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論文要旨

Supply chain models for fresh agricultural products are more complicated than the supply chain models for usual industrial products with no deterioration because of some special properties such that (1) the plant flowering and growing process depends on the climate in farmland; (2) the amount of fresh products to be harvested is restricted by the growing process which is hardly controllable; (3) the loss process of any fresh products begins just after harvested and depends on the handling process; and (4) all fresh products should be consumed directly by customers or used as fresh materials in food and beverage industries before they become rotten. It is regrettable that the total loss of fresh agricultural products can be up to 20-60% of the amount of harvested products in any country. A major cause of this large loss may be a mismatch between harvesting and delivery processes in terms of timing and quantity. Therefore, an optimal supply chain model for harvesting and delivery in agro-industries should be constructed to reduce the total loss and to maximize the total consumer satisfaction.

This thesis formulates basic agricultural models, especially a growing process of the related plant on farmland and a loss process of fresh products after harvested. The former process is identified as a maturing curve expressing the maximum amount of harvestable fresh products after flowering on the farmland. Successive multiple flowering and growing processes are also formulated to express the maximum amount of harvestable fresh products, provided that any requirements for harvesting fresh products should be satisfied through the earliest possible flowering. The loss process is identified by a loss function expressing the amount of available fresh products whose quality is good enough to consume. Successive multiple deliveries to multiple markets are also formulated to express the maximum amount of available fresh products, provided that any requirements for satisfying demand should be satisfied through the earliest possible delivery. Decision problems based on these models are formulated to find an optimal harvesting pattern of fresh agricultural products for maximizing a demand level to be satisfied in the market under the condition of periodical flowering. Two cases, a restricted inventory case and an unrestricted inventory case, are discussed separately, and two kinds of problems, a single-market problem and a multiple-market problem, are constructed for each case. The multiple-market problems are finally extended into decisions problems for selecting optimal combination of transportation methods to deliver the fresh products from farmland to the markets.

The thesis is organized as follows.

In Chapter 1, the introduction of the thesis is described.

In Chapter 2, three basic agricultural models are formulated in mathematical form to be applied or extended in the remaining chapters. The first model, flowering-harvesting model, is formulated to express the relationships between flowering-growing process and harvesting activity. The bound for fresh agricultural products to be harvested at any period is given by a combination of plant maturing curves in multiple flowering of agricultural plants. In this bound, the remaining amount of harvestable fresh products in any maturing curve was appropriately assessed by considering the remaining growing process on the farmland. The second model, harvesting-delivering model, is formulated to explain the relationships between harvesting and delivery of fresh products for consumption in each market. The bound for demand of fresh agricultural products in each market at any period is given by a sum of fresh products delivered with a given lead time and carried as on-hand inventory. In this bound, the loss process inevitable for delivery and carrying inventory is considered to obtain the amount of available fresh products in each market. The third model, periodical flowering model, is formulated to describe the process of harvesting-delivering through periodical flowering, provided that harvesting pattern for each flowering is all the same and is repeated periodically, and that any requirement for harvesting fresh products should be satisfied through the earliest possible plant maturing. The relationships between an effective harvesting pattern and a maturing curve in periodical flowering is expressed in mathematical form, and effective bounds for a demand level to be satisfied constantly at any period are derived by eliminating a wasteful on-hand inventory from the primary model.

In Chapter 3, decision problems based on the models provided in Chapter 2 are formulated to maximize a demand level to be satisfied constantly every period by periodical harvesting-delivery process of fresh agricultural products in a “single market” or “multiple markets” under the condition that inventory can be carried as on-hand inventory in the market for at most one period. In the multiple-market problem, demand in each market is assumed to be satisfied in proportion to each market size so that the original problem is converted to a “two-stage” optimization problem by decomposing it into a main problem and a set of subproblems related to each market. An optimization algorithm is proposed and applied to each decision problem to find an optimal harvesting pattern. The proof is given in an analytical manner to show that the proposed algorithms provide an optimal harvesting pattern to each problem. Numerical examples are demonstrated to show how the proposed optimization algorithm works well. From the computational results, we found that the optimal harvesting pattern is affected by a change in an interval of flowering cycle and in a delivery lead time, and that fresh products can be harvested only for carrying them as on-hand inventory as long as the loss of fresh products is less than the loss caused by the deterioration on farmland in case of harvesting the products later.

In Chapter 4, the periodical flowering-harvesting problems discussed in Chapter 3 are extended to more general cases, where fresh products are delivered to a single market or multiple markets immediately after harvested and on-hand inventory in the market can be carried for more than one period. In the multiple-market problem, the original problem is decomposed into a main problem and a set of subproblems in the same way as in Chapter 3. An optimal harvesting pattern to a single-market problem is derived analytically and an optimization algorithm to solve a multiple-market problem is developed by exploiting the optimal algorithm for the single-market problem. The proof is also given to show that the solution obtained through the proposed algorithm is optimal. Numerical examples for the two models are demonstrated to show the effectiveness of the proposed algorithm. It is made clear that harvesting fresh products at any period just after multiple harvest assigned to use only for carrying them as on-hand inventory is possible as long as the loss of fresh products is less than the loss caused by the deterioration on farmland in case of harvesting the products later.

