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Note

Where should Captain Scott's support parties have turned back?

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ABSTRACT. Captain Robert Falcon Scott's plan for the attempt to reach the South Pole during the Terra Nova Expedition was to use horses, motorised sledges and dog teams to lay depots on the Ross Ice Shelf to advance the effective starting point for the three man-hauling groups to the foot of the Beardmore Glacier. His idea was that two of the groups would turn back after two and four weeks, after depositing supplies for the final polar party to rely on during the return journey. In this paper, the logic of the mathematical 'jeep problem' is applied to derive the theoretically optimal points at which the support parties should have turned back in order to optimise the relationship between distance and consumption of supplies. The results show that, according to this model, Scott took both his support parties along too far, especially the last support party under Lieutenant E.R.G.R. 'Teddy' Evans.

Introduction

The introduction of advanced depot strategies in the 19th century was a major development in exploration logistics. Using a well-planned depot strategy, an explorer might be able to reach places that would be unreachable with a poor strategy. The 'jeep problem' is an applied mathematics model that can be used to derive optimal depot strategies for maximising the range of expeditions consisting of several groups in cases where it is possible to lay depots in advance (Chen, Ding, & Fan, 2010). While the mathematical aspects of the jeep model will be outlined later in this paper, the conceptual idea behind the model is that it becomes possible to reach places further away before having to return to base if supply depots are laid in advance and/or if supporting parties travel with the expedition's main party some of the way in order to depot supplies.

Depot strategies in line with the jeep model were used by 19th century explorers such as Francis Leopold McClintock in the 1850s (Holland, 1994) and to some extent even earlier by Lewis and Clark (Ahn & de Weck, 2010). However, such strategies were an important, even essential, logistical feature in many expeditions during the Heroic Age of Antarctic exploration, in which living off the 'land' was only possible at the coastline. Without previously laid depots and/or support parties, it was simply not possible for expeditions to reach goals distant enough to make the potential reward worth the stakes and risks. Roald Amundsen, for example, made several depot journeys in early 1911 to facilitate the following season's journey to the South Pole and to secure the polar party's return journey (Amundsen, 1913).

Robert Falcon Scott's overall plan for his South Pole attempt in the 1911/1912 season (Debenham, 1992; Scott, 2008) was to use ponies, his two dog teams and motorised sledges to tow supplies across the Ross Ice Shelf to the Beardmore Glacier, laying depots as they went and using the previously laid One Ton Depot at 79°29'S for resupplying. The horses would be slaughtered for food as they tired, and the last horses would be shot at the foot of the Beardmore Glacier. From there, 12 men in three groups would man-haul three heavily loaded sledges up the glacier and towards the Pole. According to the plan, one group would return after a fortnight and another (the 'last support party') after a further two weeks, leaving one group (the 'polar party') with the mission to claim the South Pole and return, relying on the supply depots laid by the support parties at the points where they turned back. The plan was implemented with only minor changes, but the polar party perished after a long and heroic march in terribly cold weather (Solomon, 2001) on their way back, having discovered that Amundsen had reached the Pole a month before Scott's group (Amundsen, 1913; Scott, 2008).

Scott's plan, its execution, and his leadership during the expedition have been subject to various criticisms over the years (for example, Huntford, 1999). The fact that his One Ton Depot was laid more than half a degree short of its planned position at 80°S is the basis of much of the criticism, largely because Scott and his two remaining men, Edward Wilson and Henry 'Birdie' Bowers, died of starvation and exposure in their tent at a location between 80°S and the One Ton Depot, and therefore might have survived had the depot been where it was planned to be. However, the question of whether 80°S was the best position for the depot in the first place has not been subject to much analysis in the literature.

This paper will examine a related and potentially vital part of Scott's plan that has not been discussed in the literature to any significant extent, with the aim of providing an analysis of where Scott's two support parties should have been scheduled to turn back in order to optimise the use of the available resources. It will also discuss the possible implications of such a schedule in relation to Scott's plan.

The jeep problem

The jeep problem is a fictitious mathematics problem in which the driver of a jeep in a desert uses a depot strategy either to reach a certain point outside the jeep's initial range while minimising the fuel consumed or to reach a point as far as possible with a given quantity of fuel. The problem was originally solved by Fine (1947) and has many different applications in logistics and operations research. More complex versions of the problem have also been discussed in the mathematics literature (for example, Chen et al., 2010; Gale, 1970; Giffen, 2004). Even though the model simplifies reality quite considerably, it is a useful way to analyse many types of logistical problems.

