Chapter 2
Literature Review

The goal of this chapter is to provide prior work done with linear-programming approaches for the resource-allocation problem. Operations-research (OR) modeling often concerns finding the best quantitative solution for management problems [HL01, Mom01]. The OR methods include mathematical-optimization modeling as simulation, and using OR methods has grown significantly since their origination during World War II. Templeman [Tem91] describes quantitative OR methods for designing and controlling industrial and economical operations. Many private and government organizations have improved their operations by successfully using mathematical programming [Wad83, Aro02, Chv83, Dan63, SS85]. This book focuses on a resource-allocation problem and applies linear programming for the solution approach.

2.1 Linear Programming in Practice

LP problems are decision problems where the purpose is to compute values for a set of decision variables in order to optimize (maximize or minimize) a linear-objective function, subject to a set of linear constraints. A formal definition for the class of LP problems is given below; because this book is primarily about solving LP problems in practice, I, first, briefly consider the context in which such problems arise and the importance of being able to solve them.

A diverse range of real-world problems can be approximated and formulated as LP problems, and there is often great economic or other value attached to finding an optimal solution. The LP field was originally developed to plan military-logistic operations during the Second World War (The word "programming" in LP means "planning."), and since then, the range of applications has flourished. Examples include industrial diamond blending, hired-car fleet management, distribution warehousing and supply chain management, oil refining, and gas-pipeline flow.

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(Many other applications are described in the literature [GPS00, BBG77, Bou01, Bou02, Wil93].)

The value of being able to identify an optimum solution, as opposed to a feasible solution or sometimes no solution, can run into the order of many millions of dollars. For instance, a difference of 1% in the objective value in the yearlong PowerGen problem represents an annual cost difference of $520 million [Pow98].

Dr. Warren Powell of Princeton University and others developed a model for the Commercial Transport Division of North American Van Lines. Under high levels of demand uncertainty, this model dispatches thousands of trucks from customer origins to customer destinations each week. Working closely with upper management, the project team developed a new type of network model for assigning drivers to loads. The model, LOADMAP, combined real-time information about drivers and loads with an elaborate forecast of future loads and truck activities in order to maximize profits and service. It gave management a new understanding about the economics of truckload operations; integrated load evaluation, pricing, marketing, and load solicitation with truck and load assignment; and increased profits by an estimated $2.5 million annually while providing a higher level of service [PSN88].

The growth of LP as a practical technique would not have been possible without simultaneous progress in the power and availability of computing. Today, software for LP optimization is highly sophisticated, with several commercial codes being actively developed and marketed. A symbiotic relationship exists between the capacity of the codes and the growth of applications, with solutions for larger problems being demanded in less time as codes improve. This book investigates a well-known, but not well-used, method which has the potential to solve large problems quickly by exploiting the structure.

LP optimization software uses two main method classes. The simplex method is a gradient-descent method that moves along the edge of the feasible region [Chv83, Dan63]. Interior-point methods (IPM) move through the interior of the feasible region [Wri97]. We do not dwell on these well-known methods but take the solution of an LP problem with either of these methods as granted, provided that practical considerations allow it. DW decomposition was developed in the late 1950s, a decade after the simplex method and many years before interior-point methods were applied to LPs [Dan63, Dan83]. The DW procedure immediately aroused widespread interest, and many attempts were made to implement it as a computational method. Practical experiences, however, were mixed, with some claims of success but no lasting achievements when measured by the methods used to solve practical problems. There has been no evaluation about and development of different options and strategies for computational implementations, whereas there have been continued research and development for over 50 years with the simplex method and for over 20 years with the Integer Programming Method (IPM). Perhaps the greatest challenge with the Dantzig-Wolfe decomposition has been that, when viewed simply as an alternative LP optimization method, successes have been rapidly overtaken by improvements in simplex and IPM implementations. The continued improvement with LP optimization technology could be used to enhance the implementation of the Dantzig-Wolfe decomposition.

In the book, we primarily focus on the technique referred to as Dantzig-Wolfe decomposition (DW), an optimization technique for solving large-scale, block-structured, linear-programming (LP) problems. Opportunities from many different fields, such as production planning, refinery optimization, and resource allocation, may be formulated as LP problems. Where there is some structure arising from repeated problem components, such as handling multiple periods, locations, or products, the problem may potentially be solved by using the Dantzig-Wolfe decomposition.

As preparation for our practical work, we investigate how suitable block structures can be identified in practical LP problems. We develop the decomposition algorithm from first principles, delineating the theoretical requirements and showing which aspects are open for experimentation in a practical implementation. We illustrate, geometrically, the transformation from the original problem to the Dantzig-Wolfe master problem, and we establish precisely how solutions obtained from the decomposition algorithm correspond to answers for the original problem. We critically review previous practical work.

