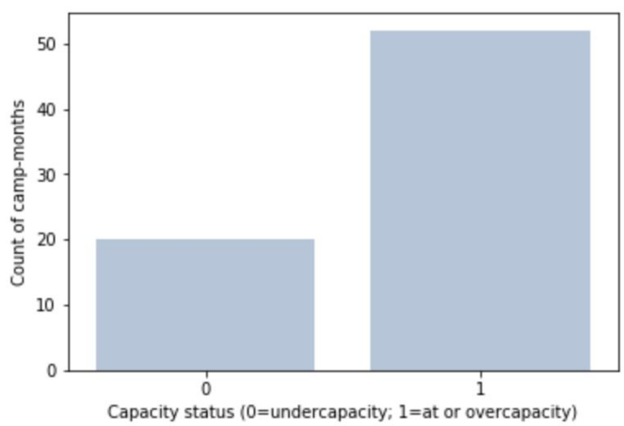



Figure 8: Bar chart with camps that are over capacity vs. under at a given month.

Monthly Data Analysis - Camp Administration Type and Capacity Status

For the analyses on the individual effects of camp administration type and capacity status and the interaction between the two factors, the dependent measure of percentage downtime or each month at a given camp was used with the sample size of 72 data points (6 months multiplied by 12 camps). Non-parametric tests were selected for all of the following analyses due to the non-normal distribution and treatment groups with small sample sizes.

Rather than a normal independent samples t-test, a Mann-Whitney-Wilcoxon (MWW) rank-sum test was first conducted to test the effect of overcrowding. The test yielded a U-statistic of -.635 and a p-value of .525 with $n_1$=20 and $n_2$=52 (1=under-capacity, 2=over-capacity). With the high p-value of >.50, no significant effect of capacity status is observed.

With more than two independent samples, the effect of camp administration type on the rate of outages was tested using the Kruskal-Wallis test, a non-parametric alternative to the one-way ANOVA. This test yielded an H-statistic of 2.809 and p-value of .246 with $n_1$=48, $n_2$=18, and $n_3$=6 (1=military, 2=national government - immigration, 3=national government - non-immigration), implying that camp administration type also does not have a significant effect on network reliability.

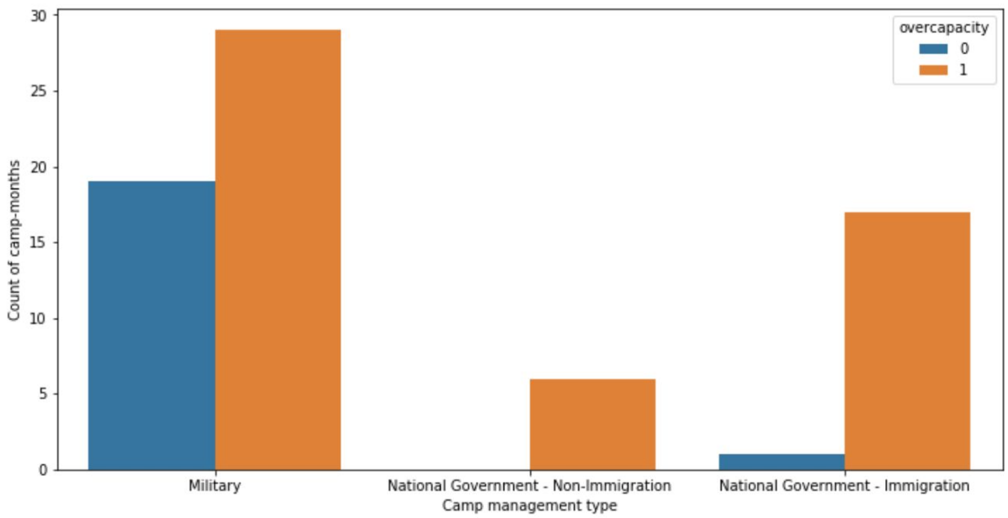



Figure 9: Bar chart with the number of months of camps of certain camp administration type and capacity status combination.