The jeep problem is relatively easy to understand on a conceptual level. Assume that you are at the edge of a large desert, with a jeep, and that you want to reach a point as far in the desert as possible before returning back to base. The jeep has a maximum range of 1,000 miles. For simplicity, assume that the jeep consumes one unit of fuel per mile and that it can carry up to 1,000 units of fuel. The jeep is currently fully fuelled, but there is no spare fuel. You can obviously not drive more than 500 miles out before turning back because you would run out of fuel on the

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return journey if you did. In this case, there is no point to using a depot strategy because you can bring all the available fuel with you.

Now, assume that you have two fully fuelled jeeps at the base. Given that both jeeps must return to base, the strategy that lets you go as far into the desert as possible with the final jeep is the following: drive both jeeps for 250 miles, refuel jeep 2 with 250 units from jeep 1, depot 250 units from jeep 1 that jeep 2 can use on its return trip, and have jeep 1 return to base. Jeep 2 can then effectively go 750 miles from the base before having to turn back. Moreover, any other depot strategy with two jeeps using the same amount of fuel would be less efficient, as it would restrict the furthest reachable point to less than 750 miles.

The same logic can be extended to any number of jeeps. For example, the optimal solution for three jeeps would be to let jeep 1 return after 166.7 miles and jeep 2 after 416.7 miles, which would make it possible for jeep 3 to reach 916.7 miles out before turning back. In other words, jeep 1 should turn back after 18.18% and jeep 2 after 45.45% of the full distance of the third jeep. Solving more complex versions of the jeep problem would require advanced mathematical methods such as dynamic programming.

Scott's strategy

Imagine that you are Captain Scott on the evening of 9 December 1911 at the Lower Glacier Depot, at about 83°30'S at the foot of the Beardmore Glacier. You know that there are enough supplies at various depots on the Ross Ice Shelf to enable all men to return safely to base from here. Hence, the main problem is to plan the advance from the current location in order to maximise the chances of reaching the Pole with one sledging group and then survive the return journey. Your strategy is to take three sledges up the Beardmore Glacier towards the Pole, planning for one to turn back after resupplying the other two and creating a depot with the surplus supplies at the turning point. Another one of the remaining two sledges would turn back later after resupplying the final party's sledge and also creating a depot at that turning point. With this in mind, where would you schedule your two supporting parties to turn back?

Based on first-hand accounts (Bull & Wright, 1993; Debenham, 1992; Scott, 2008), it seems like Scott's plan at this point was to do more or less what he actually did, that is, having the first support party turn back at the top of the Beardmore Glacier and the last support party about half-way to the Pole from there. When they started ascending the glacier, Scott had access to about 21 units of food (one unit equals one week of supplies for four men) and 12 men with three sledges. In his overall plan, Scott estimated that he would be able to cover the 1,530 miles in 144 days, travelling on average 10.6 miles per day (Debenham, 1992). Hence, 49 days of supplies per sledge was supposed to yield a range of 519.4 miles per sledge, and an application of the jeep model shows that one could optimally reach 476 miles with access to three such sledges. As the distance between the Lower Glacier Depot and the South Pole is 384 miles as the crow flies, the party must have felt confident when they began the man-hauling part of the expedition. However, according to the jeep model, the optimal strategy for reaching a point 384 miles away with access to three sufficiently supplied vehicles is to have the first one return after about 70 miles (that is, 18.18% of the full distance) and the second one after about 175 miles (that is, 45.45% of the full distance), which in this case corresponds with the latitudes 84°40'S and 86°25'S, respectively. In reality, however, the first support party turned back two-thirds of a degree further south than this and the last support party more than a full degree further south. The difference between the optimal and the actual schedule for the support parties in terms of supplies available to the final party during their march back from the Pole is close to two units of food and fuel. In hindsight, such an amount of additional supplies could have made a difference in the polar party's fate.

Discussion

As has been shown from the application of the jeep model, Scott could certainly have used his support parties more efficiently from a theoretical point of view. However, like all models, the jeep model is a simplification of reality, so potential issues with its validity in a situation like Captain Scott's should be noted before stating something more definitive from the practical perspective.

First, the base case jeep model used here is deterministic; that is, it does not allow variation in fuel consumption. Given that Scott had incomplete information regarding the nature of the expected journey and what problems he might face, it was difficult for him to make advanced analyses on where the support parties should turn back. In practice, many factors made his plan sensitive to unpredictable events. The main differences between a deterministic and a stochastic solution of the jeep problem are that the expected achievable distance for the expedition as a whole is reduced, and the optimal inter-depot distances are also reduced (Giffen, 2004). Without going through the mathematics of these results, they probably make intuitive sense to most readers; if the covered distance per unit of fuel varies, one has to build safety margins into one's plan so as not to risk running out of fuel before reaching the next depot. Hence, the stochastic nature of the situation supports Scott's decision to keep the last support party for somewhat longer.

