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A bi-level partial interdiction problem on hierarchical facilities

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***Abstract*—In this paper a partial interdiction problem on a capacitated hierarchical system is studied. We consider an attacker who can interdict facilities at different levels and each interdiction level causes a specified reduction in the capacity of a facility depending upon its service level in the hierarchy. First, the interdictor identifies her interdiction strategy whose aim is to cause the most demand satisfaction cost subject to her budgetary limitation. Subsequently, the defender tries to optimize the objective function which is similar to the attacker's one but in the opposite direction. The defender is responsible for choosing the least cost strategy in order to satisfy all customers' demand. She can achieve this goal by two ways: (1) allocating their demand to the hierarchical facilities subject to their residual capacity, (2) benefiting from outsourcing option. This problem can be regarded as a static Stackelberg game between a malicious interdictor as the leader and a system defender as the follower. In this paper we propose a bi-level mathematical formulation in order to model the problem. To solve this problem with exhaustive enumeration, CPLEX has been used.**

Keywords-hierarchical capacitated facilities; interdiction; outsourcing; bi-level programming

I. INTRODUCTION AND OVERVIEW

Introduced in 1960 [1], interdiction problem has a variety of applications. An intentional strike against a system is called interdiction [2]. According to [3], two of the most common types of interdiction used are disruption and destruction. Disruption involves ''upsetting the flow of information, operational tempo, effective interaction, or cohesion of the enemy force or those systems'' while destruction means ''damage the structure, function, or condition of a target so that it can neither perform as intended nor be restored to a usable condition, rendering it ineffective or useless'' [4]

In this paper we study a partial interdiction problem on a hierarchical system. The concept of partial interdiction first introduced in 1970 [5]. Adding partial option in contrast to the full version of interdiction, demonstrates the ability to plan more freely for spending interdiction budget on interdiction strategies. In [6], a reasonably comprehensive survey of partial interdiction problems is conducted. Our work can be considered as a development of [6] on the problem that was proposed in [7].

In our problem, we consider a situation which each attack causes a specified reduction in the capacity of a facility regarding to the service level of the facility and the level of interdiction. In this paper, inspiring of many real service systems we consider a *nested* hierarchical system with different service levels. Hierarchical systems have multiple layers of interacting facilities. A system is classified as *nested* or *non-nested* according to the service availability at the levels of hierarchy. In a nested hierarchy, a higher-level facility provides all the services provided by a lower level facility and at least one additional service. In a non-nested hierarchy, facilities on each level offer different services.

This problem could be considered as a two-player game. The attacker, as the leader, determines the most destructive interdiction strategy with respect to her budgetary limitation. Later, the defender tries to choose the best strategy to satisfy all customers' demand. The objective function of these two players is the same. To optimize the objective, the interdictor tries to maximize the total cost of demand satisfaction and the defender tries to minimize it regarding available facilities. As the two-player game nature of this problem, we use bi-level programming to model it. For solving the model, we implement a comprehensive enumeration code in CPLEX software [8]. In this way, it needs to call CPLEX to solve the second level in the exact way.

The rest of the paper is organized as follows. A bi-level mathematical formulation is given in section 2. In section 3, we present an example with computational result analysis to illustrate the problem that is proposed in this paper. Finally, section 4 concludes the paper with a brief summary of the findings.

II. A BI-LEVEL FORMULATION

A. Problem Definition

In this problem we consider a nested hierarchical system with two levels of facilities. Due to its nested nature, the facilities at level 2 can serve the customers who require the first and second level of services. Each facility has a specific capacity for serving each level of services. For a facility at level one, the capacity for the second level service is zero.

By experience, it is known that the specific percentages of demand of each demand point are required particular service