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Optimizing a Heritage Railway Provider's Volunteer Workforce Allocation: The Case of Swanage Railways

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Abstract. Heritage railways are railway operations that are not mainstream and serve as a reminiscent of past railways to build a cultural and national identity. They are among the main forms of heritage tourism. The heritage railway industry differs fundamentally from other forms of tourism and travel due to the significantly large fraction of volunteers in its workforce; additionally, heritage railways are of an extremely smaller scale than mainstream railways with lower annual revenues. Although the regular railway industry extensively employs mathematical decision-making technologies for its daily operations, there is little evidence or case studies demonstrating such value for heritage railways. In among the first of such studies, we present our experiences in employing mathematical optimization models that improved the workforce allocation at a premier UK-based heritage railway company: Swanage Railways. Our collaboratively developed optimization models show four hours of reduction in weekly overtime for some employees during emergencies. If volunteers are efficiently integrated into the workforce, we find a reduction in overall workload by 26.7% for some of the existing employees. Finally, our models present a potential to reduce staffing costs by up to 35% if an hourly wage system is employed instead of a fixed salary system.

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1. Introduction

1.1. Background

The United Kingdom (UK)'s Office of Rail and Road defines heritage railways as " 'lines of local interest', museum railways or tourist railways that preserve, recreate or simulate railways of the past." (Office of Rail and Road 2024a). In today's world, heritage railways serve to demonstrate the importance railway travel once played in building a collective cultural identity (Lowenthal 1998). The UK is among the world's leading demonstrator of heritage travel via railways for tourists (Rhoden et al. 2009) with over 200 such railways in operation (Office of Rail and Road

2024a). Indeed, from the eight railways selected worldwide by the participants of the 1998 World Railway Heritage Conference, two were from the UK (Coulls et al. 1999).

The Swanage Railway is one of the UK's premium heritage railways. It operates primarily a steam-hauled service between four locations in the county of Dorset in the south-west of England: Corfe Castle, Harmans Cross, Swanage, and Norden; see, Fig. 1 for a map of these stations. The railway is run by a limited company (i.e., the company is an entity distinct from its owners) responsible for sourcing and maintaining locomotives, negotiating with locomotive owners, training staff for daily operations, and ensuring safety of railway operations. The limited company is controlled by the Swanage Railway Trust which is managed by a group of bi-annually elected trustees. In addition to managing the Trust's finances, the trustees are responsible for setting company targets and appointing the company's directors. The Trust also operates the Swanage Railway Museum in Corfe Castle (Swanage Railway 2024).

Every year, Swanage Railway carries up to 200,000 passengers and contributes ≈ £15 million to the economy of the local Dorset region (Department for Science, Innovation & Technology 2024). The railway sells souvenirs and memorabilia online as well as in-store. In addition to tourism, the railway is also credited for providing so-called "green tourism" transport, e.g., it removes 60,000 cars off the road by connecting the towns of Wareham and Swanage (Department for Science, Innovation & Technology 2024) and it prevents congestion on the picturesque village of Corfe Castle by providing a ride service (All Party Parliamentary Group on Heritage Railways 2013). Compared to the UK's overall rail usage, the operations of Swanage Railway are of an extremely low scale: UK's annual passenger revenue is ≈ £10 billion with three to four hundred million annual passenger journeys (Office of Rail and Road 2024b).

Another inherent difference between heritage tourism and mainstream tourism is that of workforce composition. The heritage tourism (and, also, the heritage railways) industry is dominated by