Smart-grid control systems have used both centralized and decentralized (distributed) approaches [BCP08]. Centralized control systems have the best performance for small-scale power networks and delivering power in one direction (i.e., from substation to loads). Today, the evolution of some power-distribution routines, such as distributed power storage and distributed generators (DGs), requires deploying smart-control systems [NF12]. Most traditional power-control systems act preventively or reactively to events, whereas more recent control systems add active control options to their strategies [Wan01]. Control architectures for power grids have widely utilized central and hierarchal methods. Considering their higher efficiency and reliability, decentralized and fully distributed intelligent controllers are beginning to appear [DNS95].

Optimization techniques have been used for power systems and have been studied with many resource-allocation applications [Son99, Moo91, Sal04]. Power-distribution networks are usually designed radially with load-feed flows in one direction. This type of network experiences increased loss, decreased voltage amplitude, and voltage instability (when using a motorized maximum load) due to its radial design and, probably, its long length. One effective solution for improving the performance of distribution networks, from a technical point of view, is using distributed generation supplies. Generally speaking, the advantages of using a distributed generation pattern can be categorized into two technical and economic aspects [KHS05].

The technical advantages of a distributed generation include decreased line loss, improved voltage profile, decreased environmental pollution, increased energy efficiency, higher-quality power, improved system reliability, and security. On the other hand, the economic advantages of applying distributed generation patterns include various investments to improve facilities, decreased operational costs, optimized production, decreased costs to save energy, and increased security for critical loads. A distributed allocation technique using branch and bound is studied for allocating DERS in the context of a smart grid [RN10]. A probabilistic approach using linear programming is applied for a Smart-grid resource-allocation problem. Several other Smart-grid implementations for a self-healing grid using LP are studied [PFR09]. LP-based decision support for situational awareness is outlined. Comprehensive universal markup language (UML) representations of micro-grid architecture are developed. The preliminary results of the resource-allocation problem in a Smart grid using the Dantzig-Wolfe procedure are presented.

2.2 Development of a Distributed Linear-Programming Model

A massive power blackout that caused some five million people in Arizona, California, and Mexico to lose electricity was apparently triggered by one person in Arizona. Figure 2.1 shows a map of the electric outage areas. An Arizona Public Service worker "removed a piece of monitoring equipment" which set off a chain reaction across the region, according to the Associated Press [RN12]. The outage appeared to be related to a procedure that an Arizona Public Service (APS) employee was performing at the North Gila substation which is located northeast of Yuma. Operating and protection protocols typically would have isolated the resulting outage to the Yuma area. The reason that the isolation did not occur in this case was mostly blamed on a lack of automated programs and reliance on heavy manpower. Our approach addresses such outage events through the LP programs discussed in the next paragraph [DCN04, FES12, GPR09].

We restrict the attention to the general LP approach and the Dantzig-Wolfe decomposition technique in the context of a Smart grid. The following macro-grid architecture has a centralized agent called an independent system operator (ISO) which coordinates the micro-grid activities. An agent is a piece of software code that performs tasks autonomously in the event action is needed to restore the grid process, such as self-healing the grid during an outage, running resource allocation, or scheduling tasks [NF12]. Thus, every micro-grid has an objective function and constraints that are formulated as an LP problem. We treat each individual LP program as an individual agent that monitors these micro-grids and associated activities as shown in Fig. 2.2.

Similarly, any macro-operations, such as coordinating all micro-grids, are conducted by an independent system operator, and they are treated as a master LP program and constraints run by AMPL. The master LP program interacts with the sub-problems via the exchange of dual variables. Figure 2.3. shows the distributed linear programming architecture.

As an information infrastructure with monitoring, control, and protection functions in a smart-transmission grid, the wide-area measurement system (WAMS), based on a synchronized phasor measurement unit (PMU), gradually becomes an important guarantee for the security and stability of power systems. The WAMS can be used to conduct real-time monitoring and control for dynamic system states,

