

# Chapter 1

## Introduction

### 1.1 Continuous Haulage System

At the present time, the Continuous Haulage System (CHS) is one of the most efficient in the underground mining industry. The main function of a CHS is to transport mined material from the mine face to a more-or-less fixed belt conveyor. The system follows the continuous miner forward and backward, accepting the mined material from the miner's discharge boom and transporting it hundreds of feet continuously to the belt conveyor. The system consists of an alternating series of Mobile Bridge Carriers (MBCs) and Piggyback Bridge Conveyors (Pigs) connected together in cascade fashion, and a Rigid Frame Modular (RFM) Tailpiece as shown in Figure 1.1. Adding MBC-Pig pairs into the system can extend the overall length of the system to meet users' requirement [Long-Airdox, 1998].



Figure 1.1. Continuous Haulage System

A Mobile Bridge Carrier (MBC) is a tracked-vehicle which has a conveyor mounted on top. Both front and rear ends of the conveyor are attached to the Pigs by connecting pins, and their heights can be adjusted to accommodate the mine floor's condition. On top of the front conveyor, there is a 5-foot traveling slider, called a "Dolly" to which the Pig is attached, allowing the MBC to be moved with significant length flexibility with the other MBCs in the system. The MBC can be maneuvered in desired directions by commanding appropriate speeds to its crawlers. Figure 1.2 shows the picture of an MBC.

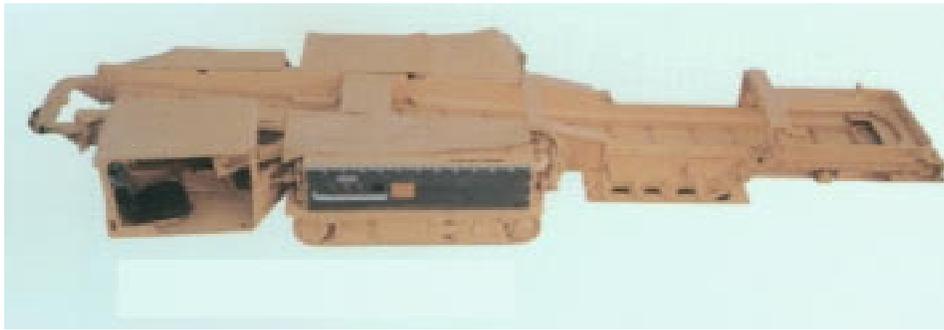


Figure 1.2. Mobile Bridge Carrier

A Piggyback Bridge Conveyor (Pig) is a bridge conveyor that is carried by two MBCs or by one MBC and the RFM tailpiece. It links two MBCs together, and transfers the mined material from the front one to the following one. The receiving end of the Pig is joined to the discharge boom of the front MBC while the discharge end is connected to a travelling dolly on the outby MBC. The Pig mainly comprises a rigid frame and a chain conveyor as shown in Figure 1.3.

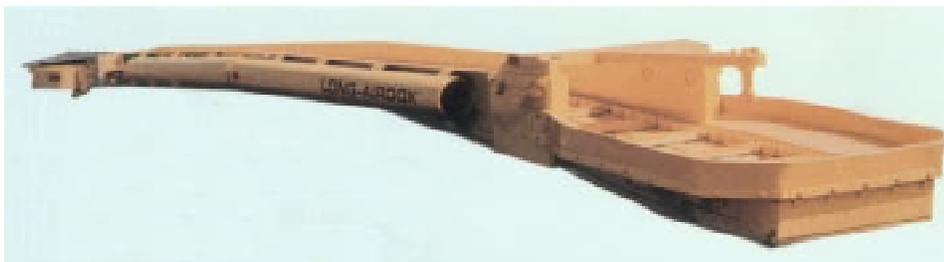


Figure 1.3. Piggyback Bridge Conveyor

The Rigid Frame Modular (RFM) Tailpiece in Figure 1.4 is a belt conveyor that has a traveling dolly (tail dolly) on top of it. This tail dolly is attached to the discharge end of the outby Pig (last Pig), and can slide along the whole length of the RFM. The RFM Tailpiece permits the entire system to advance and retreat with the continuous miner; as a result, the length of the RFM, at least, must be equal to the sum of the length of the system and that of the continuous miner.