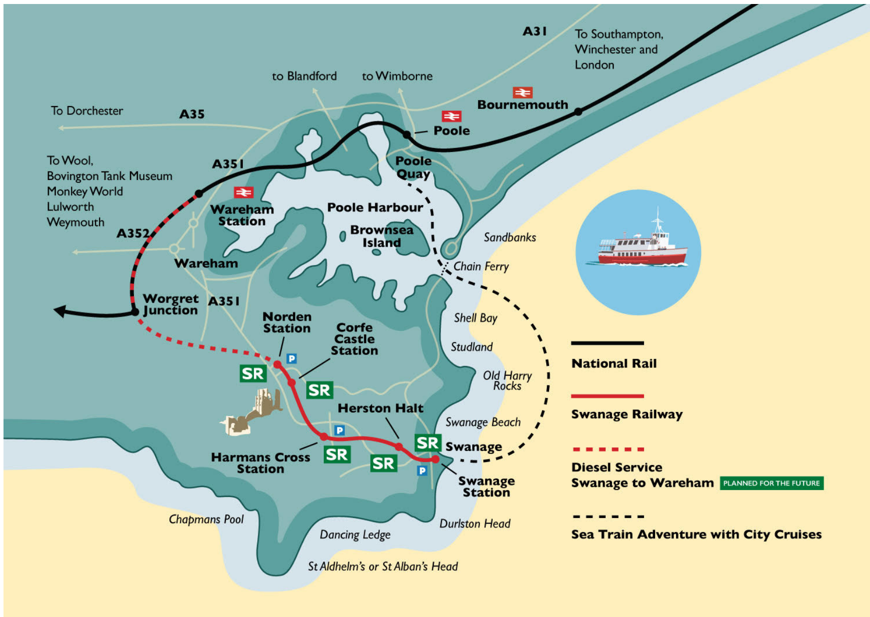

Figure 1 **A map of stations served by Swanage Railways. For reference, Poole Harbour is about 115 miles south-west of London and leads to the English Channel. Image taken from: `https://www.swanagerailway.co.uk/`.**

volunteers, see, e.g, (Graham 2004). This pattern is especially strong in the UK, where several heritage sites such as museums and cultural tourism sites were established entirely by volunteers; further, they are also managed by volunteers (Holmes 2007). Although there is an extensive body of research on the reasons for volunteering for the travel and tourism industry, there is limited research on the motivation of volunteers for heritage railways; see, e.g., (Goddin 2002, Rhoden et al. 2009) for two of the few such studies. The high level of volunteer motivation is clear from a 2002 survey that shows the average distance commuted by volunteers to Swanage Railways was 59.2 miles (Goddin 2002). Further, there are no analytical case-studies documenting experiences of increasing the efficiency of such volunteer-based workforce in the heritage tourism and travel industry using operations research methodologies. Swanage Railways, too, relies primarily on volunteers as part of its workforce: it currently has only 25 full-time equivalent (FTE) employees, and has about 450 regular volunteers who are available to run services. This ratio is significantly higher than the 1:2.1 ratio of volunteers to FTE employees estimated by the UK's Heritage Railway Association (Rhoden et al. 2009). With these skewed numbers, an optimal allocation of the workforce is of paramount importance in the neglected heritage travel industry.

1.2. Post-pandemic operational challenges

The COVID-19 pandemic had a profound impact on public transport systems at all levels — local, national, and international — with the railway travel sector being particularly affected. Due to social distancing measures, and as people transitioned into remote-working environments, passenger volumes in the UK dropped to around 5% of pre-pandemic volumes (Vickerman 2021). Later stages of the pandemic saw gradual easing of lockdowns and a corresponding increase in railway passenger volumes; however, rail passenger volumes were limited to only about 15% of the maximum capacity by June 2020 (Vickerman 2021). Post-pandemic homeworking patterns remained at elevated levels; further, employees reported a declining inclination to use the railways as a mode of transportation (Magriço et al. 2023). In September 2020, the UK Government issued an Emergency Measures Agreement, primarily designed to end UK's rail franchising system[1], which additionally asked railway operators to continue running at nearly full capacity (Department for Transport and The Rt Hon Grant Shapps 2020). However, around the time of this study, railway operation levels in the UK were still not back to pre-COVID levels, e.g., during the peak of February 2023, passenger levels were 94% of pre-COVID levels (Department for Transport 2024).

Due to the scale of operations involved, compared to the mainstream transportation and travel industry, such impacts of the pandemic were particularly severe on the relatively smaller scale heritage tourism and travel industry where operators typically have both lower annual revenues as well as workforce volumes. Further, almost all heritage railway providers have an associated museum presenting the transportation provider's history (Steam Heritage 2024). Thus, the operators

[1] The state-owned rail company British Rail was privatized in the mid-90s following which franchises were given by the government to companies. Currently, 24 such Train Operating Companies operate in the UK.

of this industry saw dwindling profits from a twofold front: reduced number of rail travelers and a reduced number of visitors to the museums. Despite an increasing enthusiasm to revisit such sites after the relaxation of physical distancing measures, the footfall of visitors fell, motivated by an increasing digitalization of the museums (Guo 2024). Although Swanage Railways saw a gradual increase in passenger volume following COVID-19, it faced economic losses of $\approx$ £200,000 in 2022. Compounding its financial concerns, the company has faced increasing costs and an overall drop in passenger volumes since 2015. Although volunteers are not paid, annual staffing costs are $\approx$ £800,000. With this background, it was imperative that Swanage Railway's existing workforce is managed efficiently.