| | Degrees of freedom | Sum of Squares | H-Statistic | P-value |
|---|---|---|---|---|
| Capacity Status | 1 | 220.016 | 0.565 | 0.435 |
| Administration Type | 2 | 2428.563 | 6.509 | 0.035 |
| Interaction | 2 | 22974.922 | 63.925 | 0.0 |

Figure 10: Table of the outcome of the Scheirer-Ray-Hare test on the effects of capacity status, administration type, and the interaction between the two

To test for the interaction between the camp administration type and capacity status, a Scheirer-Ray-Hare test, a non-parametric alternative to the two-way ANOVA test, was conducted due to small sample sizes (see Figure 10 and 11). This test does find the interaction between the capacity status and the administration type of each camp significant in its effect on network reliability (p>0.00, H=63.66). This might, however, be due to the fact that in the sample, there is no instance of a non-immigration-ministry-headed camp being undercapacity and only 1 of an immigration-ministry-headed camp being undercapacity. Because of this, the validity of this effect is questionable.

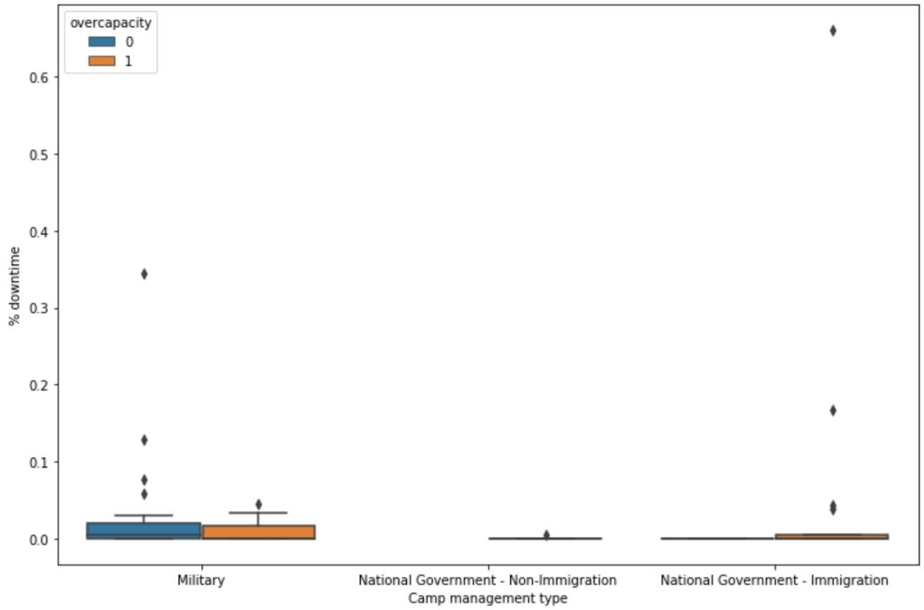



Figure 11: Box plots of outage rate by camps' administration type and capacity status.

<u>Daily Analysis - Correlational Analysis of Weather</u>

For this part of the analysis, additional dependent variables were only considered as measures of performance - data usage per client and data usage per camp resident. These measures were plotted against the following weather factors: (1) minimum, maximum, and average temperature of the day; (2) maximum wind speed (MPH); and (3) precipitation (in.). Without taking into account the days with only partial weather data, the sample included 2712 data points.

As shown in Figure 12, no test between the listed dependent and independent measures were found to be significant (see Appendix D for the correlation matrix of this analysis) when looking across all the camps in the sample. The same analysis was performed for individual camps and negative high linear correlation was found between temperature values and usage metrics for some camps (Alexandria - r=-0.74, n=181 between average temperature and usage per person; Skaramangas - r=-0.85, n=181 between average temperature and usage per person; see Appendix E for the corresponding scatter plots), but this effect is not necessarily related to outages as usage in general can decrease as temperature increases.