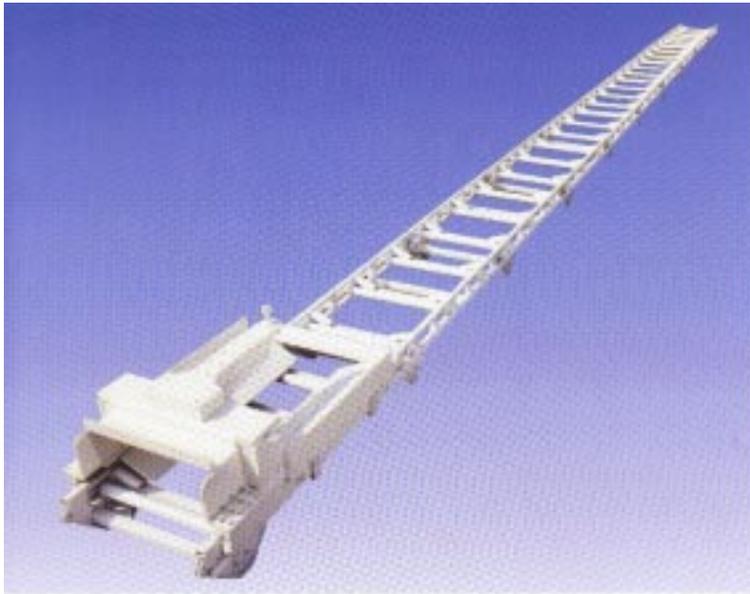


Figure 1.4. Rigid Frame Modular

The CHS can be mainly categorized into two different types of systems. One is an attached system, and the other is a detached system. In the attached system, the receiving boom of the first MBC is linked to the discharge boom of the continuous miner via a Pig. On the other hand, with the detached system, the first MBC has no Pig in the front, but is equipped with a receiving hopper instead. Figure 1.5 and 1.6 represent each system respectively.