2. Methodology

In this section, we describe our experiences from a unique collaboration between us and Swanage Railways. We developed and applied data-driven mathematical optimization models with the aim of efficiently managing Swanage Railway's assorted workforce comprising of FTE employees, apprentices, and volunteers. There were two key questions Swanage Railways presented us: (i) could they perform better than their status quo?, and (ii) could we provide data-driven guidance and recommendations to reduce their financial strain?

2.1. Mathematical decision-making

Mathematical optimization is the science of decision-making that helps determine a set of policies that ensure feasible operations while maximizing overall revenue. The railway travel industry relies heavily on mathematical optimization, e.g., to determine crew assignments (Roth et al. 2018) and crew schedules (Jütte et al. 2011), or to optimize daily operations (Martinelli and Teng 1996) and train movements (Yang et al. 2012). The underlying quantitative data-science methods are suitable for solving large-scale problems involving millions of complex multilayered decision-variables. Although such mathematical methods are, naturally, also suitable to handle daily operations of a relatively small-scale heritage railway company there are no research case studies providing such a demonstration.

Specifically, the models we develop seek to maximize the value that different employees — whether FTE employees or volunteers — assigned to their different departments bring to Swanage Railways as a whole. Although we cannot share these data-driven models due to confidentiality agreements, this novel work seeks to describe the impact that a theory-backed framework could create on Swanage Railway's operations. This, in turn, shows how mathematical optimization can play a major role in improving a small-scale heritage travel company's efficiency.

2.2. Optimizing Workforce Allocation

Past studies have demonstrated the positive financial impact that an efficient workforce allocation can make, see, e.g., (Lesaint et al. 2000). Specific to the mainstream railway industry, there is also research on the relationship of employee well-being with workforce allocation. Poor health among employees of the Spanish Railways (RENFE) who work irregular hours is documented (Aguirre and Foret 1994). Within the UK, railway panel operators report inadequate sleep with some workers who use visual display units working in excess of 48 hours/week (Ryan et al. 2009). Fatigue resulting from such detrimental work conditions also results in human errors leading to an overall loss of efficiency, see, e.g., an empirical study from railway workers in Belgium showing the relationship of fatigue with worker shift patterns (Roets and Christiaens 2017). With this background, it is particularly important for a small-scale railway company to balance workforce efficiency with worker well-being.

Workforce at Swanage Railways is allocated to handle regular operational *tasks* as well as conducting *repairs* plus *maintenance*. Examples of regular operational tasks include coaling the engines, accepting coal deliveries, and conducting repairs of facilities. Steam engines employed by heritage railways require constant maintenance and frequent repairs; often, the training required to carry out such repairs is acquired from outside a technical manual (Wain 2017). There are two types of repairs: (a) "urgent" repairs without which an engine simply cannot run, and (b) "non-urgent" repairs which allow an engine to keep running but at a reduced performance. Handling urgent repairs is the key priority, followed by non-urgent repairs, and further followed by regular routine maintenance. At the time of our research in August 2023, the workforce equipped to handling tasks other than regular maintenance was limited to only a few FTE employees plus an apprentice who had a flexible schedule when away from academic studies; however, the apprentice still required at least one weekday completely off from work. In August 2023, the apprentice worked up to four days a week.

Before operating any of the steam engines present at Swanage Railways, each of its urgent-categorized tasks must be fully completed. Steam-engines being paraded in special public events require all priority-marked tasks to be successfully completed before the start of the event; there was (at least) one such event during the period of our study. Further, unavoidable emergency repairs that demand immediate attention require employees to drop any tasks they are currently working on. Consequently, at least one employee must always remain assigned to a lower priority task to allow the possibility of handling unexpected failures. A manual allocation is likely to face challenges in handling such multifaceted constraints that can be efficiently formulated as priority-based rules (see, e.g., (Kolisch 1996)) in an optimization model.