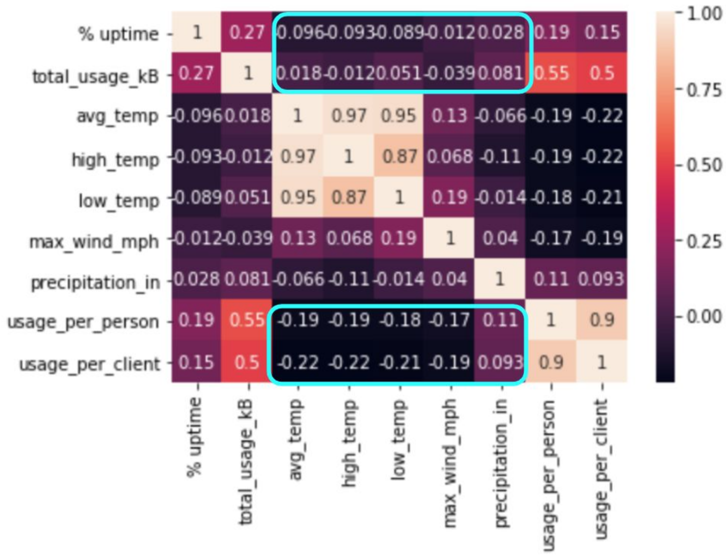



Figure 12: Correlation heat map showing the Pearson correlation coefficient for each test. The blue outlines indicates the cross-sections of variables that are of interest for this analysis.

**Discussion & Conclusion**

From the 72 camp-month data points, a mean downtime of 2.606% was observed with a standard deviation of 8.984%. This spread was mostly due to an outlier camp (Vathi-Samos) which experienced three weeks of total outage in one of the months. This study then looked at three possible factors - (1) the type of institution constituting the camp administration; (2) the capacity status of a camp; and (3) other weather-related factors - and found no significant effect on the rate of outage.

This analysis implies the lack of effect by the listed possible factors on wireless network outages in refugee camps and it emphasizes the need to continue exploring this question with some camps still experiencing a significant rate of outages. This begs a new question - what differentiates higher-performing camps from lower-performing ones?

The next recommended steps are to look outside of the data collected for the database to get a more in-depth look at possible causes of poor network performance and failures. While difficult and possibly impossible to collect, looking at additional data sources such as power logs and network failure logs to isolate network failures from electricity failures and get a more granular look at the data so as to detect shorter partial outages would be a valuable step towards answering the questions this analysis attempted to address. Access to more granular data would allow the use of more accurate measures of outages including mean length of uptime and downtime (MUT and MDT), as well as mean time to recovery and failure (MTTR and MTTF), which are recommended measures of network failures (Cholda et al., 2013). While outages themselves are unlikely, significant outages lasting at least four hours are even more rare. Capturing more granular data would give a more accurate picture what is going on when it comes to network failures in these camps.

Even without the access to this kind of granularity, more could be done. Another interesting question worth exploring is what can Greek camps do to enhance their Wi-Fi network reliability such that they experience no significant outages like their Serbian counterparts? While the sample did not exhibit any significant outages, future research can look at longer periods and periods of significantly low usage in the sample as a part of a "brownout" analysis of partial outages. The sample can also be increased as more sites are available. This would help pick out more relevant patterns in the data that may or may not show some effect of the factors explored in this study.

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## Appendices

### Appendix A: Catalog of sample camps in each month

Greek Camps

*April 2016 (23 total camps)*
Alexandria, Andravida, Cherso, Derveni-Alexil, Diavata, Doliana, Drama, Eleonas, Eliniko-Hockey, Filipiada, Konitsa, Koutsochero, Lagkadikia, Lavrio, Malakasa, Nea-Kavala, Olympic Stadium, Ritsona, Sindos-Frakapore, Skaramangas, Softex, Veria, Volos

*October 2016 (32 total camps)*
Alexandria, Andravida, Cherso, Derveni-Alexil, Diavata, Doliana, Drama, Eleonas, Eliniko-Hockey, Filipiada, Illiadi, Kavala, Konitsa, Kos, Lagkadikia, Lavrio, Leros-Lepida, Malakasa, Moria, Nea-Kavala, Olympic Stadium, Rafina, Ritsona, Serres, Sindos-Frakapore, Skaramangas, Softex, Souda-Samns-Purse, Trikala, Vathi-Samos, Veria, Vial-Chios