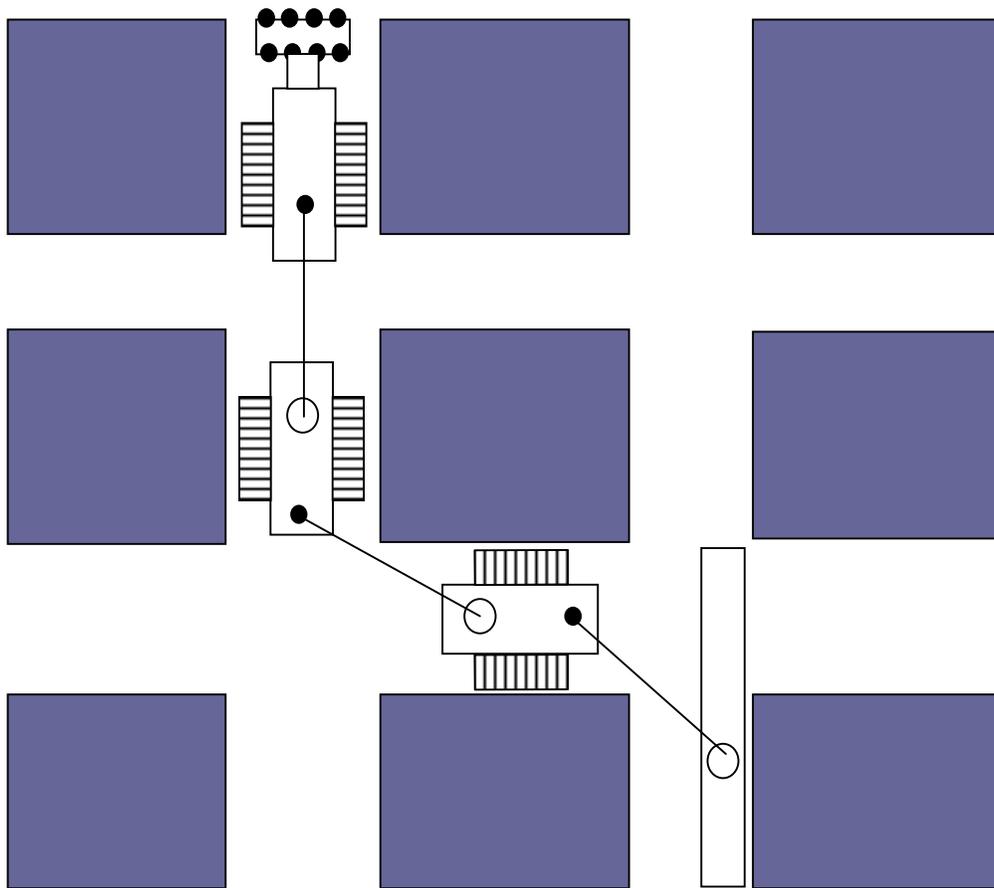


Figure 1.5. Attached System

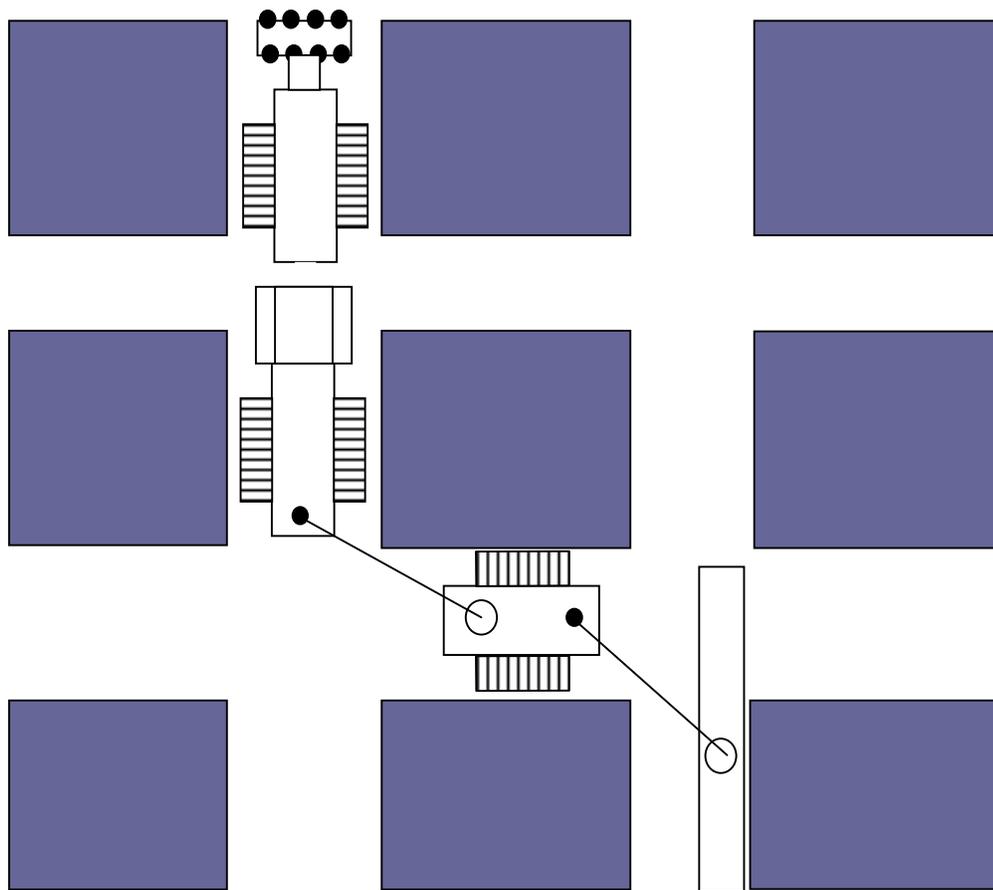


Figure 1.6. Detached System

## 1.2 Underground Mining Automation

The safety in underground mining is always of paramount concern for many mine equipment manufacturers. One of the effective ways to assure safety for mine operators is moving people farther away from the mine face or potentially hazardous areas. That means the equipment must be operated in the underground mine without the operators sitting in the cabs or, ideally, without operators' close proximity.