We briefly describe the mathematical optimization model we employed; further details are available in the Appendix. The indices our integer linear optimization model indicate the sets of employee types, the different tasks, and days of the week. The decision variables of the model are binary variables (i.e., YES or NO) which indicate whether a particular task is assigned to a given employee on a certain day or not. The constraints of the model formulate the enforced or desired requirements for the availability of employees, the duration of tasks, any specific requirements of special tasks, and deadlines of certain tasks; not all of these were strictly followed by Swanage Railways before employing the optimization model. These include:

(i) Workday compliance: Employees must adhere to prescribed weekday schedules while accommodating their respective varied offsite schedules, e.g., FTE employees work at most five days/week and apprentices work at most four days/week.

(ii) Hourly limits: Working hours are to remain within 7.5 hours/day for all employees, ensuring compliance with both national labor regulations and Swanage Railway's internal policies.

(iii) Task deadlines: All tasks are to be completed within the specified time-frames prior to the deadlines, thereby facilitating timely project execution without fines or penalties.

The objective function then seeks to ensure a balanced workforce allocation by minimizing the absolute difference of an employee's workload with the targeted average workload of the employees. This results in an optimization model which has binary decision variables, linear constraints, and a linear objective function. Populating the problem with data from Swanage Railways, we then solve it using the open-source Python-based optimization solver Pyomo coupled with the open-source GLPK solver.

3. Analysis and Recommendations

The optimization model we proposed is a first prototype model for Swanage Railways and, despite its relatively simple structure, delivered promising results for the financially stressed heritage railway company. We present a synopsis of our results for the heritage railway company highlighting the value of such a decision-making framework over the current manual allocation. Before using our optimization model, employees worked five hours/week of overtime (on average) in the first half of the month to finish all the tasks characterized as urgent; this requirement arises, for example, due to events planned in the middle of the month. The second half of the month included a relatively relaxed (average) workload of 30 hours/week. Using our model, ensures a more well-distributed workload among the different employees while efficiently allocating the tasks. Our suggested schedule allows each employee to work only up to five days/week ensuring a balanced workload allocation. Further, no employee works overtime in this suggested schedule, thereby additionally enhancing employee well-being and increasing overall workforce sustainability. All operational restrictions desired by Swanage Railways were achieved; i.e., all constraints of the optimization model were satisfied.

To assess the model's performance outside of Swanage's daily routine operations, we simulated two potential situations that Swanage Railways frequently encounters: (a) emergency task management and (b) the integration of additional volunteer support. First, consider situation (a). As we mention in Section 2.2, at least one employee is designated for regular maintenance and non-urgent tasks to allow potential handling of "emergencies". Our analysis helped identify certain employees who are not allocated any tasks on certain days, thereby providing a trivial feasible solution for handling emergencies on these days. Completion times of regular tasks become longer during emergencies, due to them being placed on a hold, while the reassigned employees complete the newly allocated pressing tasks. However, despite this reallocation, all routine tasks are completed before the deadline using the schedule prescribed by our optimization model. For example, in a simulated mild scenario where an emergency task currently requires up to five hours/day of work, the model successfully reallocates employees such that no overtime is required. However, in an extreme scenario which requires 12 hours/day of work, we find potential for completing such an emergency task in 11.2 hours/day; i.e., a 20% reduction in employee overtime. Integrating volunteers into the workforce, as we show next in situation (b), completely obviates the need of overtime hours. Importantly, such an effective task reassignment alleviates the need for excessive employee overtime thereby promoting both a better work-life balance and productivity during emergencies. Obtaining such solutions is easy using a mathematical optimization framework.

Now, consider situation (b). Past studies have encouraged an inclusion of volunteers into the regular workforce to augment overall productivity (Kolar et al. 2016). We considered the scenario of replacing the Train Protection & Warning System of a steam engine (an urgent task) that is currently done only by employees. However, allowing volunteers to execute such tasks frees up the employees who are often working on continuous days to complete urgent tasks. Doing so with our mathematical model reduces the assigned employee's weekly workload significantly: from 30 hours/week to 22 hours/week; i.e., a reduction in weekly workload by 26.7% (such a reduction is, naturally, at the expense of increased volunteer hours). These findings demonstrate the resiliency and adaptability of employing mathematical optimization methods, such as ours, compared to a manual reallocation particularly in dynamically changing environments.