*January 2017 (28 total camps)*
Alexandria, Andravida, Derveni-Alexil, Diavata, Doliana, Eleonas, Eliniko-Hockey, Filipiada, Illiadi, Konitsa, Kos, Lagkadikia, Lavrio, Leros-Lepida, Malakasa, Moria, Nea-Kavala, Olympic Stadium, Rafina, Ritsona, Sindos-Frakapore, Skaramangas, Softex, Souda-Samns-Purse, Trikala, Vathi-Samos, Veria, Vial-Chios

*June 2017 (21 total camps)*
Alexandria, Andravida, Derveni-Alexil, Diavata, Doliana, Filipiada, Konitsa, Kos, Koutsochero, Lagkadikia, Lavrio, Nea-Kavala, Rafina, Skaramangas, Softex, Souda-Samns-Purse, Trikala, Vathi-Samos, Veria, Vial-Chios, Volos

*February 2018 (18 total camps)*
Alexandria, Diavata, Doliana, Eleonas, Filipiada, Kato-Milia, Konitsa, Kos, Koutsochero, Lagkadikia, Lavrio, Leros-Lepida, Moria, Nea-Kavala, Pikpa-Leros, Skaramangas, Vathi-Samos, Vial-Chios

*March 2018 (22 total camps)*
Alexandria, Andravida, Diavata, Doliana, Drama, Eleonas, Kato-Milia, Kavala, Konitsa, Koutsochero, Lagkadikia, Lavrio, Leros-Lepida, Malakasa, Moria, Nea-Kavala, Ritsona, Serres, Skaramangas, Vathi-Samos, Veria, Vial-Chios

*April 2018 (25 total camps)*
Alexandria, Andravida, Diavata, Doliana, Drama, Eleonas, Filipiada, Kato-Milia, Kavala, Konitsa, Kos, Koutsochero, Lagkadikia, Lavrio, Leros-Lepida, Malakasa, Moria, Nea-Kavala, Pikpa-Leros, Ritsona, Serres, Skaramangas, Vathi-Samos, Veria, Vial-Chios

*May 2018 (26 total camps)*
Alexandria, Andravida, Diavata, Doliana, Drama, Eleonas, Filipiada, Kato-Milia, Kavala, Konitsa, Kos, Koutsochero, Lagkadikia, Lavrio, Leros-Lepida, Malakasa, Moria, Nea-Kavala, Pikpa-Leros, Ritsona, Serres, Skaramangas, Vathi-Samos, Veria, Vial-Chios, Volos

*June 2018 (26 total camps)*
Alexandria, Andravida, Diavata, Doliana, Drama, Eleonas, Filipiada, Kato-Milia, Kavala, Konitsa, Kos, Koutsochero, Lagkadikia, Lavrio, Leros-Lepida, Malakasa, Moria, Nea-Kavala, Pikpa-Leros, Ritsona, Serres, Skaramangas, Vathi-Samos, Veria, Vial-Chios, Volos

*July 2018 (26 total camps)*
Alexandria, Andravida, Diavata, Doliana, Drama, Eleonas, Filipiada, Kato-Milia, Kavala, Konitsa, Kos, Koutsochero, Lagkadikia, Lavrio, Leros-Lepida, Malakasa, Moria, Nea-Kavala, Pikpa-Leros, Ritsona, Serres, Skaramangas, Vathi-Samos, Veria, Vial-Chios, Volos

*September 2018 (34 total camps)*
Adasevci, Alexandria, Andravida, Bujanovac, Diavata, Divljana, Doliana, Drama, Eleonas, Filipiada, Kato-Milia, Kavala, Kikinda, Kos, Koutsochero, Krnjaca, Lagkadikia, Lavrio, Leros-Lepida, Malakasa, Moria, Nea-Kavala, Obrenovac, Pikpa-Leros, Pirot, Presevo, Ritsona, Serres, Skaramangas, Sombor, Vathi-Samos, Veria, Vial-Chios, Volos