In Chapter 5, the two-stage decision problems for multiple markets discussed in Chapters 3 and 4 are finally extended into a “two-phase, two-stage” periodical flowering-harvesting-transportation problem for selecting a best combination of transportation methods from a single farmland to multiple markets to maximize the total gross revenue obtained from the harvesting-delivery process of fresh agricultural products, provided that the delivery lead time from farmland to the markets can be changed through selecting one of available transportation methods. The restricted inventory case and the unrestricted inventory case are dealt with separately in formulating the related optimization problem, and in developing the optimization algorithm. A graphical method on a two-objective space, to maximize the total relative sales and to minimize the total transportation cost, is proposed for selecting the optimal combination of transportation methods to maximize the total revenue under a given set of prices in multiple markets. Sensitivity analyses are implemented to provide a range of prices so that the combination of transportation methods remains optimal. Numerical examples with real data on transportation costs available in Indonesia are demonstrated to show the effectiveness of the proposed method for providing an optimal combination of transportation methods and an optimal harvesting pattern.

In Chapter 6, the results obtained in this thesis are summarized and some perspectives for the future work are given.

List of Publications

No.	Title of the Article	Author(s)	Journal's/Conference's Name, Vol., Pages (Year)	Corresponding Chapter(s)
1	Basic Supply Chain Management Models in Harvesting and Delivering Agricultural Fresh Products	K.H. Widodo H. Nagasawa K. Morizawa M. Ota	Proc. of the 17th International Conference on Production Research, Blacksburg, Virginia, USA. ISBN 0-9721257-3-6, #0171, pp.1-18 (2003)	Chapter 2 Chapter 3
2	A Periodical Flowering-Harvesting Model for Delivering Agricultural Fresh Products	K.H. Widodo H. Nagasawa K. Morizawa M. Ota	European Journal of Operational Research (in press)	Chapter 2 Chapter 3
3	A Periodical Flowering-Harvesting Model for Delivering Agricultural Fresh Products to Multiple Markets	K.H. Widodo H. Nagasawa K. Morizawa M. Ota	Journal of Japan Industrial Management Association (accepted for publication)	Chapter 3
4	A Periodical Flowering-Harvesting Model for Delivering Fresh Agricultural Products to Multiple Markets with Inventory	K.H. Widodo H. Nagasawa K. Morizawa M. Ota	European Journal of Operational Research (submitted for publication)	Chapter 4
5	Optimal Harvesting-Delivering Pattern of Agricultural Fresh Products to Multiple Markets in Periodical Flowering	K.H. Widodo H. Nagasawa K. Morizawa M. Ota	Proc. of the 8th International Conference on Manufacturing and Management, Gold Coast, Queensland, Australia. ISBN 0-9578296-1-2, pp.731-738 (2004)	Chapter 5
6	Two-Phase Optimization Method for Harvesting and Delivering Agricultural Fresh Products with Periodical Flowering to Multiple Markets	K.H. Widodo H. Nagasawa K. Morizawa M. Ota	Journal of Japan Industrial Management Association Vol. 55, No. 6, pp.334-340 (2005)	Chapter 5
7	Optimal Harvesting-Delivery Pattern of Fresh Agricultural Products to Multiple Markets with Inventory under Periodical Flowering	K.H. Widodo H. Nagasawa K. Morizawa M. Ota	International Journal of Logistics (submitted for publication)	Chapter 5

審査結果の要旨

本論文は、生鮮農産物のサプライチェーンにおいて、農産物の成熟・劣化過程を考慮しながら、農地での収穫と市場への配送を最適に計画するための基本モデルを定式化し、その解法を提案したものであり、次のような成果を得ている。

(1) 農産物の開花・成熟過程および損失過程を数学モデルで定式化し、農産物の基本的なサプライチェーン・モデルを構築している。これに基づき、パパイヤのように連続的に開花・成熟して日常的に消費される農産物のサプライチェーンをモデル化し、市場規模に応じて各期で常に一定水準の農産物が供給されるという条件下で、その水準を最大にするための連続開花・収穫・配送問題を定式化している。

(2) 各市場における生鮮農産物の手持ち在庫が１期しか許されない場合と２期以上許される場合のそれぞれについて、単一市場および複数市場への連続開花・収穫・配送問題を定式化し、解析的に最適収穫・配送パターンを求め、最適性の証明を与えている。複数市場の場合には主問題と副問題からなる２段階意思決定問題に分割できることを示し、単一市場問題の解法を副問題へ適用し、システマティックに解いている。

(3) 数値例により、(a)成熟ピーク期までの最適収穫・配送パターンは単期分連続収穫になるが、ピーク期以降は複数期分収穫と無収穫が混在すること、(b)成熟ピーク期以降の最適収穫・配送パターンは開花周期が長いほど複雑になること、(c)複数期分収穫を行った次の期においても在庫のための単期収穫または複数期収穫が生じうること、(d)農地から市場までの配送リードタイムが長いほど最適収穫・配送パターンが一層複雑になることを明らかにしている。

(4) トラック輸送、貨車輸送、海上輸送、空輸など輸送手段を選択することによって配送リードタイムが変えられる場合を取りあげ、最適配送手段の選択問題を定式化している。この意思決定問題に対し、生鮮農産物価格が全市場で同じである場合(均一価格)と市場によって比例的に変わる場合(相対価格)の２通りについて、相対的総販売量最大化と総配送費最小化の２目的空間上で図式的に解く方法を提案し、数値例を示している。

以上の研究成果は、経営工学分野におけるサプライチェーン最適化手法の発展に貢献するところ大である。また、申請者が自立して研究活動を行うに必要な能力と学識を有することを証したものである。