# Chapter 2
# An Integer Programming Model to Maximize Battery Manufacturing Productivity

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## ABSTRACT

*An Integer Programming (IP) model is formulated and optimally solved for a real-life production planning problem. The model is used to determine the optimum production plan for the formation stage of battery manufacturing in a local battery-producing company. Battery manufacturing is a complicated process that involves several stages and several chemical and physical operations. The formation stage is considered the bottleneck of this process because it has the most critical limitations of time and production resources. In the formation stage, batteries are filled with acid and charged with electricity using different types of circuits. The objective of the model is to maximize the productivity of the critical formation stage by allowing the best utilization of the limited time and equipment resources. The model is able to consider a large number of battery sizes and types and also a large number of charging circuits with different capacities and charging speeds. The model-generated optimum production plans increase daily profits by 12% on average in comparison to manually-generated production plans.*

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## INTRODUCTION AND BACKGROUND

Battery production is complex process that involves several products, many components, and multiple manufacturing stages. The manufacturing of automotive batteries for cars, trucks, and boats is done through a unique manufacturing process that includes several physical and chemical operations. These operations include lead strip manufacturing, steaming, chemical curing, acid filling, formation, electrical charging, and final assembly. The distinctive nature of the battery manufacturing process lead to special considerations and objectives in planning and scheduling of battery production activities. This chapter presents an integer programming model for achieving the maximum profitability in the formation stage of the battery manufacturing process at a mid-size battery making company. The model is formulated and applied to actual production problem using real data from the Middle East Battery Company (MEBCO) in Saudi Arabia. Optimum production plans generated by the model have shown significant improvement in profitability over the previously used manually generated production plans.

Middle East Battery Company (MEBCO) is a joint venture between a group of Saudi Industrialists and business leaders and Johnson Control International (JCI). MEBCO produces AC Delco, JCI and Toyota branded maintenance free batteries. The plant is located in 2nd Industrial City in Dammam, Kingdom of Saudi Arabia. JCI is a 49% equity partner in MEBCO and has management responsibility for the plant operation. The plant is the first Delphi battery plant built specifically to serve the after-market and is Delphi's first manufacturing operation in the Middle East producing batteries for comprehensive vehicle market, including European, Asian, North American, as well as marine, commercial and industrial applications.

The plant started its test production in November 1997 and had the first shipment to customers on January 14, 1998. MEBCO's primary market is the Gulf Cooperation Council states: Saudi Arabia, United Arab Emirates, Kuwait, Bahrain, Qatar and Oman. Other markets include Egypt, Lebanon, Jordan, Syria, Asia Pacific, North America and South Africa. The production has been consistently growing and passed the 2.5 million mark in October 2006. The plant produces batteries for all vehicle types, as well as marine, commercial and industrial applications. MEBCO's primary market is the Middle East, but it also has growing markets in Asia, Europe, and North America. Other potential markets and part numbers are continuously explored to suit the market demands and application requirements.

MEBCO's battery manufacturing plant is divided into 4 main areas; X-Met, Green Group, Formation, and Final Assembly. The Formation area's main function is the electrical charging of batteries for periods that range from 14.5 hours to 24 hours, depending on the type of battery. Because of the limited time per day, and also because of space limitations that restrict the number of charging circuits, the Formation area is considered to be the bottleneck of the battery production capacity.

According to the theory of constraints, the throughput rate of any multi-component system is controlled by the slowest component (called the constraint or the bottleneck). In order to maximize the productivity (profitability) of the battery production line, the company needs to optimize the production planning output in the formation stage. As shown in the following section, a variety of optimization and heuristic techniques have been used to solve battery production planning problems. In this chapter, an integer programming (IP) model is used to maximize the profitability of the formation area. This IP model has been practically applied to optimally schedule the daily production of 74 battery models. The model considers different battery sizes, charging times, and daily demands, as well as limitations on times, capacities, and numbers of different types of charging circuits. Compared to manually generated production plans,

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