<u>Serbian Camps</u>

*January 2018 (9 total camps)*
Adasevci, Bujanovac, Divljana, Kikinda, Krnjaca, Obrenovac, Pirot, Presevo, Sombor

*February 2018 (9 total camps)*
Adasevci, Bujanovac, Divljana, Kikinda, Krnjaca, Obrenovac, Pirot, Presevo, Sombor

*March 2018 (9 total camps)*
Adasevci, Bujanovac, Divljana, Kikinda, Krnjaca, Obrenovac, Pirot, Presevo, Sombor

**Appendix B: Taxonomy of camp administration type**

Greek Camps

*Military*
Hellenic Army
Hellenic Navy
Hellenic Airforce

*Police*
Hellenic Police

*Local Government*
Municipality

*National Government - Immigration Ministry*
RIS (Reception & Identification Service)
MoMP (Ministry of Migration Policy)
FRS (First Reception Service)

*National Government - Non-Immigration Ministry*
MoD (Ministry of Defense)
MoLSS (Ministry of Labour and Social Solidarity)
Ministry of Eastern Macedonia

Serbian Camps

*National Government - Immigration Ministry*
SCRM (Serbian Commissariat for Refugees and Migration)

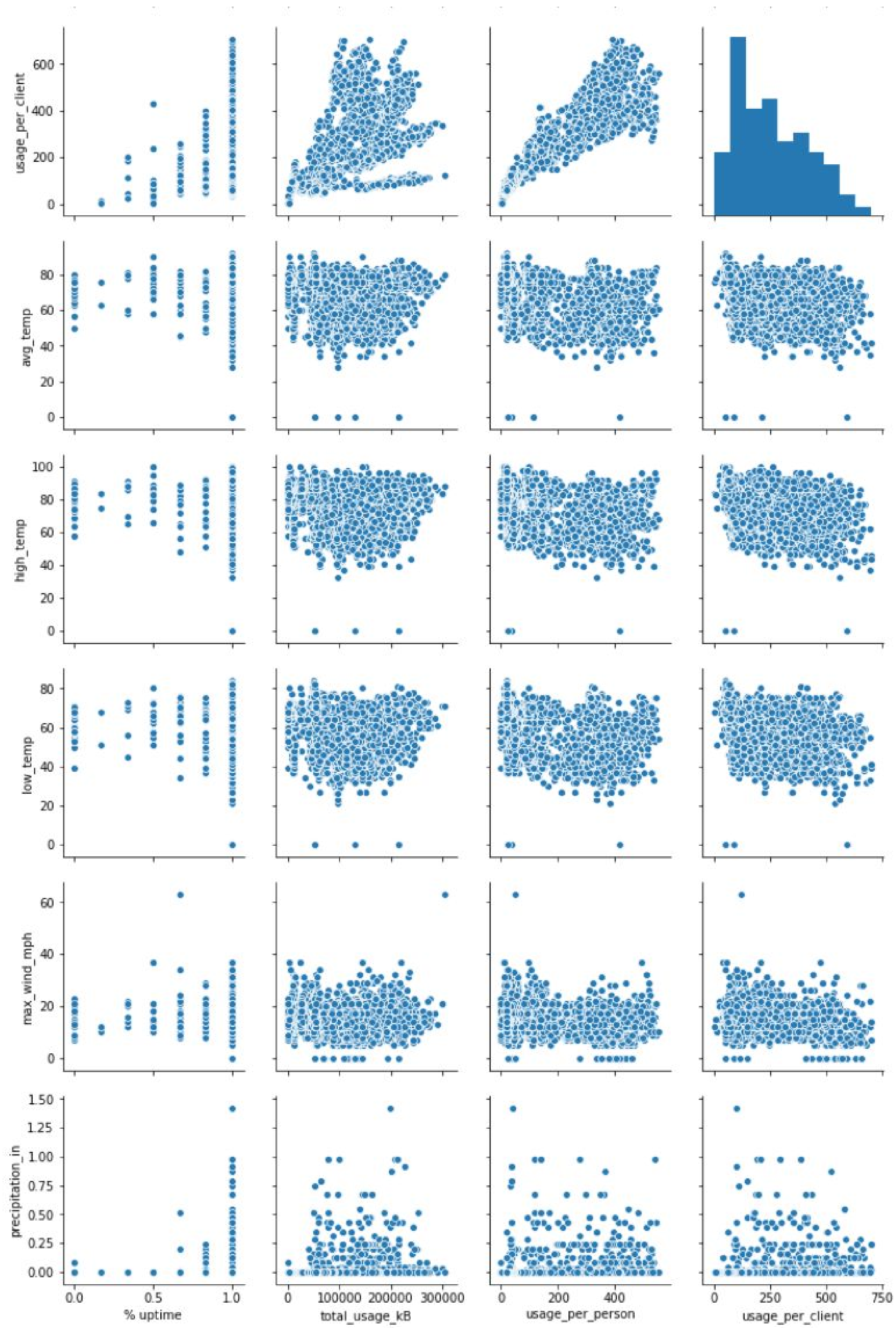
*National Government - Non-Immigration Ministry*
MoL (Ministry of Labor)