Figure 2 A steam-engine employed by the heritage company Swanage Railways. Photograph by first author.

Next, as we mention in Section 1.2, Swanage Railway grappled with decreasing post-pandemic passenger volumes which directly impacted its revenue. This financial strain necessitated a strategic review of their‘ cost management. We provided recommendations aimed at mitigating such challenges by reducing expenses on staffing. Currently, employees are paid fixed annual salaries regardless of their actual work hours; i.e., regardless of the amount of overtime hours (however, employing our optimization model ensures employees do not work over five hours/day). Transitioning to an hourly-wage system would offer even greater control over labor costs, particularly during periods of economic uncertainty. To quantify the potential savings of this alternative fiscal arrangement, we employed a metric of overall staffing costs. Running our optimization model with this new objective function which minimizes these costs (and, the same set of constraints as our original model) suggests a potential reduction in overall staffing expenses by up to 35%. Intangible benefits include offering flexible working hours for employees, thereby improving overall job satisfaction; implementing such reforms for the tourism industry have been discussed before (Lockstone 2004). However, implementing such a transition would require a careful managerial review in discussion with trade unions. Different countries have different definitions of wages and salary, e.g., an increase in minimum wage in the US requires the vote of the Congress, while in the UK the government may increase it at any time (Askenazy 2014). Further differences exists in terms of associated employee benefits such as pensions, healthcare contributions, and leave allowances[2].

Scenario	Current	Balanced	Hourly wages	Volunteer inclusion
Monthly hours	132.25	106.6	104	92.5

Table 1 Comparison of monthly hours worked by one FTE employee at Swanage Railways under various scenarios. Currently the employee is working 132.25 hours/month; this number is potentially reducible to 106.6 hours/month employing our optimization model. Paying employees an hourly wage further reduces the employee's workload to 104 hours/month, while integrating volunteers results in the least workload for this employee to 92.5 hours/month.

Finally, we recommend providing training to bridge skill-gaps for new employees which could result in an even more efficient system of task distribution; such patterns of employment are rising

[2] For an overview of the UK's salary structure, with benefits and deductions, see `https://www.tuc.org.uk/resource/rights-pay`.

in the UK (O'Connor 2015). In our optimization model, we constrained certain tasks to be assigned only to specifically skilled FTE employees. However, following adequate training, apprentices could be trained to also undertake such tasks. This allows a relaxation of an optimization constraint yielding a further reduction in the monthly workload of some of the FTE employees. Table 1 presents an illustration of the value of our analysis for one FTE employee at Swanage Railways based on our optimization models.

4. The Future of Heritage Railways

Recent financial reports reveal the severe strain on UK heritage railways highlighting their precarious future. The North Yorkshire Moors Railway (NYMR) reported a loss of over £500,000 for the year ending February 2023, driven by high inflation, coal supply issues, and lingering pandemic impacts on tourism (Fewster 2024). Similarly, Peterborough's Nene Valley Railway (NVR) launched a £300,000 fundraiser to combat rising operating costs and declining passenger numbers, crucial for its survival (Ahmed 2024). Thus, there is a need for innovative management decisions and an efficient utilization of existing resources to ensure their sustainability and preserve these cultural assets for future generations.

Employing optimization models, such as those we propose, provides quantifiable benefits for small-scale heritage railways. Such mathematical models identify the most effective schedules and maintenance routines, enabling small-scale railways to make informed decisions that boost profitability and ensure long-term viability. Such data-driven approaches also offer a powerful tool for enhancing economic performance and operational efficiency of the heritage railways. By strategically allocating resources, these heritage railways can reduce their operational costs and thereby fully leverage the contributions of both the paid staff and volunteers. Strategies to manage payments of such a diverse workforce comprising of volunteers, part-time workers, and full-time workers have been studied before from an operations research perspective, see, e.g., (Berenguer et al. 2024). However, this study is the first use of mathematical optimization for a heritage railway industry; we hope it serves to inspire further studies in this culturally valuable, but often neglected, sector.

