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# Landfill space consumption dynamics in the Lower Rio Grande Valley by grey integer programming-based games

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**Abstract**

The Lower Rio Grande Valley (LRGV) region in South Texas emerges as a warehouse and transportation center between Central America and the US with positive growth impacts due to the North American Free Trade Agreement (NAFTA). In 10 years time, a 39.8% population increase has resulted in a 25% boost in solid waste per capita disposal rate in the region. A landfill space shortage drives a need for landfill operators to understand their optimal management strategies in this highly-competitive market. Initially, a strategic plan for optimal solid waste pattern distribution minimizes net costs for cities. This is accomplished through a grey integer programming algorithm that encapsulates all uncertainty present in the solid waste system. Secondly, a series of grey integer submodels construct payoff matrices for a zero-sum two-person game. The ensuing game theoretic analysis is critical for evaluating optimal pricing strategies for tipping fees available to the most significant regional landfills (e.g. Browning-Ferris Industries (BFI) and City of Edinburg) as they compete over disposal contracts. The BFI landfill intrinsically benefits from its competitive pricing policy and central location to solid waste generators. The City of Edinburg landfill, on the other hand, wishes to secure its lucrative solid waste management revenue. It desires a gaming strategy backed by optimality that integrates ambiguity in solid waste generation, design capacity boundaries, and unitary shipping costs. Results show that a two-tiered analysis via grey integer programming-based games may pave the way for 'grey Nash equilibria' pricing tactics that will help the Edinburg landfill maintain its waste contracts.


*Keywords:* Landfill space; Pricing; Solid waste management; Grey integer programming; Game theory; Nash equilibrium; The Lower Rio Grande Valley

## 1. Introduction

The Lower Rio Grande Valley (LRGV or Valley) is one of the fastest growing regions in Texas and the Nation. Population growth, industrial development, proximity to the border with Mexico, and other North American Free Trade Agreement-induced (NAFTA-induced) factors are behind the explosion in Valley development. The area's population has increased by 39.8% in the last 10 years. It is expected to continue growing at an estimated rate of 4% per year in the coming years. The population is projected to be over 1.7 million people by 2022 (LRGVDC, 2002). The growth in the population in the region is influenced by immigration from Mexico, high-birth rates in the Valley, and the growing employment opportunities in the Valley. Synonymous with this economic development is an alarming rise in the solid waste generation that leaves the area with only 12 more years of landfill life. With receding landfill space and limited agents equipped to meet the solid waste management (SWM) demands, public and private landfills compete for municipal clients to ensure capital to extend landfill life or apply for new permits. In the LRGV, the City of Edinburg landfill and the Browning-Ferris Industries (BFI) landfill are the main SWM competitors over the solid waste management market of the Valley.

Game theory is an interactive decision making process that attempts to identify optimal strategies at equilibrium between several players who make choices that affect the interests of other players (Ray, 2000; Turocy and Stengel, 2001). It is a mathematical concept to delineate competitive interactions in order to visualize or anticipate the competitors' optimal moves. In 1950, John Nash demonstrated that

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finite games always have an equilibrium point at which all players choose one action that is in balance with their antagonist (Vorob'ev, 1977). Non-cooperative game theory is a central concept that revolutionized the study of economics and economic behavior since the 1970s. Additionally, its application thrives in sociology, psychology, and evolutionary biology (Turocy and Stengel, 2001). Game theory applications for environmental planning include Hoel (1992), who proposes a dynamic game surrounding environmental policies for strategic international trade that reveal both Nash and subgame perfect equilibria (Ulph, 1992). Guth and Pethig (1992) analyze a signaling game between a monitoring controller and a firm looking to illegally pollute in order to save on abatement costs.