Not only is the issue of safety a major interest, but also the issue of productivity. According to Scheduling, et. al. [1997], mining automation is able to increase productivity, and reduce mine-operating costs. These advantages attract many companies in the industry to invest in developing automation.

Many research projects related to underground mining automation have been conducted; however, most of the developed systems are essentially teleoperated systems controlled by the operators using remote controllers. Only a few of the underground mining systems are designed to work fully autonomously. Furthermore, all of them to date are implemented on Load, Haul, and Dump (LHD) and haulage trucks [Hurteau, et. al., 1993].

Long-Airbox, one of the leading mine equipment companies in the world, has realized the necessity and benefit of automating a conventional CHS; as a result, the cooperative research project between Virginia Tech, Long-Airbox Company, and CIT was initiated in early 1998. In the middle of 1998, The Full Dimension<sup>®</sup> Guidance System project, lead by Dr. Robert H. Sturges as a principal investigator, was established. The goal of this project is to design and evaluate a prototype guidance system for a Long-Airbox Full Dimension<sup>®</sup> continuous haulage system within one year [Sturges, 1998].

### **1.3 Project Objectives**

The overall objective of this project is to develop a prototype of a guidance and navigation system for a Full Dimension<sup>®</sup> CHS, and is broken down into three subgoals, which must be accomplished upon the completion of the project. These subgoals are the following:

- The autonomous CHS should navigate by itself, and follow the continuous miner through a room-pillar type mine without operators. Only the first MBC would be manually driven in the detached system.

- No need for adding any kind of artificial landmarks to the walls or roofs of the mine passages in order to guide the autonomous CHS.
- The guidance and navigation system would not depend on accurate maps in any form, but would entirely rely on real-time proximity measurements.

#### **1.4 Research Objective**

In order to achieve all three subgoals above, the system models, both kinematic and dynamic models, must be investigated before one can begin to develop the algorithms for navigation and system control. Moreover, the simulation software developed, based on both models, can be used as a tool to simulate the response of the system or any kinds of multi-unit tracked vehicles to the control command. This allows us to have a clear understanding of the system behavior and control. Hence, the primary objective of this research will place emphasis on study of kinematic and dynamic models of the CHS, which can also be applied to other types of the CHS-like vehicles, as the first task of the project.

#### **1.5 Approach**

Since the CHS is usually operated over a fairly flat and level mine floor except in some extreme cases, the whole system is sufficiently represented by a 2-D model. Therefore, in this research, we will develop only 2-D kinematic and dynamic models of the system. A kinematic model can be obtained from modeling the system as a planar mechanism comprising rigid links connected together by revolute and/or prismatic joints. This model not only represents the current configuration of the system at any time, but also provides important data that the dynamic model requires.

As one will notice, the prime movers of the CHS are MBCs, which are essentially tracked-vehicles. In the development of the dynamic model, first, each MBC in the system will be treated as an independent unit, and separately modeled as if it is not attached to the other units. Tracked-vehicle mechanics, including terramechanics, is investigated, modified, and simulated on a digital computer. Then, the simulation result will be verified with the experimental data obtained from a test of a full-scaled MBC. Second, each MBC is linked together by a Pig, which is modeled as a rigid link with the

forces acting on each connecting pin. Finally, the system of linear equations is set up and solved, and the solution is displayed on the screen in graphical form.

It is useful to notice that the kinematic chain comprising a CHS bears more than a superficial similarity to a planar articulated robot. This fact has been exploited in our approach to motion planning and system control.

MATLAB<sup>®</sup>, an interactive program for scientific and engineering calculations capable of solving the system of linear equations and displaying two-dimensional graphics, has been selected to be the programming language for simulating the dynamic response of the system. All computational functions and graphics display functions will be written as separated modules in one file for ease of understanding and modifying. A Personal Computer with high-speed microprocessor, 200 MHz clock-speed or more, will be used as a platform to run the simulation since it provides acceptable run-time speed, and running cost is inexpensive.