Appendix. Supplementary Information

Here, we summarize the optimization model we employ in this work. There are three indices in the model we employ for this work. These denote the employees, tasks, and days of the week. The size of the model is small which does not allow confidentiality of the data we use. Hence, we provide a textual explanation of the model rather than the concrete optimization model.

Employees are distinguished based on whether they are salaried or are volunteers. Employees are also distinguished based on whether they are full time equivalents (FTEs) or are apprentices; the latter have lower salaries than the former. The maximum duration of a day's work for any employee is eight hours which includes 30 minutes of a paid lunch break. Any working hours beyond this are considered overtime; however, employees are paid a fixed salary as stipulated in their contracts. In August 2023, when this work was conducted, one apprentice was employed who received a salary lower than the FTEs. Typically, the apprentice must have Monday off to attend college and may work for up to four days a week. However, in August, the apprentice was on summer break and thereby available for any four days of the week.

Tasks are allocated from two departments: Engineering and Operations. There are three types of tasks: urgent, non-urgent, and routine maintenance. The urgent tasks are the most important without which a steam engine simply cannot operate. The non-urgent tasks are those without which a steam engine could operate, however it leads to reduced performance and is detrimental for the long-run. For example, tightening a middle valve cover is an urgent task and cleaning the auto drain is a non-urgent task. The routine tasks have the lowest priority. Then, the optimization model takes the following form.

$$\min \quad \texttt{employee workload deviation} \tag{1a}$$

$$\text{s.t.} \quad \texttt{weekday compliance} \tag{1b}$$

$$\texttt{special task assignments} \tag{1c}$$

$$\texttt{ordering restrictions} \tag{1d}$$

$$\texttt{daily assignments.} \tag{1e}$$

We formulate model (1) as a deterministic integer linear program. A binary variable indicates whether an employee is assigned a given task on a given day or not. The objective function given by equation (1a) seeks to minimize the dispersion of an employee's allocated monthly workload from the average monthly duration of all tasks. We define the workload of an employee as the sum of the duration of all tasks conducted by an employee over a month. The average workload is then defined correspondingly. Other dispersion measures could include the variance of an employee's workload assignment which would then require a quadratic solver. The weekday compliance constraints in (1b) are a set of constraints that restrict employees to work no more than 7.5 hours a day and no more than a given number of days a week (e.g., at most 4 days a week). The special task assignments given by constraint (1c) enforce only certain employees may be assigned to certain routine task(s) daily. An example of such a routine task is the so-called "fitness to run exam" that trains must go through[3]. Further, this constraint set enforces certain task(s) to be performed at regular intervals (for us, this includes: daily, weekly, twice a week, monthly, any two days of the month, and any ten days of the month) by any employee. Finally, this constraint set also enforces certain task(s) to be conducted twice by certain employee(s). Examples of such tasks include those by the Operations department, such as accepting deliveries (weekly, taking 15 minutes) and shunting (twice a week for 30 minutes each).

The ordering restrictions given by constraint (1d) enforce miscellaneous precedence and timing restrictions that determine when certain tasks must be performed on certain engines. For example, a certain steam engine at Swanage Railays can only be operated towards the end of the month and, then, two employees must be assigned to operate a certain task on it. However, certain urgent tasks on another steam engine at Swanage Railways must be completed in the beginning of the month. As a concrete illustration, two employees must be assigned together to perform an urgent task of renewing the middle valve rings of a given steam engine. The timing restrictions could be more involved, e.g., the constraint (1d) includes restrictions for a certain task on a given steam engine to be performed by any employee for three consecutive days only in the beginning of the third week of the month. Finally, constraint (1e) enforces that there must be at least one employee assigned to work on routine maintenance or non-urgent tasks daily.

Our model was run with a subset of the actual data that we obtained from Swanage Railways. The analysis was conducted for the 31 days in the month of August 2023 for 41 tasks. An example of a steam engine included in our analysis is the nearly six decades old "34028" Eddystone steam engine[4].

[3] see, e.g., `https://edinburgh-sme.org.uk/busy-busy/`.

[4] see, e.g., `https://preservedbritishsteamlocomotives.com/34028-eddystone-sr-21c128-br-34028/`.

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