Economically-driven environmental games are deficient in ways to construct game matrices with optimization involving uncertainty. While games can cope with probabilistic moves, they have yet captured variance due to forecast values or the effects of incomplete information. Grey integer programming (GIP) is part of a succession of optimization models for sequencing and screening alternatives integrating grey systems theory with mixed integer programming (MIP). The purpose is to address a theoretical waste management facility expansion and waste flow allocation within a solid waste management system by an all-inclusive method under uncertainty (Huang et al., 1992, Huang and Moore, 1993; Huang et al., 1993, 1994, 1995). Its roots lie in Moore's (1979) interval analysis and successive refinement in China in the form of grey systems, where all systems are divided into three categories: white (completely certain), grey (somewhat uncertain), and black (completely uncertain) parts (Huang et al., 1994).

Grey variable configurations lead to flexible screening of decision alternatives with regard to facility selection or expansion (Huang et al., 1993). GIP's principal innovation is that it provides a set management option, whereas conventional MIP provides only one, and the effects of system change are explored piecemeal. For systems embedded with vague intricacies from uncertain inputs, all variance can be optimized 'once-through' with no need to run subsequent models, since parameter sensitivity is considered upfront and not as an afterthought.

Capturing the dynamics between 16 populous cities and two major competing landfills in the Valley requires a two-tiered grey integer programming-based game theory (GIP-based game theory) to perform system optimization and a powerful cost-benefit analysis. Greyness affecting the optimal waste distribution patterns is handled by grey integer programming, while competition in the solid waste market is scrutinized through game theory. The games themselves offer deeper insight to the effects of competitive pricing in a system under uncertainty which leads to more efficient solid waste allocation strategies in the region.

## 2. Study area

The cities selected for solid waste management analysis that lie in the LRGV are Alamo, Brownsville, Donna, Edinburg, Harlingen, McAllen, Mercedes, Mission, Pharr, San Benito, San Juan, Weslaco, La Feria, Hidalgo, Elsa, and Raymondville. An inventory of the open landfills in the Valley is illustrated with the study area shown in Fig. 1. The Lower Rio Grande Valley (LRGV) is a 9324 km$^2$ area in the southernmost part of Texas is formed by Cameron, Hidalgo, Willacy, and Starr counties. The Office of Management and Budget (OMB) ranks Metropolitan Statistical Areas (MSA) according to their population and economic growth. Cameron County contains the 28th MSA-Brownsville-Harlingen-San Benito—while Hidalgo County, with roughly half of the LRGV area, is mostly urbanized and has the fourth fastest growing area in the nation: the McAllen-Edinburg-Mission MSA. The increasing

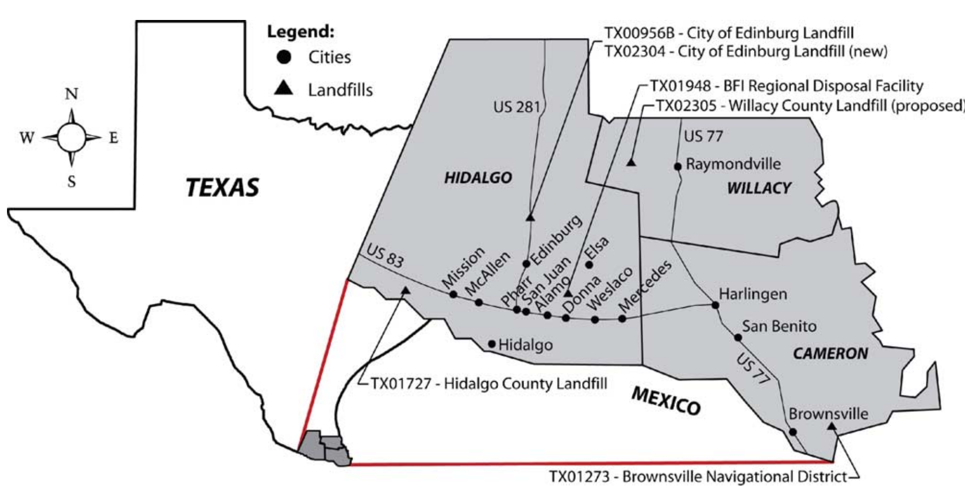


Fig. 1. The LRGV study area.