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Developing an efficient algorithm for balancing mass-haul diagrams

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ABSTRACT

A number of linear and integer programming techniques have been used to minimize the total cost of earthwork by considering the various factors involved in the process. Although these models often ensure a global optimum for the problem, they required sophisticated formulations and are quite involved in their setup and definition as well as being expensive computationally and therefore may be of limited use in real life. In construction practice, Mass-haul diagrams (MD) have been an essential tool for planning earthwork construction for many applications including roadwork, piping, and other linear infrastructure facilities. One of the most common heuristics that is used widely by practicing engineers in the field to balance the MD is the "shortest-haul-first" strategy. Balancing the MD using this heuristic is usually carried out either graphically on the drawing, or manually by computing values from the mass-haul diagram itself. However performing this approach graphically or manually is fairly tedious and time consuming. In addition manual and graphical approaches are prone to error. More importantly, if the project considered has a large number of stations (in the order of hundreds), then performing this balance manually becomes impractical. A robust algorithm is therefore needed that can automatically balance the MD. The research discussed here presents a formal definition of an algorithm that uses a sequential pruning technique for automatically computing balances of mass-haul diagrams. It is shown that the new algorithm is more efficient than existing integer programming techniques and computationally runs in level of complexity of O(log n) time in most cases. Thus this algorithm can handle problems with a large number of stations within a reasonable amount of time. In addition, a computer implementation and extensive computational experiments are provided. Suggestions for how this algorithm can be used in cost-based or grade-based optimization of hauling distances and quantities are discussed.

1. Introduction

Balancing of earthworks volume is very important in many construction projects involving earthwork because of its effect on the overall cost. Mass Diagrams (MD) have been used for quite some time to help construction engineers plan for excavation and embankment operations. The primary use of MD has been to determine points where the cut and the fill balances out, as well as planning for haul routes and distances (Anderson and Mikhail [3]; Oglesby and Russell [13]; Stark and Mayer [15]). MD usually provide the construction engineer with a visually presentation to determine which cut sections will fit in which fill sections and what are the average hauling distance for each section. Mathematical programming models of earthwork allocations have also been formulated which aim at minimizing the total earthwork costs considering various technological, physical, and operational constraints (Mayer and Stark [11]; Nandgaonkar [12]; Easa [7,8]; Akay [2]; Zhang and Wright [16]). These models usually solve the optimization problem using Linear or Integer Programming (LP and IP) techniques.

Although these models insure a global optimum for the problem, they required sophisticated formulations and are quite involved in their setup and definition and therefore may be of limited use in practice. In addition it has been shown that problems with a realistic number of stations (in the order a hundred) cannot be solved in a reasonable amount of time. Henderson et. al. [9] showed that four hours are needed to solve a problem with 81 stations using a Branch and Bound method and an IP formulation. On the other hand, one of the most common strategies used by practicing engineers in the field to balance the MD is the "shortest-haul-first" strategy. This approach usually is sufficient for most roadwork construction problems and is widely used in practice (Anderson and Mikhail [3]). There are two ways for determining a balance for an MD using this approach; graphical and manual. In the graphical approach the engineer has to plot the MD on a scale drawing and then measure (scale) from the drawing hauling distance and quantities that balance the MD. In the manual approach, some calculations are required in order to do the same thing. However performing this approach graphically and manually is fairly tedious and time consuming [9]. In addition manual

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