On the other hand, the 'fuel' consumption of a sledging party is not entirely out of its own control, as its members have the option of temporarily going on short rations, which would extend their achievable distance, all else being equal. In fact, during some days of their march, the members of Scott's polar party did go on short rations in order to make sure that they could reach their next depot without running out of food. However, all else is of course not equal when one goes on short rations while performing hard work in extreme cold because one will quickly become weaker. Even the full summit ration used in the expedition was calorifically insufficient; the polar party probably had to endure a daily energy deficit of about 1,500–2,400 kcal (Stroud, 1998) for a long period of time. Not surprisingly, Scott frequently mentioned in his diary that they were hungry on the return march.

The jeep model is, of course, not entirely accurate even from a deterministic perspective because, for example, it assumes that fuel consumption in terms of miles per gallon is independent of the jeep's load, while in reality sledging must be assumed to be slower with heavier loads. Of course, Scott knew that lighter loads on the sledges in general meant higher speed and lower 'fuel consumption'. On the other hand, he also knew that, as the loads would on average be lighter in the latter part of his journey when the men were more worn out, the two effects could be assumed to cancel each other out.

If the last support party had returned earlier, in line with the analysis here, the polar party would have had to pull a heavier load for a longer distance, which would certainly have worn the

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men out even more. On the other hand, having fewer teams for a larger part of the journey could have increased their average speed, as it is the slowest team that decides the speed of the fleet. In his diary, Scott often complained about having to wait for a slower group. However, by choosing to keep support parties around for longer, Scott kept his options open regarding which men to take with him depending on who was strongest and which, and how many, to send back. All else being equal, having one's options open is a good thing.

Scott's seemingly last-minute decision to send three men back as the last support party and continue as a five-man party to the Pole has been subject to criticism (for example, Hayes, 1928; Huntford, 1999; Thomson, 1977). However, from a purely logistical perspective, the decision makes sense. According to the jeep model, the final sledge has to be loaded more heavily with supplies than the returning one, and it has to be hauled for a longer distance. Therefore, having five men in the polar party and three in the last support party made the weight each man had to pull more equally distributed. Scott's diary suggests that more pulling power was a major reason Scott wanted an extra man in the polar party. The obvious drawbacks of this decision, such as the support party having to take only three-quarters of their planned share of supplies from the depots on their way back, and the polar party having to squeeze five men into a tent intended for four, must have seemed small in comparison. However, as noted by Scott, the unexpected consequence of a substantially increased cooking time for a party of five did not bode well.

From the diaries and narratives of Scott and other party members (for example, Bull & Wright, 1993; Cherry-Garrard, 1922; Evans, 1921; Wilson, 1972), there is no indication that Scott ever considered any revision of his initial strategy regarding the turning points for the two support parties. In fact, Scott noted, satisfactorily, in his diary on 20 December that he would be almost exactly in his planned position for the first support party to return. The letters Scott sent back with the different returning parties at various points in the march have certainly been subject to discussion among historians. The main controversy pertains to Scott's seemingly conflicting orders about how the dog teams were to be employed after their return from the first stage of the journey (for example, May & Airriess, 2015). The only substantial change Scott made regarding the support parties was to transfer Bowers to the polar party before sending the last support party back, a decision which has been widely discussed. Besides Scott himself, Bowers was the one expedition member that could reasonably have had justified objections about the depot strategy, as he was responsible for stores and the day-to-day logistics of the party. However, there are no indications that Bowers ever doubted Scott's plan regarding the support parties, which is not surprising given Bowers' loyalty to Scott (Strathie, 2012). In fact, all figures of the plan had been checked by Bowers (Scott, 2008). Moreover, Bowers seems to have considered Scott's plan regarding the turning points as the natural and final one, even though he, for some time during the march, expected Scott to send him back in charge of the last support party (Bowers, 1911).

To conclude, Captain Scott kept his two support parties around for too long, at least from the mathematical perspective of the jeep problem. Theoretically, by using a better depot strategy, more resources would have been available for the polar party's return journey, increasing the men's likelihood of survival. However, in practice, the jeep model does not account for all aspects of the situation Scott faced during his South Pole march of 1911/1912. Hence, this analysis should be taken primarily as an attempt to initiate further discussion and research about the depot strategies used in the different polar expeditions during the Heroic Age, rather than as criticism of Scott and his expedition.

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Conflict of interest

None.

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