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論　文　内　容　の　要　旨

氏　　名	（高　振中　GAO Zhenzhong）
論文題名	ROBUST APPROACHES TO LINEAR PROGRAMMING PROBLEMS WITH UNCERTAIN COEFFICIENTS （不確実な係数をもつ線形計画問題に対するロバストアプローチ）

論文内容の要旨

When formulating real-world problems as linear programming (LP) problems, decision makers may not be able to know the accurate and precise values of some parameters. We call such parameters uncertain coefficients. Using speculated values for these uncertain coefficients may lead to a great loss when implementing the obtained solution back to the real-world problem. Therefore, it is important to collect the information about the uncertain coefficients, such as historical data and ranges of conceivable values, and to analyse their effect while obtaining a solution. A desirable solution can fulfil the decision maker's requirements or preserve the optimality for all conceivable values of uncertain coefficients. The approach to obtaining such a solution is considered a robust approach to the programming problems.

A lot of researchers have been focusing on this subject and proposing numerous approaches by representing the uncertain coefficients as intervals, fuzzy numbers and random numbers. These approaches have earned remarkable achievements, despite many aspects being left unsolved. This thesis focuses on two of those unsolved problems - one is the robust optimality analysis, and the other is the trade-off between robustness and satisfaction.

For the first problem, we treat an LP problem with uncertain objective function coefficients (OFCs). In the problem, the conceivable range of OFC vectors is given by a subset or a fuzzy subset. To such a problem, it is known that the necessarily optimal solution is the most reasonable solution. As it remains optimal against the certain fluctuations of OFCs, the necessarily optimal solution can be regarded as a robust optimal solution. In Chapter 3, we demonstrate that the necessary optimality degree of a non-degenerate basic feasible (NBF) solution can be obtained easily by representing the uncertain OFC vector to a fuzzy vector and using the tolerance approach. The necessary optimality degree evaluates to what extent the solution remains optimal against the fluctuations of OFCs. Several types of fuzzy subsets showing the conceivable range of OFC vectors are considered. For each type of fuzzy subset, an efficient calculation method of necessary optimality degree is proposed. Numerical examples are given to illustrate the proposed methods.

In real life, we come across cases where some OFCs' ranges depend on the remaining OFCs' values. For example, the prices of products rise together in tandem with raw materials, the gross profit of exported products increases while that of imported products decreases because they depend on the currency exchange rates, and so on. Such dependencies cannot be expressed well by the types of fuzzy subsets treated in Chapter 3. A convex polytope can express such dependencies among marginal ranges of uncertain OFCs to a certain degree. Hence, in Chapter 4, we extend the robust optimality analysis when the conceivable range of OFC vectors is specified by a convex polytope. In this case, the tolerance approach cannot be applied. To test the necessary optimality degree of an NBF solution, we need to check the inclusion of the convex polytope in the convex cone assuring the optimality of the NBF solution. For solving this test problem, we propose an algorithm based on the outer approximation approach. By numerical simulations, we demonstrate the efficiency of the proposed algorithm compared to a conventional vertex-listing method for checking the inclusion.

For the second problem, we consider LP problems where the coefficients of constraints are uncertain in Chapter 5. Such a problem is formulated as LP problems with set-inclusive constraints to ensure that the left-hand side coefficients' values are included in the given satisfactory ranges for all conceivable coefficient values. When the conceivable ranges of coefficients are given by fuzzy subsets, the set-inclusive constraints are treated by a necessity measure as it shows the degree of inclusion between fuzzy subsets. However, the necessity measure cannot express well the decision maker's requirement about the trade-off between the robustness level and satisfaction level of the constraints. We extend the necessity measure to incorporate the trade-off between the robustness level and satisfaction level of the constraints. We apply the extended necessity measure to LP problems with fuzzy coefficients. After the problem is formulated and reduced to the conventional programming problem, we propose an algorithm to solve it. Numerical examples are given to illustrate the proposed approach.

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論文審査の結果の要旨及び担当者

氏　　名	（高　　振中　GAO Zhenzhong）

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論文審査の結果の要旨

本論文は，不明確な係数をもつ線形計画問題について，係数変動に対する解の最適性の維持性能評価と，ロバスト性と満足度をバランスよく満たす解に関する新しい成果をまとめたものである．

第1章の序論と第６章の結論を含め，以下の各章から構成されている．

第2章では，基礎理論を説明している．

第3章と第4章では，目的関数の係数が不明確である線形計画問題の実行可能解の係数変動に対する最適性の維持性能，すなわち，ロバスト最適性の評価方法を扱っている．

第3章では，不明確な係数ベクトルの変動範囲が区間ベクトルや，レベル集合が矩形になるファジィベクトル，および斜交ファジィベクトルで与えられる場合を扱っている．トレランス解析の利用により，ロバスト最適性の度合が二分法により算出できることが示されている．特に，対称なファジィ数により定められる場合には，ロバスト最適性の度合の単純な計算法が与えられている．

第4章では，目的関数の不明確な係数ベクトルの変動範囲が凸多面体で与えられる場合を扱っている．ロバスト最適性の確認に有用な定理が与えられ，外部近似法に基づく解法が構成されている。この解法により頂点列挙法より高速にロバスト最適性が確認できることが理論的かつ実験的に示されている．

第5章では，制約条件の係数がファジィ数で与えられる線形計画問題を扱っている．制約条件の不明確な左辺値が確実に満足できる領域に入る解を取り上げ，左辺値の不明確性の見積りと満足度レベルをバランスよく扱う方法を考究している．これを数学的に扱う拡張必然性測度を提案するとともに，その性質を調べ，この問題の近似解法を与えている．

以上のように，本論文は不明確な係数を持つ線形計画問題の新しいロバストなアプローチを提案し，有用な解法を与えたものであり，この分野の発展に貢献している．よって、博士（工学）の学位論文として価値のあるものと認める．