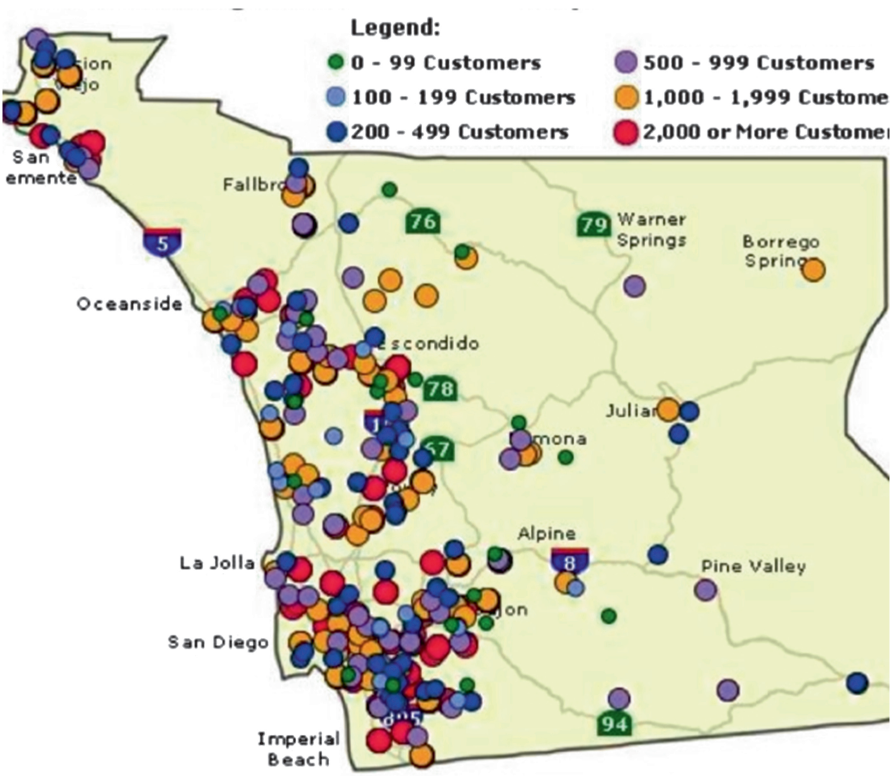
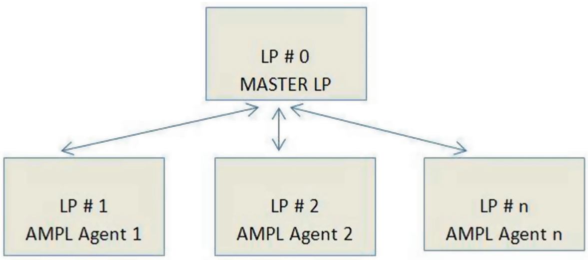


Fig. 2.1 Electric outages in the Sandiego Gas and Electric (SDG and E) Territory: September 8, 2011, 6:39 pm [RN12]

Fig. 2.2 LP as agents



enhancing the system's security level because it utilizes the highly precise, synchronous clock in a global positioning system (GPS) to build unified time-space synchronization. The WAMS usually includes the PMUs, phasor data concentrator (PDC), control center (CC), and the high-speed data communication networks. Figure 2.4 shows a local micro-grid with PMU-PDC integration as part of the

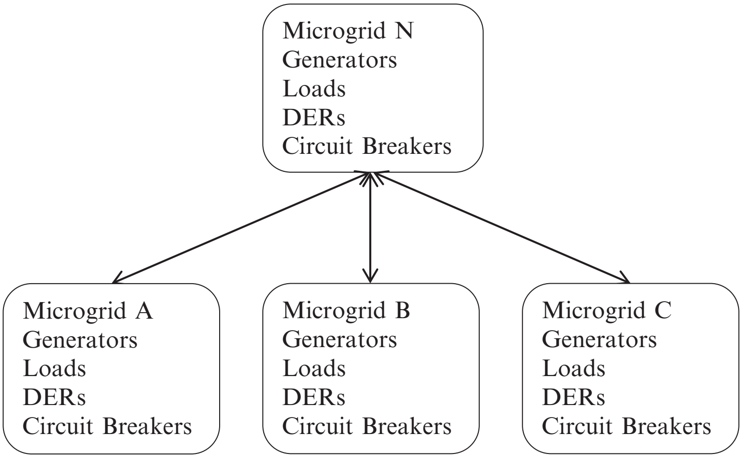


Fig. 2.3 A distributed linear-programming architecture.

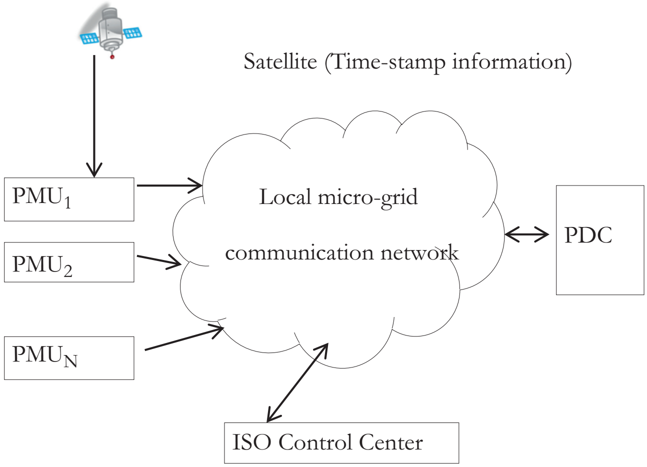


Fig. 2.4 Local micro-grid integration as part of the WAMS

WAMS. I assume that each block of the micro-grid structure shown in Fig. 2.4 has these units and integration in place.

Applying the Dantzig-Wolfe procedure would be significant if it is used with the WAMS or micro-grid architecture. In the book, we will show the computational significance of a small-scale grid, such as an IEEE bus network, to demonstrate its computational efficiency. Chapters 3 and 4 discuss a resource-allocation procedure where the preliminary results motivated us to continue the computational study of the Dantzig-Wolfe procedure.

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