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Modelling and genetic algorithm based optimisation of inverse supply chain

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The design and control of recycling systems of products with environmental risk have been discussed in the world already for a long time. The main reasons to address this subject are the followings: reduction of waste volume, intensification of recycling of materials, closing the loop, use of less resource, reducing environmental risk [1, 2]. The development of recycling systems is based on the integrated solution of technological and logistic resources and know-how [3]. However the financial conditions of recycling systems is partly based on the recovery, disassembly and remanufacturing options of the used products [4, 5, 6], but the investment and operation costs of recycling systems can be characterised with high logistic costs caused by the geographically wide collection system with more collection level and a high number of operation points of the inverse supply chain. The reduction of these costs is a popular area of the logistics researches. These researches include the design and implementation of comprehensive environmental waste and recycling program to suit business strategies (global system), design and supply all equipment for production line collection (external system), design logistics process to suit the economical and ecological requirements (external system) [7]. To the knowledge of the author, there has been no research work on supply chain design problems that purpose is the logistics oriented optimisation of inverse supply chain in the case of non-linear total cost function consisting not only operation costs but also environmental risk cost.

The antecedent of this research is, that the author has taken part in some research projects in the field of closed loop economy ("Closing the loop of electr(on)ic products and domestic appliances from product planning to end-of-life technologies), environmental friendly disassembly (Concept for logistical and environmental disassembly technologies) and design of recycling systems of household appliances (Recycling of household appliances with emphasis on reuse options).

The purpose of this paper is the presentation of a possible method for avoiding the unnecessary environmental risk and landscape use through unprovoked large supply chain of collection systems of recycling processes. In the first part of the paper the author presents the mathematical model of recycling related collection systems (applied especially for wastes of electric and electronic products) and in the second part of the work a genetic algorithm based optimisation method will be demonstrated, by the aid of which it is possible to determine the optimal structure of the inverse supply chain from the point of view economical, ecological and logistic objective functions.

The model of the inverse supply chain is based on a multi-level, hierarchical collection system. In case of this static model it is assumed that technical conditions are permanent. The total costs consist of three parts: total infrastructure costs, total material handling costs and environmental risk costs. The infrastructure-related costs are dependent only on the specific fixed costs and the specific unit costs of the operation points (collection, pre-treatment, treatment, recycling and reuse plants). The costs of warehousing and transportation are represented by the material handling related costs. The most important factors determining the level of environmental risk cost are the number of out of time recycled (treated or reused) products, the number of supply chain objects and the length of transportation routes. The objective function is the minimization of the total cost taking into consideration the constraints. However a lot of research work discussed the design of supply chain [8], but most of them concentrate on linear cost functions. In the case of this model non-linear cost functions were used.

The non-linear cost functions and the possible high number of objects of the inverse supply chain leaded to the problem of choosing a possible solution method. By the aid of analytical methods, the problem can not be solved, so a genetic algorithm based heuristic optimisation method was chosen to find the optimal solution. The input parameters of the optimisation are the followings: specific fixed, unit and environmental risk costs of the collection points of the inverse supply chain, specific warehousing and transportation costs and environmental risk costs of transportation. The output parameters are the followings: the number of objects in the different hierarchical levels of the collection system, infrastructure costs, logistics costs and environmental risk costs from used infrastructures, transportation and number of products recycled out of time.

The next step of the research work was the application of the above mentioned method. The developed application makes it possible to define the input parameters of the real system, the graphical view of the chosen optimal solution in the case of the given input parameters, graphical view of the cost structure of the optimal solution, determination of the parameters of the algorithm (e.g. number of individuals, operators and termination conditions). The sensibility analysis of the objective function and the test results showed that the structure of the inverse supply chain depends on the proportion of the specific costs. Especially the proportion of the specific environmental risk costs influences the structure of the system and the number of objects at each hierarchical level of the collection system.

The sensitivity analysis of the total cost function was performed in three cases. In the first case the effect of the proportion of specific infrastructure and logistics costs were analysed. If the infrastructure costs are significantly lower than the total costs of warehousing and transportation, then almost all objects of the first hierarchical level of the collection (collection directly from the users) were set up. In the other case of the proportion of costs the first level of the collection is not necessary, because it is replaceable by the more expensive transportation directly to the objects of the second or lower hierarchical level. In the second case the effect of the proportion of the logistics and environmental risk costs were analysed. In this case the analysis resulted to the followings: if the logistics costs are significantly higher than the total environmental risk costs, then because of the constant infrastructure costs the preference of logistics operations depends on the proportion of the environmental risk costs caused by of out of time recycled products and transportation. In the third case of the analysis the effect of the proportion of infrastructure and environmental risk costs were examined. If the infrastructure costs are significantly lower than the environmental risk costs, then almost all objects of the first hierarchical level of the collection (collection directly from the users) were set up. In the other case of the proportion of costs the first collection phase will be shifted near to the last hierarchical level of the supply chain to avoid a very high infrastructure set up and operation cost.

The advantages of the presented model and solution method can be summarised in the followings: the model makes it possible to decide the structure of the inverse supply chain (which object to open or close); reduces infrastructure cost, especially for supply chain with high specific fixed costs; reduces the environmental risk cost through finding an optimal balance between number of objects of the system and out of time recycled products, reduces the logistics costs through determining the optimal quantitative parameters of material flow operations. The future of this research work is the use of differentiated lead-time, which makes it possible to take into consideration the above mentioned non-linear infrastructure, transportation, warehousing and environmental risk costs in the case of a given product portfolio segmented by lead-time.

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