## Additional Appendices Specific to Refugee Camp Outage Analysis

### Appendix C: Percentage downtime by camp over the six-month period of February-July 2018

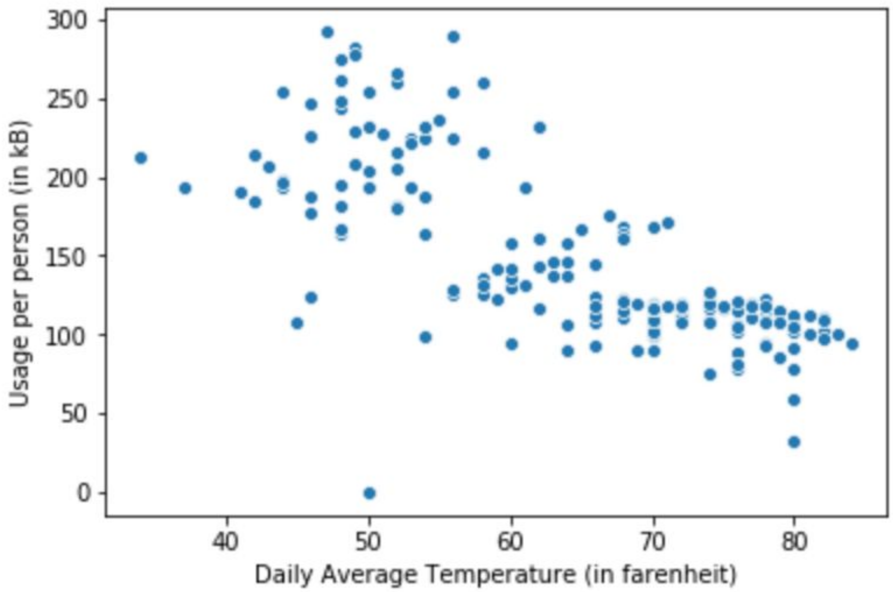
| Camp | % Downtime |
|---|---|
| Vathi-Samos | 0.138889 |
| Lavrio | 0.087157 |
| Nea-Kavala | 0.026645 |
| Alexandria | 0.020095 |
| Lagkadikia | 0.014546 |
| Moria | 0.008244 |
| Skaramangas | 0.005376 |
| Koutsochero | 0.004480 |
| Kato-Milia | 0.003674 |
| Leros-Lepida | 0.001792 |
| Diavata | 0.000896 |
| Eleonas | 0.000896 |

**Appendix D: Weather correlational analysis correlation matrix**



**Appendix D: Scatterplot for correlations between temperature and usage**

<u>Alexandria - r=-0.74, n=181</u>




<u>Skaramangas - r=-0.85, n=181</u>